NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

SUMMARY OF PROGRESS THROUGH 1988

SPECIAL EDITION

This Summary of Progress is a compilation of information on all projects initiated under the NCHRP from its inception in 1962 through 1988. Annually, for 27 years, the National Cooperative Highway Research Program has issued a Summary of Progress comprised of up-to-date status reports on all on-going projects and brief statements on those that have been completed. With rising publication costs, and in the interest of keeping this book within manageable size, future summaries will not contain the completed projects that are found in this volume. Therefore, it is suggested that this edition be preserved as the last complete source of information on all NCHRP projects. Subsequent editions will update the Summary of Progress series, including only projects active after January 1, 1989.

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

SUMMARY OF PROGRESS THROUGH 1988

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. More predominantly, however, the need for more efficient, economical, and safer highway transportation and the importance of meshing with other modes and other societal concerns leads to national problems of increasing complexity. A coordinated program of high-quality cooperative research provides a highly effective approach to such problems.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. AASHTO's program is supported on a continuing basis by funds from participating member states of the Association and receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer AASHTO's research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; and it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

Research programs are developed annually by AASHTO on the basis of research needs identified by chief administrators of the highway and transportation departments, by committees of AASHTO, and by the Federal Highway Administrator. The programs are then referred for administration through the Transportation Research Board, and research projects addressing the specific needs are defined by the Board on the basis of the AASHTO problem statements. The projects are advertised widely for proposals, and qualified agencies are selected on the basis of research plans offering the greatest probabilities of success. The research is carried out under contract, and administration and surveillance are responsibilities of a Board-appointed staff.

The needs for highway research are many, and the National Cooperative Highway Research Program is an efficient mechanism for providing timely solutions to problems of mutual concern to many responsible groups. The Program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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MAILING ADDRESS:

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

SUMMARY OF PROGRESS

THROUGH 1988

INTRODUCTION

The National Cooperative Highway Research Program (NCHRP) was established in 1962 to provide a continuing program of highway research. It is sponsored by member departments of the American Association of State Highway and Transportation Officials (AASHTO) in cooperation with the Federal Highway Administration (FHWA), U.S. Department of Transportation, and is carried out under a three-way agreement among these agencies and the National Academy of Sciences. AASHTO annually proposes specific research problems for inclusion in the NCHRP fiscal year activities. At least two-thirds of the member departments must approve the research problems and agree to their financial support before they can be brought into the Program. Following balloting by the member departments, the approved problems are referred to the Academy, where they are reviewed to determine their acceptability to the Academy for administration by the Transportation Research Board. Each State annually contracts with the Academy to commit a portion of its Federal-aid highway planning research (HPR) funds. These funds presently make available a cooperative pool of about $8.0 million for NCHRP each year.

Each research project in the program is assigned to a panel made up of persons knowledgeable in the particular problem area. The panel analyzes the problem, outlines the particular project and its objectives, and then prepares a research project statement by which proposals are solicited from qualified research agencies. The panels review the proposals, recommend contract awards, and provide counsel to the NCHRP staff responsible for surveillance of work under the research contracts. Finally, they review final reports for acceptability and for accomplishment of the approved research plan. There are presently some 711 members on these panels coming from 45 States, the District of Columbia, Puerto Rico, Canada, and New Zealand.

A professional staff is assigned to NCHRP by the Board. Projects engineers with training and experience in the many research areas encompassed by the Program are responsible for administrative and technical surveillance of the contracts. If necessary, frequent meetings involving the staff, panel, and agency personnel are held to review project progress and provide guidance for ongoing work.

The research findings are published in either of two regular NCHRP report series or as a *Research Results Digest*. Each state highway administrator receives a copy immediately on publication, and as many as 6,000 copies are issued through the Transportation Research Board's Publication's Office.

Twice each year, detailed progress reports are submitted by the NCHRP to the sponsors to provide them with current information on the specifics of technical progress of the projects, as well as the specifics of administrative matters relating to Program operation. These reports are supplemented by publication of an annual summary of progress that is made available at the end of each year to both the sponsors and the public at large.

HOW NCHRP PROGRAMS ARE FORMULATED

NCHRP programs are initiated on an annual basis, and there are many steps between initiation and the time that the final reports are published. Each fiscal year's program must start with the *identification of critical problems* by: state highway and transportation departments, AASHTO Committees, and the Federal Highway Administration.

The many problems (usually for more than 150) received from these sources each year are first screened to determine:

- If the proposed problem represents an immediate research need and is of interest to many states.
- If it can be handled effectively under a cooperative program.
- If similar efforts are already under way, or if satisfactory answers are already available. In these respects, a search is made of the relevant literature stored in the Board's automated Highway Research Information Service.
- The probability of success.

The technical merits of the problems that survive this initial screening (usually about 50 percent) are then evaluated in depth by the AASHTO Standing Committee on

Research. Final priorities are determined each year at a meeting to formulate research programs for the NCHRP.

After the program is approved, by AASHTO, it is referred to TRB for execution.

PROGRAMS RECEIVED TO DATE

Through most of NCHRP's history, each year's program generally has consisted of from 7 to 10 new problems, each with funding usually ranging between $150,000 and $300,000 and a like number of continuations of projects funded in earlier years. Measured against the large number of research needs, as evidenced by the list that has ranged as high as 188 problems submitted for evaluation in a single year, the funds made available to the NCHRP each year have been far too limited. For about 15 years, annual funding for the NCHRP remained nearly constant at just below $5 million, while, during this period, the purchasing power of the research dollar was severely reduced by inflation. This decline was reversed with enactment of the Surface Transportation Assistance Act of 1982 which resulted in an approximately 50 percent funding increase for NCHRP. The federal-aid highway legislation enacted in 1987 had the effect of reducing NCHRP funding by 18 percent to a level of about $6.8 million. In February 1988, AASHTO approved a new formula for NCHRP contributions (5.5% of Federal-Aid Highway Planning and Research apportionments) to restore NCHRP funding to approximately $8.3 million starting in fiscal year 1989.

In 1988 AASHTO referred the twenty-seventh program (FY '89) of research problems. From all programs through FY '89, 541 research contracts have resulted, totaling some $86.5 million. The subject matter of the projects ranges across the full spectrum of concern within the highway industry and evidences the sponsor's immediate interest in acquiring answers at an early date to the many acute problems facing administrators and engineers. The twenty-eighth program (FY '90) was formulated in September 1988 by the Standing Committee on Research. Proposals will be solicited in March 1989. AASHTO's initial steps toward development of the twenty-ninth research program (FY '91) were taken in October 1989.

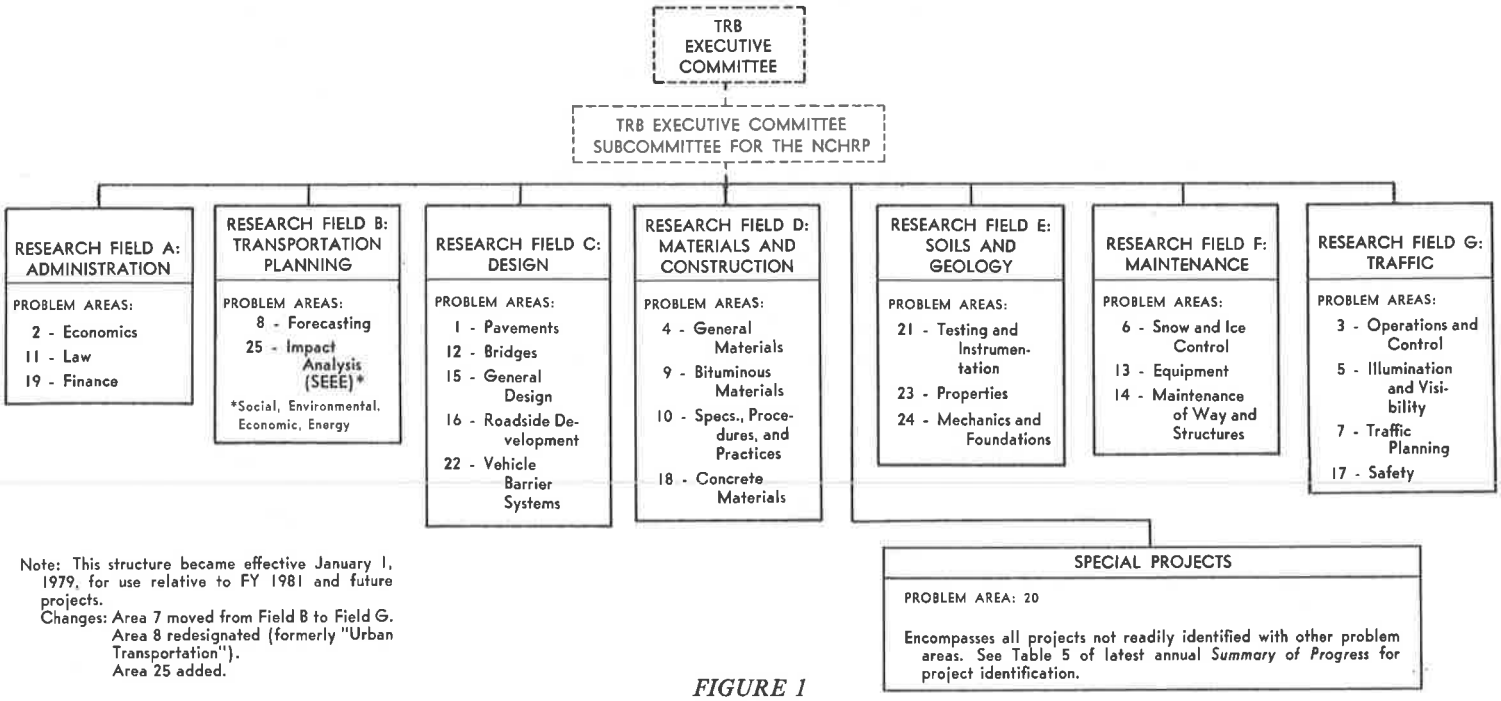
FINANCING THE PROGRAM

Each year, each State contracts with the National Academy of Sciences to support the Program. The agreement commits the State to 5½ percent of its 1½ percent federal-aid highway planning and research (HPR) funds. From these contributions a cooperative pool of about $8.3 million is presently made available each year for NCHRP's administrative and contract research operations. Funds are scheduled to become available such that research can begin near the end of each year; for example, projects in the FY '89 program were scheduled to begin in December 1988.

HOW THE NCHRP IS ORGANIZED TO ADMINISTER RESEARCH PROGRAMS

All problems are assigned to specific problem areas within each of the eight broad research fields shown in

NCHRP RESEARCH FIELDS AND AREAS



Note: This structure became effective January 1, 1979, for use relative to FY 1981 and future projects.
Changes: Area 7 moved from Field B to Field G.
Area 8 redesignated (formerly "Urban Transportation").
Area 25 added.

FIGURE 1

TABLE 1
DISTRIBUTION OF PROJECTS WITH RESPECT TO GENERALIZED SUBJECT AREAS

NO. OF PROJECTS	PERCENT OF FUNDS	GENERALIZED SUBJECT AREAS
52	9.0	Socio-economic and environmental issues
60	12.5	Urban issues
13	3.4	Multimodal issues
82	13.9	Safety and accident prevention
20	3.5	Legal studies
26	13.8	Special projects (including in-house)
31	4.7	Improved materials quality and performance
31	8.0	Highway maintenance
69	12.3	Specifications, tests, and construction control
100	18.9	Structural design and performance

Figure 1 and are given related NCHRP project numbers. In terms of generalized subject areas, the distribution of all projects through FY 1989 is shown in Table 1.

Each project is assigned to a panel consisting of outstanding individuals very knowledgeable in the project area who are looked to for technical guidance and counsel throughout the research and reporting phases. A broad search is made for these individuals, and the Board usually receives about four to five times as many nominees as can be used in the available panel positions. The panels are in existence for the life of their projects. Members do not act as consultants or advisors to project investigators; they may not submit proposals for research. All members serve without compensation, and their total yearly contribution to the Program adds up to thousands of man-days. The panel members are drawn from all walks of professional life, and, as shown in Table 2, heavy dependence is placed on the states for providing members. The perspective of state people in defining the research needed to solve operational problems is most important if projects that are both practical and feasible within the limits of available funds are to be structured.

The duties and responsibilities of project panels include:

- Defining the scope of problems assigned by AASHTO and drafting project statements requesting proposals for studies.
- Evaluating proposals and making recommendations regarding selection of research agencies.
- Monitoring research progress.
- Providing guidance regarding technical aspects of the research.
- Reviewing and evaluating project reports as to the accomplishment of objectives and suitability for publication.
- Making recommendations as to whether or not studies should be continued.

HOW THE PROJECTS ARE PLACED UNDER CONTRACT

It is important to note that the NCHRP is not in the business of awarding grants for basic research. Rather, the Program calls for contract research with specific objectives that, if achieved, will result in solutions that are practical and readily usable. As the NCHRP gets each year's program under way, the project panels meet to write research project statements based on the research problems referred by AASHTO.

These statements are then sent automatically to a mailing list of some 3,000 research agencies ranging from individuals to large corporations. Anyone may be added to this list by request addressed to the Director, Cooperative Research Programs at TRB. Because NCHRP operates on a fixed-schedule, proposals must be submitted according to fixed deadlines.

Contracts have been let to agencies headquartered in more than 25 States, the District of Columbia, and one foreign country. The types of agencies selected to conduct NCHRP research are listed in Table 3. The opportunity to propose is open to anyone possessing extensive, demonstrated capability and experience in the problem area. Because the projects call for practical remedies to pressing operational problems, it is expected that only the highest level of agency capability will be applied in meeting the commitments of the proposal—capability cannot be developed at project expense. Consonant with the goal of providing practical, readily usable solutions to pressing problems, time and experience have led to the development of fairly stringent specifications for proposals and agency attributes that are acceptable to the mission-oriented nature of the NCHRP. Proposals must comply with the format in the current brochure, *Information and Instructions for Preparing Proposals.*

TABLE 2
DISTRIBUTION OF PROJECT PANEL AND COMMITTEE MEMBERSHIP WITH RESPECT TO AFFILIATION

AFFILIATION	NO. OF MEMBERS	POSITIONS INVOLVED
State highway and transportation departments	330	371
Federal Highway Administration*	37	48
Special transportation and other governmental agencies	66	67
Educational institutions	110	131
Research institutes	7	7
Industry, consultants, and trade associations	153	187
Professional societies and service organizations	8	11
All	711	822

* Does not include liaison representatives

TABLE 3

AGENCY DISTRIBUTION OF FY '63 THROUGH FY '89 PROJECTS

TYPE OF AGENCY	CONTRACTS NO.	%
Educational institutions	181	34
Research institutes	84	16
Industry, consultants, and trade associations	242	46
Professional societies and service organizations	13	2
State highway and transportation departments	5	1
Special transportation and other governmental agencies	4	1
All	529	100

The staff and panel members evaluate all proposals in a uniform manner, with primary consideration given to:

- The understanding of the problem and the merit of the research plan and approach.
- The experiment design and the promise of fulfilling the objectives of the project statement.
- The qualifications of the principal investigator and other members of the research team.
- The adequacy of the facilities.

The proposed budget is not one of the primary factors because the funds available for reseach are announced in the project statement. The budget does not enter the evaluation process leading to agency selection, except when specific items are reviewed to better determine manpower allocations and distribution of resources. When the proposed cost exceeds the funds stated to be available, the proposal is rejected on receipt.

A panel meeting is held to select an agency for each project, and a review is made of all known aspects of performance of the proposers on other research projects under NCHRP or elsewhere. The successful proposals are retained by the panel members for use in monitoring the research. Proposals are considered to be privileged, and the information in them is not released outside the TRB unless explicit approval is obtained from the agency. Policy also holds that panel deliberations and meeting notes are privileged.

Following the selection meetings, a list of recommended research agencies is transmitted to AASHTO and the Federal Highway Administration for their review and approval. Contracts between the Academy and the research agencies are executed, and research is begun. Again, it should be emphasized that the NCHRP is a program of *contract* research—it does not operate on a grant basis. Further, proposals can be received only in response to advertised project statements, as the funds available each year to the Program are earmarked in their entirety for research problems specified by the sponsor—AASHTO.

From the standpoint of AASHTO's interests, needs, and capital investments, it is important to understand that a contract is not signed with the selected agency until the staff and project panel are satisfied that the proposed scope of work provides the best probability for success in meeting AASHTO's needs. In the period between agency selection and contract execution, a concerted effort is made to resolve questions and clarify matters of technical substance emanating from the selection process. This action usually results in an addendum to the research plan in the agency's approved proposal; therefore, both the proposal and the addendum are incorporated in the contract as the binding scope of work. Furthermore, soon after contract execution, the agency is required to submit a Working Plan that is intended to be an amplified version of the research plan. It is against this document that progress of the project is monitored by the staff and project panel.

The policy of the NCHRP is to provide a debriefing to unsuccessful proposers to indicate the technical areas in which their proposals were judged weak and deficient and how the weaknesses or deficiencies were factors in their not having been selected.

The projects included in the 27 fiscal year programs conducted to date are listed in Table 4.

The Academy's research contract is either:

- Cost-Reimbursement
- Cost-Reimbursement Plus Fixed Fee
- Fixed Price

The Academy decides, in agreement with the agency, which type of contract will be used in each case.

KEEPING TRACK OF RESEARCH IN PROGRESS

Once research starts, administrative and technical surveillance of its progress is performed by NCHRP staff, presently standing at 16—8 professional, 8 support. In-depth surveillance by projects engineers with wide-ranging expertise contributes much to the probability of project success and can be one of the most significant of the several elements influencing how well objectives are met. It is recognized, however, that a delicate balance must be maintained in the practical exercise of surveillance. It must be penetrating enough to be effective, yet it must not be so complex or burdensome as to distract the researchers from their primary efforts or add unreasonably to the agency's cost of doing business.

In addition to reviewing monthly progress schedules and quarterly progress reports, the projects engineers maintain frequent telephone contacts and regularly visit the research agencies throughout the contract periods. They talk with each principal investigator about the project's status to learn if the research is being pursued in

line with the approved research plan, and they provide guidance in all technical and administrative matters. They provide liaison in whatever manner is required to keep their project panels abreast of progress and to acquire panel guidance and counsel in technical matters, particularly as regards the relationships between research objectives and the needs of the practicing engineer. Because the agency's proposal is incorporated in its entirety in the contract, the agency's approved budget is among the items subject to the terms of the agreement. The principal investigator has flexibility in managing the budget up to the point of not materially departing from the approved research plan or exceeding the contract's maximum allowable cost. Major changes to account for promising new leads or unproductive lines of study must be approved in advance by the staff and project panel and are authorized through a contract amendment. Agency invoices are checked monthly by staff for deviations from the approved budget. Based on all surveillance activities, staff prepares its own progress reports, which are sent to the sponsors to provide a current awareness of ongoing work. Finally, the staff and panels evaluate the completed research to determine the degree of technical compliance with the contract so that recommendations for contract close-out can be made.

A point heavily stressed with the research agencies at the time of the first surveillance visit is that they must orient their thinking toward presentation of their research results in a form that is directly usable by practicing engineers. Further, to enable an easy determination of the usefulness of the results to practice, each final report includes a "Summary of Findings" and a chapter on "Interpretation, Appraisal, and Application of Results." The detailed research techniques and analyses of interest primarily to researchers are offered in appendixes. Such specification of the style and organization of reports guides the researcher in presenting results so that maximum use by the sponsors may be obtained.

NCHRP publications consist of:

- Project reports in the regular NCHRP Report series.
- Reports in the NCHRP Synthesis of Highway Practice series.
- Annual summary of progress through December 31.
- NCHRP Research Results Digests.
- NCHRP Legal Research Digests.
- Semiannual progress reports.

The semiannual progress reports are issued only to the various program participants. The other publications are distributed more widely through the NCHRP and through the Board's selective distribution process; the print order for reports in the formal NCHRP series ranges from 3,500 to 7,000 copies. In addition to AASHTO and the Chief Administrative Officers, copies automatically go to:

- Individual TRB members who have selected publications in the particular subject area of the report.
- About 100 libraries.
- Transportation Research Board representatives in the state highway and transportation departments.
- Educational institutions.
- Liaison representatives.
- Appropriate panels and committees.

News releases announcing the publication of NCHRP reports are sent to appropriate trade publications and other news media. For each report, the NCHRP staff writes a foreword that identifies the fields of specialty of those individuals having most interest in the results. It also suggests how the results fit into present knowledge and practice. Furthermore, the Board's Technical Activities Staff follows the progress of the work and is therefore able to discuss the potential application of research results during their periodic visits to State highway and transportation departments. All published reports are offered for sale through the Board's Publications Office and are also entered in the National Technical Information Service (NTIS). All unpublished reports are placed on microfiche for ready availability to interested parties.

SYSTEMATIC PLANNING FOR GETTING RESEARCH RESULTS FROM NCHRP PROJECTS INTO PRACTICE

Promoting Useful Results

Previous reference has been made to the fact that many activities take place between initiation of research programs and execution of research contracts. Many additional ones take place before formal publication of the final reports is realized. At milestones in the process network reflecting all activities, NCHRP concentrates on the opportunities to increase the probability that useful results will find their way into practice more quickly. Beyond the sponsor's initial contribution of setting the goals for a program of applied research dedicated to solving pressing operational problems, the NCHRP tries to further increase the probability by:

- Establishing the agency and personnel qualifications that are mandatory if the goals are to be achieved. Emphasis is placed on the importance of a record of successful past performance in endeavors similar to those to be undertaken. Further, it is also stipulated that proposals are not acceptable if they do not contain specific statements as to how the anticipated results can be used to improve practice.
- Making use of panel members, who not only are experts in the particular problem area but who also have a complete understanding of the needs of the practitioners, to define the research problem and its objectives in the form of a precise project statement on which fully re-

sponsive research proposals can be based. Experts drawn from the highway and transportation departments play a major role in this task.

- Exercising extreme care in the process of selecting research agencies to ensure not only that the proposed research plan is the best possible in addressing the specifics of the objectives but that it also culminates in the best promise for providing the practitioner with a product that is both usable and readily implementable.

- Establishing—on the basis of staff and project panel review of and suggested modifications to the research plan—a clear meeting of the minds as to what specifically is expected from the project and the researchers in order to meet the needs of the practitioner.

- Acquiring an amplified research plan that is intended to detail comprehensively the approved research plan and to include a specific schedule of events for the major tasks. This document is used by the staff in the day-to-day surveillance of the project's progress and by the project panel as required.

- Carrying out project surveillance sufficient to keeping the research in line with the approved research plan, constantly keeping the researchers aware of the needs of the practitioner, and insuring that all project developments through final reporting center around these needs.

- Requiring research reports in a format that is designed specifically to first meet the needs of the busy administrator and the practitioner. Different treatment is given to the material that would be of interest to other researchers.

NCHRP Reporting of Research Results

In an applied research program such as the NCHRP, the sponsor rightfully expects not only results that are accurate but also findings that can be readily put into practice. This means that the final research reports must be presented in language understandable to both administrators and engineers and in such format as to permit easy assimilation. Research reports are sometimes so clouded by obscure language and format that the reader must spend precious time and effort in translating them into concise and readily usable working documents. Research agencies for the NCHRP are required to report their results in a form that succinctly summarizes the findings for the busy administrator and likewise informs the practitioner of the application of the findings. The detailed research techniques and analyses in which a researcher would be interested are presented in appendixes and do not have to be labored through to extract the findings. The Program specifies style and organization of all reports to guide the researcher in his writing so that maximum use by the sponsors may be obtained.

IMPLEMENTING RESEARCH RESULTS

Over the years there have been opportunities for the Program staff and various AASHTO committees to work together to structure the research findings into the best possible form for immediate use by the practitioner. Such joint efforts are highly desirable and represent the ultimate in the steps that the Program can take to weight the odds in favor of implementation of the findings.

AASHTO has provided the NCHRP with frequent opportunities for staff and project researchers to go before the various committees of the Association to present their findings and recommendations directly to the user community.

EXAMPLES OF UTILIZATION OF NCHRP RESEARCH RESULTS

Beyond the uses of NCHRP research results cited in Table 5, there undoubtedly are many other uses that are unknown to the Program. NCHRP reports have been abstracted by numerous foreign countries, including Russia, with subsequent utilization being reported here. In the interest of all potential users, the Program will be grateful for any information on actual application of results and associated cost savings. This will be reported in the hope that widespread interest will develop in the States and that, consequently, research results will find their way more quickly into policies, practices, procedures, specifications, and standards of the highway and transportation departments.

AWARD-WINNING RESEARCH UNDER NCHRP

Several projects have been honored to date as outstanding contributions to the field of highway safety and have received Metropolitan Life Awards for Research in Accident Prevention from the National Safety Council. They are:

- NCHRP Project 1-7, "Development of Interim Skid-Resistance Requirements for Highway Pavement Surfaces." In 1968, this project, reported as *NCHRP Report 37,* "Tentative Skid-Resistance Requirements for Main Rural Highways," received the Award of Merit ($500).

- NCHRP Project 3-8, "Factors Influencing Safety at Highway-Rail Grade Crossings." In 1969, this project, reported as *NCHRP Report 50,* "Factors Influencing Safety at Highway-Rail Grade Crossings," received top honors—the Award of Honor ($1,000).

- NCHRP Project 2-3, "Analysis of Motor Vehicle Accident Data as Related to Highway Classes and Design Elements." Also in 1969, this project, reported as *NCHRP Report 47,* "Accident Rates as Related to Design Elements of Rural Highways," placed second and received the Award of Merit ($500).

Other projects prominent in various other classes of awards are:

- NCHRP Project 20-7, Task 2, "The Relation of Side Slope Design to Highway Safety." In 1977, Eugene D. Marquis and Graeme D. Weaver shared the 1977 Arthur M. Wellington Prize of the American Society of Civil Engineers for their paper, "Roadside Slope Design for Safety," which was based on the research reported in *NCHRP Report 158,* "Selection of Safe Roadside Cross Sections."

- NCHRP Project 20-3, "Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control." In 1969, a paper based on this project received Honorable Mention under the Past President's Award, Institute of Traffic Engineers.

- NCHRP Project 9-1, "Asphalt Durability and Its Relation to Pavement Performance." In 1969, a paper based on this project, reported in *NCHRP Report 67,* "Relation of Asphalt Rheological Properties to Pavement Durability," received the W. J. Emmons Annual Award of the Association of Asphalt Paving Technologists as the best paper at the annual meeting.

- NCHRP Project 5-8, "Warrants for Highway Lighting." In 1973, a paper based on this project, reported in *NCHRP Report 152,* "Warrants for Highway Lighting," received the Highway Research Board Award as the most outstanding paper presented at the Board's Annual Meeting.

- NCHRP Project 12-7, "Effects of Weldments on Fatigue Strength of Steel Beams." In 1977, the Principal Investigator, Professor John W. Fisher, received the T. R. Higgins Award from the American Institute of Steel Construction as author of *NCHRP Report 147,* "Fatigue Strength of Steel Beams with Welded Stiffeners."

- NCHRP Project 12-12, "Welded Steel Bridge Members Under Variable-Cycle Fatigue Loadings." In 1979, the Principal Investigators, Karl H. Klippstein and Charles G. Schilling, were co-recipients of the Arthur M. Wellington Prize from the American Society of Civil Engineers for their paper, "Fatigue of Steel Beams by Simulated Bridge Traffic," published in the *Journal of the Structural Division,* August 1977. The paper was based on Project 12-12.

- NCHRP Project 20-9, "Socioeconomic Consequences of Right-of-Way Acquisition Induced Resident Dislocation." The Principal Investigator, Mr. Jon E. Burkhardt, received the 1980 Pyke Johnson Award from the Transportation Research Board as author of the paper "Residential Dislocation: Costs and Consequences."

- NCHRP Project 1-17, "Guidelines for Recycling Pavement Materials." In 1981, a paper based on this project, reported in *NCHRP Report 224,* "Guidelines for Recycling Pavement Materials," received the W. J. Emmons award for the best technical paper at the annual meeting of the Association of Asphalt Paving Technologists.

SUMMARY

The National Cooperative Highway Research Program is a unique contract research effort designed to respond quickly and efficiently to the needs of State highway and transportation departments through the solution of the pressing transportation problems. Although the Transportation Research Board administers the Program, the research content is solely the prerogative of the American Association of State Highway and Transportation Officials and its member departments. The Program is one of applied (rather than basic) research, and every possible effort is made to help administrators and engineers put the findings to early use. Program policy ensures maximum exposure of the research while in progress in the hope that research results will, in fact, more quickly find their way into practice in the form of policies, procedures, specifications, and standards of State highway and transportation departments.

TABLE 4
SUMMARY OF STATUS THROUGH DECEMBER 31, 1988 FOR FY '63 THROUGH FY '89 PROJECTS

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA ONE: DESIGN—PAVEMENTS		
1-1(1)	Development of Procedures for Comparing the AASHO Road Test Findings with Performance of (1) Existing Pavements and (2) Newly Constructed Experimental Pavements	HRB	42,800*
1-1(2)	Guidelines for Extending the Findings of the AASHO Road Test—Implementation Phase	HRB	11,356*
1-2	Comparison of Different Methods for Evaluating Pavement Conditions	Purdue U	29,957*
1-3(1)	Factors Influencing Pavement Performance—Regional	Purdue U	45,982*
1-3(2)	Factors Influencing Pavement Performance—Local	Northwestern U	19,850*
1-3(3)	Factors Influencing Pavement Performance	U of California	19,800*
1-4(1)	Extension of Road Test Performance Concepts	Georgia Tech	10,000*
1-4(1)A	Extension of Road Test Performance Concepts	Duke U	19,924*
1-4(2)	Extension of Road Test Performance Concepts	Purdue U	12,243*
1-5	Detecting Variations in Load-Carrying Capacity of Flexible Pavements	Cornell Aero Lab	49,011*
1-5(2)	Detecting Seasonal Changes in Load-Carrying Capabilities of Flexible Pavements	Texas A & M	49,428*
1-6	Standard Measurements for Satellite Program—Measurement Team	Texas A & M	61,353*
1-7	Development of Interim Skid-Resistance Requirements for Highway Pavement Surfaces	Penn State U	24,815*
1-8	Factors Involved in the Design of Asphalt Pavement Surfaces	Materials R & D	23,255*
1-9	Evaluation of Studded Tires	Cornell Aero Lab	24,998*
1-10	Translating AASHO Road Test Findings—Basic Properties of Pavement Components	Materials R & D	99,803* 103,291*
1-10A	Systems Approach to Pavement Design—Implementation Phase	Texas A & M	100,000*
1-10B	Development of Pavement Structural Subsystems	Woodward-Clyde	447,941*
1-11	Evaluation of AASHO Interim Guides for Design of Pavement Structures	Materials R & D	63,720* 20,205*
1-12	Determination of Pavement Friction Coefficients Required for Driving Tasks	Franklin Inst	309,244*
1-12A	Wet-Weather Skidding Accident Reduction at Intersections	Ohio DOT	199,955*
1-12(2)	Locked-Wheel Pavement Skid Tester Correlation and Calibration Techniques	Penn State U	319,000*
1-12(3)	Requirements for Wear-Resistant and Skid-Resistant Highway Pavement Surfaces	Materials R & D	261,955*
1-13	Effects of Studded Tires on Highway Safety	Calspan Corp	208,898*
1-13(2)	Effects of Studded Tires on Highway Safety—Non-Winter Driving Conditions	U of Michigan	39,450*
1-14	Influence of Combined Highway Grade and Horizontal Alignment on Skidding	U of Michigan	69,968*
1-15	Design of Continuously Reinforced Concrete Pavements for Highways	U of Texas	151,870*
1-16	Evaluation of Winter-Driving Traction Aids	Penn State U	304,400*
1-17	Guidelines for Recycling Pavement Materials	Texas A&M	199,470*
1-18	Calibration and Correlation of Response-Type Road Roughness Measuring Systems	U of Michigan	250,000*
1-19	Development of a System for Nationwide Evaluation of PCC Pavements	U of Illinois	225,000*
1-20	Influence of Asphalt Temperature Susceptibility on Pavement Construction and Performance	Texas A & M	200,000*
1-21	Repair of Joint-Related Distress in Portland Cement Concrete Pavements	U of Illinois	300,000*
1-22	Shoulder Geometrics and Use Guidelines	Hugh Downs/RK&K	100,000*
1-23	Pavement Roughness and Rideability	KETRON, Inc	249,990*
1-23(2)	Pavement Roughness and Rideability—Field Evaluation	JMJ Research	199,983*
1-24	Revision of AASHTO Interim Guide for Design of Pavement Structures	McCullough/Finn	—
1-25	Effects of Heavy Vehicle Characteristics on Pavement Response and Performance	TRB	100,000
1-25(1)	Effects of Heavy Vehicle Characteristics on Pavement Response and Performance—Phase II	U of Michigan	400,000
1-26	Calibrated Mechanistic Structural Analysis Procedures for Pavements	U of Illinois	250,000
1-27	Video Image Processing for Evaluating Pavement Surface Distress	—	350,000
	AREA TWO: ADMINISTRATION—ECONOMICS		
2-1	Criteria for Highway Benefit Analysis	U of Washington	101,948*
2-2	Guidelines for the Determination of Community Consequences	U of Washington	48,873*
2-3	Analysis of Motor Vehicle Accident Data as Related to Highway Classes and Design Elements	Cornell Aero Lab	155,972*
2-4	The Value of Highway Travel Time, Comfort, Convenience, and Uniform Driving Speed	Texas A & M	77,100*

STARTING DATE	COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
3/1/63	2/29/64	Completed—Published as NCHRP Reports 2, 2A	1-1(1)
3/1/64	8/31/65	Contract terminated—No report	1-1(2)
2/15/63	2/28/65	Completed—Init. ph. publ. as NCHRP Rep. 7; final rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	1-2 1-2
2/15/63	9/30/67	Completed—Published as NCHRP Report 132	1-3(1)
9/1/63	9/30/64	Completed—Published as NCHRP Report 22	1-3(2)
4/1/64	10/31/65	Completed—Published as NCHRP Report 35	1-3(3)
10/1/63	9/30/64	Completed—Published as NCHRP Report 10	1-4(1)
2/1/65	9/30/66	Completed—Published as NCHRP Report 97	1-4(1)A
2/1/64	1/31/66	Completed—Published as NCHRP Report 30	1-4(2)
1/15/64	7/15/65	Completed—Published as NCHRP Report 21	1-5
9/1/66	6/30/68	Completed—Published as NCHRP Report 76	1-5(2)
3/31/64	1/31/67	Completed—Published as NCHRP Report 59	1-6
6/15/65	12/15/66	Completed—Published as NCHRP Report 37	1-7
1/1/65	2/28/66	Completed—Published as NCHRP Report 39	1-8
10/1/66	6/30/67	Completed—Published as NCHRP Report 61	1-9
9/12/66	3/11/68	Completed—Report included in NCHRP Reports 139, 140	1-10
12/1/68	12/31/70	Completed—Published as NCHRP Reports 139, 140	1-10
3/1/72	12/31/73	Completed—Published as NCHRP Report 160	1-10A
2/1/74	7/31/86	Completed—Published as NCHRP Report 291	1-10B
10/23/67	6/30/70	Completed—Published as NCHRP Report 128	1-11
8/1/70	4/30/71	Completed—Published by AASHTO	1-11
8/25/69	6/8/73	Completed—Published as NCHRP Report 154	1-12
7/1/75	7/1/78	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	1-12A
9/16/70	5/15/73	Completed—Published as NCHRP Report 151	1-12(2)
11/1/71	9/30/75	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	1-12(3)
4/19/71	8/20/74	Completed—Published as NCHRP Report 183	1-13
2/15/72	5/31/73	Completed—Published as NCHRP Report 176	1-13(2)
10/15/72	1/14/74	Completed—Published as NCHRP Report 184	1-14
8/1/72	8/31/75	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	1-15
6/3/74	10/31/81	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	1-16
11/1/76	9/30/79	Completed—Published as NCHRP Report 224	1-17
10/1/77	9/30/80	Completed—Published as NCHRP Report 228	1-18
1/23/78	3/15/85	Completed—Published in NCHRP Report 277	1-19
5/1/79	7/16/84	Completed—Published as NCHRP Reports 268 and 269	1-20
5/15/80	6/28/85	Completed—Published as NCHRP Report 281	1-21
9/8/81	4/7/83	Completed—Published as NCHRP Report 254	1-22
1/4/82	11/30/84	Completed—Published as NCRP Report 275	1-23
1/6/86	12/31/87	Completed—Published as NCHRP Report 308	1-23(2)
—	—	Conducted under Project 20-7, Task 24	1-24
6/12/86	11/30/87	Report not publ., for avail., see project writeup	1-25
9/1/88	8/31/91	Research in progress	1-25(1)
2/6/87	6/30/89	Research in progress	1-26
30 months		In developmental stage	1-27
6/1/63	11/30/67	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	2-1
7/1/63	8/31/64	Completed—Published as NCHRP Report 18	2-2
6/1/63	8/31/66	Completed—Published as NCHRP Report 47	2-3
6/1/63	8/31/66	Completed—Published as NCHRP Report 33	2-4

TABLE 4 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA TWO (*Continued*)		
2-5	Running Cost of Motor Vehicles as Affected by Highway Design and Traffic	Catholic U	49,998* 51,265*
2-5A	Running Cost of Motor Vehicles as Affected by Highway Design and Traffic	Paul J. Claffey	35,000* 30,665*
2-6	Warranted Levels of Improvement for Local Rural Roads	Stanford U	40,000*
2-7	Road User Costs in Urban Areas	Catholic U	99,376*
2-8	Estimation and Evaluation of Diverted and Generated (Induced) Traffic	Northwestern U	40,000*
2-9	Effect of Highway Landscape Development on Nearby Property	Franklin Inst	149,103*
2-10	Future Needs for Oversize-Overweight Permit Operation on State Highways	Jorgensen & Assoc	99,655*
2-11	Summary and Evaluation of Economic Consequences of Highway Improvements	HRB	110,000*
2-12	Highway User Economic Analysis	Stanford Res Inst	90,074* 9,995*
2-13	Multilane Design Alternatives for Improving Suburban Highways	Midwest Res Inst	100,000
2-14	Public/Private Partnerships for Financing Highway Improvements	Kimley-Horn & Assoc	125,000
2-15	Identifying, Measuring, and Evaluating the Benefits of Safety Roadside Rest Areas	KLD Assoc	236,560
2-16	Relationships Between Vehicle Configurations and Highway Design	TRB	900,000
2-17	Transportation and Economic Development	—	250,000
	AREA THREE: TRAFFIC—OPERATIONS AND CONTROL		
3-1	Development of Criteria for Evaluating Traffic Operations	Cornell Aero Lab	78,965* 79,913*
3-2	Surveillance Methods and Ways and Means of Communicating with Drivers	Cornell Aero Lab	246,756*
3-3	Sensing and Communication Between Vehicles	Ohio State U	163,190*
3-4	Means of Locating Disabled or Stopped Vehicles and Methods of Communication with a Central Location	Airborne Instr	78,517* 49,474*
3-5	Improved Criteria for Designing and Timing Traffic Signal Systems	Planning Research	123,030* 48,155* 93,717*
3-6	Effect of Regulatory Devices on Intersectional Capacity and Operation	De Leuw, Cather	153,175*
3-7	Establishment of Standards for Highway Noise Levels	Bolt, Beranek	144,920* 69,930* 49,927* 307,486*
3-8	Factors Influencing Safety at Highway-Rail Grade Crossings	Voorhees & Assoc	17,171* 74,250*
3-9	Analysis and Projection of Research on Traffic Surveillance, Communication, and Control	Jorgensen & Assoc	23,760*
3-10	Application of Vehicle Operating Characteristics to Geometric Design and Traffic Operations	Cornell Aero Lab	41,520*
3-11	Optimizing Street Operations Through Traffic Regulations and Control	Peat, Marwick et al	258,331*
3-12	Development of Information Requirements and Transmission Techniques for Highway Users	Airborne Instr	198,655* 100,500* 99,821*
3-13	Guidelines for Medial and Marginal Access Control of Major Roadways	Texas A & M	149,293*
3-14	Optimizing Flow on Existing Street Networks	Edwards & Kelcey	990,000*
3-15	Weaving Area Operations Study	Poly Inst of NY	300,000*
3-16	Freeway Lane Drops	System Dev Corp	99,789* 76,815*
3-17	Improving Traffic Operations and Safety at Exit Gore Areas	Penn State U	79,983*
3-18(1)	Improved Control Logic for Use with Computer-Controlled Traffic	Stanford Res Inst	323,998* 57,662*
3-18(2)	Traffic Control in Oversaturated Street Networks	Poly Inst of NY	200,000*
3-18(3)	Cost-Effectiveness Methodology for Evaluation of Signalized Street Network Surveillance and Control Systems	JHK & Assoc	123,267*
3-18(4)	Methodology for Performance Evaluation of Signalized Network Control Strategies	Computran	148,705*
3-19	Grade Effects on Traffic Flow Stability and Capacity	Midwest Res Inst	220,443*
3-20	Traffic Signal Warrants	KLD Associates	120,000* 81,935*

STARTING DATE	COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
6/1/63	8/31/64	Completed—Published as NCHRP Report 13	2-5
6/1/65	12/31/66	Completed—Report included in NCHRP Report 111	2-5
7/1/67	12/31/68	Completed—Report included in NCHRP Report 111	2-5A
8/11/69	8/10/70	Completed—Report included in NCHRP Report 111	2-5A
6/1/63	9/30/66	Completed—Published as NCHRP Report 63	2-6
2/1/64	5/31/66	Completed—Report included in NCHRP Report 111	2-7
5/1/64	8/31/66	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	2-8
11/8/65	1/31/68	Completed—Published as NCHRP Report 75	2-9
11/1/66	4/30/68	Completed—Published as NCHRP Report 80	2-10
1/1/67	7/31/70	Completed—Published as NCHRP Report 122	2-11
4/1/74	10/31/75	Completed—Report not published	2-12
10/11/76	5/31/77	Completed—Report published by AASHTO	2-12
7/18/83	3/31/85	Completed—Published as NCHRP Report 282	2-13
1/1/86	3/31/88	Completed—Published as NCHRP Report 307	2-14
1/13/86	9/30/89	Research in progress	2-15
3/2/87	6/30/90	Research in progress	2-16
24 months		In developmental stage	2-17
2/15/63	2/29/64	Completed—Report included in Phase II report	3-1
7/2/64	2/28/66	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	3-1
2/15/63	4/30/66	Completed—Published as NCHRP Reports 9, 28, 29	3-2
2/15/63	11/30/65	Completed—Published as NCHRP Report 51	3-3
3/1/63	3/31/65	Completed—Published as NCHRP Report 6	3-4
7/1/65	12/15/66	Completed—Published as NCHRP Report 40	3-4
3/1/63	12/31/65	Completed—Published as NCHRP Reports 3, 32	3-5
7/1/66	7/31/67	Completed—Published as NCHRP Report 73	3-5
8/1/68	12/31/69	Completed—Published as NCHRP Report 124	3-5
4/1/63	8/15/66	Completed—Published as NCHRP Reports 11, 41	3-6
2/1/64	4/30/67	Completed—Published as NCHRP Report 78	3-7
10/14/68	1/15/70	Completed—Published as NCHRP Report 117	3-7
4/1/71	6/30/72	Completed—Published as NCHRP Report 144	3-7
9/1/72	11/30/74	Completed—Published as NCHRP Reports 173, 174	3-7
12/1/63	12/31/64	Completed—Report included in NCHRP Report 50	3-8
4/1/65	1/6/67	Completed—Total project published as NCHRP Report 50	3-8
10/15/66	1/14/68	Completed—Published as NCHRP Report 84	3-9
1/1/66	3/10/67	Completed—Published as NCHRP Report 68	3-10
9/1/66	9/30/68	Completed—Published as NCHRP Report 110	3-11
10/1/66	12/31/67	Completed—Report included in NCHRP Report 123	3-12
4/1/68	12/1/69	Completed—Report included in NCHRP Report 123	3-12
3/29/71	12/11/72	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	3-12
9/1/67	11/30/69	Completed—Published as NCHRP Report 93	3-13
10/1/67	1/10/70	Completed—Published as NCHRP Report 113	3-14
10/1/69	12/31/73	Completed—Published as NCHRP Report 159	3-15
11/1/69	4/30/71	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	3-16
5/1/72	10/31/73	Completed—Published as NCHRP Report 175	3-16
1/1/71	11/30/72	Completed—Published as NCHRP Report 145	3-17
7/15/71	5/15/74	Completed—Report included in Phase II report	3-18(1)
4/15/75	6/30/77	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	3-18(1)
9/1/71	6/30/75	Completed—Published as NCHRP Report 194	3-18(2)
5/1/75	4/15/77	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	3-18(3)
7/21/77	11/20/80	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	3-18(4)
9/1/71	8/31/74	Completed—Published as NCHRP Report 185	3-19
9/1/72	4/15/74	Completed—Report included in Phase II report	3-20
11/1/74	12/31/76	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	3-20

TABLE 4 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA THREE (*Continued*)		
3-20A	Peak-Hour Traffic Signal Warrants	JHK & Assoc	150,000*
3-21	Motorist Response to Highway Guide Signing	BioTechnology	272,071*
3-21(2)	Effectiveness of Changeable-Message Displays in Advance of High-Speed Freeway Lane Closures	BioTechnology	170,993*
3-22	Guidelines for Design and Operation of Ramp Control Systems	Stanford Res Inst	199,030*
3-22A	Guidelines for Design and Operation of Ramp Control Systems	Texas A & M	249,538*
3-23	Guidelines for Uniformity in Traffic Control Signal Design Configurations	KLD Associates	308,779*
3-24	Determine the Luminous Requirements for Retroreflective Highway Signing	U of Michigan	100,000*
3-25	Cost and Safety Effectiveness of Highway Design Elements	Jorgensen & Assoc	260,576*
3-26	Investigation of Selected Noise Barrier Acoustical Parameters	Penn State U	224,494*
3-27	Guidelines for Selecting Traffic Signal Control at Individual Intersections	Voorhees & Assoc	150,000*
3-28	Development of an Improved Highway Capacity Manual	JHK & Assoc	161,000*
3-28A	Two-Lane, Two-Way Rural Highway Capacity	Texas A & M	157,492*
3-28B	New Highway Capacity Manual	Poly Inst of NY	283,440*
3-28C	Effects of Quality of Traffic Signal Progression on Delay	Texas A & M	165,000
3-28(2)	Urban Signalized Intersection Capacity	JHK & Assoc	331,000*
3-29	Traffic Signal Display Complexity	Systems Tech Inc	196,284*
3-30	Intersection Channelization	Jack Leisch Assoc	130,000*
3-31	Guidelines for Evaluating Alternatives for Replacing a Grade-Separated Rail/Highway Crossing	Ernst & Whinney	200,000
3-32	Temporary Pavement Markings for Work Zones	Texas A & M	164,990*
3-33	Capacity and Level-of-Service Procedures for Multilane Rural and Suburban Highways	JHK & Assoc	475,132
3-34	The Feasibility of a National Heavy-Vehicle Monitoring System	Arthur D. Little	499,791
3-35	Speed-Change Lanes	JHK & Assoc	250,000
3-36	Development of a Low-Cost Bridge Weigh-In-Motion System	Bridge Weighing Sys	400,000
3-37	Capacity of Ramp-Freeway Junctions	—	500,000
3-38(1)	Assessment of Alternative Technologies for Relieving Urban Traffic Congestion	Castle Rock Consult	199,752
3-38(1)A	A Study to Assess Advanced Vehicle and Highway Technologies	TRB	42,500
3-38(2)	Travel Characteristics of Large-Scale Suburban Activity Centers	JHK & Assoc	300,000
3-38(3)	Traffic Adaptive Control (Phase I)—Critical Intersection Control Strategies	Farradyne Systems	149,951
3-38(4)	Traffic Signal Control for Saturated Conditions	KLD Assoc	270,000
3-38(5)	Effective Utilization of Street Width	Midwest Res Inst	160,000
3-38(6)	Cost Sharing for Transportation Improvements Near Major Suburban Employment Centers	Indiana U Fdn	125,000
3-38(7)	Access Management Policies and Guidelines for Activity Centers	—	125,000
3-39	Evaluation and Calibration Procedures for Weigh-In-Motion Systems	Texas A&M	265,000
3-40	Single Point Urban Interchange Design and Operations Analysis	—	250,000
	AREA FOUR: MATERIALS AND CONSTRUCTION—GENERAL MATERIALS		
4-1	Development of Appropriate Methods for Evaluating the Effectiveness of Stabilizing Agents	U of Illinois	114,991*
4-2	A Study of Degrading Aggregates in Bases and Subbases with Production of Excessive Amounts of and/or Harmful Types of Fines	Purdue U	63,990*
4-3(1)	Development of Methods to Identify Aggregate Particles Which Undergo Destructive Volume Changes When Frozen in Concrete	V P I	20,000* 23,337*
4-3(2)	Development of Methods to Identify Aggregate Particles Which Undergo Destructive Volume Changes When Frozen in Concrete	Penn State U	56,457* 49,756*
4-4	Synthetic Aggregates for Highway Uses	Battelle Mem Inst	14,790*
4-5	A Study of the Mechanism Whereby the Strength of Bases and Subbases Is Affected by Frost and Moisture	Michigan Tech U	64,105*
4-6	Protective Coatings for Highway Structural Steel	Steel Str Paint	25,000*
4-7	Fatigue Strength of High-Yield Reinforcing Bars	P C A	100,000* 50,000*
4-8	Research Needs Relating to Performance of Aggregates in Highway Construction	V P I	55,254*
4-8(2)	Density Standards for Field Compaction of Granular Bases and Subbases	Clemson U	95,248*
4-8(3)	Predicting Moisture-Induced Damage to Asphaltic Concrete	U of Idaho	190,177* 70,860*
4-8(4)	Predicting Moisture-Induced Damage to Asphaltic Concrete—10-year Field Evaluation	U of Idaho	24,402*
4-9	Evaluation of Preformed Elastomeric Pavement Joint Sealing Systems and Practices	Utah DOT	93,494*

STARTING DATE	COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
6/23/80	7/31/82	Completed—Published as NCHRP Report 249	3-20A
4/1/74	1/31/76	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	3-21
12/1/79	8/31/81	Completed—Published as NCHRP Report 235	3-21(2)
4/15/74	12/31/75	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	3-22
2/1/77	3/31/81	Completed—Published as NCHRP Report 232	3-22A
4/8/74	7/28/77	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	3-23
9/1/74	4/30/77	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	3-24
7/15/75	4/16/78	Completed—Published as NCHRP Report 197	3-25
12/1/76	2/28/80	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	3-26
11/15/76	7/31/79	Completed—Published as NCHRP Report 233	3-27
12/15/77	8/15/79	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	3-28
5/1/80	2/28/83	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	3-28A
7/1/82	3/31/85	Completed—Published as Highway Capacity Manual (TRB Special Report 209)	3-28B
8/1/86	7/31/88	Report in review stage	3-28C
10/1/79	8/31/82	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	3-28(2)
7/1/83	3/31/86	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	3-29
7/1/83	5/15/85	Completed—Published as NCHRP Report 279	3-30
9/4/84	2/28/87	Completed—Published as NCHRP Report 288	3-31
5/1/85	2/28/87	Completed—Rep. not publ., for avail., see project writeup in latest Sum. of Prog.	3-32
6/1/85	5/31/89	Research in progress	3-33
11/1/85	9/30/88	Completed—Published as NCHRP Report 303	3-34
6/1/86	3/30/89	Report in review stage	3-35
2/16/87	8/16/89	Research in progress	3-36
36 months		In developmental stage	3-37
7/1/87	6/30/89	Research in progress	3-38(1)
18 months		In developmental stage	3-38(1)A
6/1/87	2/28/89	Research in progress	3-38(2)
9/1/87	6/30/89	Research in progress	3-38(3)
10/1/87	3/31/89	Research in progress	3-38(4)
4/1/88	4/1/90	Research in progress	3-38(5)
5/15/88	8/31/89	Research in progress	3-38(6)
18 months		In developmental stage	3-38(7)
3/1/88	2/28/89	Research in progress	3-39
21 months		In developmental stage	3-40
6/1/63	10/31/66	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	4-1
2/15/63	11/30/66	Completed—Published as NCHRP Report 98	4-2
3/1/63	9/30/64	Completed—Published as NCHRP Report 12	4-3(1)
7/1/65	3/31/67	Completed—Published as NCHRP Report 65	4-3(1)
3/25/63	1/31/65	Completed—Published as HRB Special Report 80 and NCHRP Report 15	4-3(2)
7/1/65	8/3/67	Completed—Published as NCHRP Report 66	4-3(2)
3/1/63	4/15/64	Completed—Published as NCHRP Report 8	4-4
2/15/63	8/31/65	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	4-5
3/1/65	11/30/66	Completed—Published as NCHRP Reports 74, 74A, 74B	4-6
10/1/67	2/28/70	Completed—Report included in NCHRP Report 164	4-7
2/1/71	8/31/73	Completed—Report included in NCHRP Report 164	4-7
1/1/68	4/30/69	Completed—Published as NCHRP Report 100	4-8
4/1/71	6/30/73	Completed—Published as NCHRP Report 172	4-8(2)
9/1/71	3/31/74	Completed—Published as NCHRP Report 192	4-8(3)
8/1/75	1/31/82	Completed—Published as NCHRP Report 246	4-8(3)
6/1/85	1/31/87	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	4-8(4)
10/1/68	6/30/71	Completed—Report included in Phase II report	4-9

TABLE 4 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA FOUR (*Continued*)		
4-9(1)	Preformed Elastomeric Pavement Joint Sealing Systems—Field Evaluation Phase	Utah DOT	144,837*
4-10	Promising Replacements for Conventional Aggregates for Highway Use	U of Illinois	50,000*
4-10A	Waste Materials as Potential Replacements for Highway Aggregates	Valley Forge Lab	53,663*
4-11	Buried Plastic Pipe for Drainage of Transportation Facilities	Simpson Gumpertz	200,000*
4-12	Upgrading of Poor or Marginal Aggregates for PCC and Bituminous Pavements	Penn State U	149,941*
4-13	Temporary Pavement Marking Systems	Sw Research Inst	49,500*
4-13A	Temporary Pavement Marking Paint Systems	Georgia Tech	69,971*
4-14	Coating Systems for Painting Old and New Structural Steel	Georgia Tech	199,302*
4-15	Corrosion Protection of Prestressing Systems in Concrete Bridges	Wiss, Janney, Elstner	250,000
4-16	Cost and Service Life of Pavement Markings	Penn State U	340,327
4-17	Environmental Monitoring and Evaluation of Calcium Magnesium Acetate (CMA)	U of Washington	199,943
	AREA FIVE: TRAFFIC—ILLUMINATION AND VISIBILITY		
5-2(1)	Effects of Illumination on Operating Characteristics of Freeways—Traffic Flow, Driver Behavior, and Accidents	Yale University	124,319* 21,530*
5-2(2)	Effects of Illumination on Operating Characteristics of Freeways—Driver Response, Visibility, and Visual Discomfort	Ohio State U	81,187*
5-2(3)	Effects of Illumination on Operating Characteristics of Freeways—Driver Discomfort	Inst for Research	37,460*
5-3	Visual Information Needed by the Driver at Night	Ohio State U	100,940*
5-4	Economic Study of Roadway Lighting	Franklin Inst	19,412*
5-5	Nighttime Use of Highway Pavement Delineation Materials	Sw Research Inst	50,000* 100,000*
5-5A	Development of Optimum Specifications for Glass Beads in Pavement Markings	Penn State U	99,350*
5-5B	Pavement Marking Systems for Improved Wet-Night Visibility Where Snowplowing Is Prevalent	Texas A & M	200,000*
5-6	Highway Fog	Cornell Aero Lab	99,955*
5-6A	Highway Fog	Sperry Rand	93,540*
5-7	Roadway Delineation Systems	Penn State U	469,526*
5-8	Warrants for Highway Lighting	Texas A & M	198,875*
5-9	Partial Lighting of Interchanges	KETRON, Inc	199,999*
5-10	A Mobile System for Measuring Retroreflectance of Traffic Signs	EKTRON Appl. Image.	199,094
5-11	Implementation Strategies for Sign Retroreflectivity Standards	—	200,000
	AREA SIX: MAINTENANCE—SNOW AND ICE CONTROL		
6-1	Development of Economical and Effective Chemical Deicing Agents to Minimize Injury to Highway Structures and Vehicles	IIT Research Inst	40,000*
6-2	Nonchemical Methods for Preventing or Removing Snow and Ice Accumulations on Highway Structures	Jorgensen & Assoc	25,000*
6-3	Development and Evaluation of Protective Coatings to Prevent Deterioration of Concrete Structures by Deicing Agents	Battelle Mem Inst	58,557*
6-4	Evaluation and Development of Methods for Reducing Corrosion of Reinforcing Steel	Battelle Mem Inst	39,330*
6-5	Study of Physical Factors Influencing Resistance of Concrete to Deicing Agents	U of Illinois	72,500*
6-6	To Evaluate Existing Methods and/or Develop Improved Methods for the Measurement of Certain Properties of Concrete	Ohio State U	69,393*
6-7	Estimation of Disintegration in Concrete Structures	Geotechnics	8,547*
6-7A	Estimation of Disintegration in Concrete Structures	IIT Research Inst	44,614*
6-8	Evaluation of Methods of Replacement of Deteriorated Concrete in Structures	Tallamy Assoc	25,000*
6-9	Potential Accelerating Effects of Chemical Deicing Damage by Traffic and Other Environmental-Induced Stresses in Concrete Bridge Decks	U of Illinois	200,000*
6-10	Develop Improved Snow Removal and Ice Control Techniques at Interchanges	Tallamy Assoc	95,000*
6-11	Economic Evaluation of the Effects of Ice and Frost on Bridge Decks	Midwest Res Inst	50,000* 50,000*
	AREA SEVEN: TRAFFIC—TRAFFIC PLANNING		
7-1	The Influence of Land Use on Urban Travel Patterns	Louis E. Keefer	62,674* 66,894*

STARTING DATE	COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
10/1/72	12/31/79	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	4-9(1)
10/15/69	3/31/71	Completed—Published as NCHRP Report 135	4-10
9/1/72	11/30/73	Completed—Published as NCHRP Report 166	4-10A
9/16/74	1/26/79	Completed—Published as NCHRP Report 225	4-11
12/1/76	5/31/79	Completed—Published as NCHRP Report 207	4-12
11/1/76	2/28/78	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	4-13
4/1/78	9/30/79	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	4-13A
1/1/78	12/31/81	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	4-14
7/1/82	11/30/85	Report in publication process	4-15
10/1/84	9/30/88	Report in review stage	4-16
1/7/85	10/31/87	Completed—Published as NCHRP Report 305	4-17
2/15/63	5/31/66	Completed—Report included in NCHRP Report 60	5-2(1)
2/1/67	7/31/67	Completed—Report included in NCHRP Report 60	5-2(1)
2/15/63	8/31/65	Completed—Report included in NCHRP Report 60	5-2(2)
2/20/63	2/28/66	Completed—Report included in NCHRP Report 60	5-2(3)
9/1/64	3/31/67	Completed—Published as NCHRP Report 99	5-3
7/20/64	8/31/65	Completed—Published as NCHRP Report 20	5-4
3/1/65	12/31/66	Completed—Published as NCHRP Report 45	5-5
7/15/67	9/15/69	Completed—Published as NCHRP Report 85	5-5
5/1/71	6/30/73	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	5-5A
9/1/71	12/31/74	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	5-5B
10/2/67	4/30/69	Completed—Published as NCHRP Report 95	5-6
9/1/70	5/31/73	Completed—Published as NCHRP Report 171	5-6A
10/1/68	6/30/71	Completed—Published as NCHRP Report 130	5-7
3/16/70	2/15/73	Completed—Published as NCHRP Report 152	5-8
12/1/80	1/31/83	Completed—Published as NCHRP Report 256	5-9
9/7/87	3/7/89	Research in progress	5-10
27 months		In developmental stage	5-11
2/15/63	9/30/64	Completed—Published as NCHRP Report 19	6-1
2/15/63	2/29/64	Completed—Published as NCHRP Report 4	6-2
3/1/63	2/28/65	Completed—Published as NCHRP Report 16	6-3
3/1/63	4/30/65	Completed—Published as NCHRP Report 23	6-4
3/1/63	8/31/65	Completed—Published as NCHRP Report 27	6-5
3/1/63	2/28/66	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	6-6
3/1/63	8/31/64	Contract terminated—no report; research resumed under Project 6-7A	6-7
2/1/65	7/31/66	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	6-7A
2/15/63	2/29/64	Completed—Published as NCHRP Report 1	6-8
1/1/65	6/15/68	Completed—Published as NCHRP Report 101	6-9
9/1/67	9/30/70	Completed—Published as NCHRP Report 127	6-10
9/1/70	11/30/71	Completed—Report included in Phase II report	6-11
9/12/72	9/11/74	Completed—Published as NCHRP Report 182	6-11
2/1/64	1/31/66	Completed—Published as NCHRP Report 24	7-1
4/1/66	9/30/67	Completed—Published as NCHRP Report 62	7-1

TABLE 4 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA SEVEN (*Continued*)		
7-2	Traffic Attraction of Rural Outdoor Recreational Areas	IIT Research Inst	24,652* 24,844*
7-3	Weighing Vehicles in Motion	Franklin Inst	73,391*
7-4	Factors and Trends in Trip Lengths	Voorhees & Assoc	89,250* 61,730*
7-5	Predicted Traffic Usage of a Major Highway Facility Versus Actual Usage	Yale University	99,675*
7-6	Multiple Use of Lands Within Highway Rights-of-Way	Barton-Aschman	24,220*
7-7	Motorists' Needs and Services on Interstate Highways	Airborne Instr	99,267*
7-8	User Cost and Related Consequences of Alternative Levels of Highway Service	Stanford Res Inst	99,070*
7-9	Development of Models for Predicting Weekend Recreational Traffic	Midwest Res Inst	74,983*
7-10	Peak-Period Traffic Congestion	Remak/Rosenbloom	49,624*
7-10(2)	The Institutional Aspects of Implementing Congestion-Reducing Techniques	Remak/Rosenbloom	74,703*
7-11	Low-Cost TSM Projects—Simplified Procedures for Evaluation and Setting Priorities	Multiplications Inc	199,988*
7-11A	Low-Cost TSM Projects—Simplified Procedures for Evaluation, Phase II	Texas A & M	150,000
7-12	Microcomputer Evaluation of Highway User Benefits	—	200,000
	AREA EIGHT: TRANSPORTATION PLANNING—FORECASTING		
8-1	Social and Economic Factors Affecting Travel	Vogt, Ivers	94,558*
8-2	Factors Influencing Modal Trip Assignment	IIT Research Inst	298,033*
8-3	Individual Preferences for Various Means of Transportation	U of Penn	63,282*
8-4	Criteria for Evaluating Alternative Transportation Plans	Northwestern U	89,900*
8-4A	Criteria for Evaluating Alternative Transportation Plans	U of Illinois	5,000*
8-5	Transportation Aspects of Land-Use Controls	Victor Gruen	25,967* 99,571*
8-6	Individual Preferences for Alternative Dwelling Types and Environments	U of N Carolina	99,897*
8-7	Evaluation of Data Requirements and Collection Techniques for Transportation Planning	Creighton-Hamburg	190,000*
8-7A	Data Requirements and Transportation Planning Procedures in Small Urban Areas	U of Tennessee	98,005*
8-8(1)	The Impact of Highways upon Environmental Values (Study Design)	M I T	29,654*
8-8(2)	The Impact of Highways upon Environmental Values (Study Design)	Daniel, Mann et al	28,950*
8-8(3)	The Impact of Highways upon Environmental Values	M I T	470,000*
8-9	Comparative Economic Analysis of Alternative Multimodal Passenger Transportation Systems	Creighton-Hamburg	100,000*
8-10	Planning and Design Guidelines for Efficient Bus Utilization of Highway Facilities	Wilbur Smith	149,907*
8-11	Social, Economic, Environmental Consequences of Not Constructing a Transportation Facility	DACP, Inc	364,363*
8-12	Travel Estimation Procedures for Quick Response to Urban Policy Issues	Metro Wash COG	39,895*
8-12A	Travel Estimation Procedures for Quick Response to Urban Policy Issues	COMSIS Corp	239,331*
8-13	Disaggregate Travel Demand Models	Chas River Assoc	100,000*
8-13(2)	Disaggregate Travel Demand Models	Chas River Assoc	200,000*
8-14	New Approaches to Understanding Travel Behavior	Boston College	144,135*
8-14A	New Approaches to Understanding Travel Behavior: Phase II	Chas River Assoc	221,250*
8-15	State and Regional Transportation Impact Identification and Measurement	Bigelow-Crain	80,000*
8-15A	Economic Impacts of State Transportation Policies and Programs	Reg Sc Res Inst	117,852*
8-16	Guidelines for Public Transportation Levels of Service and Evaluation	U of Tennessee	489,952*
8-17	Freight Data Requirements for Statewide Transportation Systems Planning	R. Creighton Assoc	231,147*
8-18	Techniques for Evaluating Options in Statewide Transportation Planning/Programming	Plng Envr Int/AMV	300,393*
8-19	The Relationship of Changes in Urban Highway Supply to Vehicle-Miles of Travel	Cambridge Syst Inc	199,954*
8-20	Improved Methods for Vehicle Counting and Determining Vehicle-Miles of Travel	Hamburg & Assoc	200,000*
8-21	Guidelines for Use of Vanpools and Carpools as a Transportation System Management Technique	Geo Washington U	265,486*
8-22	Transportation Financing Within the Context of Energy Constraints	System Des Concepts	100,000*
8-23	Fuel Supply Limitations and Passenger Travel	Chas River Assoc	110,000*
8-24	Forecasting the Basic Inputs to Transportation Planning	Hamburg & Assoc	81,000*
8-24A	Forecasting the Basic Inputs to Transportation Planning at the Zonal Level	COMSIS Corp	200,000
8-25	Intercity Bus Transportation Planning	Peat, Marwick et al.	200,000*
8-26	Development of Highway Traffic Data for Project Planning and Design in Urbanized Areas	JHK & Assoc	100,000*
8-27	Cost-Effectiveness of Transportation Services for Handicapped Persons	U of Tennessee	199,543*
8-28	Strategic Planning and Management for Transportation Agencies	Ernst & Whinney	180,000

STARTING DATE	COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
2/1/64	3/15/65	Completed—Report included in NCHRP Report 44	7-2
5/1/65	5/31/66	Completed—Total project published as NCHRP Report 44	7-2
2/1/64	8/31/67	Completed—Published as NCHRP Report 71	7-3
2/1/64	10/31/66	Completed—Published as NCHRP Report 48	7-4
10/23/67	1/10/69	Completed—Published as NCHRP Report 89	7-4
2/1/64	11/30/66	Completed—Published as NCHRP Report 58	7-5
2/1/66	2/28/67	Completed—Published as NCHRP Report 53	7-6
1/1/66	12/31/67	Completed—Published as NCHRP Report 64	7-7
9/1/70	4/15/72	Completed—Published as NCHRP Report 133	7-8
9/1/72	5/15/74	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	7-9
4/1/74	3/31/75	Completed—Published as NCHRP Report 169	7-10
4/1/75	11/30/78	Completed—Published as NCHRP Report 205	7-10(2)
4/6/81	11/30/83	Completed—Published as NCHRP Report 263	7-11
3/4/85	8/3/86	Completed—Published as NCHRP Report 283	7-11A
24 months		In developmental stage	7-12
2/1/64	9/23/66	Completed—Published as NCHRP Report 70	8-1
2/1/64	8/31/66	Completed—Published as NCHRP Report 57	8-2
2/1/64	3/31/65	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	8-3
2/1/65	8/1/67	Completed—Report included in NCHRP Report 96	8-4
10/14/68	1/10/69	Completed—Published as NCHRP Report 96	8-4A
4/1/65	5/31/66	Completed—Published as NCHRP Report 31	8-5
8/7/67	1/15/70	Completed—Published as NCHRP Report 121	8-5
2/14/66	3/13/68	Completed—Published as NCHRP Report 81	8-6
9/13/68	8/28/70	Completed—Published as NCHRP Report 120	8-7
6/1/73	6/14/75	Completed—Published as NCHRP Report 167	8-7A
9/16/68	3/14/69	Completed—Study design, not published	8-8(1)
9/9/68	3/7/69	Completed—Study design, not published	8-8(2)
9/15/69	7/31/74	Completed—Published as NCHRP Report 156	8-8(3)
9/1/71	1/31/73	Completed—Published as NCHRP Report 146	8-9
9/1/71	7/31/73	Completed—Published as NCHRP Reports 143 and 155	8-10
9/16/74	11/30/79	Completed—Phase I rep. not publ.; for avail., see project writeup in latest Sum. of Prog. Phase II report published as NCHRP Reports 216 and 217	8-11 8-11
9/3/74	12/31/75	Completed—Results published in 8-12A report	8-12
11/1/75	10/31/78	Completed—Published as NCHRP Reports 186 and 187	8-12A
9/15/74	1/31/76	Completed—Phase I rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	8-13
5/1/76	12/31/80	Completed—Published as NCHRP Report 253	8-13(2)
1/1/75	4/30/77	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	8-14
1/1/78	6/30/82	Completed—Published as NCHRP Report 250	8-14A
9/1/74	5/31/76	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	8-15
10/1/77	3/31/80	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	8-15A
1/1/76	12/31/80	Completed—Publ. as NCHRP Rep. 208, 209, 210, 211, 212	8-16
7/15/75	2/15/77	Completed—Published as NCHRP Reports 177 and 178	8-17
9/1/75	6/30/78	Completed—Published as NCHRP Reports 179 and 199	8-18
12/1/76	11/30/78	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	8-19
1/2/78	7/31/80	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	8-20
3/1/79	6/30/81	Completed—Guidelines published as NCHRP Report 241; research rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	8-21
3/26/79	2/27/81	Completed—Published as NCHRP Report 231	8-22
4/2/79	9/1/80	Completed—Published as NCHRP Report 229	8-23
1/21/80	4/30/82	Completed—Published as NCHRP Report 266	8-24
4/1/87	6/1/89	Research in progress	8-24A
4/1/80	1/31/82	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	8-25
5/15/81	12/31/82	Completed—Published as NCHRP Report 255	8-26
9/1/81	4/30/83	Completed—Published as NCHRP Reports 261 and 262	8-27
6/1/87	9/30/88	Report in review stage	8-28

TABLE 4 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA NINE: MATERIALS AND CONSTRUCTION—BITUMINOUS MATERIALS		
9-1	Asphalt Durability and Its Relation to Pavement Performance	American Oil	50,000* 50,000*
9-2	Asphalt Durability and Its Relation to Pavement Performance—Adhesion	Montana College	101,903*
9-3	Evaluation of Pavement Joint and Crack Sealing Materials and Practices	Rensselaer	24,996*
9-4	Minimizing Premature Cracking of Asphaltic Concrete Pavements	Materials R & D	99,560*
9-4A	Bayesian Analysis Methodology for Verifying Recommendations to Minimize Asphalt Pavement Distress	Woodward-Clyde	204,194*
9-5	Design of Emulsified Asphalt Paving Mixtures	Asphalt Inst	150,172*
9-6A	Development of Asphalt Aggregate Mixture Analysis System: Phase I	ARE Inc	25,000*
9-6B	Development of Asphalt Aggregate Mixture Analysis System: Phase I	Brent Rauhut Eng	25,000*
9-6C	Development of Asphalt Aggregate Mixture Analysis System: Phase I	U of Maryland	24,879*
9-6(1)	Development of Asphalt Aggregate Mixture Analysis System: Phase II	Brent Rauhut Eng	425,000
	AREA TEN: MATERIALS AND CONSTRUCTION—SPECIFICATIONS, PROCEDURES, AND PRACTICES		
10-1	Development of Guidelines for Practical and Realistic Construction Specifications	Miller-Warden	25,000*
10-2	Evaluation of Construction Control Procedures	Miller-Warden	59,750*
10-2A	Evaluation of Construction Control Procedures	Materials R & D	70,945*
10-3	Effects of Different Methods of Stockpiling and Handling Aggregates	Miller-Warden	25,000* 30,000*
10-4	Rapid Test Methods for Field Control of Construction	Clemson U	30,000* 69,320*
10-5	Density and Moisture Content Measurements by Nuclear Methods	Res Triangle Inst	28,801* 59,835*
10-5A	Optimization of Nuclear Density and Moisture Content Measurement Methods	N Carolina State U	51,214*
10-6	Measurement of Pavement Thicknesses by Rapid and Nondestructive Methods	IIT Research Inst	108,821*
10-7	Potential Uses of Sonic and Ultrasonic Devices in Highway Construction	Ohio State U	24,310*
10-8	Evaluating Procedures for Determining Concrete Pavement Thickness and Reinforcement Position	Pa Dept of Transp	151,982*
10-9	Criteria for Need of Seal Coats for Bituminous Pavements	U of Minnesota	50,000*
10-10	Acceptance Criteria for Electroslag Weldments in Bridges	US Steel	300,000*
10-11	Development of a Performance Specification for Bridge Deck Joint-Sealing Systems	Howard, Needles et al	29,996*
10-12	Acceptance of Aggregates Used in Bituminous Paving Mixtures	Texas A & M	174,411*
10-13	Ultrasonic Measurement of Weld Flaw Size	The Welding Inst	126,000* 250,000
10-14	Locating Voids Beneath Pavement Using Pulsed Electromagnetic Wave Techniques	Georgia Tech	99,850*
10-15	Structural Strength Evaluation of Existing Reinforced Concrete Bridges	Engrg Comp Corp	125,000* 100,000*
10-16	Assessment of Deficiencies and Preservation of Bridge Substructures Below the Waterline	Byrd, Tallamy et al	150,000*
10-17	Use of Antistripping Additives in Asphaltic Concrete Mixtures	David G. Tunnicliff	500,000
10-18	Specifying and Obtaining Entrained Air in Concrete	Const Tech Lab/PCA	73,585*
10-19	Adding Dust Collector Fines to Asphalt Paving Mixtures	Penn State U	49,926*
10-20	Elastomeric Bearings Design, Construction, and Materials	U of Washington	74,715* 150,000* 150,000
10-20A	High-Load, Multi-Rotational Bridge Bearings: Design, Materials, and Construction	—	250,000
10-21	Performance of Bridge Deck Concrete Subjected to Traffic-Induced Vibrations During Placement	TRB	25,000*
10-22	The Performance of Weathering Steel in Bridges	Sheladia Assoc	74,851* 120,699
10-23	Removal of Lead-Based Bridge Paints	Midwest Res Inst	81,118*
10-24	Rapid Replacement of PCC Pavement Segments	ARE Inc	240,000
10-25	Measurement of Cement and Water Content of Fresh Concrete	USACE Wtwys Exp Sta	149,995
10-25A	Instantaneous Determination of Water-Cement Ratio in Fresh Concrete	Wiss, Janney, Elstner	300,000
10-26	Data Bases for Performance-Related Specifications for Highway Construction	ARE Inc	60,000*
10-26A	Performance-Related Specifications for Hot Mix Asphaltic Concrete	Penn State U	250,000
10-27	Determination of Asphaltic Concrete Pavement Structural Properties by Nondestructive Testing	Texas A & M	450,000
10-28	A Method to Determine Deteriorated Areas in Portland Cement Concrete Pavements	Gulf Applied Res	199,784
10-29	Anchorage Zone Reinforcement for Post-Tensioned Concrete Girders	U of Texas	490,000

STARTING DATE	COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
2/1/64	7/31/65	Completed—Report included in NCHRP Report 67	9-1
11/1/65	4/30/67	Completed—Total project published as NCHRP Report 67	9-1
1/1/65	10/31/67	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	9-2
6/1/65	6/30/66	Completed—Published as NCHRP Report 38	9-3
11/1/71	6/30/73	Completed—Published as NCHRP Report 195	9-4
9/15/75	11/1/78	Completed—Published as NCHRP Report 213	9-4A
4/1/80	6/30/84	Completed—Published as NCHRP Report 259	9-5
6/2/86	10/2/86	Completed—Report not published	9-6A
6/2/86	10/2/86	Completed—Report not published	9-6B
6/2/86	10/2/86	Completed—Report not published	9-6C
1/5/87	11/4/88	Report in review stage	9-6(1)
11/15/63	11/14/64	Completed—Published as NCHRP Report 17	10-1
11/4/63	2/1/66	Completed—Published as NCHRP Report 34	10-2
7/15/66	11/14/67	Completed—Published as NCHRP Report 69	10-2A
10/22/63	4/30/64	Completed—Published as NCHRP Report 5	10-3
10/15/64	10/16/65	Completed—Published as NCHRP Report 46	10-3
2/1/64	2/28/65	Completed—Report included in NCHRP Report 103	10-4
5/1/65	2/28/67	Completed—Published as NCHRP Report 103	10-4
1/15/64	1/31/65	Completed—Published as NCHRP Report 14	10-5
4/1/65	10/7/66	Completed—Published as NCHRP Report 43	10-5
2/1/68	1/31/70	Completed—Published as NCHRP Report 125	10-5A
2/1/64	10/31/66	Completed—Published as NCHRP Report 52	10-6
2/1/64	3/31/65	Completed—Published as NCHRP Report 25	10-7
3/2/70	7/31/73	Completed—Published as NCHRP Report 168	10-8
11/1/69	2/28/74	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	10-9
5/1/74	9/30/78	Completed—Published as NCHRP Report 201	10-10
12/1/76	4/30/78	Completed—Published as NCHRP Report 204	10-11
9/1/77	6/30/81	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	10-12
7/1/79	10/31/81	Completed—Published as NCHRP Report 242	10-13
10/1/82	8/31/85	Report in revision stage	10-13
4/2/79	5/1/81	Completed—Published as NCHRP Report 237	10-14
4/1/80	9/30/82	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	10-15
4/1/84	4/30/86	Completed—Published as NCHRP Report 292	10-15
2/16/81	12/1/82	Completed—Published as NCHRP Report 251	10-16
3/1/81	7/1/89	Research in progress; laboratory phase published as NCHRP Report 274	10-17
5/4/81	6/1/83	Completed—Published as NCHRP Report 258	10-18
3/1/81	11/30/82	Completed—Published as NCHRP Report 252	10-19
2/1/81	6/30/82	Completed—Published as NCHRP Report 248	10-20
6/1/83	11/30/86	Completed—Published as NCHRP 298	10-20
6/1/86	5/31/89	Research in progress	10-20
30 months		In developmental stage	10-20A
2/1/80	9/30/81	Completed—Published as NCHRP Synthesis 86	10-21
4/1/82	2/29/84	Completed—Published as NCHRP Report 272	10-22
7/23/84	8/31/87	Report in review stage	10-22
7/1/82	6/30/83	Completed—Published as NCHRP Report 265	10-23
3/15/82	3/14/88	Completed—Rep. not publ.; summary of findings publ. in RRD 169; for avail., see project writeup in latest Sum. of Prog.	10-24
10/13/83	9/5/86	Completed—Published as NCHRP Report 284	10-25
6/1/85	12/31/88	Report in review stage	10-25A
6/15/83	9/14/84	Completed—Rep. not publ., for avail., see project writeup in latest Sum. of Prog.	10-26
1/6/86	6/6/88	Report in review stage	10-26A
9/17/84	8/31/89	Research in progress; Phase I report avail. on a loan basis from the NCHRP	10-27
11/1/85	12/31/87	Completed—Published as NCHRP Report 304	10-28
10/1/86	9/30/91	Research in progress	10-29

TABLE 4 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA TEN (*Continued*)		
10-30(1)	Nondestructive Methods for Field Inspection of Embedded or Encased High Strength Steel Rods and Cables	U of Manchester	25,000
10-30(2)	Nondestructive Methods for Field Inspection of Embedded or Encased High Strength Steel Rods and Cables	Sw Research Inst	25,000*
10-30(3)	Nondestructive Methods for Field Inspection of Embedded or Encased High Strength Steel Rods and Cables	U of Manchester	400,000
10-31	Acceptance Criteria for Steel Bridge Welds	Matls Res Lab Inc	348,350
10-32	Durability of In-Place Concrete Containing High-Range Water-Reducing Admixtures	Const Tech Lab/PCA	99,811
10-32A	Durability Testing of High-Strength Concrete Containing High-Range Water-Reducing Admixtures	Utah State U	249,238
10-33	Potential Benefits of Geosynthetics in Flexible Pavement Systems	Georgia Tech Res	100,000
10-34	Transient Protection, Grounding and Shielding of Electronic Traffic Control Equipment	Georgia Tech Res	179,992
10-35	Fatigue Behavior of Welded and Mechanical Splices in Reinforcing Steel	Wiss, Janney, Elstner	300,000
10-36	Evaluation of Weldments Incorporating Backing Materials	Fleet Technology	259,503
	AREA ELEVEN: ADMINISTRATION—LAW		
11-1	Rules of Compensability and Valuation in Highway Land Acquisition	U of Wisconsin	84,840*
11-1(1)	Eliminating Enhancement or Diminution Effects on Right-of-Way Valuation	Real Estate Res	5,000*
11-1(2)	Recognition of Benefits to Remainder Property in Highway Valuation	Montano & Assoc	5,000*
11-1(3)	Taxation Aspects of Right-of-Way Acquisition	U of Tulsa	2,250*
11-1(4)	Compensation in the Nature of Additives to Market Value	U of Oklahoma	2,500*
11-1(5)	Rules of Discovery and Disclosure in Highway Condemnation Proceedings	Long, Mikkelborg	2,500*
11-1(6)	Valuation and Condemnation Problems of Selected Special Purpose Properties	Edward E. Level	7,500*
11-1(7)	Valuation and Compensability of Noise, Pollution, and Other Environmental Factors	U of Oklahoma	2,500*
11-1(8)	Remainder Damages Caused by Drainage, Runoff, Blasting, and Slides	Harrison Lewis	7,500*
11-1(9)	Valuation and Condemnation Problems Involving Trade Fixtures	Edward L. Snitzer	5,000*
11-1(10)	Compensability and Valuation Aspects of Residential Displacement in Highway Programs	Ross, Hardies et al	5,000*
11-1(11)	Valuation Elements of Joint Development Projects, Including Air Rights	Real Estate Res	5,000*
11-2	Theory and Practice in Inverse Condemnation	Reg & Urban Plan	15,000*
11-3	Valuation and Legal Implications of Scenic, Conservation, and Roadside Easements	Sutte, Jr. & Assoc	25,000*
11-3(1)	Public Control of Roadside Advertising Signs for Highway Beautification	Sutte, Jr. & Assoc	20,000*
11-3(2)	Public Control of Junkyards for Highway Beautification	Real Estate Res	13,300*
11-4	Elimination of Wide Divergence in Right-of-Way Valuation	Am Inst Rl Est App	24,959*
11-5	Valuation of Air Space	Daniel, Mann et al	49,800*
11-6	Valuation and Compensability of Noise Pollution	Jack Faucett Assoc	94,744*
	AREA TWELVE: DESIGN—BRIDGES		
12-1	Deformation of Steel Beams Related to Permitted Highway Bridge Overloads	U of Missouri	50,000*
12-2	Distribution of Wheel Loads on Highway Bridges	Iowa State U	79,512*
12-3	Development of Waterproof Roadway Joints for Bridges	Sw Research Inst	149,895*
12-4	Thermal Characteristics of Highway Bridges	Sw Research Inst	102,400*
12-5	Protection of Steel in Prestressed Concrete Bridges	U of Denver	173,255*
12-6	Prediction of Permanent Camber of Bridges	U of Missouri	82,253*
12-7	Effects of Weldments on Fatigue Strength of Steel Beams	Lehigh University	199,023* 200,000*
12-8	Bridge Rail Service Requirements as a Basis for Design Criteria	Texas A & M	28,793* 69,753*
12-9	Elastomeric Bearing Research	Battelle Mem Inst	84,800*
12-10	Analysis and Design of Bridge Bents	PCA	297,900*
12-11	Waterproof Membranes for Protection of Concrete Bridge Decks	Materials R & D	206,025* 96,979*
12-12	Welded Steel Bridge Members Under Variable-Cycle Fatigue Loadings	US Steel	310,000*
12-13	Cathodic Protection for Reinforced Concrete Bridge Decks	USS Eng & Consult	174,601*
12-13A	Field Evaluation of Galvanic Cathodic Protection for Reinforced Concrete Bridge Decks	PCA	74,405*
12-14	Subcritical Crack Growth in Steel Bridge Members	US Steel	99,923*
12-15	Detection and Repair of Fatigue Cracking in Highway Bridges	Lehigh U	100,000*
12-15(2)	Retrofitting Procedures for Fatigue-Damaged Full-Scale Welded Bridge Beams	Lehigh U	150,000*
12-15(3)	Fatigue Behavior of Full-Scale Welded Bridge Attachments	Lehigh U	125,000*
12-15(4)	Steel Bridge Members Under Variable-Amplitude, Long-Life Fatigue Loading	Lehigh U	150,000*
12-15(5)	Fatigue Behavior of Variable-Loaded Bridge Details Near the Fatigue Limit	Lehigh U	399,999
12-16	Influence of Bridge Deck Repairs on Corrosion of Reinforcing Steel	Battelle Columbus	214,912*

STARTING DATE	COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
1/6/86	9/29/86	Completed—Rep. not publ., for avail., see project writeup in latest Sum. of Prog.	10-30(1)
1/20/86	10/3/86	Completed—Rep. not publ., for avail., see project writeup in latest Sum. of Prog.	10-30(2)
7/1/87	9/30/89	Research in progress	10-30(3)
1/1/86	12/31/89	Research in progress	10-31
1/6/86	7/5/87	Completed—Published as NCHRP Report 296	10-32
10/1/87	3/31/90	Research in progress	10-32A
1/6/86	12/15/88	Report in review stage	10-33
3/1/86	1/31/89	Report in revision stage	10-34
11/1/87	4/30/90	Research in progress	10-35
5/2/88	5/1/91	Research in progress	10-36
1/1/65	4/30/67	Completed—Published as NCHRP Report 104	11-1
9/2/68	2/28/69	Completed—Published as NCHRP Report 114	11-1(1)
10/1/68	3/31/69	Completed—Published as NCHRP Report 88	11-1(2)
9/16/68	4/30/69	No final report—Project terminated	11-1(3)
12/1/68	5/31/69	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	11-1(4)
9/15/68	4/14/69	Completed—Published as NCHRP Report 87	11-1(5)
9/2/68	11/28/69	Completed—Published as NCHRP Report 92	11-1(6)
10/1/68	3/31/69	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	11-1(7)
10/15/68	1/15/70	Completed—Published as NCHRP Report 134	11-1(8)
3/15/69	12/1/69	Completed—Published as NCHRP Report 94	11-1(9)
3/15/69	9/15/69	Completed—Published as NCHRP Report 107	11-1(10)
2/24/69	8/25/69	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	11-1(11)
2/1/65	6/30/66	Completed—Published as NCHRP Report 72	11-2
11/1/66	12/15/67	Completed—Published as NCHRP Report 56	11-3
10/1/68	12/31/69	Completed—Published as NCHRP Report 119	11-3(1)
9/2/68	2/28/70	Completed—Published as NCHRP Report 112	11-3(2)
7/1/69	2/28/71	Completed—Published as NCHRP Report 126	11-4
10/1/70	5/31/72	Completed—Published as NCHRP Report 142	11-5
4/1/74	7/31/75	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	11-6
2/1/65	6/30/67	Completed—Report included in Project 12-6 report	12-1
6/1/66	12/31/68	Completed—Published as NCHRP Report 83	12-2
12/15/65	3/14/69	Completed—Report available only to sponsors	12-3
12/15/65	3/31/68	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	12-4
9/15/66	11/15/68	Completed—Published as NCHRP Report 90	12-5
2/1/67	4/30/72	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	12-6
10/1/66	1/31/70	Completed—Published as NCHRP Report 102	12-7
7/1/70	12/31/72	Completed—Published as NCHRP Report 147	12-7
3/1/68	2/28/69	Completed—Published as NCHRP Report 86	12-8
1/2/70	6/30/71	Completed—Published as NCHRP Report 149	12-8
9/1/67	1/31/70	Completed—Published as NCHRP Report 109	12-9
1/1/70	12/31/73	Completed—Published as NCHRP Report 163	12-10
8/1/70	3/31/73	Completed—Published as NCHRP Report 165	12-11
7/15/73	9/30/78	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	12-11
10/1/70	10/31/75	Completed—Published as NCHRP Report 188	12-12
10/1/72	7/31/74	Completed—Published as NCHRP Report 180	12-13
8/1/75	5/15/81	Completed—Published as NCHRP Report 234	12-13A
10/1/72	6/30/74	Completed—Published as NCHRP Report 181	12-14
10/1/72	4/30/75	Completed—Published as NCHRP Report 206	12-15
6/1/76	11/30/78	Completed—Published as NCHRP Report 206	12-15(2)
2/1/78	7/31/80	Completed—Published as NCHRP Report 227	12-15(3)
4/1/80	9/30/83	Completed—Published as NCHRP Report 267	12-15(4)
9/1/83	12/31/89	Research in progress	12-15(5)
9/1/74	11/30/77	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	12-16

TABLE 4 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA TWELVE (*Continued*)		
12-17	Evaluation of Repair Techniques for Damaged Steel Bridge Members	Battelle Columbus	49,974*
12-17A	Guidelines for Evaluation and Repair of Damaged Steel Bridge Members	Shanafelt/Horn	99,950*
12-18	Development of an Integrated Bridge Design System	Multiplications Inc	224,985*
12-18A	Assessment of an Integrated Bridge Design System	Engrg Comp Corp	15,000
12-19	Cathodic Protection of Concrete Bridge Structures	Corrosion Eng & Res	250,000*
12-19A	Concrete Sealers for Protection of Bridge Structures	Wiss, Janney, Elstner	99,190*
12-19B	Cathodic Protection of Concrete Bridge Structures	Wiss, Janney, Elstner	138,900*
12-20	Bridges on Secondary Highways and Local Roads: Rehabilitation and Replacement	U of Virginia	119,923* 49,955*
12-21	Evaluation of Damage and Methods of Repair for Prestressed Concrete Bridge Members	G. O. Shanafelt Shanafelt/Horn	58,520* 129,934*
12-22	Thermal Effects in Concrete Bridge Superstructures	Engrg Comp Corp	100,000*
12-23	Recommended Revisions to the AASHTO *Manual for Maintenance Inspection of Bridges*	A. G. Lichtenstein	200,000
12-24	Design of Multi-Beam Precast Bridge Superstructures	U of Washington	149,879*
12-25	Fatigue and Fracture Evaluation for Rating Riveted Steel Bridges	Lehigh U	199,957*
12-26	Distribution of Wheel Loads on Highway Bridges	Imbsen & Assoc	300,000* 200,000
12-27	Welded Repair of Cracks in Steel Bridge Members	The Welding Inst	374,575
12-28(1)	Load Capacity Evaluation of Existing Bridges	Case Western Res U	302,000
12-28(2)	Bridge Management Systems	ARE Inc	225,000* 250,000
12-28(3)	Fatigue Evaluation Procedures for Steel Bridges	Case Western Res U	200,000*
12-28(4)	Methods of Strengthening Existing Highway Bridges	Iowa State U	164,985
12-28(5)	Standard Methodology for Conducting Condition Surveys of Concrete Bridge Components	New Mexico State U	98,338
12-28(6)	Distortion-Induced Fatigue Cracking in Steel Bridges	Lehigh U	250,000
12-28(7)	Guidelines for Evaluating Corrosion Effects in Existing Steel Bridges	Modjeski and Masters	298,644
12-28(8)	Improving Bridge Load Capacity Estimates by Correlation with Test Data	U of Tennessee	199,994
12-28(9)	Methods of Flaw Detection in Concrete Bridge Components	—	—
12-28(10)	Guidelines for Determining Redundancy in Steel Bridges	Lehigh U	299,995
12-28(11)	Development of Site-Specific Load Models for Bridge Rating	Imbsen & Assoc	200,000
12-28(12)	Inelastic Rating Procedures for Steel Beam and Girder Bridges	U of Minnesota	199,898
12-28(13)	Nondestructive Load Testing for Bridge Evaluation and Rating	Raths, Raths et al	150,000
12-29	Design of Simple-Span Precast Prestressed Bridge Girders Made Continuous	Constr Tech Lab/PCA	241,993
12-30	Fatigue of Cables in Cable-Stayed Bridges	Acer Freeman Fox Ltd	124,975
12-31	Notch Toughness Variability in Bridge Steel Plates	U of Texas	355,000
12-32	Evaluation of Bridge Deck Protective Strategies	U of Washington	92,515*
12-33	Development of a Comprehensive Bridge Specification and Commentary	Modjeski and Masters	295,000
12-33A	Development of a Comprehensive Bridge Specification and Commentary—Timber Structures and Code Calibration	Sensei Engineers	20,000
12-33B	Development of a Comprehensive Bridge Specification and Commentary—Concrete Structures	Imbsen & Assoc	20,000
12-34	Update of AASHTO *Standard Specifications for Highway Bridges:* Division II—Construction	Imbsen & Assoc	200,000
12-35	Recommended Specifications for the Design of Foundations, Retaining Walls, and Substructures	D'Appolonia	100,000
	AREA THIRTEEN: MAINTENANCE—EQUIPMENT		
13-1	Equipment Rental Rates	Ernst & Ernst	22,800*
	AREA FOURTEEN: MAINTENANCE—MAINTENANCE OF WAY AND STRUCTURES		
14-1	Upgrading of Unit Maintenance Cost Index and Development of Interstate Maintenance Requirements	Tallamy Assoc	205,128*
14-2	Techniques for Reducing Roadway Occupancy During Routine Maintenance Activities	Byrd, Tallamy et al	200,000*
14-3	Improved Pavement-Shoulder Joint Design	Georgia Tech	100,838*
14-4	Reconditioning Heavy-Duty Freeways in Urban Areas	Texas A & M	99,665*
14-5	Maintenance Levels-of-Service Guidelines	Woodward-Clyde	204,200*
14-5(2)	Maintenance Levels-of-Service Guidelines	Woodward-Clyde	107,950*
14-6	Evaluating Deferred Maintenance Strategies	ARE Inc	325,000*
14-7	Interactive Microcomputer Network for Innovative Maintenance Operations	Woodward-Clyde	75,000

STARTING DATE	COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
11/15/76	4/30/78	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	12-17
10/1/81	5/31/84	Completed—Published as NCHRP Report 271	12-17A
9/6/77	12/31/82	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	12-18
2/1/84	1/3/86	Completed—Report not published	12-18A
1/1/78	12/31/80	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	12-19
8/1/79	12/1/81	Completed—Published as NCHRP Report 244	12-19A
11/1/82	4/30/85	Completed—Published as NCHRP Report 278	12-19B
3/1/78	2/29/80	Completed—Published as NCHRP Report 222	12-20
6/1/80	11/30/81	Completed—Published as NCHRP Report 243	12-20
4/15/79	9/14/80	Completed—Published as NCHRP Report 226	12-21
5/15/82	7/8/85	Completed—Published as NCHRP Report 280	12-21
10/1/81	1/31/84	Completed—Published as NCHRP Report 276	12-22
1/3/89	1/2/91	Research to begin January 3, 1989	12-23
8/1/83	5/31/86	Completed—Published as NCHRP Report 287	12-24
9/1/84	9/30/87	Completed—Published as NCHRP Report 302	12-25
4/15/85	12/15/87	Completed—Rep. not publ.; for avail., see proj. writeup in latest Sum. of Prog.	12-26
8/22/88	5/21/90	Research in progress	12-26
10/15/84	2/28/89	Report in revision stage	12-27
9/1/85	8/31/89	Phase I rept. published as NCHRP Report 301; Phase II research in progress	12-28(1)
6/24/85	6/23/87	Completed—Published as NCHRP Report 300	12-28(2)
11/2/87	11/1/89	Research in progress	12-28(2)
7/1/85	9/30/87	Completed—Published as NCHRP Report 299	12-28(3)
7/1/85	7/31/87	Completed—Published as NCHRP Report 293	12-28(4)
8/1/85	8/31/87	Completed—Published as NCHRP Report 312	12-28(5)
10/1/85	6/30/89	Research in progress	12-28(6)
5/5/86	7/31/89	Research in progress	12-28(7)
2/1/86	2/19/88	Completed—Published as NCHRP Report 306	12-28(8)
—		Combined with Project 10-30(3)	12-28(9)
3/1/86	1/31/89	Report in review stage	12-28(10)
2/9/87	2/8/89	Research in progress	12-28(11)
9/1/87	11/30/89	Research in progress	12-28(12)
10/4/87	4/3/89	Research in progress	12-28(13)
8/26/85	5/31/88	Report in revision stage	12-29
1/13/86	2/12/89	Report in review stage	12-30
9/1/87	2/28/90	Research in progress	12-31
4/1/86	5/15/87	Completed—Published as NCHRP Report 297	12-32
7/1/88	12/31/91	Research in progress	12-33
9/16/88	12/31/91	Research in progress	12-33A
9/16/88	12/31/91	Research in progress	12-33B
10/19/87	10/18/89	Research in progress	12-34
			12-34
1/4/88	7/3/89	Research in progress	12-35
2/1/65	1/31/66	Completed—Published as NCHRP Report 26	13-1
3/1/65	3/31/67	Completed—Published as NCHRP Report 42	14-1
10/1/70	3/31/73	Completed—Published as NCHRP Report 161	14-2
9/11/72	3/15/76	Completed—Published as NCHRP Report 202	14-3
4/15/74	3/24/76	Completed—Published as NCHRP Report 196	14-4
1/1/78	4/30/80	Completed—Published as NCHRP Report 223	14-5
9/15/81	8/31/84	Completed—Published as NCHRP Report 273	14-5(2)
6/1/82	12/31/85	Completed—Published as NCHRP Report 285	14-6
9/1/87	2/1/89	Report in review stage	14-7

TABLE 4 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA FOURTEEN (*Continued*)		
14-8	Chip Seal Coats for High-Traffic-Volume Asphalt Concrete Pavements	Intermtn Res Fdn	240,000
14-9	Workshop on Research Needs in the Management of Highway Maintenance	TRB	42,000
14-10	Improvements in Data Acquisition Technology for Maintenance Management Systems	—	100,000
14-11	Effective Motivation of Highway Maintenance Personnel	—	200,000
	AREA FIFTEEN: DESIGN—GENERAL DESIGN		
15-1	Guardrail Design	Cornell Aero Lab	19,723*
15-1(2)	Guardrail Performance and Design	Sw Research Inst	280,000*
			100,000*
15-2	Design to Control Erosion in Roadside Drainage Channels	U of Minnesota	97,300*
15-3	Rational Structural Analysis and Design of Pipe Culverts	Northwestern U	49,937*
15-4	Estimating Runoff Rates from Small Rural Watersheds	Travelers Res Cen	299,902*
15-5	Dynamic Characteristics of Heavy Highway Vehicles	Gen Mot Corp	135,000*
15-6	Development of Criteria for Safer Luminaire Supports	Texas A & M	147,254*
15-7	Flow Modifications by Storage Loss Through Flood Plain Encroachment	Dames & Moore	99,730*
15-8	Parameters Affecting Stopping Sight Distance and Vehicle Acceleration/Deceleration Characteristics	U of Michigan	274,482*
15-9	Encasement of Pipelines Through Highway Roadbeds	Byrd, Tallamy et al	30,000
15-10	Development of a Design/Graphics Interface System	Beilfuss & Assoc	500,000
15-11	Computer-Aided Analysis of Highway Encroachments on Mobile Boundary Streams	Simons & Assoc	249,360
15-12	Roadway Width Standards for Low Traffic Volume Roads	—	250,000
	AREA SIXTEEN: DESIGN—ROADSIDE DEVELOPMENT		
16-1	Effects of Deicing Compounds on Vegetation and Water Supplies	V P I	217,300*
16-2	Evaluation of Research on Roadside Development	Western States	100,000*
16-3	Erosion Control During Highway Construction	Utah State U	179,224*
			70,776*
	AREA SEVENTEEN: TRAFFIC—SAFETY		
17-1	Development of Improved Methods for Reduction of Traffic Accidents	Cornell Aero Lab	247,847*
17-2	Methods for Evaluating Highway Safety Improvements	ORI	29,973*
17-2A	Methods for Evaluating Highway Safety Improvements	Jorgensen & Assoc	98,403*
17-3	Application of Traffic Conflicts Analysis at Intersections	Midwest Res Inst	190,000*
17-4	Evaluation of Traffic Controls for Street and Highway Work Zones	BioTechnology	200,000*
17-4(2)	Evaluation of Traffic Cones and Tubes for Street and Highway Work Zones	BioTechnology	125,000*
17-5	Effectiveness of Clear Recovery Zones	Midwest Res Inst	200,000*
17-6	Service Vehicle Lighting and Traffic Control Systems for Short-Term and Moving Work Zones—Phase I	BioTechnology	85,069
17-6A	Service Vehicle Lighting and Traffic Control Systems for Short-Term and Moving Work Zones—Phase II	Transp Res Corp	252,277
17-7	Guidelines for Converting STOP TO YIELD Control at Intersections	Bellomo-McGee Inc	200,000
17-8	Traffic Barrier and Control Treatments for Restricted Work Zones	Texas A&M	450,000
	AREA EIGHTEEN: MATERIALS AND CONSTRUCTION—CONCRETE MATERIALS		
18-1	Revibration of Retarded Concrete for Continuous Bridge Decks	U of Illinois	103,895*
18-2	Use of Polymers in Highway Concrete	Lehigh U	300,000*
18-2(2)	Polymer Concrete in Highway Bridge Decks	Lehigh U	30,000*
18-2(3)	Long-Term Rehabilitation of Salt-Contaminated Bridge Decks	Lehigh U	199,900*
	AREA NINETEEN: ADMINISTRATION—FINANCE		
19-1	Budgeting for State Highway Departments	Ernst & Ernst	45,000*
19-2(1)	Develop Performance Budgeting System to Serve Highway Maintenance Management	Booz·Allen & Ham.	6,000*
19-2(2)	Develop Performance Budgeting System to Serve Highway Maintenance Management	Ernst & Ernst	6,000*
19-2(3)	Develop Performance Budgeting System to Serve Highway Maintenance Management	Jorgensen & Assoc	6,000*
19-2(4)	Develop Performance Budgeting System to Serve Highway Maintenance Management	Jorgensen & Assoc	220,000*
19-3	Economic Effects of Changes in Legal Vehicle Weights and Dimensions on Highways	Wilbur Smith	96,728*

STARTING DATE	COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
7/6/87	10/5/90	Research in progress	14-8
6/12/88	6/15/88	See project writeup in latest Sum. of Prog.	14-9
12 months		In developmental stage	14-10
27 months		In developmental stage	14-11
12/15/65	6/14/66	Completed—Published as NCHRP Report 36	15-1
7/1/67	8/31/70	Completed—Published as NCHRP Reports 54, 115	15-1(2)
5/1/70	12/31/71	Completed—Published as NCHRP Reports 118, 129	15-1(2)
7/1/66	6/30/74	Completed—Ph. I rep. publ. as NCHRP Rep. 108	15-2
		Ph. II rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	15-2
10/1/67	12/31/68	Completed—Published as NCHRP Report 116	15-3
9/1/67	3/16/70	Completed—Published as NCHRP Report 136	15-4
8/15/67	1/10/69	Completed—Published as NCHRP Report 105	15-5
9/1/67	8/31/68	Completed—Published as NCHRP Report 77	15-6
5/1/80	1/31/82	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	15-7
5/1/82	5/31/84	Completed—Published as NCHRP Report 270	15-8
10/1/86	6/30/88	Completed—Published as NCHRP Report 309	15-9
8/1/85	11/30/88	Report in review stage	15-10
7/1/87	3/31/90	Research in progress	15-11
30 months		In developmental stage	15-12
3/1/66	4/30/72	Completed—Published as NCHRP Reports 91 and 170	16-1
10/1/67	3/31/69	Completed—Published as NCHRP Report 137	16-2
11/1/73	6/30/76	Completed—Rep. included in Phase II report	16-3
3/1/78	11/30/79	Completed—Published as NCHRP Reports 220, 221	16-3
2/1/66	5/31/68	Completed—Published as NCHRP Report 79	17-1
1/10/72	6/20/72	Contract terminated—no report; research resumed under Project 17-2A	17-2
2/1/73	7/31/74	Completed—Published as NCHRP Report 162	17-2A
12/15/77	10/31/79	Completed—Published as NCHRP Report 219	17-3
1/2/78	6/30/79	Completed—Rep. included in NCHRP Report 236	17-4
4/23/80	9/30/81	Completed—Published as NCHRP Report 236	17-4(2)
4/1/80	4/30/82	Completed—Published as NCHRP Report 247	17-5
11/1/82	7/24/84	Completed—Research continued as Project 17-6A	17-6
10/15/84	5/16/88	Report in review stage	17-6A
12/16/85	12/16/88	Research in progress	17-7
6/1/88	5/31/91	Research in progress	17-8
9/1/67	12/1/69	Completed—Published as NCHRP Report 106	18-1
10/1/72	9/30/75	Completed—Published as NCHRP Report 190	18-2
1/1/78	3/15/79	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	18-2(2)
5/1/80	4/29/83	Completed—Published as NCHRP Report 257	18-2(3)
9/5/67	9/4/68	Completed—Report not publ.; summarized in NCHRP Research Results Digest 20	19-1
9/2/68	10/31/68	Completed—working plan, not published	19-2(1)
9/2/68	10/31/68	Completed—working plan, not published	19-2(2)
9/2/68	10/31/68	Completed—Research continued as Project 19-2(4)	19-2(3)
2/1/69	11/30/71	Completed—Published as NCHRP Report 131	19-2(4)
9/15/70	6/14/72	Completed—Published as NCHRP Report 141	19-3

TABLE 4 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA TWENTY: SPECIAL PROJECTS		
20-1	Highway Research Information Service	HRB	455,000*
20-2	Research Needs in Highway Transportation	Tallamy/Smith	98,760*
20-3	Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control	Texas A & M	394,016* 200,540[a]
20-3A	Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control	U of Michigan	505,631* 20,000[b]
20-3B	Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control—Summary Reporting	Patrick J. Athol	31,116*
20-3C	Summary of the Lodge Freeway Research	Asriel Taragin	10,183*
20-3D	Summary of All Freeway Surveillance, Communication and Control Experience	Voorhees & Assoc	40,000*
20-4	Public Preference for Future Individual Transportation	Chilton Research National Analysts	195,260* 83,911*
20-5	Synthesis of Information Related to Highway Problems	TRB	550,000[c]
20-6	Legal Problems Arising out of Highway Programs	TRB	100,000[c]
20-7	Research for AASHTO Standing Committee on Highways		
	Task 1: Development of a Cost-Effectiveness Approach to the Programming of Roadside Safety Improvements	Texas A & M	32,837*
	Task 2: The Relation of Side Slope Design to Highway Safety	Texas A & M	104,088*
	Task 3: Development of an Effective Earth-Berm Vehicle Deflector	Texas A & M	33,973*
	Task 4: Lateral Accelerations and Lateral Tire-Pavement Forces in a Vehicle Traversing Curves Relative to Available Pavement Skid-Resistance Measures	Texas A & M	112,702*
	Task 5: Effect of Curb Geometry and Location	Texas A & M	49,996*
	Task 6: Development of Impact Attenuators Utilizing Waste Materials	Texas A & M	74,852*
	Task 7: Safety at Narrow Bridge Sites	Texas A & M	100,000*
	Task 8: Energy and Transportation Systems	CalDOT	104,440*
	Task 9: Review of Highway Management Studies Co-Sponsored by AASHTO and HUFSAM	Mgmt & Trans Assoc	49,820*
	Task 10: Review of Vehicle Weight/Horsepower Ratio as Related to Passing-Lane Design Criteria	Penn State U	15,493*
	Task 11: Longitudinal Occupancy of Freeways by Utilities	Byrd, Tallamy et al	50,000*
	Task 12: Guidelines for Citizen Participation in Transportation Planning	K. S. Hudson	15,500*
	Task 13: Guidelines for Safety Criteria for Low-Volume Roads	J. C. Glennon	33,226*
	Task 14: A Policy on Geometric Design of Highways and Streets	John F. Holman Co	98,563
	Task 15: Development of a Simplified Pavement Management System	ARE Inc	103,600*
	Task 16: Regulation of Movement of Hazardous Cargoes	D. M. Baldwin	7,341*
	Task 17: Evaluation of AASHO Road Test Satellite and Environment Studies	Texas A & M	94,402
	Task 18: Standard Specifications for Highway Bridges	Howard, Needles et al	110,000*
	Task 19: Engineering Aspects of Highway Traffic Safety in an Age of Limited Resources	TRB	25,000*
	Task 20: Vehicle Acceleration and Deceleration Characteristics	U of Michigan	25,000
	Task 21: Need for Pavement Markings on Low-Volume Roads	J. C. Glennon	25,000*
	Task 22: Encasement of Pipelines Through Highway and Railroad Roadbeds	Byrd, Tallamy et al	20,000*
	Task 23: Contracting Practices and Payment Procedures	Bergstralh-Shaw et al	80,340*
	Task 24: AASHTO Pavement Design Guide	McCullough/Finn	558,200*
	Task 25: STRS Support Task	TRB	52,640*
	Task 26: Research and Development Needs in Construction and Engineering Management	Bergstralh-Shaw et al	25,000*
	Task 27: Relationships Between Vehicle Configurations and Highway Design	TRB	50,593
	Task 28: AASHTO Guide for Design of Pavement Structures-Training Program	ARE Inc	135,000
	Task 29: Pavement Roughness and Rideability—Field Evaluation	JMJ Research	—
	Task 30: Manual on Subsurface Investigations	Adrian Pelzner	24,125*
	Task 31: Development of Comprehensive Bridge Specifications and Commentary	Modjeski and Masters	82,492*
	Task 32: Design and Construction Specifications for Segmental Concrete Bridges	Post-Tensioning Inst	74,585*
	Task 33: Study of FHWA Research Program	L. G. Byrd	50,000
	Task 34: AWS/AASHTO Bridge Welding Code	Warren G. Alexander	25,000
	Task 35: Review of Traffic Signal Intensity Standards	—	75,000
	Task 36: Critical Assessment of Tire Pressure Research	—	15,000
	Task 37: Development of an Asphalt Paving Handbook	TRB	45,000[d]
	Task 38: AASHTO Guidelines for Pavement Management Systems	—	75,000

STARTING DATE	COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
3/16/64	10/31/67	Completed—Informal publication only; service is operational	20-1
4/1/66	12/31/67	Completed—Published as NCHRP Report 55	20-2
12/15/66	1/31/69	Completed—Results summarized in Project 20-3C report	20-3
1/1/67	12/31/68		20-3
11/20/68	5/31/71	Completed—Results summarized in Project 20-3C report	20-3A
1/1/69	12/31/69		20-3A
7/1/72	9/27/74	Project terminated uncompleted; no reports prepared	20-3B
11/15/75	7/15/76	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	20-3C
5/15/77	12/31/78	Completed—Spec. publ.; for avail., see project writeup in latest Sum. of Prog.	20-3D
5/2/67	1/21/69	Completed—Published as NCHRP Reports 49, 82	20-4
5/2/67	1/2/68	Completed—Published as NCHRP Reports 49, 82	20-4
12/15/67	c	Research in progress: Topic reports published as NCHRP Syntheses 1 through 144	20-5
11/1/68	c	Research in progress: Refer to Tables 7 & 8 for publications	20-6
			20-7
12/2/68	3/31/72	Completed—Published as NCHRP Report 148	(Task 1) 20-7
12/2/68	1/31/74	Completed—Published as NCHRP Report 158	(Task 2) 20-7
12/2/68	3/3/71	Completed—Rep. not publ.; sum. in NCHRP Res. Results Digest 77	(Task 3) 20-7
12/2/68	7/15/71	Completed—Rep. not publ.; sum. in NCHRP Res. Results Digest 55	(Task 4) 20-7
11/1/71	10/31/72	Completed—Published as NCHRP Report 150	(Task 5) 20-7
11/1/71	1/2/74	Completed—Published as NCHRP Report 157	(Task 6) 20-7
7/2/73	6/3/75	Completed—Published as NCHRP Report 203	(Task 7) 20-7
12/1/75	10/1/79	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	(Task 8) 20-7
12/1/75	8/31/76	Completed—Report not publ.; available only to sponsors	(Task 9) 20-7
1/3/77	12/15/78	Completed—Report not publ.; available only to sponsors	(Task 10) 20-7
1/1/77	10/31/78	Completed—Report not publ.; available only to sponsors	(Task 11) 20-7
6/1/77	6/30/78	Completed—Report publ. by AASHTO	(Task 12) 20-7
7/1/77	9/30/78	Completed—Published as NCHRP Report 214	(Task 13) 20-7
4/3/78	4/30/84	Completed—Report published by AASHTO	(Task 14) 20-7
8/29/78	12/31/81	Completed—Phase I rep. publ. as NCHRP Report 215; Phase II rep. not publ., but available for loan	(Task 15) 20-7
9/4/79	5/31/80	Completed—Report not publ.; distributed to sponsors	(Task 16) 20-7
7/1/79	12/31/83	Completed—Report not publ.; for avail., see project writeup in latest Sum. of Prog.	(Task 17) 20-7
12/1/80	12/31/82	Completed—Report published by AASHTO	(Task 18) 20-7
5/19/81	2/15/82	Completed—Report not publ.; for avail., see project writeup in latest Sum. of Prog.	(Task 19) 20-7
—	—	Completed—Results published in NCHRP Report 270	(Task 20) 20-7
7/1/82	12/31/83	Completed—Report not publ.; for avail., see project writeup in latest Sum. of Prog.	(Task 21) 20-7
3/1/82	11/30/82	Completed—Report not publ.; for avail., see project writeup in latest Sum. of Prog.	(Task 22) 20-7
7/26/82	4/17/84	Completed—Report not publ.; for avail., see project writeup in latest Sum. of Prog.	(Task 23) 20-7
5/15/83	8/31/85	Completed—Report published by AASHTO	(Task 24) 20-7
3/1/84	5/7/84	Completed—Report available only to sponsors	(Task 25) 20-7
5/20/85	2/19/86	Completed—Report not publ.; for avail., see project writeup in latest Sum. of Prog.	(Task 26) 20-7
1/3/86	7/3/86	Completed—Report distributed to sponsors	(Task 27) 20-7
1/3/86	9/3/86	Completed—Rep. not publ., for avail., see project writeup in latest Sum. of Prog.	(Task 28) 20-7
—	—	Conducted under Project 1-23(2)	(Task 29) 20-7
12/12/86	9/30/87	Completed—Report being published by AASHTO	(Task 30) 20-7
10/15/86	10/14/87	Completed—Report distributed to program sponsors	(Task 31) 20-7
11/1/86	3/31/88	Completed—Report distributed to program sponsors	(Task 32) 20-7
9/29/86	7/31/87	Completed—Report distributed to program sponsors	(Task 33) 20-7
9/6/88	9/5/90	Research in progress	(Task 34) 20-7
12 months		In developmental stage	(Task 35) 20-7
8 months		In developmental stage	(Task 36) 20-7
4/15/88	10/15/89	Research in progress	(Task 37) 20-7
9 months		In developmental stage	(Task 38) 20-7

TABLE 4 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA TWENTY (*Continued*)		
	Task 39: Revision of the AASHTO Pavement Overlay Design Procedures	L. G. Byrd	75,000
	Task 40: Analytical Support for the Highway Research Coordinating Council	L. G. Byrd	10,000[e]
20-8	Interactive Graphic Systems for Highway Design	Control Data	49,672*
20-9	Socioeconomic Consequences of Right-of-Way Acquisition Induced Resident Dislocation	RMC Res Corp	202,579*
20-10	The Benefits of Separating Pedestrians and Vehicles	Stanford Res Inst	100,000*
20-10(2)	The Benefits of Separating Pedestrians and Vehicles	SRI International	100,000*
20-11	Toward Environmental Benefit/Cost Analysis—Measurement Methodology	Poly Inst of NY	100,000*
20-11A	Toward Environmental Benefit/Cost Analysis—Measurement Methodology	Cornell U	27,212*
20-11B	Toward Environmental Benefit/Cost Analysis: Energy-Flow Analysis (Manual)	Cornell U	140,450*
20-11C	Toward Environmental Benefit/Cost Methodology: Energy-Flow Analysis (Study Design)	The Cannon Group	14,786*
20-12	Effects of Air Pollution Regulations on Highway Construction and Maintenance	Howard, Needles et al	80,446*
20-13	Beneficial Environmental Effects Associated with Freeway Construction	Penn State U	49,965*
20-14	Monitoring Carbon Monoxide Concentrations in Urban Areas	Technol Serv Corp	99,973*
20-14A	Statistical Analysis of Ozone Data for Transportation/Air Quality Planning	SRI International	193,907*
20-15	Ecological Effects of Highway Fills on Wetlands	U of Mass	152,085*
20-16	State Laws and Regulations on Truck Size, Weight, and Speed	R. J. Hansen Assoc	281,975*
20-17	Statewide Freight Demand Forecasting Procedures	Cambridge Syst Inc	73,151*
20-17A	Application of Statewide Freight Demand Forecasting Techniques	R. Creighton Assoc	193,500*
20-18	Evaluation of Highway Air Pollution Dispersion Models	SRI International	207,509*
20-19	Pedestrian Convenience and Safety on Suburban and Rural Highways	JHK & Assoc	160,000*
20-19(2)	Pedestrian Safety and Convenience on Suburban and Rural Highways—Implementation Phase	JHK & Assoc	125,000
20-20	SHRP Pre-Implementation Research	AASHTO	500,000
20-20(2)	SHRP Overview and Integration Planning	U of Maryland	90,000*
20-20(3)	SHRP Detailed Planning for Research on Asphalt Properties	ARE Inc	115,000*
20-20(5)	SHRP Detailed Planning for Research on Maintenance Effectiveness	Texas Res & Devel	90,000*
20-20(6)	SHRP Detailed Planning for Research on Bridge Component Protection	David G. Manning	80,000*
20-20(7)	SHRP Detailed Planning for Research on Cement and Concrete	Const Tech Lab/PCA	75,000*
20-20(8)	SHRP Detailed Planning for Research on Snow and Ice Removal	USA CRREL	73,781*
20-21	Development of an Automated Field Survey Data Collection System	ARE Inc/Cooper Tech	200,000
20-22	Factors to be Considered by Highway Agencies in the Identification and Remediation of Hazardous Waste Sites	HMM Assoc	148,015
20-23	Kinematic Differential GPS Satellite Surveying	GPS Services/NGS	298,793
20-24	Research Program Design—Administration of Highway and Transportation Agencies	Apogee Research Inc.	125,000
20-24(1)	Using Market Research to Improve the Management of Transportation Systems	Apogee Research Inc.	200,000
20-25	Training Needs for Highway Construction Personnel	—	75,000
20-26	Bond and Insurance Coverages for Highway Construction Contractors	—	100,000
	AREA TWENTY-ONE: SOILS AND GEOLOGY—TESTING AND INSTRUMENTATION		
21-1	Instrumentation for Measurement of Moisture	Res Triangle Inst	35,027*
21-2	Instrumentation for Moisture Measurement—Bases, Subgrades, and Earth Materials (Sensor Development)	Sw Research Inst	64,976*
21-2(2)	Instrumentation for Moisture Measurement—Bases, Subgrades, and Earth Materials (Sensor Development)	SUNY Buffalo	29,953*
21-2(3)	Instrumentation for Moisture Measurement—Bases, Subgrades, and Earth Materials (Sensor Evaluation)	Sw Research Inst	154,452*
	AREA TWENTY-TWO: DESIGN—VEHICLE BARRIER SYSTEMS		
22-1	Concepts for Improved Traffic Barrier Systems	Walter W. White	25,000*
22-1A	Testing and Evaluation of Bridge Rail Concepts	Texas A & M	40,000*
22-2	Traffic Barrier Performance and Design	Sw Research Inst	125,000* 80,000*

STARTING DATE	COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
12 months		In developmental stage	(Task 39) 20-7
9/1/88	8/31/89	Research in progress	(Task 40) 20-7
9/1/70	7/31/71	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	20-8
8/1/72	12/17/76	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	20-9
8/26/74	4/30/76	Completed—Published as NCHRP Report 189	20-10
9/1/78	7/31/81	Completed—Published as NCHRP Report 240	20-10(2)
9/1/72	5/31/74	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	20-11
9/1/75	11/30/76	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	20-11A
1/24/77	5/4/79	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.; sum. in NCHRP Res. Results Digest 114	20-11B 20-11B
4/1/77	3/31/78	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	20-11C
4/1/74	7/31/75	Completed—Published as NCHRP Report 191	20-12
9/3/74	8/2/75	Completed—Published as NCHRP Report 193	20-13
10/1/76	3/31/78	Completed—Published as NCHRP Report 200	20-14
9/15/79	12/18/81	Completed—Published as NCHRP Report 238	20-14A
12/1/76	12/31/79	Completed—Published as NCHRP Reports 218A and 218B	20-15
10/11/76	9/1/78	Completed—Published as NCHRP Report 198	20-16
4/1/79	7/31/80	Completed—Rep. not publ.; for avail., see proj. writeup in latest Sum. of Prog.	20-17
6/1/81	1/31/84	Completed—Published as NCHRP Report 260	20-17A
3/15/79	2/28/82	Completed—Published as NCHRP Report 245	20-18
5/1/85	12/31/86	Completed—Published as NCHRP Reports 294A and 294B	20-19
9/1/87	3/31/89	Report in review stage	20-19(2)
10/1/84	9/30/86	Completed—See proj. writeup for report availability	20-20
3/15/85	5/31/86	Completed—Rep. not publ.; for avail., see latest Sum. of Prog.	20-20(2)
3/15/85	1/31/86	Completed—Rep. not publ.; for avail., see latest Sum. of Prog.	20-20(3)
3/15/85	1/31/86	Completed—Rep. not publ.; for avail., see latest Sum. of Prog.	20-20(5)
3/15/85	1/31/86	Completed—Rep. not publ.; for avail., see latest Sum. of Prog.	20-20(6)
3/15/85	1/31/86	Completed—Rep. not publ.; for avail., see latest Sum. of Prog.	20-20(7)
4/12/85	2/26/86	Completed—Rep. not publ.; for avail., see latest Sum. of Prog.	20-20(8)
2/3/86	5/5/87	Completed—Published as NCHRP Report 295	20-21
11/1/86	7/1/88	Completed—Published as NCHRP Report 310	20-22
9/15/88	9/14/90	Research in progress	20-23
5/11/87	9/30/88	Report in review stage	20-24
10/1/88	9/30/89	Research in progress	20-24(1)
12 months		In developmental stage	20-25
16 months		In developmental stage	20-26
8/25/69	2/24/71	Completed—Published as NCHRP Report 138	21-1
2/1/72	1/31/74	Completed—Report not publ.; included in Project 21-2(3) report	21-2
4/1/72	9/30/73	Completed—Report not publ.; included in Project 21-2(3) report	21-2(2)
9/3/74	12/31/79	Completed—Report not publ.; agency rep. avail. for loan	21-2(3)
10/1/70	12/31/71	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	22-1
3/1/74	5/30/75	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.; sum. in NCHRP Res. Results Dig. 81	22-1A 22-1A
1/1/72	9/30/73	Completed—Phase I and Phase II (Task 1) reports not published; for avail., see project writeup in	22-2
10/1/73	3/31/75	latest Sum. of Prog.; sum. in NCHRP Res. Results Digests 84 and 102; Task 2 rep. publ. as NCHRP Rep. 153	22-2 22-2

TABLE 4 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA TWENTY-TWO (*Continued*)		
22-2(2)	Multiple Service Level Highway Bridge Railings—Performance and Design Criteria	Sw Research Inst	195,000*
22-2(3)	Multiple Service Level Highway Bridge Railings—Selection Procedures	Sw Research Inst	200,000*
22-2(4)	Procedures for Testing Highway Appurtenances	Sw Research Inst	30,000*
22-3	Field Evaluation of Vehicle Barrier Systems	Calspan Corp	25,000*
22-3A	Field Evaluation of Vehicle Barrier Systems	Arthur L. Elliott	10,000*
22-4	Performance of Longitudinal Traffic Barriers	Southwest Res Inst	503,954*
22-5	Develop Performance Standards and Hardware for Low Service Level Guardrail Systems	Southwest Res Inst	200,000
22-6	Roadside Safety Design for Small Vehicles	Texas A & M	350,000
22-7	Update of "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances"	—	200,000
22-8	Evaluation of Performance Level Selection Criteria for Bridge Railings	—	200,000
	AREA TWENTY-THREE: SOILS AND GEOLOGY—PROPERTIES		
	No Projects		
	AREA TWENTY-FOUR: SOILS AND GEOLOGY—MECHANICS AND FOUNDATIONS		
24-1	Manual on Subsurface Investigations	Haley & Aldrich	75,000*
24-2	Reinforcement of Earth Slopes and Embankments	Dames & Moore	150,000
24-3	Laboratory Evaluation of Piles Installed with Vibratory Drivers	U of Houston	200,000
24-4	Load Factor Design Criteria for Highway Structure Foundations	VPI	375,000
24-5	Downdrag on Bitumen-Coated Piles	Texas A&M	200,000
	AREA TWENTY-FIVE: TRANSPORTATION PLANNING—IMPACT ANALYSIS		
	This area became effective January 1, 1979, and includes only those projects beginning with the FY 1981 program. Refer to Areas 7, 8, and 20 for previous projects in the realm of Impact Analysis.		
25-1	Effects of Highway Runoff on Wetlands	Rexnord, Inc	162,189*
25-2	Predicting Stop-and-Go Traffic Noise Levels	Vanderbilt U	64,999
25-3	Guidelines for the Development of Wetland Replacement Areas	—	299,711

* Final contract cost. ** Addresses: Publications Office, Transportation Research Board, 2101 Constitution Avenue NW, Washington, D.C. 20418; American Association of State Highway and Transportation Officials, 444 North Capitol Street NW, Washington, D.C. 20001.

[a] NCHRP funds obligated under the $314,340 four-way agreement among the National Academy of Sciences, Michigan Department of State Highways, Wayne County, and the City of Detroit.

STARTING DATE	COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
8/1/76	4/30/79	Completed—Agency reps. on Ph. I and Ph. II avail. for loan	22-2(2)
1/1/79	5/31/81	Completed—Published as NCHRP Report 239	22-2(3)
5/1/79	2/28/81	Completed—Published as NCHRP Report 230	22-2(4)
1/1/74	2/15/75	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.; sum. in NCHRP Res. Results Dig. 76	22-3 22-3
7/1/74	12/31/74	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.; sum. in NCHRP Res. Results Dig. 76	22-3A 22-3A
7/1/83	7/15/87	Completed—Published as NCHRP Report 289	22-4
5/1/85	1/31/89	Report in review stage	22-5
6/1/85	6/30/88	Report in revision stage	22-6
30 months		In developmental stage	22-7
21 months		In developmental stage	22-8
4/2/79	12/31/80	Completed—Report to be published by AASHTO	24-1
8/22/83	5/21/87	Completed—Published as NCHRP Report 290	24-2
1/6/86	8/31/88	Report in revision stage	24-3
9/1/87	5/31/90	Research in progress	24-4
6/15/88	6/14/91	Research in progress	24-5
2/16/81	3/16/84	Completed—Published as NCHRP Report 264	25-1
1/18/88	1/17/89	Report in review stage	25-2
27 months		Contract pending	25-3

[b] NCHRP funds obligated under the $70,000 five-way agreement among the National Academy of Sciences, Michigan Department of State Highways, Wayne County, the City of Detroit, and the University of Michigan.

[c] Continuing activity. Amount shown is for latest fiscal year in which funding was provided.

[d] NCHRP funds obligated under the $150,000 five-way agreement among the National Asphalt Pavement Association (NAPA), AASHTO, FHWA, U.S. Army Corps of Engineers, and Federal Aviation Administration (FAA).

[e] NCHRP funds obligated under the $30,000 three-way agreement among AASHTO, FHWA, and U.S. Army Corps of Engineers.

TABLE 5
EXAMPLES OF UTILIZATION OF NCHRP RESULTS*

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
1-1	Reports 2, 2A	Illinois Div. of Hwys., Bur. of Res. and Devel.	In studies of existing pavements and the rehabilitated AASHTO Road Test project at Ottawa, Ill. Particular use made of recommendations for experimental designs, measurement programs, and data processing analysis.
		Conn. DOT	To design experimental pavement projects.
1-2	Report 7	N. Y. DOT	To develop a flexible pavement performance equation; in use June 1968.
		Tallamy, Byrd,—	In study of highway maintenance quality levels for Ohio Dept. of Hwys.
1-3(2)	Report 22	Conn. DOT	In evaluating flexible experimental pavements.
1-3(3)	Report 35	Conn. DOT	In evaluating flexible experimental pavements.
1-4	Report 10	Conn. DOT	In analyses of data from experimental pavements.
1-4(2)	Report 30	Conn. DOT	In evaluating flexible experimental pavements.
1-5	Report 21	Conn. DOT	In evaluating flexible experimental pavements.
1-5(2)	Report 76	N. Dak. SHD	Major equipment purchase based on successful use of similar equipment in conduct of project.
		Conn. DOT	In evaluating flexible experimental pavements.
1-7	Report 37	Nat'l. Hwy. Safety Bur.	In preparation of a *Highway Safety Program Manual* for issuance to the States.
		92nd Cong., 1 Sess.	House of Representatives subcommittee hearings on highway safety and skidding.
		Conn. DOT	As justification to establish skid test program in Connecticut.
1-8	Agency final report	Consult. for USN and USAF	Development of new approach to pavement design for heavy aircraft loadings; used for redesign of Salt Lake City runway to accommodate B747 aircraft and in design of runway, taxiways, and aprons at Air Force Plant No. 42 near Palmdale, Calif., where design load is 500 tons (gross) from B2707 (SST) configuration.
1-9	Report 61	Calif. Div. of Hwys.	In evaluation of proposed State legislation regarding use of studded tires.
		Conn. DOT	In providing documentation for studded tire legislation.
1-10	Agency final report	Consult. for USN and USAF	See Project 1-8.
1-11	Agency report	U.S. Forest Serv.	In preparation of an Engineering Technical Report evaluating several commonly accepted pavement design methods, as to their applicability for design of pavement systems for Forest Service roads.
		AASHTO	Partly published as *Interim Guide for Design of Pavement Structures, 1972*
1-12	—	92nd Congress, 1st Sess.	House of Representatives subcommittee hearings on highway safety and skidding.
	Report 154	Conn. DOT	As background information on skid-testing program.
1-12(2)	—	92nd Cong., 1 Sess.	See Project 1-12.
	Report 151	Conn. DOT	As background information on skid-testing program.
		N. Y. DOT	Leans heavily on the suggestions presented when purchasing or altering skid trailers and when modifying operational procedures.
		ASTM	As basis for updating ASTM Method E274.
1-12(3)	—	92nd Cong., 1 Sess.	See Project 1-12.
1-14	Agency final report	Va. DOT	Safety Committee reviewed agency recommendations for improvements at high accident site, with resulting request for FHWA approval as an Interstate Safety Project.
1-17	Report 224	Washington DOT	In the design of pavement rehabilitation programs.
		Japan Road Contractors Association	Translated in Japanese.
1-18	Report 228	World Bank	Basis for designing an international calibration exercise for road meters.
1-19	Agency interim report	FHWA	As input to FHWA-AASHTO Long-Term Pavement Monitoring Program documents.
		Illinois DOT	As reference for identifying concrete pavement distress.
1-21	Agency draft guide, "Specs. for Joint Repair"	FHWA	As input to internal publication titled, "Construction Handbook on PCC Pavement Rehabilitation."
		Penn. DOT	As a guide for developing policies and repair techniques.
2-5	Reports 13, 111	One State (unkn.)	To replace outdated material in AASHTO book, *Urban Freeway Design.*
2-5A	Report 111	AASHTO	In draft of proposed AASHTO publication, *A Policy on Arterial Highways in Urban Areas.*
		W. W. Rankin, I.T.E.	In preparing textbook on traffic engineering.
2-6	Report 63	E. L. Grant, W. G. Ireson	In textbook, *Principles of Engineering Economy.*

* Project titles, as well as project status, are given in Table 4. Publication titles are given in Tables 6 and 7.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
2-11	Report 122	World Bank	For teaching purposes by the Economic Development Institute of the International Bank for Reconstruction and Development.
2-12	Agency rep. and Rep. 111	Federal Supply Serv., Gen. Serv. Adm.	Vehicle operating cost data applied in review of Govt. employee automobile costs.
	Agency report	J. Leisch & Assoc.	As an aid in conducting a planning-design course for the South Carolina SHD in coordination with the Governor's Safety Program.
		AASHTO	Published by AASHTO as *A Manual on User Benefit Analysis of Highway and Bus Transit Improvements.*
		Colorado SHD	As a partial basis for development of the State's "Benefit/Cost Analysis Manual."
3-2	Reports 9, 29	Illinois Div. of Hwys., Bur. of Traffic	In a FAI 80 Motorist Communication project. Also, more emphasis being placed on influence of pedestrians on signal timing, because signals in small cities are almost always in the CBD where there are many pedestrians.
3-4	Reports 6, 40	Calif. Div. of Hwys.	Source of background information for highway and law enforcement officials facing problem decisions on location of disabled or stopped vehicles.
3-5	Reports 3, 32, 73, 124	D.C. Dept. of Hwys. and Traffic	Incremental travel cost technique applied to a comprehensive determination of existing effectiveness of operation in D.C. traffic signal system. Annual incremental travel costs in D.C. system were estimated and used in benefit/cost analysis of traffic signal system improvement alternatives.
		Minn. DOH	Steps taken toward implementation of the delay difference offset technique in an existing signal network.
		Calif. Div. of Hwys.	Source of information to supplement and improve the effectiveness with which the Division can carry out its program of reducing delay to the motorist. Also of value in designing innovative signals; in fact, the Division engaged the principal investigator on a consulting basis to help simulate different levels of traffic for a project under design in Riverside County.
	Agency final report	Goodell, Grivas and Assoc.	Obtained contract to use model described in report on a network in Detroit.
3-7	Reports 78, 117 and "Illustrative Recording of Traffic Noise"	Hwy. Depts., FHWA offices, universities, consulting firms, County Bd. of Educ.	Demand for the tape has been large, and loan copies have been circulated widely. Although the principal use of the tape has been educational in nature, one County Board of Education was so impressed with the noise differential between open and closed window situations that consideration was given to installation of air conditioning and storm windows for school buildings adjacent to freeways.
		Georgia SHD	Noise design guide used in design of urban freeway system.
		Minnesota Legislature	For demonstration purposes in hearings by House "Transportation" Committee, and Senate "Highways" and "Natural Resources and Environment" Committees. Both Senate committees took favorable action on a Truck Noise Control bill patterned after the California law.
		Virginia DOH	To evaluate noise for several proposed highways and to make subsequent explanations to the public on the impact of the noise on the community. One instance involved I-195, a six-lane depressed highway in a residential area of Richmond. Using the computer program from *Report 78,* peak-hour traffic was used to project the noise levels; comparisons were made with actual readings taken in the area. Another case involved projecting noise levels on I-66 in the vicinity of Washington, D.C., to determine if they would be within an acceptable limit. Revisions were made in the cross sections where estimates exceed the acceptable limit. The Department estimates that almost $18,000 was saved by doing the evaluation work in-house, rather than contracting it. Annual savings of $50,000 to $75,000 have been forecast in the instance of standard evaluations of major projects.
		Arizona cons. firm	In design and location of a 4.5-mi segment of I-10 (Papago Freeway) traversing a high-density area of downtown Phoenix. Recommendations made are expected to substantially reduce noise levels in areas adjacent to the Freeway.
		Natl. Assn. of Home-builders	In development of a *Builders' Acoustical Manual* that includes guidelines for prediction of site noise due to traffic.
		Missouri SH Comm.	Highway traffic noise simulation program used to establish noise projections on new project designs.
		FHWA	In developing highway noise level standards PPM 90-2, "Interim Noise Standards and Procedures for Implementing Section 109(I) 23 U.S.C."
		Louisiana DOH	As primary texts in a "noise school" for parish (county) engineers.
		AASHTO	As source documents for new (1974) publication, "Guide on Evaluation and Attenuation of Traffic Noise."
	Report 117	Howard, Needles, et al.	Model for predicting highway traffic noise validated under contract to a state highway department.
		Express Hwy. Res. Fdn. (Japan)	Abridgment (8 pp.) published in April 1972 issue of *Expressways and Automobiles* (in Japanese).

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
		Colorado DOH	Projected noise study based on a U.S. DOT program developed directly from this report, considered to represent the best study procedure from available empirical and theoretical research on highway noise.
		Minnesota DOH	Predictions for use in design of I-35W noise barrier in S. Minneapolis.
	Agency final rep. draft	Envir. Protection Agency	In evaluating alternatives for truck noise emission regulations.
	Agency final rep.	Nat. Bur. Stand.	Published a form of the Noise Prediction Nomogram adapted to an "L-equivalent" measure.
		Md.-Natl. Cap. Park and Plan. Comm.	Found to be useful and quite accurate as a tool in preparation of land-use plans.
	Rep. 78, 117, 144	Conn. DOT	As a basis for noise analyses.
3-8	Report 50	Orange Co. (Calif.) Traf. Eng. Council	Extensive use as best available source of information for preparation of warrants for installation of protective devices at rail-grade crossings.
		Illinois Div. of Hwys., Bur. of Design	In a continuing program toward grade crossing safety, with particular use seen for portion dealing with crossings where flashing light signals—with or without gates—are not warranted.
		Conn. DOT	Source reference for Railroad-Highway Safety Grade Crossing Program.
3-9	Report 84	Calif. Div. of Hwys.	Recommendations used on Freeway Surveillance and Control Project (Los Angeles), involving expenditure of about $8 million in three years.
3-12	Report 123	Transp. Syst. Center	Information on fixed highway signing principles particularly helpful in providing control signals to pilots at Kennedy International Airport (New York).
	Agency report	Street Name Signing Comm., ITE	As background information in review of street name signing applications to meet motorists' needs.
3-12(2)	Agency final report	AAA Found, for Traffic Safety	As the primary reference for preparation of the pamphlet, "Improving Road Guide Signs . . . What Can You Do About It?"
3-13	Report 93	City of Waco, Tex.	Plans to incorporate in subdivision and zoning regulations many of the controls recommended as a means of protecting facility capacity and safety.
3-14	Film, "Relief for Tired Streets"	New York DOT	To encourage municipalities in State to apply traffic engineering solutions to their congestion problems.
3-15	Agency report	Consultant	Using nomographs and incorporating the research findings into some current projects.
3-16	Agency report	FHWA	As support material in resolving an operations problem.
3-18(1)	Agency interim report	City of Lincoln, Nebr.	In design of digital computer-controlled traffic control system to supervise 250-300 signalized intersections.
	Agency report	New Zealand Ministry of Works	To reduce hardware costs by applying greater software capabilities to computer-controlled traffic signal operations.
		New York DOT	As background and design evaluation for a centralized computer traffic surveillance and control system in the Northern Long Island Corridor.
3-18(2)	Agency report	Dade Cty., Fla.	As basis for operational changes at selected locations.
3-18(3)	Agency interim report	FHWA	A summary report presenting results of a survey of traffic signal system design and operation practices was used in development of a FHWA training program for traffic engineering personnel.
	Agency report	Texas SDH and Pub. Transp.	Report selected as a textbook for a course for city and state traffic engineers in traffic signal system design.
3-19	Agency report	Utah DOT	In highway analysis.
3-20	Agency report	FHWA	To develop interest in warrant improvement within Signals Subcommittee of National Advisory Committee on Uniform Traffic Devices.
3-21	Agency report	N.J. Tpk. Auth.	In conjunction with research project studying visual effects of variable-message signs.
3-22A	Report 232	Texas SDHPT	Text material for the "Freeway Management Operations Workshop." Participants included SDHPT district personnel, state and city traffic engineers, and state and city police.
3-23	Agency report	AMV Australia	In developing a manual for design of signalized intersections for Road Safety and Traffic Authority, Victoria, Australia.
		FHWA	To amend Sections 4B-8, 4B-10, 4B-11, and 4B-12 of the *Manual on Uniform Traffic Control Devices.*
3-25	Agency final report	Consultant	To determine the safety impacts of lower design standards related to construction and maintenance activities in the context of energy conservation.
3-26	Agency interim report	City of Edmonton, Alberta, Can.	In designing noise-barrier walls.
	Agency final report	County of Sacramento Plng. & Commun. Dev. Dept.	As a supplement to the FHWA Highway Noise Prediction Model used to conduct environmental analyses of proposed highway projects.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
3-27	Report 233	Fuel Efficient Traffic Signal Mgmt. Program	In their Bulletin, readers were referred to various Report figures that would aid in determining timing parameters for traffic-actuated controllers.
3-28	Unpublished by NCHRP. TRB Circular 212	Polytechnic Inst. of N.Y.	Highway capacity workshop materials.
3-28B	TRB Special Rpt 209	States, FHWA, Universities	As primary resource document for highway capacity analysis and as basic document for training programs and computer software.
3-31	Report 288	FHWA/NHI	Material incorporated into National Highway Institute training course.
4-3	Reports 12, 15, 65, 66	ASTM	Basis for development of C671, "Tentative Method of Test for Critical Dilation of Concrete Specimens Subject to Freezing," and C682, "Resistance of Aggregates to Freezing."
4-6	Reports 74, 74A, 74B	Conn. DOT	As backup in developing paint systems for highway bridges.
4-7	Report 164	AASHTO	Recommendations for consideration of fatigue of reinforcement in concrete highway bridges incorporated in 1975 as provisions in AASHTO "Standard Specifications for Highway Bridges."
4-8(3)	Agency final report	Arizona DOT	To revise Department's asphalt paving mix design criteria
	Report 246	AASHTO	Test procedure adopted by AASHTO Subcommittee on Materials and published in AASHTO *Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part II,* 1986, as T283-85, "Resistance of Compacted Bituminous Mixtures to Moisture-Induced Damage."
4-11	Agency interim report	Fed. Aviation Admin.	Tentative guidelines for selection and installation of plastic pipe were used to reduce time and funds required for a research project on plastic pipe for airport drainage.
		State Hwy. and Transp. Materials Engrs.	On basis of advisory panel member comments that information in report would be useful to practicing engineers, report was distributed to members of AASHTO Operating Sub-Committee on Materials.
		U.S. Forest Serv.	Distributed to each regional office on basis of headquarters office determination that it will prove of use to engineers involved in design of road and sanitary sewer projects.
		Albuquerque, N.M.	In deciding on use of certain materials for city sewers.
		Illinois DOT	In preparing specifications and purchase of plastic pipe.
	Report 225	Soil Conservation Service, USDA	As a guide in developing a technical release on plastic piping materials for use by field personnel in planning and design of plastic pipe systems.
		AASHTO	In developing materials' specifications.
5-4	Report 20	AASHTO Stdg. Comm. on Engrg. and Opers.	Input (with Report 77, Proj. 15-6) to the March 1969 publication, *Informational Guide to Roadway Lighting.*
5-5A, B	Agency report	DeLeuw Cather	Findings incorporated in research study.
5-7	Report 130	Ohio DOH	Reference source of current and complete information on individual delineation techniques.
		Org. for Econ. Coop. and Devel. Res. Group C-8	In preparing report on Visual Effectiveness and Durability of Road Markings, Reflectors, and Delineators.
		FHWA	In a report of two FHWA Delineation Conferences, summarized in four parts for group presentations, NCHRP Project 5-7 is described as the most comprehensive delineation research in recent years and its report as giving the best available description of the guidance function of delineation.
5-9	Report 256	AASHTO	Referenced in "An Informational Guide for Roadway Lighting."
6-1	Report 19	California Div. of Hwys.	Source material and bibliography simplified literature search and saved much valuable time. Results incorporated in planning and design of new projects.
		Conn. DOT	In developing deicing chemical policy.
6-2	Report 4	Calif. Div. of Hwys.	See Project 6-1.
		Conn. DOT	In developing snow and ice policies.
6-3	Report 16	Calif. Div. of Hwys.	See Project 6-1.
		Natl. Flaxseed Processors Assn.	Advertising (*Civil Eng.,* Feb. 1966) highlighting research results in stating ". . . considering both the economy and performance, the best results by far were obtained by vegetable oil, and particularly linseed oil solutions."
		Conn. DOT	In developing treatments to prevent deterioration of PCC bridge decks.
6-4	Report 23	Iowa SH Conn.	Constructed bridge with galvanized reinforcing bars in one-half of deck. This follows recommendations to the effect that more field evaluation is required of zinc, nickel, and asphalt-epoxy coatings.
6-5	Report 27	Calif. Div. of Hwys.	See Project 6-1.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
6-8	Report 1	Calif. Div. of Hwys.	See Project 6-1.
		U.S. Park Serv.	Techniques used by consulting engineering firm for deck repair of Memorial Bridge, Washington, D.C., depended heavily on reported results.
6-10	Agency reports	Calif. Div. of Hwys.	In preparation of plans for two sections of US 50 from Riverton to the Nevada State line. Design consideration given to those factors considered vital to increased safety and reduced maintenance at interchanges under the adverse conditions of snow and ice.
	Report 127	Conn. DOT	As source reference for snow and ice policy.
	Report 127 and 35-mm slides	New York DOT	Region 5 duplicated a loan set of 35-mm slides illustrating Appendix J for showing at Region meetings. They have proven helpful for both design and maintenance activities.
7-4	Report 89	Illinois DOT, Bur. Planning	Findings have been found useful, and practice has been modified to conform with them.
7-7	Report 64	Ohio DOH	Implemented several recommendations pertaining to rest areas with maps and other information of interest to motorists, signing conformity, service patrols, patrol aircraft, and medicopter service.
7-8	Report 133	Conn. DOT	As a basis for noise analyses.
		Dept. of Eng., Univ. of Wisconsin	As a reference text for an extension course entitled "Data Collection and Evaluation Techniques for Transportation Systems Management."
7-10	Agency interim report	Oregon County Transit Dist.	In preparation of an energy contingency plan.
	Agency report	U.S. Environmental Protection Agency	To brief members of Senate Public Works Committee on the state of the art of transportation controls.
	Report 169	N.Y. State DOT	As examples of how to develop possible air quality packages for seminars to state and metropolitan planning organization transportation planners.
		Hawaii DOT	As a basic guide for the State's TSM plan.
7-10(2)	Agency final report	N.Y. State DOT	Same as Project 7-10
7-11	Report 263	FHWA	Material for transportation planning methods course.
8-3	Agency report	Arizona HD	Source material for decisions based on consumer sensitivity to the various factors considered in trip making.
8-4	Report 96	Dept. of Eng., Univ. of Wisconsin	As a text in short course on Urban Transportation Planning.
8-5	Report 121	Dept. of Eng., Univ. of Wisconsin	As a text in Traffic Engineering Seminar.
8-5A	Report 121	G. E. Pidcock Co.	To forecast volume of traffic generated by proposed subdivisions and developments.
8-8(3)	Agency interim report	Iowa SH Comm.	In development of an action plan in conformance with FHWA PPM 90-4.
		Delaware DOH & T	In development of an action plan in conformance with FHWA PPM 90-4.
	Agency report	N.Y. DOT, Transp. Planning Div.	In preparation of a synthesis report giving background to regional personnel responsible for citizen participation. Also useful in development of N.Y. State Action Plan.
		FHWA	Assisted in development of PPM 90-4.
		Michigan DOT	Assisted in preparation of the state's Action Plan.
	Report 156	Nat'l. Inst. for Road Res., S. Africa	In developing similar procedures in South Africa.
		Conn. DOT	In preparing environmental impact statements.
8-10	Report 155	Harvard Professor	In preparing a textbook.
8-11	Agency report	Illinois DOT	Portions incorporated into a manual on assessment of ecological impacts from highways for distribution to district engineers and others doing work for the department.
8-12	Agency report	FHWA	By regional transportation planners to provide technical support to the states.
		Princeton Univ.	In graduate courses.
8-12A	Agency final report and User's Guide	NYS DOT	User's Guide distributed to all regional planning offices to provide a quick-response capability for estimating travel demand.
		Consultant to Nat'l. Inst. for Transport and Road Res., S. Africa	To develop guidelines for undertaking urban transportation studies.
	Reports 186 and 187	Harvard Univ.	As course material.
		Univ. of Wisconsin Extension	As course material in conjunction with the NCHRP training material.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
		FHWA, Urban Planning Div.	Practical applications by state and local agencies were documented in a report entitled "Application of Quick Response Travel Estimation Procedures." Site impact, corridor, and system analyses were included.
	Report 187, Training Materials, and microcomputer applications	FHWA, National Hwy. Inst., State/Local Agencies, & Numerous Universities	As the basic training aid for short courses. More than 1,000 state and local officials have participated in 35 courses sponsored by FHWA's Urban Planning Div. in cooperation with MHI. Six additional courses are planned for next year.
8-16	Agency final report Appendix, "Transportation	Am. Public Transit Assoc.	Testimony on proposed DOT regulations to implement Sec. 504 of the Older Americans Rehabilitation Act.
	Services for the Transportation Disadvantaged"	U.S. Congress	Evaluation of DOT regulations to implement Sec. 504 of the Older Americans Rehabilitation Act.
8-16	Report 208	Division of Mass Transp., Caltrans	For determining alternatives for service implementation.
	Report 209	Division of Mass Transp., Caltrans	In development of transportation services for the transportation disadvantaged.
	Report 210	Division of Mass Transp., Caltrans	As a resource document for over-all planning activities.
	Report 211	Division of Mass Transp., Caltrans	To restructure and reorient marketing efforts.
8-20	Preliminary Draft Rpt.	Nat'l Inst. for Transport & Road Res., S. Africa	To design traffic counting program for four provinces of South Africa
8-23	Agency report	North Central Texas Council of Govts.	In quarterly report on DOE contract, the projected automotive operating costs of gasoline and non-gasoline engines.
8-25	Agency report	Montana Dept. of Commerce	To redesign approach of an analysis of intercity buses.
8-26	Report 255	FHWA	As a primary reference for training course material (National Highway Institute).
8-27	Report 262	New York MTA	To develop handicapped ridership for rail system.
8-3	Report 38	Ford Motor Co.	Saved countless hours of search and survey by state-of-the-art section on highways joint and crack sealing materials and methods. Useful in further understanding various design, construction, and maintenance problems, in analyzing specific failures, and in adapting future developments in highways to their industrial and other roadway problems.
10-1	Report 17	North Dakota State Univ.	Basic text for a course in statistical quality control taught to both undergraduates and a sizable number of engineers, the majority of the latter being highway department employees.
		Illinois Div. H, Bur. Materials	In conjunction with FHWA sigma bank, and data developed by our field testing, to develop special provisions covering statistical acceptance of bituminous concrete pavement.
		Conn. DOT.	As reference by Specifications Division.
10-2	Report 34	Illinois Div. H, Bur. Materials	In conjunction with supplementary materials, as a basis for recommending and/or limiting stockpiling methods to be included in the policy being developed for aggregate inspection and acceptance.
10-2A	Report 69	Conn. DOT	In developing statistical specifications.
10-5	Reports 14, 13	Conn. DOT	In establishing nuclear density and moisture tests in soils.
10-6	Report 52	Illinois Div. H, Bur. R&D	Considering a trial of recommendation for use of nuclear pellet technique for measuring pavement thickness.
10-8	Agency final report	Penn. DOT	The Ohio State ultrasonic gauge, several eddy current proximity gauges, and additional pachometers used with the new statistically based acceptance specifications to reduce over-all construction costs.
10-9	Res. Results Digest 48	U. Minn. and Minnesota DOH	In seminars conducted throughout Minnesota to train city and county personnel in use of the pavement surface condition rating system.
10-10	Report 201	FHWA	As a basis to prohibit use of electroslag welding in main structural tension members on federal-aid projects and to institute a program of rigorous inspection in existing structures welded by the electroslag process.
10-17	Report 274	ASTM	Adopted test method as ASTM Standard D 4867, Test Method for Effect of Moisture on Asphalt Concrete Paving Mixtures
10-18	Report 258	Concrete Construction Magazine	A condensed version of this report appeared in the August 1984 issue. The magazine is distributed nationally to engineers and contractors by a number of State ready-mixed-concrete associations.
10-20	Report 248	AASHTO	Unconfined elastomeric bearing specifications adopted in toto in the "1985 Interim AASHTO Standard Specifications for Highway Bridges."

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
10-21	Synthesis 86	Delaware River Joint Toll Bridge Comm.	Information of direct relevance in decision regarding replacement of bridge deck on a major bridge.
11-1(6)	Report 92	N. Mex. SH Comm.	In settling negotiations for purchase of an airport.
11-3	Report 56	Indiana SH Comm.	Rated as "excellent" by Land Acquisition Division, which requested extra copies for use in development of new work in area of responsibility.
		Illinois Div. H, Bur. Rt.-of-Way	Most of the principles set forth have been in practice. Land Economic Study unit conducted a study according to the report recommendation for one method of analysis of the value of scenic easements.
12-2	Report 83	California Div. of Hwys.	Own research project on "Analysis, Design and Behavior of Highway Bridges" used both basic knowledge and example of a well-devised rational approach to further simplify the proposed formulas and criteria recommended as revisions to the AASHTO Specifications, and to consolidate and authenticate the proposed criteria by further model and prototype verification of analytically obtained values.
12-5	Report 90	California Div. of Hwys.	Confirmed the Division's present practices, gave reassurance that its long-term investment in prestressed concrete structures is sound, and answered the question as to practicability of protective coatings.
12-7	Report 102	Naval Ship Res. and Devel. Lab.	Limited portions used in a technical report entitled "Some Observations on the Fatigue Behavior of Specimens and Structures."
		Illinois DOT, Bur. Design	Findings have been found useful, and practice has been modified to conform with them.
		Conn. DOT	To change bridge design parameters in order to reduce fatigue cracking.
	Report 147	AASHTO	Fatigue specification recommendations adopted in total in "1974 Interim AASHTO Standard Specifications for Highway Bridges."
		Conn. DOT.	To accomplish bridge design modifications intended to reduce fatigue cracking.
		Am. Rwy. Eng. Assn.	To develop modifications to fatigue provisions in AREA Specifications (1975).
12-8	Report 86	Canadian Stds. Assn.	Committee on Design of Highway Bridges used results in updating standards for bridge railing loads.
		Conn. DOT	To provide backup information for current bridge-rail design.
12-11	Report 165	Minnesota DOT	In selecting waterproof membrane systems for field evaluation.
12-15(3)	Report 227	Wisc. DOT Iowa DOT Ill. DOT Kans. DOT Pa. DOT Conn. DOT	To retrofit fatigue-susceptible structural details in welded steel highway bridges.
12-19A	Report 244	Kansas DOT	As reference for guidance in selecting concrete sealers.
		Commercial product manufacturers	As a standard for establishing their own specifications on specific products.
		Industrywide	Results of study have caused many states and industry to be more concerned with technical support on claims made for the performance of concrete sealers. Test procedures in report have become an unofficial standard.
12-22	Report 276	AASHTO	Subcommittee on Bridges and Structures adopted recommendations for thermal gradient design as a Guide Specification to the 1988 Interim AASHTO "Standard Specifications for Highway Bridges."
12-24	Report 287	AASHTO	Subcommittee on Bridges and Structures adopted recommended changes to the load distribution requirements for multibeam bridge superstructures in the *Standard Specifications for Highway Bridges* in 1988.
12-28(1)	Report 301	AASHTO	The second phase from Project 12-28(1) developed a comprehensive bridge load capacity specification based on the results of Projects 10-15(1) and 12-28(1). The Subcommittee on Bridges and Structures adopted the load capacity evaluation guidelines as a Guide Specification in 1988.
12-28(3)	Report 299	AASHTO	The fatigue design guidelines were adopted by the Subcommittee on Bridges and Structures as a Guide Specification in 1988. The fatigue evaluation guidelines were added as an alternative (by reference) in the *Manual for Maintenance Inspection of Bridges.*
12-32	Report 297	AASHTO	The corrosion protection requirements for reinforcing steel in the *Standard Specifications for Highway Bridges* were revised by the Subcommittee on Bridges and Structures in 1988 as a result of the recommendations included in the report.
13-1	Report 26	Delaware SHD	In a study of highway maintenance management, Advanced Management Planning, Inc., recommended use as a guide in establishing equipment rental rates.
14-1	Report 42	Minnesota DOH	Of considerable assistance to the investigators in the Maintenance Program Budget Pilot Study, which includes a determination of the sets of road characteristics to which quality and quantity standards codes should be assigned.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
		Washington State SH Comm.	In development of a unit maintenance expenditure index for the State.
		Ohio Dept. of Hwys.	In a study to develop a forecast of maintenance needs for the 1970-80 decade and compare it with the trends in highway maintenance needs for the U.S. as a whole and for the Northeast region in particular.
		Conn. DOT	In establishing Maintenance Management System.
14-5	Report 223	Penn. DOT	To determine tradeoffs between various maintnenace activities for resource allocation. Allowing gross to grow 6 in. higher before cutting saves $600,000 a year that may be used to reduce edge-drop-off.
15-1	Report 36	Commercial firm	In formulating a design for a new fiberglass guardrail system.
15-1(2)	Report 54	Federal and State agencies	In planning, design, construction, maintenance, replacement of guardrails and median barriers.
		American Iron and Steel Inst.	Recommendations on standardization of guardrail hardware by the Highway Task Force of the Institute's Sheet Committee to include use of the flat washer illustrated on page 29 of *Report 54.*
		Illinois Div. of Hwys.	Included in highway design policies and standards by Bur. of Design. New Bur. of Maintenance standards for guardrail and median barriers adapted from report. Bur. of Traffic comments highlight *Design Manual* or *Highway Standards* areas that could be improved by the findings; the warranting of trial installations of various types of median barriers, for reasons of both safety and economy; and the value of certain information as a tool to determine whether to remove or upgrade existing installations.
		Nevada DOH	In evaluating acceptability of the Department's design criteria and standards.
	Report 115	Illinois DOT, Bur. Design	Findings have been found useful, and practice has been modified to conform with them.
		Conn. DOT	As a basis of guardrail systems currently used in Connecticut.
	Report 118	New York DOT	As a vital supplement to a recently prepared design manual covering policies, procedures, and standards. Design guide refers to report for further information.
15-2	Report 108	Connecticut DOT	On trial basis, used the design technique developed for channels lined with riprap. Major relocation of a stream and tributaries having a design flood discharge of 3,900 cfs from a drainage area of 7.3 sq mi was involved. Saving from use of riprap instead of paving was estimated to be more than $90,000. Evaluation of the effectiveness of the treatment is continuing, especially observation of behavior during and after any significant storms.
		Wisconsin DOT	Channel design procedure applied to ditches along the Lake Wissota—Cadott Road in Chippewa County, previously subject to erosion, but none has occurred since use of riprap according to the procedure.
		Kansas SH Comm.	As basis for publication, "Design of Stable Roadside Channels."
		Minnesota DOH	To design riprap for a stream relocation at Moose Lake. Riprap erosion protection functioned as planned during rainstorms providing discharges approximating the design value of 275 cfs.
		Colorado DOH	Method to size riprap protection included in Ch. 8 of Design Manual.
		Soil Conserv. Serv., U.S. Dept. of Agr.	Recommendations used in preparation of *SCS Tech. Release No. 59,* "Hydraulic Design of Riprap Gradient Control Structures."
	Report 108 and agency draft	Hydr. Br., Bridge Div., FHWA	As source documents for "Stable Channel Designs"; design procedures for riprap linings developed principally from Report 108.
	Report 108 and agency report	Consultant, Madrid, Spain	Riprap design procedure applied to channels along motorways in Spain.
15-4	Report 136	Indiana SH Comm.	Used National Small Streams Data Inventory compiled during project as an additional check on flood flow estimates.
15-6	Report 77	AASHTO Stdg. Comm. on Hwys.	Input (with Report 20, Proj. 5-4) to March 1969 publication, *Informational Guide to Roadway Lighting.*
		California Div. of Hwys.	Instrumental in setting the standards for California and aiding in developing the most satisfactory breakaway base. The California research, without that done under NCHRP, reportedly would have cost well over $100,000 to develop or affirm preliminary designs of this type.
		Conn. DOT	As a basis for breakaway luminaires for highway lighting.
15-7	Agency final report and User's Manual	Wyoming Hwy. Dept.	As reference for guidance in determining flow modifications caused by storage losses on encroached flood plains.
16-1	Report 91	California Div. of Hwys.	Appendix D ("Effects of Salts on Plant Biota") is the most complete dissertation on soil salinity and salt-tolerant plants in the Division's reference files.
		U.S. Government	As a primary reference in formulating the National Environmental Policy Act of 1969 and Executive Order 11514 on "Protection and Enhancement of Environmental Quality."

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
		Conn. DOT	In preparation of environmental impact statements.
16-3	Agency report	Iowa DOT	In a training program on erosion control for state personnel.
	Report 221	Hittman Assoc. Inc.	Information and illustrations used in a field manual for the Office of Surface Mining, U.S. Dept. of Interior.
	Reports 220 and 221	Utah DOT Park City, Utah	To develop a manual. Developers are required by city ordinance to comply with provisions set forth in the reports.
17-1	Report 79	Robley Winfrey	In development of college textbook, *Economic Analysis for Highways.*
		Calspan	As starting point for a Tri-Level Accident Research Program for NHTSA and the Motor Vehicle Mfrs. Assn.
		Min. of Transp., Brazil	Translated into Portuguese.
17-2A	Agency report	S. Dak. DOT., Div. of Hwys.	To assist in evaluating safety improvements accomplished under an ongoing safety program.
	Report 162	Northwestern Univ.	As a reference and teaching aid in a graduate course in highway safety programming.
		Office of Highway Safety, FHWA	By staff serving as instructors for a series of regional seminars on evaluation of safety improvements.
17-3	Report 219	FHWA Office of Traffic Operation	As source document for FHWA's Positive Guidance series on planning and collection of field data.
		The Israel Nat'l Council for Prevention of Accidents	The final report and a training film prepared to this research were used in a pilot project to study conflicting traffic movements at intersections.
17-4	Report 236	FHWA, Nat'l Comm. on Uniform Traffic Control Devices	As a basis for changes in a Uniform Manual of Traffic Control Devices, Part VI, Traffic Control for Street and Highway Construction and Maintenance Operations
18-2(3)	Report 257	Penn. DOT	To develop a field trial for the deep polymer impregnation of a bridge deck with the "deep grooving technique."
19-2(4)	Report 131	Off. of R&D, FHWA	As a primary reference in training courses on managing highway maintenance.
19-3	Report 141	Nat'l. Inst. for Road Res., S. Africa	As source document in investigating certain aspects of vehicle sizes and weights on South African highways.
20-1	(HRIS)	Many diverse agencies	The Highway Research Information Service is known to be used widely by a number of organizations in addition to state highway departments. Recognition has been given to the periodic issues of *Highway Research in Progress* as being very useful and of great value to many other government agencies.
20-2	Report 55	Illinois Div. H, Bur. R&D	A committee within the Illinois Highway Research Council, having the assignment of developing a system of establishing research priorities for the Division's program, uses the method outlined for structuring research programs.
20-3	—	California Div. of Hwys.	Although not yet published, results from the second year of research are being used as background for installing surveillance and control systems and in planning alternative methods of improving operations on the Los Angeles Area freeway system.
20-5	Synthesis 1	Conn. DOT	As a basis for current signing patterns from Maintenance.
	Synthesis 2	Lab. de Eng., Angola	Translated into Portuguese.
	Synthesis 4	California Div. of Hwys.	As a basic document in the continuing development of Division practices and procedures to cope with the bridge deck deterioration problem. Also used as a guide for those lines of research that will yield the highest return.
		U.S. DOT	In preparation of *Instructional Memorandum 40-2-70.*
		N. Mex. SHD	In revising the Department's *Bridge Construction Manual.*
	Synthesis 5	Ctr. for PW Studies and Exper. (Spain)	Translated into Spanish as an "Information Bulletin" of the Transport and Soil Mechanics Laboratory.
		Louisiana DOH	As procedural guide to emergency measures to contain and/or control scour at bridge sites.
	Synthesis 6	Conn. DOT	In project scheduling.
	Synthesis 7	92nd Cong., 1 Sess.	See Project 1-12.
		Conn. DOT	Provided justification for motorist aid call-box system.
	Synthesis 10	Conn. DOT	By Maintenance in training personnel for equipment responsibilities.
	Synthesis 11	AASHTO	As a text in Highway Management Course (conducted by the Highway Management Institute at the Univ. of Mississippi).
	Synthesis 12	Conn. DOT	As a basis for Maintenance Telecommunication System.
	Synthesis 14	Texas Hwy. Dept.	Recommended to District offices as a reference to answer skid-resistance questions from both Departmental and non-Departmental personnel.
		Conn. DOT	To provide guidelines for skid-resistance program.
	Synthesis 16	Conn. DOT	Reference source for design of CRC pavements.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
	Synthesis 18	Texas HD and Tex. Div., FHWA	As background information in plan preparation and review; construction supervision and inspection; maintenance activity.
	Synthesis 24	Conn. DOT	As input into snow and ice policy.
	Synthesis 32	Conn. DOT	As backup for studded-tire legislation.
	Synthesis 37	Upper Plains States Innovation Group	Used in stabilization handbook for local governments.
	Syntheses 56 and 60	Texas SDH and Public Transp.	For review by district offices prior to Pavement Rehabilitation Conference.
	Synthesis 81	Texas SDH and Public Transp.	Text material for Corridor Management Team Conference. Participants included city and state personnel from 12 largest urban areas within Texas. Also used as text for Urban Traffic Operations and Management Seminar.
		FHWA	As source material in short courses on Organization and Management of Ridesharing.
	Syntheses 81 and 93	Univ. of Calif.—Berkeley	As reference material for course work.
20-6	Res. Dig. 11	Md. Rds. Comm.	In a case before September 1969 term, State Court of Appeals.
	Syntheses 96 and 99	FHWA	As a supplement to the training sessions on drainage and overlay designs in a "Pavement Design Training Course."
	Res. Dig. 11 and others	Colorado DOH	Used on several occasions involving condemnation cases and other legal matters. Digests noted as being extremely helpful in view of their discussions of current problems and consequent saving of legal staff time.
	Res. Results Digest 3	Sec. of Transp.	Included *in toto* in 1970 Annual Report to the Congress in respect to progress made in administration of the highway relocation assistance program as enacted under the Federal-Aid Highway Act of 1968.
	Res. Results Digests	Virginia Atty. Genl. Office	As an aid to maintaining a current awareness of legal research of an original nature, as a basis for further research by personnel of the Office, and as a point of departure for reviews of settled law.
	Res. Dig. 25	U. Wis., Dept. Eng.	As a text in short course on Urban Transportation Planning.
20-7	—	92nd Congress, 1st Sess.	Task 4, "Laternal Accelerations and Lateral Tire-Pavement Forces in a Vehicle Traversing Curves Relating to Available Pavement Skid-Resistant Measures." See Project 1-12.
	Report 157	Conn. DOT	In developing the scrap tire attenuation system.
	Res. Dig. 98	FHWA	To analyze Oklahoma DOT structure upgrading program.
	Agency final report (Task 8)	New York DOT	As primary source of information on energy used in construction and maintenance of transportation facilities for estimation of energy savings by Transportation System Management (TSM) actions. TSM actions are estimated to save 37.1 million gal of gasoline in the State of N.Y. during the 1978 calendar year.
		FHWA	As the primary source document for preparing the Workshop Notes for Energy Requirements for Transportation Systems.
	Agency final report (Task 12)	AASHTO	Published by AASHTO as *Guidelines on Citizen Participation in Transportation Planning.*
	Agency final report (Task 16)	North Central Council of Governments	As an aid in the validation of a survey regarding hazardous materials shipments.
	AASHTO Guide for Design of Pavement Structures (Task 24)	States, Counties, Cities, Consultants West Virginia University	In addition to copies distributed free to AASHTO members, more than 29,000 copies of the document have been purchased from AASHTO by the various users. Primary basis for development of pavement design manual for West Virginia Department of Highways.
	AASHTO Software Program DNPS 86/PC$_{TM}$ (Task 28)	States, Counties, Cities, Consultants	This personal computer program for new pavement design is based on the *AASHTO Guide for Design of Pavement Structures* and greatly simplifies implementation of the Guide. Under a licensing agreement, copies of the program have been sold by AASHTO to potential users.
	Agency final report (Task 32)	AASHTO	Adopted by the Subcommittee on Bridges and Structures as a Guide Specification in 1988.
20-12	Agency report	FHWA	In preparation of handbook on "Air Pollution Control for Construction and Maintenance."
20-13	Report 193	Metro. Expy. Public Corp. Tokyo, Japan	Translated into Japanese and distributed within the Corporation.
20-15	Report 218	Florida Dept. of Environ. Regs.	To write rules related to wetland protection.
20-16	Report 198	AASHTO	Findings used in testimony before U.S. Senate.
22-2	Res. Results Dig. 84, 102, 124	State highway agencies	Breakaway cable terminal (BCT) installed as a guardrail end treatment in at least 40 states since 1973.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
		Federal Aviation Administration	To install breakaway cable terminals as part of a demonstration project on the Dulles Airport Access Highway.
	Report 153	AASHTO	Referenced in Section 1.1.9A(2), Loadings and Geometrics, of the 1975 "Interim Bridge Specifications."
	Res. Results Dig. 84, 102	Australian state hwy. agencies	Breakaway cable terminal (BCT) installed as a guardrail and treatment in at least two Australian states.
22-4	Report 289	FHWA/AASHTO	Crash test results used in updating the AASHTO Barrier Guide and by individual states in selecting barrier designs.
25-1	Agency draft final report	U.S. Army Corps of Engineers Waterways Experiment Station	As a resource document.

TABLE 6

PUBLISHED REPORTS OF THE NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

REPORT NO.	TITLE, PROJECT, PAGES, PRICE
—*	A Critical Review of Literature Treating Methods of Identifying Aggregates Subject to Destructive Volume Change When Frozen in Concrete and a Proposed Program of Research—Intermediate Report (Proj. 4-3(2)), 81 p., $1.80
• 1	Evaluation of Methods of Replacement of Deteriorated Concrete in Structures (Proj. 6-8), 56 p., $2.80
• 2	An Introduction to Guidelines for Satellite Studies of Pavement Performance (Proj. 1-1), 19 p., $1.80
• 2A	Guidelines for Satellite Studies of Pavement Performance, 85 p.+9 figs., 26 tables, 4 app., $3.00
• 3	Improved Criteria for Traffic Signals at Individual Intersections—Interim Report (Proj. 3-5), 36 p., $1.60
• 4	Non-Chemical Methods of Snow and Ice Control on Highway Structures (Proj. 6-2), 74 p., $3.20
• 5	Effects of Different Methods of Stockpiling Aggregates—Interim Report (Proj. 10-3), 48 p., $2.00
• 6	Means of Locating and Communicating with Disabled Vehicles—Interim Report (Proj. 3-4), 56 p., $3.20
• 7	Comparison of Different Methods of Measuring Pavement Condition—Interim Report (Proj. 1-2), 29 p., $1.80.
• 8	Synthetic Aggregates for Highway Construction (Proj. 4-4), 13 p., $1.00
• 9	Traffic Surveillance and Means of Communicating with Drivers—Interim Report (Proj. 3-2), 28 p., $1.60
• 10	Theoretical Analysis of Structural Behavior of Road Test Flexible Pavements (Proj. 1-4), 31 p., $2.80
• 11	Effect of Control Devices on Traffic Operations—Interim Report (Proj. 3-6), 107 p., $5.80
• 12	Identification of Aggregates Causing Poor Concrete Performance When Frozen—Interim Report (Proj. 4-3(1)), 47 p., $3.00
• 13	Running Cost of Motor Vehicles as Affected by Highway Design—Interim Report (Proj. 2-5), 43 p., $2.80
• 14	Density and Moisture Content Measurements by Nuclear Methods—Interim Report (Proj. 10-5), 32 p., $3.00
• 15	Identification of Concrete Aggregates Exhibiting Frost Susceptibility—Interim Report (Proj. 4-3(2)), 66 p., $4.00
• 16	Protective Coatings to Prevent Deterioration of Concrete by Deicing Chemicals (Proj. 6-3), 21 p., $1.60
• 17	Development of Guidelines for Practical and Realistic Construction Specifications (Proj. 10-1), 109 p., $6.00
• 18	Community Consequences of Highway Improvement (Proj. 2-2), 37 p., $2.80
• 19	Economical and Effective Deicing Agents for Use on Highway Structures (Proj. 6-1), 19 p., $1.20
20	Economic Study of Roadway Lighting (Proj. 5-4), 77 p., $3.20
• 21	Detecting Variations in Load-Carrying Capacity of Flexible Pavements (Proj. 1-5), 30 p., $1.40
• 22	Factors Influencing Flexible Pavement Performance (Proj. 1-3(2)), 69 p., $2.60
• 23	Methods for Reducing Corrosion of Reinforcing Steel (Proj. 6-4), 22 p., $1.40
• 24	Urban Travel Patterns for Airports, Shopping Centers, and Industrial Plants (Proj. 7-1), 116 p., $5.20
• 25	Potential Uses of Sonic and Ultrasonic Devices in Highway Construction (Proj. 10-7), 48 p., $2.00
• 26	Development of Uniform Procedures for Establishing Construction Equipment Rental Rates (Proj. 13-1), 33 p., $1.60
• 27	Physical Factors Influencing Resistance of Concrete to Deicing Agents (Proj. 6-5), 41 p., $2.00
• 28	Surveillance Methods and Ways and Means Communicating with Drivers (Proj. 3-2), 66 p., $2.60
• 29	Digital-Computer-Controlled Traffic Signal System for a Small City (Proj. 3-2), 82 p., $4.00
• 30	Extension of AASHO Road Test Performance Concepts (Proj. 1-4(2)), 33 p., $1.60
• 31	A Review of Transportation Aspects of Land-Use Control (Proj. 8-5), 41 p., $2.00
• 32	Improved Criteria for Traffic Signals at Individual Intersections (Proj. 3-5), 134 p., $5.00
• 33	Values of Time Savings of Commercial Vehicles (Proj. 2-4), 74 p., $3.60
• 34	Evaluation of Construction Control Procedures—Interim Report (Proj. 10-2), 117 p., $5.00
• 35	Prediction of Flexible Pavement Deflections from Laboratory Repeated-Load Tests (Proj. 1-3(3)), 117 p., $5.00
• 36	Highway Guardrails—A Review of Current Practice (Proj. 15-1), 33 p., $1.60
37	Tentative Skid-Resistance Requirements for Main Rural Highways (Proj. 1-7), 80 p., $3.60
• 38	Evaluation of Pavement Joint and Crack Sealing Materials and Practices (Proj. 9-3), 40 p., $2.00
• 39	Factors Involved in the Design of Asphaltic Pavement Surfaces (Proj. 1-8), 112 p., $5.00
40	Means of Locating Disabled or Stopped Vehicles (Proj. 3-4(1)), 40 p., $2.00
• 41	Effect of Control Devices on Traffic Operations (Proj. 3-6), 83 p., $3.60
42	Interstate Highway Maintenance Requirements and Unit Maintenance Expenditure Index (Proj. 14-1), 144 p., $5.60
• 43	Density and Moisture Content Measurements by Nuclear Methods (Proj. 10-5), 38 p., $2.00
• 44	Traffic Attraction of Rural Outdoor Recreational Areas (Proj. 7-2), 28 p., $1.40
• 45	Development of Improved Pavement Marking Materials—Laboratory Phase (Proj. 5-5), 24 p., $1.40
• 46	Effects of Different Methods of Stockpiling and Handling Aggregates (Proj. 10-3), 102 p., $4.60
• 47	Accident Rates as Related to Design Elements of Rural Highways (Proj. 2-3), 173 p., $6.40
• 48	Factors and Trends in Trip Lengths (Proj. 7-4), 70 p., $3.20
• 49	National Survey of Transportation Attitudes and Be-

* Highway Research Board Special Report 80.

NOTE: Out-of-print publications marked with a bullet (•) are available only in microfiche form from the Transportation Research Board. See final page of this document for ordering information.

TABLE 6 (*Continued*)

REPORT NO.	TITLE, PROJECT, PAGES, PRICE
	havior—Phase I Summary Report (Proj. 20-4), 71 p., $3.20
• 50	Factors Influencing Safety at Highway-Rail Grade Crossings (Proj. 3-8), 113 p., $5.20
• 51	Sensing and Communication Between Vehicles (Proj. 3-3), 105 p., $5.00
• 52	Measurement of Pavement Thickness by Rapid and Nondestructive Methods (Proj. 10-6), 82 p., $3.80
• 53	Multiple Use of Lands Within Highway Rights-of-Way (Proj. 7-6), 68 p., $3.20
• 54	Location, Selection, and Maintenance of Highway Guardrails and Median Barriers (Proj. 15-1(2)), 63 p., $2.60
• 55	Research Needs in Highway Transportation (Proj. 20-2), 66 p., $2.80
• 56	Scenic Easements—Legal, Administrative, and Valuation Problems and Procedures (Proj. 11-3), 174 p., $6.40
• 57	Factors Influencing Modal Trip Assignment (Proj. 8-2), 78 p., $3.20
• 58	Comparative Analysis of Traffic Assignment Techniques with Actual Highway Use (Proj. 7-5), 85 p., $3.60
• 59	Standard Measurements for Satellite Road Test Program (Proj. 1-6), 78 p., $3.20
• 60	Effects of Illumination on Operating Characteristics of Freeways (Proj. 5-2), 148 p., $6.00
• 61	Evaluation of Studded Tire—Performance Data and Pavement Wear Measurement (Proj. 1-9), 66 p., $3.00
• 62	Urban Travel Patterns for Hospitals, Universities, Office Buildings and Capitols (Proj. 7-1), 144 p., $5.60
• 63	Economics of Design Standards for Low-Volume Rural Roads (Proj. 2-6), 93 p., $4.00
• 64	Motorists' Needs and Services on Interstate Highways (Proj. 7-7), 88 p., $3.60
65	One-Cycle Slow-Freeze Test for Evaluating Aggregate Performance in Frozen Concrete (Proj. 4-3(1)), 21 p., $1.40
66	Identification of Frost-Susceptible Particles in Concrete Aggregates (Proj. 4-3(2)), 62 p., $2.80
• 67	Relation of Asphalt Rheological Properties to Pavement Durability (Proj. 9-1), 45 p., $2.20
• 68	Application of Vehicle Operating Characteristics to Geometric Design and Traffic Operations (Proj. 3-10), 38 p., $2.00
• 69	Evaluation of Construction Control Procedures—Aggregate Gradation Variations and Effects (Proj. 10-2A), 58 p., $2.80
• 70	Social and Economic Factors Affecting Intercity Travel (Proj. 8-1), 68 p., $3.00
• 71	Analytical Study of Weighing Methods for Highway Vehicles in Motion (Proj. 7-3), 63 p., $2.80
72	Theory and Practice in Inverse Condemnation for Five Representative States (Proj. 11-2), 44 p., $2.20
• 73	Improved Criteria for Traffic Signal Systems on Urban Arterials (Proj. 3-5), 55 p., $2.80
74	Protective Coatings for Highway Structural Steel (Proj. 4-6), 64 p., $2.80
• 74A	Protective Coatings for Highway Structural Steel—Literature Survey (Proj. 4-6), 275 p., $8.00
• 74B	Protective Coatings for Highway Structural Steel—Current Highway Practices (Proj. 4-6), 102 p., $4.00
• 75	Effect of Highway Landscape Development on Nearby Property (Proj. 2-9), 82 p., $3.60
• 76	Detecting Seasonal Changes in Load-Carrying Capabilities of Flexible Pavements (Proj. 1-5(2), 37 p., $2.00
• 77	Development of Design Criteria for Safer Luminaire Supports (Proj. 15-6), 82 p., $3.80
• 78	Highway Noise—Measurement, Simulation, and Mixed Reactions (Prof. 3-7), 78 p., $3.20
79	Development of Improved Methods for Reduction of Traffic Accidents (Proj. 17-1), 163 p., $6.40
• 80	Oversize-Overweight Permit Operation on State Highways (Proj. 2-10), 120 p., $5.20
• 81	Moving Behavior and Residential Choice—A National Survey (Proj. 8-6), 129 p., $5.60
• 82	National Survey of Transportation Attitudes and Behavior—Phase II Analysis Report (Proj. 20-4), 89 p., $4.00
• 83	Distribution of Wheel Loads on Highway Bridges (Proj. 12-2), 56 p., $2.80
• 84	Analysis and Projection of Research on Traffic Surveillance, Communication, and Control (Proj. 3-9), 48 p., $2.40
• 85	Development of Formed-in-Place Wet Reflective Markers (Proj. 5-5), 28 p., $1.80
• 86	Tentative Service Requirements for Bridge Rail Systems (Proj. 12-8), 62 p., $3.20
87	Rules of Discovery and Disclosure in Highway Condemnation Proceedings (Proj. 11-1(5)), 28 p., $2.00
88	Recognition of Benefits to Remainder Property in Highway Valuation Cases (Proj. 11-1(2)), 24 p., $2.00
• 89	Factors, Trends, and Guidelines Related to Trip Length (Proj. 7-4), 59 p., $3.20
90	Protection of Steel in Prestressed Concrete Bridges (Proj. 12-5), 86 p., $4.00
91	Effects of Deicing Salts on Water Quality and Biota—Literature Review and Recommended Research (Proj. 16-1), 70 p., $3.20
92	Valuation and Condemnation of Special Purpose Properties (Proj. 11-1(6)), 47 p., $2.60
• 93	Guidelines for Medial and Marginal Access Control on Major Roadways (Proj. 3-13), 147 p., $6.20
• 94	Valuation and Condemnation Problems Involving Trade Fixtures (Proj. 11-1(9)), 22 p., $1.80
• 95	Highway Fog (Proj. 5-6), 48 p., $2.40
• 96	Strategies for the Evaluation of Alternative Transportation Plans (Proj. 8-4), 111 p., $5.40
97	Analysis of Structural Behavior of AASHO Road Test Rigid Pavements (Proj. 1-4(1)A), 35 p., $2.60
• 98	Tests for Evaluating Degradation of Base Course Aggregates (Proj. 4-2), 98 p., $5.00
• 99	Visual Requirements in Night Driving (Proj. 5-3), 38 p., $2.60
• 100	Research Needs Relating to Performance of Aggregates in Highway Construction (Proj. 4-8), 68 p., $3.40
• 101	Effect of Stress on Freeze-Thaw Durability of Concrete Bridge Decks (Proj. 6-9), 70 p., $3.60

TABLE 6 (*Continued*)

REPORT NO.	TITLE, PROJECT, PAGES, PRICE
102	Effect of Weldments on the Fatigue Strength of Steel Beams (Proj. 12-7), 114 p., $5.40
• 103	Rapid Test Methods for Field Control of Highway Construction (Proj. 10-4), 89 p., $5.00
104	Rules of Compensability and Valuation Evidence for Highway Land Acquisition (Proj. 11-1), 77 p., $4.40
• 105	Dynamic Pavement Loads of Heavy Highway Vehicles (Proj. 15-5), 94 p., $5.00
• 106	Revibration of Retarded Concrete for Continuous Bridge Decks (Proj. 18-1), 67 p., $3.40
107	New Approaches to Compensation for Residential Takings (Proj. 11-1(10)), 27 p., $2.40
• 108	Tentative Design Procedure for Riprap-Lined Channels (Proj. 15-2), 75 p., $4.00
• 109	Elastomeric Bearing Research (Proj. 12-9), 53 p., $3.00
• 110	Optimizing Street Operations Through Traffic Regulations and Control (Proj. 3-11), 100 p., $4.40
• 111	Running Costs of Motor Vehicles as Affected by Road Design and Traffic (Proj. 2-5A and 2-7), 97 p., $5.20
• 112	Junkyard Valuation—Salvage Industry Appraisal Principles Applicable to Highway Beautification (Proj. 11-3(2)), 41 p., $2.60
113	Optimizing Flow on Existing Street Networks (Proj. 3-14), 414 p., $15.60
• 114	Effects of Proposed Highway Improvements on Property Values (Proj. 11-1(1)), 42 p., $2.60
• 115	Guardrail Performance and Design (Proj. 15-1(2)), 70 p., $3.60
• 116	Structural Analysis and Design of Pipe Culverts (Proj. 15-3), 155 p., $6.40
117	Highway Noise—A Design Guide for Highway Engineers (Proj. 3-7), 79 p., $4.60
• 118	Location, Selection, and Maintenance of Highway Traffic Barriers (Proj. 15-1(2)), 96 p., $5.20
• 119	Control of Highway Advertising Signs—Some Legal Problems (Proj. 11-3(1)), 72 p., $3.60
• 120	Data Requirements for Metropolitan Transportation Planning (Proj. 8-7), 90 p., $4.80
• 121	Protection of Highway Utility (Proj. 8-5), 115 p., $5.60
• 122	Summary and Evaluation of Economic Consequences of Highway Improvements (Proj. 2-11), 324 p., $13.60
123	Development of Information Requirements and Transmission Techniques for Highway Users (Proj. 3-12), 239 p., $9.60
124	Improved Criteria for Traffic Signal Systems in Urban Networks (Proj. 3-5), 86 p., $4.80
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TABLE 6 (*Continued*)

REPORT NO.	TITLE, PROJECT, PAGES, PRICE
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158	Selection of Safe Roadside Cross Sections (Proj. 20-7), 57 p., $4.40
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TABLE 6 (*Continued*)

REPORT NO.	TITLE, PROJECT, PAGES, PRICE
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* Special publication.

TABLE 6 (*Continued*)

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260	Application of Statewide Freight Demand Forecasting Techniques (Proj. 20-17A), 210 p., $12.80
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TABLE 6 (*Continued*)

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• 2	Bridge Approach Design and Construction Practices (Proj. 20-5, Topic 2), 30 p., $2.00
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• 9	Pavement Rehabilitation—Materials and Techniques (Proj. 20-5, Topic 8), 41 p., $2.80
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52	Management and Selection Systems for Highway Maintenance equipment (Proj. 20-5, Topic 8-08), 17 p., $4.40
53	Precast Concrete Elements for Transportation Facilities (Proj. 20-5, Topic 8-05), 48 p., $5.60
• 54	Recycling Materials for Highways (Proj. 20-5, Topic 8-01), 53 p., $5.60
55	Storage and Retrieval Systems for Highway and Trans-

TABLE 6 (*Continued*)

SYNTHESIS OF HIGHWAY PRACTICE

NO.	TITLE, PAGES, PRICE
	portation Data (Proj. 20-5, Topic 8-06), 30 p., $4.80
56	Joint-Related Distress in PCC Pavement—Cause, Prevention and Rehabilitation (Proj. 20-5, Topic 7-06), 36 p., $5.20
• 57	Durability of Concrete Bridge Decks (Proj. 20-5, Topic 9-01), 61 p., $6.00
58	Consequences of Deferred Maintenance (Proj. 20-5, Topic 10-01), 24 p., $4.40
59	Relationship of Asphalt Cement Properties to Pavement Durability (Proj. 20-5, Topic 8-11), 43 p., $5.60
60	Failure and Repair of Continuously Reinforced Concrete Pavement (Proj. 20-5, Topic 9-08), 42 p., $5.60
61	Changeable Message Signs (Proj. 20-5, Topic 9-03), 37 p., $5.60
62	State Resources for Financing Transportation Programs (Proj. 20-5, Topic 9-09), 34 p., $5.20
63	Design and Use of Highway Shoulders (Proj. 20-5, Topic 8-03), 26 p., $4.80
64	Bituminous Patching Mixtures (Proj. 20-5, Topic 8-12), 26 p., $4.80
65	Quality Assurance (Proj. 20-5, Topic 9-05), 42 p., $5.60
66	Glare Screen Guidelines (Proj. 20-5, Topic 9-11), 17 p., $4.40
67	Bridge Drainage Systems (Proj. 20-5, Topic 10-06), 44 p., $5.60
68	Motor Vehicle Size and Weight Regulations, Enforcement, and Permit Operations (Proj. 20-5, Topic 10-04), 45 p., $6.00
69	Bus Route and Schedule Planning Guidelines (Proj. 20-5, Topic 7-09), 99 p., $8.00
70	Design of Sedimentation Basins (Proj. 20-5, Topic 9-10), 54 p., $6.80
71	Direction Finding from Arterials to Destinations (Proj. 20-5, Topic 9-07), 50 p., $6.40
72	Transportation Needs Studies and Financial Constraints (Proj. 20-5, Topic 11-01), 54 p., $6.80
73	Alternative Work Schedules: Impacts on Transportation (Proj. 20-5, Topic 9-06), 54 p., $6.80
74	State Transit-Management Assistance to Local Communities (Proj. 20-5, Topic 10-11), 35 p., $6.00
75	Transit Boards—Composition, Roles, and Procedures (Proj. 20-5, Topic 11-09), 24 p., $6.20
76	Collection and Use of Pavement Condition Data (Proj. 20-5, Topic 10-05), 74 p., $8.00
77	Evaluation of Pavement Maintenance Stategies (Proj. 20-5, Topic 11-08), 56 p., $7.40
78	Value Engineering in Preconstruction and Construction (Proj. 20-5, Topic 11-02, 03), 23 p., $6.40
79	Contract Time Determination (Proj. 20-5, Topic 11-10), 45 p., $7.20
80	Formulating and Justifying Highway Maintenance Budgets (Proj. 20-5, Topic 10-03), 49 p., $7.20
81	Experiences in Transportation System Management (Proj. 20-5, Topic 11-14), 88 p., $8.40
82	Criteria for Evaluation of Truck Weight Enforcement Programs (Proj. 20-5, Topic 12-02), 74 p., $7.20
83	Bus Transit Accessibility for the Handicapped in Urban Areas (Proj. 20-5, Topic 11-13), 73 p., $7.60
84	Evaluation Criteria and Priority Setting for State Highway Programs (Proj. 20-5, Topic 12-01), 32 p. $6.40
85	Energy Involved in Construction Materials and Procedures (Proj. 20-5, Topic 12-09), 34 p., $6.40
86	Effects of Traffic-Induced Vibrations on Bridge-Deck Repairs (Proj. 20-5, Topic 10-21), 40 p., $6.80
87	Highway Noise Barriers (Proj. 20-5, Topic 12-07), 82 p., $7.20
88	Underwater Inspection and Repairs of Bridge Substructures (Proj. 20-5, Topic 10-08), 77 p., $7.60
89	Geotechnical Instrumentation for Monitoring Field Performance (Proj. 20-5, Topic 11-06), 46 p., $6.80
90	New-Product Evaluation Procedures (Proj. 20-5, Topic 12-12), 34 pp., $6.80
91	Highway Accident Analysis Systems (Proj. 20-5, Topic 12-03), 69 pp., $7.60
92	Minimizing Reflection Cracking of Pavement Overlays (Proj. 20-5, Topic 11-04), 38 pp., $6.80
93	Coordination of Transportation System Management and Land Use Management (Proj. 20-5, Topic 12-08), 38 pp. $6.80
94	Photologging (Proj. 20-5, Topic 8-10), 38 p., $6.80
95	Statewide Transportation Planning (Proj. 20-5, Topic 13-05), 54 p., $7.20
96	Pavement Subsurface Drainage Systems (Proj. 20-5, Topic 11-07), 38 p., $6.80
97	Transit Ownership/Operation Options for Small Urban and Rural Areas (Proj. 20-5, Topic 13-06), 28 p., $6.40
98	Resealing Joints and Cracks in Rigid and Flexible Pavements (Proj. 20-5, Topic 12-04), 62 p., $7.20
99	Resurfacing with Portland Cement Concrete (Proj. 20-5, Topic 13-04), 90 p., $8.40
100	Managing State Highway Finance (Proj. 20-5, Topic 13-03), 23 p., $6.40
101	Historic Bridges: Criteria for Decision Making (Proj. 20-5, Topic 13-11), 84 p., $8.00
102	Material Certification and Material-Certification Effectiveness (Proj. 20-5, Topic 14-05), 24 p., $6.00
103	Risk Assessment Process for Hazardous Materials Transportation (Proj. 20-5, Topic 13-10), 36 p., $6.40
104	Criteria for Use of Asphalt Friction Surfaces (Proj. 20-5, Topic 14-08), 41 p., $6.80
105	Construction Contract Claims: Causes and Methods of Settlement (Proj. 20-5, Topic 13-01), 58 p., $7.20
106	Practical Guidelines for Minimizing Tort Liability (Proj. 20-5, Topic 14-01), 40 p., $6.80
107	Shallow Foundations for Highway Structures (Proj. 20-5, Topic 12-06), 38 p., $6.80
108	Bridge Weight Limit Posting Practice (Proj. 20-5, Topic 13-08), 30 p., $6.40
109	Highway Users of Epoxy with Concrete (Proj. 20-5, Topic 14-12), 68 p., $8.80
110	Maintenance Management Systems (Proj. 20-5, Topic 14-06), 49 p., $8.00

TABLE 6 (*Continued*)

SYNTHESIS OF HIGHWAY PRACTICE

NO.	TITLE, PAGES, PRICE
111	Distribution of Wheel Loads on Highway Bridges (Proj. 20-5, Topic 14-22), 21 p., $7.20
112	Cost Effectiveness of Hot-Dip Galvanizing for Exposed Steel (Proj. 20-5, Topic 15-19), 28 p., $7.20
113	Administration of Research, Development, and Implementation Activities in Highway Agencies (Proj. 20-5, Topic 14-11), 49 p., $8.00
114	Management of Traffic Signal Maintenance (Proj. 20-5, Topic 14-02), 133 p., $10.80
115	Reducing Construction Conflicts Between Highways and Utilities (Proj. 20-5, Topic 14-03), 72 p., $8.80
116	Asphalt Overlay Design Procedures (Proj. 20-5, Topic 14-04), 66 p., $8.40
117	Toll Highway Financing (Proj. 20-5, Topic 15-01), 29 p., $7.20
118	Detecting Defects and Deterioration in Highway Structures (Proj. 20-5, Topic 15-03), 75 p., $8.80
119	Prefabricated Bridge Elements and Systems (Proj. 20-5, Topic 15-10), 75 p., $8.80
120	Professional Resource Management and Forecasting (Proj. 20-5, Topic 15-08), 14 p., $6.80
121	Energy Conservation in Transportation (Proj. 20-5, Topic 14-09), 25 p., $7.20
122	Life-Cycle Cost Analysis of Pavements (Proj. 20-5, Topic 15-07), 136 p., $10.80
123	Bridge Designs to Reduce and Facilitate Maintenance Repairs (Proj. 20-5, Topic 12-11), 65 p., $8.40
124	Use of Weigh-In-Motion Systems for Data Collection and Enforcement (Proj. 20-5, Topic 16-02), 34 p., $7.60
125	Maintenance Activities Accomplished by Contract (Proj. 20-5, Topic 14-07), 42 p., $8.00
126	Equipment for Obtaining Pavement Condition and Traffic Loading Data (Proj. 20-5, Topic 15-04), 117 p., $11.20
127	Use of Fly Ash in Concrete (Proj. 20-5, Topic 16-07), 66 p., $8.40
128	Methods of Identifying Hazardous Highway Elements (Proj. 20-5, Topic 15-06), 80 p., $10.00
129	Freezing and Thawing Resistance of High-Strength Concrete (Proj. 20-5, Topic 16-05), 31 p., $7.60
130	Traffic Data Collection and Analysis: Methods and Procedures (Proj. 20-5, Topic 15-11), 58 p., $8.40
131	Effects of Permit and Illegal Overloads on Pavements (Proj. 20-5, Topic 15-05), 99 p., $10.40
132	System-Wide Safety Improvements: An Approach to Safety Consistency (Proj. 20-5, Topic 17-01), 20 p., $6.80
133	Integrated Highway Information Systems (Proj. 20-5, Topic 17-02), 31 p., $7.60
134	D-Cracking of Concrete Pavements (Proj. 20-5, Topic 17-08), 33 p., $7.60
135	Pavement Management Practices (Proj. 20-5, Topic 17-10), 139 p., $12.40
136	Protective Coatings for Bridge Steel (Proj. 20-5, Topic 15-09), 107 p., $11.00
137	Negotiating and Contracting for Professional Engineering Services (Proj. 20-5, Topic 18-05), 75 p., $10.00
138	Pavement Markings Materials and Application for Extended Service Life (Proj. 20-5, Topic 18-06), 45 p., $8.00
139	Pedestrians and Traffic-Control Measures (Proj. 20-5, Topic 17-11), 75 p., $9.00
140	Durability of Prestressed Concrete Highway Structures (Proj. 20-5, Topic 15-02), 65 p., $9.00
141	Bridge Deck Joints (Proj. 20-5, Topic 16-10), (In preparation)
142	Methods of Cost-Effectiveness Analysis for Highway Projects (Proj. 20-5, Topic 13-02), (In preparation)
143	Uniformity Efforts in Oversize/Overweight Permits (Proj. 20-5, Topic 19-02), (In preparation)

TABLE 7
NCHRP RESEARCH RESULTS DIGESTS [a]

DIGEST NO.	PROJ. NO.	TITLE, PAGES, PRICE
3	20-6	Relocation Assistance Under Chapter Five of the 1968 Federal-Aid Highway Act 18 p. $1.00
6	20-6	Standing to Sue for Purposes of Securing Judicial Review of Exercise of Administrative Discretion in Route Location of Federal-Aid Highways 9 p. $1.00
11	20-6	Valuation Changes Resulting from Influence of Public Improvements 25 p. $1.00
14	12-3	Waterproof Expansion Joints for Bridges 3 p. $1.00
19	20-6	Advance Acquisition Under the Federal-Aid Highway Act of 1968 21 p. $1.00
20	19-1	Budgeting for State Highway Departments 4 p. $1.00
22	20-6	Valuation in Eminent Domain as Affected by Zoning 19 p. $1.00
25	20-6	Federal Environmental Legislation and Regulations as Affecting Highways 35 p. $1.00
31	20-6	Proposed Legislation to Authorize Joint Development of Highway Rights-of-Way 12 p. $1.00
32	20-6	Changes in Existing State Law Required by the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970 13 p. $1.00
39	20-6	Legal Effect of Representations as to Subsurface Conditions 17 p. $1.00
40	20-6	Appeal Bodies for Highway Relocation Assistance 16 p. $1.00
41	20-6	Trial Strategy and Techniques to Exclude Noncompensable Damages and Improper Valuation Methods in Eminent Domain Cases 24 p. $1.00
42	20-6	Supplemental Condemnation: A Discussion of the Principles of excess and Substitute Condemnation 20 p. $1.00
45	20-6	Exclusion of Increase or Decrease in Value Caused by Public Improvement for Which Lands Are Condemned 24 p. $1.00
47	20-6	Trial Strategy and Techniques Using the Comparable Sales Approach to Valuation 13 p. $1.00
48	10-9	Surface Condition Rating System for Bituminous Pavements 24 p. $1.50
54	20-6	Trial Strategy and Techniques Using the Income Approach to Valuation 31 p. $1.00
55	20-7	Side-Friction Factors in the Design of Highway Curves (Task 4) 9 p. $1.00
67	15-2	Field Evaluation of Tentative Design Procedure for Riprap-Lined Channels 4 p. $1.00
68	20-6	The Meaning of Highway Purpose 15 p. $1.00
76	22-3, 3A	Field Evaluation of Vehicle Barrier System 3 p. $1.00
77	20-7	Earth-Berm Vehicle Deflector (Task 3) 3 p. $1.00
78	3-20	Traffic Signal Warrants—A Bibliography 42 p. $1.00
79	20-6	Personal Liability of State Highway Department Officers and Employees 22 p. $3.00
80	20-6	Liability of State Highway Departments for Design, Construction, and Maintenance Defects 49 p. $5.00
81	22-1A	Crash Testing and Evaluation of Attenuating Bridge Railing System 10 p. $1.00
82	1-15	Design of Continuously Reinforced Concrete Pavements for Highways 12 p. $1.00
83	20-6	Liability of State and Local Governments for Snow and Ice Control 16 p. $3.00
84	22-2	Breakaway Cable Terminals for Guardrails and Median Barriers 18 p. $1.00
85	12-16	Bridge Deck Repairs 22 p. $1.00
89	1-12(3)	Guidelines for Skid-Resistant Highway Pavement Surfaces 12 p. $1.00
91	3-21	Motorist Response to Guide Signing 9 p. $1.00
95	20-6	Legal Implications of Regulations Aimed at Reducing Wet-Weather Skidding Accidents on Highways 31 p. $3.00
97	3-23	Guidelines for Uniformity in Traffic Control Signal Design Configurations 8 p. $1.00
99	20-6	Liability of the State for Highway Traffic Noise 14 p. $3.00
100	20-5	Safe Conduct of Traffic Through Highway Construction and Maintenance Zones 5 p. $1.00
102	22-2	Modified Breakaway Cable Terminals for Guardrails and Median Barriers 13 p. $1.00
103	20-6	Payment of Attorney Fees in Eminent Domain and Environmental Litigation 24 p. $3.00
105	3-26	Selected Acoustical Parameters of Highway Noise Barriers 8 p. $1.00
106	20-5	Use of Waste Materials in Highway Construction and Maintenance 2 p. $1.00
108	20-6	Trial Strategy and Techniques in Highway Contract Litigation 31 p. $3.00
109	20-6	Control of Conflicts of Interest in Highway Construction Contract Administration 56 p. $3.00
110	20-6	Liability of State and Local Governments for Negligence Arising out of the Installation and Maintenance of Warning Signs, Traffic Lights, and Pavement Markings 14 p. $3.00
111	20-6	Trial Aids in Highway Condemnation Cases 11 p. $3.00
112	20-6	Legal Implications of Control of Access to Uncontrolled-Access Highways 22 p. $3.00
113	20-6	Right to Compensation in Eminent Domain for Abrogation of Restrictive Covenants 12 p. $3.00
114	20-11B	Energy Analysis Methodology for Assessing Environmental Impacts 7 p. $1.00
115	Var.	NCHRP Research on the Durability of Reinforced Concrete Bridge Components 6 p. $1.00
116	20-6	Payments to Public Utilities for Relocation of Facilities in Highway Rights-of-Way 35 p. $3.00
119	20-6	Recovery of Condemnation Blight Under Inverse Law 11 p. $3.00
121	21-2(3)	Development and Field Evaluation of Prototype Soil Moisture Sensors. 3 p. $1.00
122	3-26	Noise Barrier Acoustical Parameters—Experimental Results 5 p. $1.00
123 [b]	4-9	Evaluation of Preformed Elastomeric Pavement Joint Sealing Systems 7 p. $1.00
126	3-18(4)	Performance Evaluation of Signalized Network Control Strategies 4 p. $1.00
127	8-19	The Vehicle-Miles of Travel—Urban Highway Supply Relationship 7 p. $1.00
129	20-6	Legal Implications of Highway Department's Failure to Comply with Design, Safety, or Maintenance Guidelines 17 p. $3.00
133	1-16	Evaluation of Winter-Driving Traction Aids 7 p. $1.00

TABLE 7 *(Continued)*

DIGEST NO.	PROJ. NO.	TITLE, PAGES, PRICE
134	20-6	Procedural Aspects of Inverse Condemnation—Title on Interest Acquired by Transportation and Other Public Agencies 13 p. $3.00
135	20-6	Liability of the State for Injury-Producing Defects in Highway Surface 14 p. $3.00
136	20-6	State Highway Programs Versus the Spending Powers of Congress 18 p. $3.00
137	20-6	The Effects of Federal and State Public Information Acts on Highway and Transportation Department Activities 23 p. $3.00
138	20-6	Legal Aspects of Historic Preservation in Highway Programs 27 p. $3.00
141	20-6	Liability of State Highway Departments for Defects in Design, Construction, and Maintenance of Bridges 20 p. $3.00
145	20-6	First Amendment Aspects of Control of Outdoor Advertising 31 p. $5.00
146	20-6	Minority and Disadvantaged Business Enterprise Requirements in Public Contracting 31 p. $5.00
147	20-6	Mineral Rights in Rights-of-Way: Acquisition, Valuations, and Disposition 15 p. $5.00
149	20-6	Exaction of Right-of-Way by Exercise of Police Power 13 p. $5.00
150	20-6	Planning and Precondemnation Activities as Constituting a Taking under Inverse Law 14 p. $5.00
151	20-6	Liability of State for Injury or Damage Occurring in Motor Vehicle Accident Caused by Trees, Shrubbery, or Other Vegetative Obstruction Located in Right-of-Way or Growing on Adjacent Private Property 20 p. $5.00
152	20-6	Enforceability of the Requirement of Notice in Highway Construction Contracts 17 p. $5.00
153	20-6	Liability of the State for Injuries Caused by Obstruction or Defects in Highway Shoulder or Berm 19 p. $5.00
154	20-6	Trial Strategy and Techniques in Enforcing Laws Relating to Truck Weights and Sizes 35 p. $5.00
157	20-6	Supplement to Licensing and Qualification of Bidders in Selected Studies in Highway Law 19 p. $5.00
158	20-6	Legal Procedural Issues Related to Relocation Assistance 25 p. $5.00
160	20-6	Acquisition of Uneconomic Remnants Under 23 U.S.C. 109(f) 13 p. $5.00
161	2-14	Public and Private Partnerships for Financing Highway Improvements 34 p. $5.00
163	20-6	Supplement to Competitive Bidding and Award of Construction Contracts in *Selected Studies in Highway Law* 32 p. $6.00
164	20-6	Rights of Abutting Property Owner Upon Conversion of Uncontrolled-Access Road into Limited-Access Highway 14 p. $6.00
165	20-6	Legal Techniques for Reserving Right-of-Way for Future Projects Including Corridor Protection 44 p. $6.00
167	Var.	NCHRP Research on Bridge Engineering 8 p. $3.00
168	20-5	Continuing Project to Synthesize Information on Highway Projects 7 p. $3.00

[a] See Table 4 for project titles. All items listed are final publications except where noted. Numbers missing from the series have been superseded by a later publication. See final page of this document for ordering information.
[b] Subsequent publication anticipated.

TABLE 8
NCHRP LEGAL RESEARCH DIGESTS [a]

DIGEST NO.	PROJ. NO.	TITLE, PAGES, PRICE
1	20-6	Continuing Project on Legal Problems Arising Out of Highway Programs 6 p. $3.00
2	20-6	Supplement to Liability of State Highway Departments for Design, Construction, and Maintenance Defects[b] 20 p. $6.00
3	20-6	Supplement to Liability of State and Local Governments for Negligence Arising Out of the Installation and Maintenance of Warning Signs, Traffic Lights, and Pavement Markings[b] 10 p. $3.00
4	20-6	Supplement to Personal Liability of State Highway Department Officers and Employees[b] 9 p. $3.00

Note: Supplements reference papers published in *Selected Studies in Highway Law,* Volumes 1, 2, 3, 4.
[a] All items listed are final publications except where noted. Numbers missing from the series have been superseded by a later publication.
[b] Subsequent publication anticipated in Addendum to *SSHL.*

PROGRESS BY PROJECT

AREA 1: PAVEMENTS

Project 1-1(1) FY'63

Development of Procedures for Comparing the AASHO Road Test Findings with Performance of (1) Existing Pavements and (2) Newly Constructed Experimental Pavements

Research Agency: Highway Research Board
Principal Invest: Dr. Paul E. Irick
Effective Date: March 1, 1963
Completion Date: February 29, 1964
Funds: $42,800

Guidelines were established for the study of existing and new experimental pavements in the satellite research program. Definitions were provided for pavement units and behavior, traffic factors, and environmental factors. Recommendations were made for experimental designs and requirements for collecting adequate data.

The final report has been published in two volumes as: NCHRP Report 2, "An Introduction to Guidelines for Satellite Studies of Pavement Performance"; NCHRP Report 2A, "Guidelines for Satellite Studies of Pavement Performance."

Report 2 contains a brief presentation of the essentials of the research, whereas Report 2A contains the details.

Project 1-1(2) Fy '64

Guidelines for Extending the Findings of the AASHO Road Test—Implementation Phase

Research Agency: Highway Research Board
Principal Invest: Dr. Paul E. Irick
Effective Date: March 1, 1964
Completion Date: August 31, 1965
Funds: $11,356

In follow-up to the development of NCHRP Report 2A, the intent of this continuation was to establish means for advising and assisting the various satellite programs in the use of the guidelines, techniques, and standards for data acquisition, procedures for data processing, and methods for updating the original guidelines in light of the findings of other research in Area One.

Inasmuch as the Bureau of Public Roads undertook implementation of the guidelines, rather than doing this through the Highway Research Board, the project was closed out.

Project 1-2 FY '63

Comparison of Different Methods for Evaluating Pavement Conditions

Research Agency: Purdue University
Principal Invest.: Prof. E. J. Yoder
Prof. B. E. Quinn
Effective Date: February 15, 1963
Completion Date: February 28, 1965
Funds: $29,957

This project was authorized to evaluate the effectiveness of various objective measurement techniques for obtaining data on road surface properties for use in the prediction of pavement serviceability ratings. Initially, a comparison was made between existing types of "road-roughness" measuring equipment. Such devices as the BPR roughometer, the AASHO slope profilometer, and the CHLOE profilometer were involved in the comparison study.

Research has been completed, and the project report published as: NCHRP Report 7, "Comparison of Different Methods of Measuring Pavement Condition."

Because the initial reseach resulted in sufficient data to permit calculation of elevation power spectra, the work was extended to consider specifically the problems associated with using these spectra as criteria of pavement condition. The report on the power spectra work was not published in the regular NCHRP series, but a copy of the agency's final report is available on microfiche (see final page of this section for ordering information).

A paper on this work was also published in *Highway Research Record No. 189.*

Project 1-3(1) FY '63 and FY '64

Factors Influencing Pavement Performance—Regional

Research Agency: Purdue University
Principal Invest.: Prof. K. B. Woods
Prof. E. J. Yoder
Prof. R. D. Miles
Dr. C. W. Lovell, Jr.
Effective Date: February 15, 1963
Completion Date: September 30, 1967
Funds: $45,982

The objectives of this project were to identify factors that influence pavement performance, to determine the relative effect of each factor, and to correlate pavement design and performance with factors common to a number of regions of the United States.

A regional classification system, using 97 physiographic units and covering the 48 contiguous states, was adapted

from the system originally developed by K. B. Woods and C. W. Lovell, Jr., and published in the *Highway Engineering Handbook,* McGraw-Hill, New York (1960). The highway factors analyzed by physiographic unit were: (1) availability of aggregates, (2) soil origin and texture, (3) high-volume-change soils, (4) potentially poor subgrade support conditions, and (5) frost-susceptible soils.

The Research has been completed, and the project report has been published as: NCHRP Report 132, "Relationships Between Physiographic Units and Highway Design Factors."

Project 1-3(2) FY '63

Factors Influencing Pavement Performance—Local

Research Agency: Northwestern University
Principal Invest.: Dr. R. L. Kondner
Effective Date: September 1, 1963
Completion Date: September 30, 1964
Funds: $19,850

In contrast with other research concerned with organizing regions into like groupings of sufficient size to permit the applications of the principles of meteorology, pedology, and geology to the identification of significant factors influencing pavement performance, this study was directed to the establishment of significant trends between flexible pavement response and various factors such as axle load, number of load applications, and thickness of pavement components. Performance data from the AASHO Road Test and other similar experiments were examined, and observed behavioral trends were expressed mathematically for consideration of the possibility of incorporating performance, expressed in terms of the present serviceability index (PSI), in flexible pavement design procedures.

This research has been completed, and the results have been published as: NCHRP Report 22, "Factors Influencing Flexible Pavement Performance."

Project 1-3(3) FY '64

Factors Influencing Pavement Performance

Research Agency: University of California
Principal Invest.: Dr. H. B. Seed
Prof. C. L. Monismith
Effective Date: April 1, 1964
Completion Date: October 31, 1965
Funds: $19,800

This research was initiated to develop procedures for predicting pavement deflections on the basis of the results from controlled repeated-load tests on materials comprising the pavement sections and within the framework of existing layered system theory.

Research has been completed, and the results have been published as: NCHRP Report 35, "Prediction of Flexible Pavement Deflections from Laboratory Repeated-Load Tests."

Project 1-4(1) FY '63

Extension of Road Test Performance Concepts

Research Agency: Georgia Institute of Technology
Principal Invest.: Dr. A. S. Vesic
Leonard Domaschuk
Effective Date: October 1, 1963
Completion Date: September 30, 1964
Funds: $10,000

This research involved a critical review of existing hypotheses and the development of new hypotheses of flexible pavement performance as related to fundamental principles of engineering mechanics and material science. New hypotheses of flexible pavement performance as related to design were sought and tested with available data from the AASHO Road Test and elsewhere.

Research has been completed, and the results have been published as: NCHRP Report 10, "Theoretical Analysis of Structural Behavior of Road Test Flexible Pavements."

Project 1-4(1)A FY '64

Extension of Road Test Performance Concepts

Research Agency: Duke University
Principal Invest.: Dr. A. S. Vesic
Effective Date: February 1, 1965
Completion Date: September 30, 1966
Funds: $19,924

This research was concerned with existing theories of structural behavior of rigid pavements. Available data on deflections, stresses, and observed structural failures of rigid pavements during the AASHO Road Test were collected and critically reviewed. Rational correlations were developed for existing theories of mechanical behavior of rigid pavements.

The project report has been published as: NCHRP Report 97, "Analysis of Structural Behavior of AASHO Road Test Rigid Pavements."

Project 1-4(2) FY '64

Extension of Road Test Performance Concepts

Research Agency: Purdue University
Principal Invest.: Dr. M. E. Harr
Effective Date: February 1, 1964
Completion Date: January 31, 1966
Funds: $12,243

This research study was authorized to examine existing hypotheses and to develop new hypotheses of pavement

performance as related to fundamental principles of engineering mechanics and materials science and, alternately, to test these hypotheses with data from any other available source.

This research has been completed, and the project report has been published as: NCHRP Report 30, "Extension of AASHO Road Test Performance Concepts."

Project 1-5 FY '64

Detecting Variations in Load-Carrying Capacity of Flexible Pavements

Research Agency:	Cornell Aeronautical Laboratory
Principal Invest.:	Dr. N. M. Isada
Effective Date:	January 15, 1964
Completion Date:	July 15, 1965
Funds:	$49,011

A need exists for an accurate method which will indicate the relative load-carrying capacity of pavements when compared with capacities during fall or other seasons so that restrictions in load limits can be more objectively applied. It is desirable that such a method be rapid and simple in operation and nondestructive to the pavement.

This research approached the objectives in terms of investigating the displacement response of flexible pavements to impulsive loadings as a measure of the seasonal changes in the elastic properties. The findings have been published as: NCHRP Report 21, "Detecting Variations in Load-Carrying Capacity of Flexible Pavements."

Project 1-5(2) Fy '67

Detecting Seasonal Changes in Load-Carrying Capabilities of Flexible Pavements

Research Agency:	Texas A & M University Research Foundation
Principal Invest.:	F. H. Scrivner W. M. Moore
Effective Date:	September 1, 1966
Completion Date:	June 30, 1968
Funds:	$49,428

Frost, temperature, moisture, and other environmental factors influence the seasonal changes in strength of flexible pavements, particularly during the spring thaw periods in the northern areas of the country. A simple, rapid, and nondestructive procedure is needed for determining the relative load-carrying capabilities of pavements during all seasons of the year. The objectives of this study were to evaluate methods of meeting this need and to develop techniques and guidelines for field use of the most promising procedure. As a result of the evaluation, the Lane-Wells Dynaflect equipment was selected for field evaluation and recommended for field operation.

Research has been completed, and the project report has been published as: NCHRP Report 76, "Detecting Seasonal Changes in Load-Carrying Capabilities of Flexible Pavements."

Project 1-6 FY '64

Standard Measurements for Satellite Program—Measurement Team

Research Agency:	Texas A & M University Research Foundation
Principal Invest.:	F. H. Scrivner
Effective Date:	March 31, 1964
Completion Date:	January 31, 1967
Funds:	$61,353

This research related to establishing measurement teams equipped, staffed, and trained to make common denominator measurements on the projects in any proposed satellite research program and to insure continuity of these measurements during the life of such a program.

The measurement program considered minimal for a nationwide coordinated satellite program was outlined in the guidelines prepared under NCHRP Project 1-1, but the guidelines did not specify actual items of test equipment nor describe team personnel requirements or procedures in detail. In addition, it did not attempt to define the testing program for the measurement teams in terms of frequency of visits to individual projects or schedules of measurements within projects.

Research has been completed, and the project report has been published as: NCHRP Report 59, "Standard Measurements for Satellite Road Test Program."

Project 1-7 FY '65

Development of Interim Skid-Resistance Requirements for Highway Pavement Surfaces

Research Agency:	The Pennsylvania State University
Principal Invest.:	Prof. W. E. Meyer
Effective Date:	June 15, 1965
Completion Date:	December 15, 1966
Funds:	$24,815

The specific objectives of this research were to (1) develop a state-of-knowledge report on skid measurement techniques and coefficients for highway pavements, (2) recommend interim design values and minimum service values for skid resistance of wet pavements in terms of safety and economy for different methods of measurements, and (3) outline a long-range program to provide verification or refinement of the recommended values.

Research has been completed, and the project report has been published as: NCHRP Report 37, "Tentative Skid-Resistance Requirements for Main Rural Highways."

Project 1-8 FY '65

Factors Involved in the Design of Asphalt Pavement Surfaces

Research Agency: Materials Research & Development
Principal Invest.: F. N. Finn
Effective Date: January 1, 1965
Completion Date: February 28, 1966
Funds: $23,255

This research was authorized to identify the factors fundamental to comprehensive design of asphalt surface courses; to appraise the state of knowledge concerning both the recognition of and accounting for these factors in design; and to recommend areas in which new test methods and research are needed if currently used test methods are inadequate to provide the necessary information concerning the fundamental factors.

Research has been completed, and the project report has been published as: NCHRP Report 39, "Factors Involved in the Design of Asphaltic Pavement Surfaces."

Project 1-9 FY '67

Evaluation of Studded Tires

Research Agency: Cornell Aeronautical Laboratory
Principal Invest.: F. R. Haselton
Effective Date: October 1, 1966
Completion Date: June 30, 1967
Funds: $24,998

This was essentially a state-of-the-art study in which currently available data on the performance of studded tires were evaluated and correlated. Correlations of published and unpublished information on both the effectiveness of studded tires and the wear resulting from their use were provided. Some recommendations were made for measuring pavement wear caused by studded tires and for a controlled systematic means for investigating the pavement wear on a nationwide basis.

Research has been completed, and the project report has been published as: NCHRP Report 61, "Evaluation of Studded Tires—Performance Data and Pavement Wear Measurement."

Project 1-10 FY '67 and FY '69

Translating AASHO Road Test Findings—Basic Properties of Pavement Components

Research Agency: Materials Research and Development
Principal Invest.: B. A. Vallerga
F. N. Finn
Dr. W. R. Hudson
Dr. Keshavan Nair

Effective Dates:	Sept. 12, 1966	Dec. 1, 1968
Completion Dates:	Mar. 11, 1968	Dec. 31, 1970
Funds:	$99,803	$103,291

This research concentrated on improving the understanding of the significant basic properties of pavement systems and components and their relationships to design and performance, with due regard to locality and environment. The specific objectives of the research were (1) development of descriptions of significant basic properties of materials used in road structures, (2) development of procedures for measuring these properties in a manner applicable to pavement design and evaluation, and (3) development of procedures for pavement design, utilizing the measured values of the basic properties, which would be applicable to all locations, environments, and traffic loadings.

Research has been completed, and project reports covering the subdivisions have been published as: NCHRP Report 139, "Flexible Pavement Design and Management—Systems Formulation" and NCHRP Report 140, "Flexible Pavement Design and Management—Materials Characterization."

Project 1-10A FY '72

Systems Approach to Pavement Design—Implementation Phase

Research Agency: Texas A & M University Research Foundation
Principal Invest.: R. L. Lytton
W. F. McFarland
Effective Date: March 1, 1972
Completion Date: December 31, 1973
Funds: $100,000

The primary objective of this project was the further development of the SAMP5 program to field application stage and its pilot testing in one or more state highway departments.

The research has been completed and the objective accomplished. The systems model (now designated as SAMP6) has been modified to include full roadbed cross sections, variable unit costs with quantity and time, stochastic variability of some values, environmental roughness, and a modified structural subsystem. Trial implementation of the SAMP6 program was undertaken in the States of Florida, Kansas, and Louisiana. An evaluation of the pilot studies indicates that SAMP6 is an operational computer program that can be a useful tool in the pavement design and management process.

The project report has been published as: NCHRP Report 160, "Flexible Pavement Design and Management—Systems Approach Implementation."

Project 1-10B FY '73

Development of Pavement Structural Subsystems

Research Agency:	Materials Redevelopment
Principal Invest.:	F. N. Finn
	Dr. C. L. Saraf
	Dr. W. S. Smith
Effective Date:	February 1, 1974
Completion Date:	July 31, 1986
Funds:	$447,941

The primary objective of this project was to develop, modularize, and demonstrate implementability of flexible-type pavement structural subsystems utilizing implementable mechanistic techniques to analyze specific distress modes in pavement structures for various environmental, traffic, and construction conditions and having the capability of being used to evaluate both new pavement structures and overlays. The analysis techniques were based on available information from previous and current research. They are applicable to all flexible-type pavements, including those with treated base and subbase courses and full-depth bituminous structures. Specific distress modes that were considered are:

(a) Cracking from repetitive traffic loading.
(b) Permanent deformation from repetitive traffic loading.
(c) Thermal cracking.

The initial phase of the research has been completed with the development of two computer programs, one referred to as PDMAP (Probabilistic Distress Models for Asphalt Pavements) for fatigue cracking and permanent deformation, and the second referred to as COLD (Computation of Low-Temperature Damage) for low-temperature cracking. The programs are capable of predicting the occurrence of pavement distress based on material properties, traffic loading, and environmental input data. They can be used in pavement management systems, diagnostic investigations, formulation of design criteria, and preparation of material and construction specifications.

The essential findings from the initial phase of the project have been published in a paper, "Mechanistic Structural Subsystems for Asphalt Concrete Pavement Design and Management," in *Transportation Research Record 602* and in the *Proceedings of the Fourth International Conference on Structural Design of Pavements.*

Phase II of the project had the objective of assisting the state highway agencies in Florida and Utah during calibration and implementation of the PDMAP and COLD programs. These efforts were intended to use materials characterization data previously developed by the participating states. However, it was determined that the existing data would be suitable for only a demonstration of the programs rather than actual implementation.

Research has been completed, and the project report has been published as: NCHRP Report 291, "Development of Pavement Structural Subsystems."

Project 1-11 FY '68

Evaluation of AASHO Interim Guides for Design of Pavement Structures

Research Agency:	Materials Research and Development	
Principal Invest.:	C. J. Van Til	
	B. F. McCullough	
Effective Dates:	Oct. 23, 1967	Aug. 1, 1970
Completion Dates:	June 30, 1970	Apr. 30, 1971
Funds:	$63,720	$20,205

The specific objectives of this research were (1) to collect, review, and summarize current State highway department pavement design procedures, and (2) to develop proposed revisions to the AASHO Interim Guides for the Design of Pavement Structures based on an evaluation of the results of the first objective.

Research has been completed, and the project reports have been published as: NCHRP Report 128, "Evaluation of AASHO Interim Guides for Design of Pavement Structures," and "AASHO Interim Guide for Design of Pavement Structures," published by the American Association of State Highway and Transportation Officials, 444 North Capitol St., N.W., Suite 225, Washington, D. C. 20001.

Project 1-12 FY '70

Determination of Pavement Friction Coefficients Required for Driving Tasks

Research Agency:	The Franklin Institute
Principal Invest.:	Eugene Farber
Effective Date:	August 25, 1969
Completion Date:	June 8, 1973
Funds:	$309,244

The ultimate objectives of research in this problem area, dealing with the frictional coupling of the vehicle tire and the pavement surface, were to (1) determine pavement skid resistance requirements, (2) improve the reliability of skid resistance measurements, and (3) improve the ability to build and maintain highly skid resistant pavements. The specific objective of this project was the development of procedures for determining pavement skid resistance requirements for various classes of highways, taking into consideration such factors as driver and vehicle characteristics, traffic, weather, and highway geometry.

Research has been completed and a procedure developed for determining skid resistance requirements for intersections and other roadway sites where braking occurs.

The project report has been published as: NCHRP Report 154, "Determining Pavement Skid Resistance Requirements at Intersections and Braking Sites."

Project 1-12A FY '74

Wet-Weather Skidding Accident Reduction at Intersections

Research Agency: Ohio Department of Transportation
Principal Invest.: R. D. Paddock
Effective Date: July 1, 1975
Completion Date: July 1, 1978
Funds: $199,955

This project was directed toward examination of methods developed under NCHRP Project 1-12 for determining vehicular longitudinal acceleration forces and to relate these forces to the incidence of vehicle skidding through loss of traction at the tire-pavement interface. The overall objective was to provide highway agencies with practical methods needed for determining where longitudinal acceleration demand exceeds available tire-pavement interface friction.

Research has been completed. It was found that vehicle deceleration profiles were strongly related to wet-weather accident rates at intersection sites and approach speed data could be used in place of the more difficult to obtain acceleration data for modeling wet-weather accident rates. The Ohio DOT is implementing on a trial basis the procedures for predicting accident rates developed during this project.

Copies of the agency report were distributed to program sponsors and will not be published in the regular NCHRP report series. Loan copies are available or microfiche of the report may be purchased (see final page of this section for ordering information).

Project 1-12(2) FY '71

Locked-Wheel Pavement Skid Tester Correlation and Calibration Techniques

Research Agency: The Pennsylvania State University
Principal Invest.: Prof. W. E. Meyer
R. R. Hegmon
Effective Date: September 16, 1970
Completion Date: May 15, 1973
Funds: $319,000

The specific objective of this project was the development and verification of methods for improving the ability to measure pavement skid resistance with skid testers in general conformance with ASTM Method E-274.

The project report has been published as: NCHRP Report 151, "Locked-Wheel Pavement Skid Tester Correlation and Calibration Techniques."

Project 1-12(3) FY '72

Requirements for Wear-Resistant and Skid-Resistant Highway Pavement Surfaces

Research Agency: Materials Research & Development
Principal Invest.: C. J. Van Til
Effective Date: November 1, 1971
Completion Date: September 30, 1975
Funds: $261,955

The objectives of this project were to (1) identify and evaluate currently available pavement surfaces, construction procedures, and treatments for improving wear resistance and skid resistance of roadways and (2) conduct an experimental program to evaluate promising innovative procedures for providing highly wear- and skid-resistant pavement surfaces.

The research has been completed. The essential findings have been published as NCHRP Research Results Digest 89. The agency report has been distributed to the Program sponsors and other interested persons. It will not be published in the regular NCHRP report series but is available on a loan basis upon written request to the NCHRP. Microfiche of the report may be purchased (see final page of this section for ordering information).

Project 1-13 FY '72

Effects of Studded Tires on Highway Safety

Research Agency: Calspan Corporation
Principal Invest.: Kenneth Perchonok
Effective Date: April 19, 1971
Completion Date: August 20, 1974
Funds: $208,898

The specific objective of this project was to measure, by study of accidents, accident records, accident investigations, or other appropriate means, the effect of studded tire use on the incidence and severity of accidents occurring under winter driving conditions. Analysis included consideration of exposure of vehicles with and without studded tires to accident occurrence.

Although all relationships that were developed did not prove to be statistically significant (at the 95 percent level) a slight safety advantage was indicated for studded tires.

The project report has been published as: NCHRP Report 183, "Studded Tires and Accident Safety—An Accident Analysis."

Project 1-13(2) FY '72

Effects of Studded Tires on Highway Safety—Non-Winter Driving Conditions

Research Agency: University of Michigan
Principal Invest.: J. A. Green, J. S. Creswell, D. F. Dunlap
Effective Date: February 15, 1972
Completion Date: May 31, 1973
Funds: $39,450

The objectives of this study were to synthesize current knowledge about studded tires related to their non-winter driving safety effects and to use this synthesis to formulate

a plan for determining the magnitude of these non-winter safety effects where this information cannot be derived with assurance from existing data.

Project work has been completed and has offered some insight into the magnitude of the further investigational work required to quantify the many stud-related influences on highway safety.

The project report has been published as: NCHRP Report 176, "Studded Tires and Highway Safety—Feasibility of Determining Indirect Benefits."

Project 1-14 FY '73

Influence of Combined Highway Grade and Horizontal Alignment on Skidding

Research Agency: University of Michigan
Principal Invest.: Paul Fancher
Effective Date: October 15, 1972
Completion Date: January 14, 1974
Funds: $69,968

The objective of the research was to develop tentative guidelines for highway geometrics and pavement surface characteristics to ensure adequate vehicle control during anticipated maneuvers on highway sections containing the combination of horizontal alignment and upgrade and downgrade vertical alignment.

Research has been completed with the finding that the AASHTO design procedures—as described in *A Policy on Geometric Design of Rural Highways, 1965* and *A Policy on Design of Urban Highways and Arterial Streets, 1973*—provide a practical method for arriving at reasonable geometric designs for sites with combined horizontal curvature and vertical grade, provided (1) the selected values of superelevation are large enough to result in adequate pavement surface drainage and (2) the pavement skid resistance is sufficient for anticipated vehicle maneuvering. However, misinterpretation of the AASHTO design procedures has resulted in design and construction of long-radius curves with inadequate superelevation for surface drainage that contributes to an extraordinary wet-weather accident rate at this type of site.

The project report has been published as: NCHRP Report 184, "Influence of Combined Highway Grade and Horizontal Alignment on Skidding."

Project 1-15 FY '73

Design of Continuously Reinforced Concrete Pavements for Highways

Research Agency: University of Texas at Austin
Principal Invest.: Dr. B. F. McCullough
Dr. W. R. Hudson
Effective Date: August 1, 1972
Completion Date: August 31, 1975
Funds: $151,870

Project work included general condition surveys of CRCP performance in a large group of states and diagnostic studies in several; laboratory studies of the behavior of model CRCP slabs under repetitive loading; and theoretical analysis of CRCP behavior. The research produced well-defined guidelines for a new CRCP design procedure; recommendations for certain of the required design criteria and for approaches to the establishment of others; and suggestions for improving the construction process.

Research has been completed. The essential findings of the study have been published as NCHRP Research Results Digest 82. The agency report has been distributed to the Program sponsors and other interested persons. It will not be published in the regular NCHRP report series but is available on a loan basis upon written request to the NCHRP or microfiche of the report may be purchased (see final page of this section for ordering information).

Project 1-16 FY '74

Evaluation of Winter-Driving Traction Aids

Research Agency: The Pennsylvania State University
Principal Invest.: Prof. W. E. Meyer
Dr. J. J. Henry
Effective Date: June 3, 1974
Completion Date: October 31, 1981
Funds: $304,400

To aid in the efficient movement of people and materials during the winter season, industry has developed various winter-driving traction aids such as tire chains, snow tires, studded tires, the limited-slip differential, nonlocking brakes, the four-wheel drive, polyethylene chains, and improved rubber compounds. These aids do not appear to be equally effective on snow-and ice-covered roads. In addition, some of these aids are quite damaging to pavement surfaces. Standard procedures are needed for evaluating the relative performance and pavement wear effects of winter-driving traction aids. There is also a need for a comprehensive investigation of currently available devices for improving vehicle performance on ice- and snow-covered roads.

Research has been completed, with partial accomplishment of project objectives. A set of vehicle performance test procedures has been selected for evaluating winter-driving traction aids. An experimental program to evaluate the performance of available winter-driving traction aid types on ice surfaces was conducted on an indoor ice rink. Testing on snow surfaces was not completed due to lack of snow and difficulties characterizing snow surfaces. A cost-effectiveness model for evaluating winter-driving traction aids has been developed and illustrative examples prepared. Although an over-all ranking of winter-driving traction aids could not be made due to the limited amount of data available, standardized test procedures are described for comparing the performance of traction aids of a similar type.

The essential findings of the study have been published as NCHRP Research Digest 133. Copies of the revised agency report have been distributed to the Program sponsors and will not be published in the regular NCHRP report series. Loan copies are available from the NCHRP upon written request or microfiche of the report may be purchased (see final page of this section for ordering information).

Project 1-17 FY '77

Guidelines for Recycling Pavement Materials

Research Agency: Texas A&M University Research Foundation
Principal Invest.: Dr. Jon A. Epps
Effective Date: November 1, 1976
Completion Date: September 30, 1979
Funds: $199,470

The over-all objective of this project was the development of realistic guidelines for the recycling of pavement materials for the rehabilitation and reconstruction of existing pavements. The objective has been accomplished and the project report published as: NCHRP Report 224, "Guidelines for Recycling Pavement Materials."

Project 1-18 FY '77

Calibration and Correlation of Response-Type Road Roughness Measuring Systems

Research Agency: University of Michigan
Principal Invest.: Dr. T. D. Gillespie
Effective Date: October 1, 1977
Completion Date: September 30, 1980
Funds: $250,000

The objective of this project was the development and verification of relatively rapid and inexpensive methods for the calibration and correlation of response-type road roughness measuring systems. Research has been completed. Road roughness measuring systems were investigated to determine their performance characteristics and the necessary conditions for calibration. Primary and secondary calibration methods were developed and evaluated during a limited correlation program.

The project report has been published as: NCHRP Report 228, "Calibration of Response-Type Road Roughness Measuring Systems."

Project 1-19 FY '78 and FY '80

Development of a System for Nationwide Evaluation of Portland Cement Concrete Pavements

Research Agency: University of Illinois
Principal Invest.: Dr. M. I. Darter
Effective Date: January 23, 1978
Completion Date: March 15, 1985
Funds: $225,000

A Concrete Pavements Evaluation System (COPES) was developed and applied to several States (Illinois, Georgia, California, Utah, Minnesota, and Louisiana). COPES provides the format and procedures for collecting data from historical records and field observations and measurements on PCC concrete pavement projects. COPES interfaces with selected, standard computer packages for data management and statistical analyses. Uses of COPES for design, construction, materials evaluation, maintenance and rehabilitation purposes were demonstrated within states and among states.

A final report was published as: NCHRP Report 277, "Portland Cement Concrete Pavement Evaluation System (COPES)." This report contains an analysis of data among states for purposes of demonstrating the system and a user's manual for implementing COPES.

An agency report titled, "Concrete Pavement Evaluation Systems (COPES), Research Report," is also available for loan or purchase (see final page of this section for ordering information). This agency report contains analyses of data per each of the participating states. Again, these analyses were meant to demonstrate potential uses of COPES; however, significant insight into the performance of concrete pavements can be gained.

Project 1-20 FY '79

Influence of Asphalt Temperature Susceptibility on Pavement Construction and Performance

Research Agency: Texas A&M University
Principal Invest.: B. M. Gallaway
J. W. Button
Dr. J. A. Epps
Effective Date: May 1, 1979
Completion Date: July 16, 1984
Funds: $200,000

The overall objectives of the research were:

1. To determine the range or extent of variability in temperature susceptibility of asphalt cements currently being used in road construction.
2. To evaluate the effects of the identified variability, in relation to other factors and over the full range of service temperatures, on pavement construction operations and short-term performance of pavements.
3. To identify the limits of variability in temperature susceptibility that can be accommodated through application of known asphalt technology by changes in asphaltic concrete construction procedures and mix design considerations.
4. To determine procedures for accommodating or controlling that variability in temperature susceptibility of asphalt cements that cannot be accommodated by known asphalt technology.

Research has been completed, and the project report has been published in 2 volumes as: NCHRP Report 268,

"Influence of Asphalt Temperature Susceptibility in Pavement Construction and Performance," and NCHRP Report 269, "Paving with Asphalt Cements Produced in the 1980."

Project 1-21 FY '80

Repair of Joint-Related Distress in Portland Cement Concrete Pavements

Research Agency: University of Illinois
Principal Invests.: Dr. M. I. Darter
Dr. E. J. Barenberg
Mr. W. G. Yrjanson
Effective Date: May 15, 1980
Completion Date: June 28, 1985
Funds: $300,000

The objective of this research was to develop guidelines and criteria for making cost-effective decisions for correcting failures related to joints (or cracks acting as joints) of jointed PCC pavements. The types of failures to be considered included faulting, D-cracking, restraint cracking, corner cracking, and load transfer. The techniques of overlay and recycling were not considered as part of this research.

Procedures for project evaluation and selection of cost effective repair and preventive techniques were developed. Detailed "Design and Construction Guidelines" and "Guide Specifications" were prepared for seven different techniques for repairing and preventing the deterioration of joints and cracks. These techniques include: (1) full-depth repair of deteriorated joints, cracks, and shattered slabs; (2) partial depth patching of joint spalls; (3) subsealing to fill voids and restore support; (4) restoration of load transfer of joints and cracks; (5) diamond grinding; (6) resealing of joints and cracks; and (7) improved slab edge support. The procedures were tested and partially verified through a series of field demonstrations. A void detection procedure was developed that utilizes nondestructive deflection testing procedures to locate areas requiring subsealing.

The final report has been published as: NCHRP Report 281, "Joint Repair Methods for Portland Cement Concrete Pavements—Design and Construction Guidelines." This report documents the research effort in general and contains the guidelines and guide specifications for the various repair and preventive techniques. Agency copies of Appendix B, "Field Demonstration Projects of Joint/Crack Repairs," and Appendix C, "Void Detection Procedures," are also available for loan or purchase (see final page of this section for ordering information).

Project 1-22 FY '81

Shoulder Geometrics and Use Guidelines

Research Agency: Hugh Downs—RK & K
Principal Invest.: H. G. Downs, Jr.
Effective Date: September 8, 1981
Completion Date: April 7, 1983
Funds: $100,000

The objective of the research was to determine optimum use of highway shoulders considering such factors as safety, economics, traffic operations, roadway functional classification, and traffic volume. Research has been completed, resulting in a set of shoulder geometric design and use guidelines that will encourage greater uniformity.

The project report has been published as: NCHRP Reprt 254, "Shoulder Geometrics and Use Guidelines."

Project 1-23 FY '82

Pavement Roughness and Rideability

Research Agency: KETRON, Inc.
Principal Invest.: M. S. Janoff
Effective Date: January 4, 1982
Completion Date: November 30, 1984
Funds: $249,990

The objectives of this research were to (1) develop a scale that accurately reflects the public's perception of pavement roughness, (2) develop transforms that relate pavement profiles to the scale developed in objective 1, and (3) show how roughness statistics produced by various RTRRMS relate to the scale developed in objective 1.

Research has been completed with accomplishment of the objectives. The project report has been published as: NCHRP Report 275, "Pavement Roughness and Rideability."

Project 1-23(2) FY '87

Pavement Roughness and Rideability—Field Evaluation

Research Agency: JMJ Research
Principal Invest.: M. S. Janoff
Effective Date: January 6, 1986
Completion Date: December 31, 1987
Funds: $199,983

The objective of this project was to conduct a field evaluation of the method developed under Project 1-23 of determining the serviceability of pavements in terms of rideability or ride number (RN) from measured profiles. The field evaluation involved collection and analysis of subjective (panel ratings of rideability) and objective (measured profiles) data for selected pavements in different regions of the country. The field evaluation verified the basic concepts of Project 1-23 and produced refined models suitable for adoption by AASHTO as a universal method for determining rideability.

Research has been completed with accomplishment of the objectives. The project report has been published as: NCHRP Report 308, "Pavement Roughness and Rideability—Field Evaluation."

Project 1-25 FY '87

Effects of Heavy Vehicle Characteristics on Pavement Response and Performance—Phase I

Research Agency: TRB Special Projects Division
Principal Invest.: Joseph R. Morris
Effective Date: June 12, 1986
Completion Date: November 30, 1987
Funds: $100,000

The lack of detailed data on characteristics of heavy vehicles relevant to pavement design has been recognized. Increasing diversity in heavy vehicle characteristics requires a reassessment of input parameters to pavement design and analysis. There are several research projects, both completed and underway, that are intended to evaluate the effects on pavement performance of tire types, tire pressures, heavy vehicle suspension kinematics, and axle configurations through the use of pavement response models and vehicle modeling techniques. A need exists for procedures and techniques for optimization of pavement and heavy vehicle design to provide efficient operation of the highway transportation system.

The objectives of Phase I of this research were to (a) determine, collect, organize, assimilate, and evaluate all available data and information relative to the effects of heavy vehicle characteristics on pavement response to wheel loads; (b) identify and describe the necessary data base for accomplishment of the overall project objective; and (c) make recommendations concerning the research required for accomplishment of the overall objective.

Research has been completed and the preliminary draft report approved by the project panel. It is being used primarily to identify specific research objectives for Phase II of the project. Consequently, the report will not be published in the regular NCHRP report series but is available on a loan basis upon written request to the NCHRP.

Project 1-25(1) FY '87 and FY '88

Effects of Heavy Vehicle Characteristics on Pavement Response and Performance—Phase II

Research Agency: University of Michigan
Principal Invest.: Dr. Thomas D. Gillespie
Effective Date: September 1, 1988
Completion Date: August 31, 1991
Funds: $400,000

The lack of detailed or conclusive data on characteristics of heavy vehicles relevant to pavement management was recognized in several workshop sessions at the North American Pavement Management Conference in 1985 and subsequent papers submitted for the Second North American Conference on Managing Pavements scheduled for November 1987. Increasing diversity in heavy vehicle characteristics requires a reassessment of input parameters to pavement design and analysis. There are several research projects, both completed and underway, that are intended to evaluate the effects on pavement performance of tire types, tire pressures, heavy vehicle suspension kinematics, and axle configurations through the use of pavement response models and vehicle modeling techniques. A need exists for procedures and techniques for optimization of pavement and heavy vehicle design to provide efficient operation of rural and urban roadways.

The objective of this research is to analyze and evaluate the interaction between heavy vehicle characteristics and pavement performance for application in pavement management. Heavy vehicle (truck and bus) characteristics shall include tire types (bias ply, radial, low profile radial, and "super-single"), tire pressures, tire contact (area and load distribution), tire configuration (single, dual, and other), suspension systems (variable load, load sharing, and dynamic response), axle configuration (spacing, location, and steering axle), axle static loads, and operating conditions (speeds and acceleration/deceleration). Pavement factors to be considered shall include design (flexible and rigid), operating conditions (high speed and low speed), surface conditions (smooth, rough, jointed), traffic mix, and geometrics. Both static and dynamic interactions between various heavy vehicle and pavement factors shall be analyzed and evaluated to determine their relationships and relative significance. Analytical and experimental procedures shall be used to investigate the effects of these interactions on pavement performance and to provide guidelines for use in pavement analysis and design applications.

Accomplishment of the project objectives is envisioned to involve the following tasks:

Task 1—Model Selection. With recognition that existing state-of-the-art models may contain deficiencies or simplistic representations with regard to the required study parameters, it is anticipated, nonetheless, that only a minor portion of the research activity would be required for model enhancement.

The report on the first phase of NCHRP Project 1-25 will assist the researcher in assessing the capabilities of various existing models, making appropriate model selections, and refining the study design to accomplish subsequent tasks. Any resulting elaboration or refinement of the research plan shall be submitted to the project panel for review and comments.

The predictive results of the vehicle simulation must be compatible with the operative requirements of the

pavement models to the extent that the latter can be used to evaluate pavement response in a qualitative sense for the range of scenarios that emerges when one or more of the input parameters is varied.

Task 2—Prepare Plan of Field Experiment. The researcher must outline desirable instrumentation and the collection of field measurements that would be necessary to accomplish Task 5. The actual collection of these data may be possible from concurrent research sponsored by the Federal Highway Administration and entitled "Impact of Truck Characteristics on Pavements-Truck Load Equivalency Factors" and the availability of such data will ultimately determine the extent of execution of Task 5. This measurement design must be submitted to the project panel as an interim report, for review and approval, no later than 90 days after the award of contract.

Task 3—Analysis. This task is the principal focus of the research and should be designed to provide an order of significance to the variables studied. The analytical efforts shall include, as a minimum, those indicated by the partial factorial matrix design plus an evaluation of other information necessary to accomplish Task 4.

Task 4—Identify Qualitative Relationships Between Vehicle and Pavement Variables. Develop trends in the performance of pavements as they are affected by the various road and vehicle factors studied. It shall be a part of this task to classify the studied variables into their probable order of impact and to identify and document those areas of consequence requiring further model development or refinement.

Task 5—Model Trend Validation. Data from the FHWA sponsored study, "Impact of Truck Characteristics on Pavements—Truck Load Equivalency Factors," or other sources shall be used by the researcher to compare the model's pavement response predictions to measurements of response to actual vehicle dynamic loadings. To the extent possible, the researcher should use these experimental results to validate the trends and sensitivities of the models used.

Task 6—Prepare a Final Report. The activities of the research shall be fully described and the report shall include reasons for the selection of the models used, their initially perceived attributes and/or insufficiencies of consequence and a post-research judgment as to their usefulness for predicting the interactions between pavements and dynamic loadings. The researchers may wish to recommend model refinements, but their principal focus should be on those developed research results that can be confidently used by highway agencies and truck and tire manufacturers to understand and assign relatively ordered consequences to any changes that might be contemplated in the analysis and design of pavements or vehicles.

Research is in progress.

Project 1-26 FY '87

Calibrated Mechanistic Structural Analysis Procedures for Pavements

Research Agency:	University of Illinois
Principal Invest.:	Dr. Marshall Thompson
	Dr. Ernest Barenberg
Effective Date:	February 6, 1987
Completion Date:	June 30, 1989
Funds:	$250,000

During the development of the revised AASHTO Guide for Design of Pavement Structures, the AASHTO Joint Task Force on Pavements decided that the new guide would incorporate the original AASHTO Road Test algorithms with modifications and improvements deemed appropriate as a result of experience and research subsequent to the Road Test. Furthermore, the Task Force decided that the new guide should present a framework for mechanistic-empirical pavement design methods as a window into the future. The guide as published incorporates these concepts.

The overall objective of research in this problem area is the development, calibration, and verification of mechanistic analysis and design procedures that will reliably predict relationships between traffic loading, environmental and material conditions, and pavement distress such as fatigue cracking, thermal cracking, rutting, and joint-faulting, suitable for use in future versions of the *AASHTO Guide for the Design of Pavement Structures.*

The specific objectives of this project are to (1) select from existing mechanistic technology those procedures suitable for accomplishment of the overall objective, (2) further develop and conduct pilot calibration and verification of the selected technology to the stage of a practical procedure for checking specific pavement designs for various forms of distress, (3) prepare a long-term plan for calibration and verification of the analysis procedure, and (4) prepare a research plan for future development of the analysis procedure to an implementable mechanistic pavement design method. It is intended that the field calibration be accomplished as part of the Long Term Pavement Performance activity of SHRP.

Research is in progress.

Project 1-27 FY '89

Video Image Processing for Evaluating Pavement Surface Distress

Research Agency:	In developmental stage
Principal Invest.:	
Effective Date:	(30 Months)
Completion Date:	
Funds:	$350,000

Measuring distress of both bituminous and portland cement concrete pavements is a primary means of eval-

uating pavement performance. Despite the importance of distress measurements, current methods are subjective and time consuming. However, significant progress has been made in electronic instrumentation and in computer technology. For example, independent efforts to fully automate crack detection, employing recent advances in image processing and pattern recognition, are underway. Nevertheless, ongoing efforts, even if successful, will not resolve all the problems in fully automating distress measurements. Additional work that builds on these efforts is needed.

An increasing number of transportation agencies have embraced the concept of data- and image-acquisition systems that record, among other things, the condition of the pavement surface in a video format. Therefore, it is anticipated that an automated means of processing video images to quantify surface distress will be widely accepted by transportation agencies. In general, the availability of a robust image processing and pavement-distress-recognition system would represent a significant contribution in the field of pavement management at both network and project levels.

The objective of this project is to develop a system for processing video images to identify, quantify, and classify pavement distress in terms of types, severity, and extent. Accomplishment of the objective will require the following tasks:

Task 1. Assess the potential capabilities of using video images to identify and quantify pavement surface distress for use in network condition assessments and for project level decisions. Prepare a preliminary system design for processing these video images. Specify the image resolution and other characteristics required for processing, and describe the equipment and conditions that would be needed for obtaining such images.

Task 2. Obtain a sample of video images suitable for the determination of pavement distress by type, severity, and extent through automated image processing. Video images obtained shall represent distress types across a full-lane width.

Task 3. Develop the video image processing system described in Task 1 with consideration for user options on hardware and video parameters specific to an individual transportation agency.

Task 4. Validate system output by comparison with visual interpretations of video images.

Task 5. Modify the system based on the Task 4 validations.

Task 6. Arrange to demonstrate the video image processing system to the NCHRP.

Task 7. Deliver the video image processing system software, program source codes, and user's and program manuals to the NCHRP.

Task 8. Prepare a final report on the total research effort.

AREA 2: ECONOMICS

Project 2-1 FY '63 and FY '64

Criteria for Highway Benefit Analysis

Research Agency: University of Washington
Principal Invest.: Prof. R. G. Hennes
Effective Date: June 1, 1963
Completion Date: November 30, 1967
Funds: $101,948

This project provided estimates of the relevance of different types of benefit and cost data to decisions in highway location. Basic guides for priorities, guidelines for data collection, and basic information related to taxation were developed.

An interdisciplinary approach to the problem was undertaken by the Departments of Civil Engineering, Political Science, Business Administration, Economics, and Sociology of the University of Washington.

The final report was not published in the NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 2-2 FY '63

Guidelines for the Determination of Community Consequences

Research Agency: University of Washington
Principal Invest.: Prof. Edgar M. Horwood
Effective Date: July 1, 1963
Completion Date: August 31, 1964
Funds: $48,873

This project was concerned with identifying and predicting community consequences arising from highway improvements. It was designed to seek out both favorable and unfavorable consequences and involved evaluation of existing economic impact studies, developing of guidelines for highway agencies to follow in these studies, and the outlining of urgent aspects of this problem needing detailed researched.

The Urban Planning and Civil Engineering Departments combined their talents and analyzed more than 600 research reports and other writings. The final report presented an analysis of bypasses, circumferentials, and radial freeway impact effects. The utility of these studies, as well as expressed gaps in knowledge, was also discussed.

This research has been completed, and the results have been published as: NCHRP Report 18, "Community Consequences of Highway Improvement."

Project 2-3 FY '63 and FY '64

Analysis of Motor Vehicle Accident Data as Related to Highway Classes and Design Elements

Research Agency:	Cornell Aeronautical Laboratory
Principal Invest.:	Dr. J. K. Kihlberg
Effective Date:	June 1, 1963
Completion Date:	August 31, 1966
Funds:	$155,972

The objective of the study was to determine the relationship of motor vehicle accidents to highway design elements. The study consisted of two phases: Phase 1 was a one-year study to determine accident and severity rates for various highway types; Phase 2 was a two-year study to extend these rates to various geometric elements of the highway.

The research has been completed, and the project report has been published as: NCHRP Report 47, "Accident Rates as Related to Design Elements of Rural Highways."

Project 2-4 FY '63 and FY '64

The Value of Highway Travel Time, Comfort, Convenience, and Uniform Driving Speed

Research Agency:	Texas A&M University Research Foundation
Principal Invest.:	Dr. W. G. Adkins
Effective Date:	June 1, 1963
Completion Date:	August 31, 1966
Funds:	$77,100

Various methods that have been proposed to evaluate time savings accruing to highway vehicles are reviewed in this report, and two selected models were used to analyze Interstate Commerce Commission data on commercial highway carriage for the year 1962. Values of time saving in dollars per hour were derived for nine geographical regions as designated by the Interstate Commerce Commission for cargo vehicles and for intercity buses. Detailed methodology of the cost-savings model is presented so that other researchers can make similar estimates under known local conditions. Also, an updating technique has been developed, and the 1962 costs were projected to 1965 utilizing equipment costs and driver wags and benefit indexes to develop multipliers. The assumptions of this technique and the limitations of applying the derived results are discussed.

The final report for this project has been published as: NCHRP Report 33, "Values of Time Savings of Commercial Vehicles."

Project 2-5 FY '63 and FY '64

Running Cost of Motor Vehicles as Affected by Highway Design and Traffic

Research Agency:	The Catholic University of America	
Principal Invest:	Dr. Paul J. Claffey	
Effective Date:	June 1, 1963	June 1, 1965
Completion Date:	Aug. 31, 1964	Dec. 31, 1966
Funds:	$49,998	$51,265

In this project, the motor vehicle running costs were developed for use in evaluating user costs related to proposed highway improvements and traffic regulations. These costs were determined from actual vehicle field tests as well as from the available literature.

A research report presenting the results of the first year's work was received and has been published as: NCHRP Report 13, "Running Cost of Motor Vehicles as Affected by Highway Design."

This report relates the fuel consumption cost of a typical passenger vehicle to various roadway geometrics and operating characteristics as measured by more than 4,000 test runs in the field. It describes the development of a precise fuel meter used to collect the data. Brief studies are reported on oil consumption, maintenance, tire wear, and depreciation costs as they are affected by highway and traffic conditions.

During the second phase of research, fuel and time consumption data were collected for a second passenger vehicle, a transit bus, a tractor semitrailer, a single-unit truck, and a diesel truck. A special fuel meter for measuring the fuel consumption of diesel trucks was developed.

The results of this project have been combined with the results of Projects 2-5A and 2-7. The findings of the combined research effort have been published as: NCHRP Report 111, "Running Costs of Motor Vehicles as Affected by Road Design and Traffic."

Project 2-5A FY '65 and FY '67

Running Cost of Motor Vehicles as Affected by Highway Design and Traffic

Research Agency:	Paul J. Claffey and Associates	
Principal Invest.:	Dr. Paul J. Claffey	
Effective Date:	July 1, 1967	Aug. 11, 1969
Completion Date:	Dec. 31, 1968	Aug. 10, 1970
Funds:	$35,000	$30,665

The original 2-5 project was continued to obtain more detailed data on running costs of motor vehicles in order to eliminate certain gaps that exist in the information available on this subject. The results of the earlier work on Project 2-5 and Project 2-7 have been combined with the additional results of this phase of the project into a single comprehensive final report. The effects that vari-

ations in gradient, road surface, speed-change frequency, and traffic volumes have on the running costs of passenger cars, pickup trucks, two-axle six-tire trucks, and tractor-trailer combinations are included in the final report, and information is provided on the operating expenditures of fuel and oil consumption, maintenance and depreciation, tire wear, and accidents. Condensed graphs of the findings of the fuel consumption and tire wear studies are presented. Each is designed to provide fuel and tire wear cost for various combinations of road design elements and speed-change conditions for a given running speed. Also included are families of curves of fuel consumption and tire wear for the eleven test vehicles used in the study and data on the maintenance costs of passenger cars and trucks relative to travel distance, together with average oil consumption rates for operation on dust-free pavements in free-flowing traffic, on dustry roads, in free-flowing traffic, and on high-type pavements under restrictive traffic conditions. Several appendices detail a comparative analysis of fuel consumption of diesel and gasoline trucks, determination of the excess fuel consumed by passenger car passing maneuvers, an investigation of devices for the measurement of tire wear, development of equipment for the measurement of vehicle fuel consumption, and an annotated bibliography on highway motor vehicle operating costs.

The final report for this project has been combined with those from Projects 2-5 and 2-7 and published as: NCHRP Report 111, "Running Costs of Motor Vehicles as Affected by Road Design and Traffic."

Project 2-6 FY '63 and FY '64

Warranted Levels of Improvement for Local Rural Roads

Research Agency: Stanford University
Principal Invest.: Prof. C. H. Oglesby
Effective Date: June 1, 1963
Completion Date: September 30, 1966
Funds: $40,000

This project was concerned with the setting of economic standards for the construction and maintenance of local rural roads. The research has been completed, and the results have been published as: NCHRP Report 63, "Economics of Design Standards for Low-Volume Rural Roads."

Project 2-7 FY '64 and FY '65

Road User Costs in Urban Areas

Research Agency: The Catholic University of America
Principal Invest.: Dr. Paul J. Claffey
Effective Date: February 1, 1964
Completion Date: May 31, 1966
Funds: $99,376

The purpose of this research was to provide data on road-user costs as classified by arterial type, operating speed, traffic composition, and delay factors. Basic tables applicable for planning and for selecting arterial street and highway systems from the various alternates in urban areas were developed.

The final report contains information on fuel and time consumption rates of a passenger vehicle, two trucks, and a bus operating on various types of urban facilities under various levels of service. Some study was devoted to determining motor vehicle accident costs and oil and maintenance costs which can be attributed to urban driving conditions. Tire wear data were collected for freeway and urban arterial comparisons.

The results presented in the project report have been combined with the results of Projects 2-5 and 2-5A and published as: NCHRP Report 111, "Running Costs of Motor Vehicles as Affected by Road Design and Traffic."

Project 2-8 FY '64

Estimation and Evaluation of Diverted and Generated (Induced) Traffic

Research Agency: Northwestern University
Principal Invest.: Prof. W. L. Garrison
Effective Date: May 1, 1964
Completion Date: August 31, 1966
Funds: $40,000

Traffic volumes on new or improved highway facilities are found to increase more than can be attributed to normal growth of existing traffic. This extraordinary traffic increase is composed of two components, diverted and generated. In making analyses of highway improvement consequences, such diverted and generated traffic must be taken into account. At the present time, sufficient information is not available concerning characteristics of this type of traffic.

The final report was not published in the NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 2-9 FY '66

Effect of Highway Landscape Development on Nearby Property

Research Agency: The Franklin Institute
Principal Invest.: Joel N. Bloom
Effective Date: November 8, 1965
Completion Date: January 31, 1968
Funds: $149,103

The intent of this research was to study how highway landscape development affects nearby property on a nationwide basis. This study determines the comparative effects of different basic types of landscape treatments in regard to property values, land use compatibility, and

general acceptability. Factors relative to the problem include geometric design as well as plantings, fencing, slope blending, and screening applications.

The report will assist highway engineers and landscape architects in developing designs that will reduce highway noise levels to an acceptable range for adjacent residents. The research results have been published as: NCHRP Report 75, "Effect of Highway Landscape Development on Nearby Property."

Project 2-10 FY '67

Future Needs for Oversize-Overweight Permit Operation on State Highways

Research Agency:	Roy Jorgensen and Associates
Principal Invest.:	Ralph D. Johnson
Effective Date:	November 1, 1966
Completion Date:	April 30, 1968
Funds:	$99,655

The purpose of this study was to evaluate the extent of current and future activities of oversize-overweight vehicles in relation to the highway transport situation. The research results have been published as: NCHRP Report 80, "Oversize-Overweight Permit Operation on State Highways."

Project 2-11 FY '67

Summary and Evaluation of Economic Consequences of Highway Improvements

Research Agency:	Highway Research Board
Principal Invest.:	Robley Winfrey
Effective Date:	January 1, 1967
Completion Date:	July 31, 1970
Funds:	$110,000

This project reviewed the reports submitted on economics in NCHRP, as well as information from other sources, and prepared the results in a form that may be used directly by engineers, economists, and others who wish to make highway economic studies.

The research was conducted in four phases: (a) to present the background and principles of engineering economy and economic analysis; (b) to present the findings of Projects 2-1 to 2-9, together with supplementary data from other sources, in an organized form for use in benefit-cost studies and other economic analyses; (c) to identify gaps in the information available and needed research to fill these gaps; and (d) to make an introductory study of probable future trends in the technology of economic analysis.

The project report has been published as: NCHRP Report 122, "Summary and Evaluation of Economic Consequences of Highway Improvements."

Project 2-12 FY '73 and FY '77

Highway User Economic Analysis

Research Agency:	Stanford Research Institute	
Principal Invest.:	D. G. Andersen	
Effective Date:	Apr. 1, 1974	Oct. 11, 1976
Completion Date:	Oct. 31, 1975	May 31, 1977
Funds:	$90,074	$9,995

The 1960 AASHO "Informational Report by Committee on Planning and Design Policies on Road User Benefit Analyses for Highway Improvements" (updated revision of the original 1952 report) was written to provide a simple, easy-to-use method for carrying out economic analyses on highway alternatives by those having only basic knowledge of principles of economics. The objective of this research was to employ, to the best possible extent, current empirical data on highway user benefits and costs (such as from NCHRP Report 122 and other research) to provide a revised and updated version of the 1960 AASHO publication. The revised version includes an analysis methodology based on sound economic theory and is suitable for immediate, direct application. The methodology provides a means of evaluating public transit operating on public highways. This evaluation allows comparisons between transit operation and additional highway improvements. Further, procedures are included that provide the user with a means for periodic updating of the numerical factors and cost coefficients through utilization of commonly available economic data. Although it was recognized that environmental and social factors are significant items of input to the decision-making process, this research was limited to road user benefits and costs only.

The final report, "A Manual on User Benefit Analysis of Highway and Bus Transit Improvements," has been published by AASHTO and can be obtained by writing to: American Association of State Highway and Transportation Officials, 444 North Capitol St., N.W., Suite 225, Washington, D.C. 20001

Project 2-13 FY '83

Multilane Design Alternatives for Improving Suburban Highways

Research Agency:	Midwest Research Institute
Principal Invest.:	Douglas W. Harwood
Effective Date:	July 18, 1983
Completion Date:	March 31, 1985
Funds:	$100,000

The objective of this research was to investigate and compare the safety, operational, and cost characteristics of selected multilane design alternatives for use in suburban areas. Operational characteristics include capacity, level of service, and accessibility. Alternatives to be investigated include:

- Three-lane with two-way left-turn lane.
- Four-lane divided with one-way left-turn lanes in the median.
- Four-lane undivided.
- Five-lane undivided, including a center two-way left-turn lane.

Each alternative was investigated under both a no-shoulder condition and a full shoulder condition. Of particular concern were highways with traffic volumes over 7,000 vehicles per day and speeds between 35 and 50 mph (i.e., these conditions usually indicate that a 2-lane highway can no longer handle the traffic demand).

A set of critical factors was identified that should be considered in making meaningful comparisons of the various highway types. The following factors were considered: median presence; shoulder width; accessibility to roadside developments; right-of-way requirements; capacity; operational characteristics; and accident experience. Accident data were obtained from California and Michigan and operational data were developed by the University of Nebraska using a computer simulation model.

The relative merits of each highway design alternative were described in terms of operations, safety, and costs. Primary advantages, disadvantages, and limitations of each alternative were delineated. An example was developed to illustrate how all of the identified factors would typically be considered by state or local authorities in the selection of a particular design. This example demonstrates the general approach, rather than a rigid methodology, to the selection process.

The final report has been published as NCHRP Report 282.

Project 2-14 FY '86

Public/Private Partnerships for Financing Highway Improvements

Research Agency: Kimley-Horn and Associates
Principal Invest.: Laurence J. Meisner
Effective Date: January 1, 1986
Completion Date: March 31, 1988
Funds: $125,000

The objective of this research was to provide guidance to state and local highway officials and private developers on existing and potential public/private partnership mechanisms, including present state and local statutes and ordinances related to private (e.g., developer) participation in financing highway improvements. The project has identified constraints on private participation in financing highway and road improvements, identifies potential opportunities and appropriate processes to implement public/private partnerships, and documents examples of state and local legislation enabling and encouraging such partnerships. Guidelines have been developed for application at the state and local levels to facilitate this form of highway financing.

The guidelines consist of a well-defined, step-by-step process which can be used at the State or local level to implement legislation to facilitate public and private financing partnerships. Specific examples of legislation include recommended language for both statutes and ordinances for three of the most promising mechanisms, namely, special assessment districts, impact fees, and development agreements. A benefit-cost analysis technique was also developed for analyzing benefits to the public and private sectors of a potential funding arrangement.

All research has been completed. NCHRP Research Results Digest 161, "Public and Private Partnerships for Financing Highway Improvements," has been published as a separate report covering only the legal issues.

The final report has been published as NCHRP Report 307, "Public and Private Partnerships for Financing Highway Improvements."

Project 2-15 FY '86

Identifying Measuring, and Evaluating the Benefits of Safety Roadside Rest Areas

Research Agency: KLD Associates, Inc.
Principal Invest.: Gerhart F. King
Effective Date: January 13, 1986
Completion Date: September 30, 1989
Funds: $236,560

There is no known reliable and generally accepted method for measuring and evaluating the benefits of safety roadside rest areas. Most states have not yet completed the originally planned rest area system and now also face the necessity of major reconstruction of many older rest areas.

Rest areas are very popular with the traveling public. Recent sharp increases have occurred in both construction and operation costs of rest areas, and competition for funding with other highway construction and maintenance programs has become difficult. Therefore, the need is extremely great for a reliable and accepted method of comparing rest area benefits with costs. A study is necessary to identify (1) how state highway agencies benefit from rest areas, (2) users and nonusers and how they benefit, and (3) the value of these benefits and related costs.

A new profile of rest area users and their needs is necessary to properly evaluate existing facilities, and to plan and design new and reconstructed rest areas.

The makeup of rest area users today has changed since rest areas were first built. Driving habits are different, motorists' attitudes toward mobility have changed, and there is an increasingly more mobile public, e.g., senior citizens, handicapped, and young families. Furthermore,

traffic speeds and conditions have changed, along with vehicle types and sizes.

While rest area benefits are viewed in a variety of ways, safety is typically near the top of the list. Investigation of experience in managing and operating highway systems with rest areas, including those with commercial facilities, and those systems without rest areas may provide useful data on driver fatigue, behavior, and accident patterns.

The objective of this research is to develop a method for measuring and evaluating the benefits of roadside rest areas to result in more cost-effective designs and operations. This research will address both the benefits and disbenefits associated with rest area facilities.

The research will include the following tasks:

Task 1—Review relevant domestic and foreign publications and research findings.

Task 2—Determine present practice and experience among the states and other appropriate sources in cost and benefit analyses relative to the planning and management of roadside rest area programs.

Task 3—Develop a profile of rest area users and their needs. The user profile should reflect the current mix of rest area users as well as forecasted trend changes over the anticipated 20-year service life of the facilities.

Task 4—On the basis of an evaluation of the methods identified in Tasks 1 and 2 and the profile developed in Task 3, develop a preliminary cost/benefit analysis method for general application. This method will identify:

- How state highway agencies benefit from rest areas.
- How users benefit and who they are.
- How nonusers benefit and who they are.
- The value of these benefits and related costs.

The method should be comprehensive and cover (1) rest area user needs, (2) functional attributes of rest areas (e.g., safety, comfort, information, security, maintainability, aesthetics), (3) resultant economic benefits or disbenefits to the user, community, tourism, local business, state economy, etc., and (4) the capital and operating costs. The method should consider the type of users (e.g., trucking, recreational), type of highway, location (rural/urban), vehicle mix, cooperation with adjoining states, speed limit, and it should be applicable to both new projects and rehabilitation of existing rest areas. Who pays and who benefits should be specifically addressed, as well as innovative funding approaches including private funding, joint use, etc.

Safety is considered to be a primary factor in the decision to provide rest areas. This research will identify and quantify, to the extent possible, the safety elements provided by rest areas. Practical operating problems such as seasonal fluctuations in demand, personnel turnover, and the like, are also of interest.

Although quantification of benefits and disbenefits is desired, many factors are too subjective to develop precise quantitative values. Therefore, the method should provide some means, such as a subjective ranking scheme, to address these factors. For example, the priority or emphasis a particular state or area places on the desire to promote tourism could be factored into the analysis.

In relating benefits to costs, the method should include a level-of-service concept. In effect, the benefits of a basic rest area (only parking and restrooms) should be assessed in relation to its cost, as well as incremental additions (e.g., picnic areas, information facilities, sanitary dumping facilities).

Task 5—Prepare an interim report that discusses the preliminary method developed in Task 4.

Task 6—Design a process to conduct a rest area cost/benefit analysis incorporating the method developed in Task 4, and apply this process to an actual case study.

The process should (1) reflect the public's perception of what a rest area should be, (2) have wide application, (3) lead to more cost-effective programs and facility designs, and (4) be clear, easily applied, reasonable, and acceptable to highway agencies and the public.

Task 7—Prepare a final research report as well as a handbook to assist managers in applying rest area cost/benefit analysis. The handbook will include the case study to illustrate how the process is applied.

Tasks 1 through 5 have been completed. The project panel has reviewed a draft "Rest Area Analysis Methodology" (RAAM). The RAAM is now being applied to a case study on Interstate 81 in Virginia under Task 6. All work is expected to be complete by mid-1989.

Project 2-16 FY '87 and FY '89

Relationships Between Vehicle Configurations and Highway Design

Research Agency:	Transportation Research Board
Principal Invest.:	Robert E. Skinner, Jr., Joseph R. Morris
Effective Date:	March 2, 1987
Completion Date:	June 30, 1990
Funds:	$900,000

Data from the AASHO Road Test and other field experience indicate that most pavement distress and damage are associated with heavy axle loads from highway vehicles. Specifically, the Road Test data show that pavement damage increases exponentially as axle loads get heavier. Analysis of the Road Test Data also indicates that increases in pavement thickness permit exponential increases in equivalent axle loads for comparable pavement performance. Mr. F. C. Turner, retired FHWA Administrator, has suggested that use of longer trucks with more axles and lower axle loads could result in reduced damage to pavements and more efficient use of transportation funds. Considerable interest has developed in investigating Mr. Turner's suggestion.

This is a very complex issue involving technical, economic, social, and other factors. No detailed systematic evaluation has been made of the influence of vehicle configurations (e.g., axle loads, axle spacing, tire pressures, and spring components) and highway design (e.g., pavement thickness, bridges and geometrics) on the efficiency of the highway transportation system.

The overall objective of this project is to develop recommendations for coordination of heavy vehicle configurations and pavement, bridge, and highway geometric design to produce the most practical and efficient transportation of goods and services over the highway system. The initial phase of the research (1) collected, reviewed, and evaluated available information pertaining to the problem; (2) conducted a pilot analytical study involving the more significant factors and sample data; and (3) assessed the feasibility and practicality of further development of an optimum solution. The end product of the initial research phase consisted of recommendations for further research intended to produce (1) short-term improvements in interactions of heavy vehicles with the existing highway system having potential for early implementations, and (2) long-term optimization of the heavy vehicle-highway design interaction intended to produce improved efficiency of the highway transportation system.

The initial phase of this research has been completed as NCHRP Project 20-7, Task 27, which concluded that the "Turner" proposal does appear feasible and that it may yield important benefits to all road users, but that further examination is necessary in the areas of carrier acceptance, alternative vehicle configurations, potential safety impacts, the costs of added bridge stress, and pavement wear effects under varying assumptions concerning which roads the new trucks would be allowed to use.

The second phase of the project, now well underway, will consist of five objectives to: (1) estimate, based on actual experience under similar circumstances, how carriers would use the new truck configurations; (2) comprehensively evaluate effects on bridges that could result from the new truck sizes; (3) analyze the safety of the new trucks compared with the vehicles they would replace; (4) refine the pavement impact estimates of the feasibility study; and (5) provide guidance to the states and the federal government on the costs and benefits of alternative truck size and weight regulations. The results of the study's second phase should be useful guidance to public agencies on vehicle regulations that will allow more efficient transportation.

Research on all major objectives is proceeding on schedule. The study committee met on September 7, 1988 to review progress and provide direction to the researchers. Drafts of some chapters of the final report are already under development. A complete draft report is scheduled for August 1989.

Project 2-17 FY '90

Transportation and Economic Development

Research Agency:	In developmental stages
Principal Invest.:	
Effective Date:	(24 months)
Completion Date:	
Funds:	$250,000

The role of an effective transportation system in building and maintaining a vital economy has been recognized as a critical issue and is currently the subject of renewed interest. It is generally recognized that there is a need for better understanding of the various relationships between transportation decisions (e.g., capital investments, regulatory actions, and taxing and pricing policies) and economic development. These relationships can be important in terms of both the net effect of the transportation system on the national economy and the impact on local and regional economies. At the national level, a 1988 AASHTO working draft, "The Bottom Line," states, "Transportation has always been a major driver of economic development and productivity. In the contemporary economy (service oriented, internationally oriented) it is less clear in what ways transportation can support the national economy. New travel patterns and new economic demands are being made and the transportation system must be prepared to respond. In the service economy transportation's role is different rather than decreased. There may well be fewer ton-miles per capita, or per dollar of GNP, in the future economy, but there will be ton-miles of very high value goods, with rigid delivery schedules and rapid travel time requirements. The demands for high quality services with assured reliability will be great. The mobility of our citizens and foreign visitors will be a crucial future economic resource. The economic power of tourism, and the importance of rapid access to all points of the country by business travelers, are just beginning to be appreciated. Recognition of the new roles of transport, and particularly surface transport, are only slowly permeating into public policy. The link between transport investment and succeeding economic development and productivity has not yet been generally recognized in policy formation. The objective of this research, at the national level, will be to gain insight into the relationship between transportation and the nation's economic vitality and competitiveness. At the State and local level it is important for decision makers to have reliable estimates of the economic health and productivity benefits of potential transportation investments or management actions at the local and regional levels. The objective of this portion of the research is to produce a synthesis of current practice and an evaluation of methods used by planners at the state level in carrying out responsibilities such as the following: prioritizing highway improvement projects based on economic considerations,

estimating the relationship between improved transportation and industrial location decisions distinguishing between those transportation decisions that create new economic development and those that merely redistribute economic activity, prioritizing the development of major highway corridors by focusing on potential economic development, estimating the economic impacts of road weight restrictions on rural communities, relating transportation investments to the job market (jobs created—directly and indirectly), estimating the portion of total cost related to transportation in various economic sectors, and assessing the economic consequences of severe metropolitan congestion examining the effects of policies and regulations, estimating intermodal relationships, developing pricing and revenue strategies.

AREA 3: OPERATIONS AND CONTROL

Project 3-1 FY '63 and FY '64

Development of Criteria for Evaluating Traffic Operations

Research Agency:	Cornell Aeronautical Laboratory	
Principal Invest.:	Jaime F. Torres	
Effective Date:	Feb. 15, 1963	July 2, 1964
Completion Date:	Feb. 29, 1964	Feb. 28, 1966
Funds:	$78,965	$79,913

This research project provided an investigation into the application of criteria based on travel time, driver comfort, safety, and vehicle running costs. The linear combination of these factors weighted by an appropriate set of cost coefficients quantified the operational performance. A procedure was studied which would provide estimates of the four components based on measurements of traffic volume and an inventory of roadway characteristics. Travel time, volume, and roadway inventory data were collected from several cities and analyzed. Estimating relationships were derived for many classes of urban arterials, whereby travel time can be obtained from the measurement of volume and a knowledge of the street characteristics. A survey vehicle was equipped to monitor skin resistance, heart pulse, and respiration of two subjects in traffic while steering, brake, throttle, and speed were being recorded to study driver comfort. Accident data in the Buffalo area were analyzed and related to the safety factor, and vehicle running costs were estimated through the use of speed distributions for a sample of streets.

The final report was not published in the NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 3-2 FY '63 and FY '64

Surveillance Methods and Ways and Means of Communicating with Drivers

Research Agency:	Cornell Aeronautical Laboratory
Principal Invest.:	Morton I. Weinberg
Effective Date:	February 15, 1963
Completion Date:	April 30, 1966
Funds:	$246,756

This project was concerned with the development, practice, and evaluation of various methods of surveillance and means of communicating with drivers.

The report of the first phase of research described a predictive model to provide warning of impending congestion, study of a ramp advisory signal, and use of an airborne observer for traffic control. It has been published as: NCHRP Report 9, "Traffic Surveillance and Means of Communicating with Drivers."

In the second phase of the project, the researchers developed the mathematical logic to predict the effects from unexpected blockages on a freeway and validated the model on the John C. Lodge Freeway in Detroit. Also included was an evaluation of an airborne surveillance and control system. The results of this phase have been published as: NCHRP Report 28, "Surveillance Methods and Ways and Means of Communicating with Drivers."

In the third phase of the project, a computer-controlled signal system for a typical urban complex was synthesized, including control logic and equipment requirements. The results of this phase have been published as: NCHRP Report 29, "Digital-Computer-Controlled Traffic Signal System for a Small City."

Project 3-3 FY '63 and FY '64

Sensing and Communication Between Vehicles

Research Agency:	The Ohio State University
Principal Invest.:	Dr. Thomas H. Rockwell
	Dr. Joseph Treiterer
Effective Date:	February 15, 1963
Completion Date:	November 30, 1965
Funds:	$163,190

This project involved establishment of the operating requirements of a communication system designed to enable better communications between vehicles on expressway-type facilities. The final report has been published as: NCHRP Report 51, "Sensing and Communication Between Vehicles."

Project 3-4 FY '63, FY '64, and FY '66

Means of Locating Disabled or Stopped Vehicles and Methods of Communication with a Central Location

Research Agency:	Airborne Instruments Laboratory	
Principal Invest.:	Fred Pogust	
Effective Date:	March 1, 1963	July 1, 1965
Completion Date:	March 31, 1965	Dec. 15, 1966
Funds:	$78,517	$49,474

This study was directed toward evaluating the nature and extent of the problem and describing the need for communication as well as the benefits of locating disabled vehicles. An additional task was researching the ways that information about disabled or stopped vehicles may be used.

An interim report has been published as: NCHRP Report 6, "Means of Locating and Communicating with Disabled Vehicles."

Following the comprehensive review of the nature, extent, and characteristics of the stopped-vehicle problem conducted during the first year of research, the researchers continued to investigate the feasibility of a detector system. A roadside vehicle detector system was developed using a silicon photo-voltair diode as the roadside receiving unit, and signalling was performed by a vehicle-mounted relay-type interrupting device which modulates infrared-emitting diodes. A prototype system was built, tested, and demonstrated to the project panel.

The final report has been published as: NCHRP Report 40, "Means of Locating Disabled or Stopped Vehicles."

Project 3-5 FY '63, FY '64, FY '66, and FY '69

Improved Criteria for Designing and Timing Traffic Signal Systems

Research Agency:	Planning Research Corp.		
Principal Invest.:	F. A. Wagner, Jr.		
Effective Date:	3/1/63	7/1/66	8/1/68
Completion Date:	12/31/65	7/31/67	12/31/69
Funds:	$123,030	$48,155	$93,717

The over-all objective of the research was to determine the most efficient method of timing traffic signals for isolated intersections, arterial highways, and grid networks of city streets. The research was accomplished in three phases.

The results of the first phase of research, involving methods of signal timing for the isolated intersection, have been published as: NCHRP Report 3, "Improved Criteria for Traffic Signals at Individual Intersections—Interim Report," and NCHRP Report 32, "Improved Criteria for Traffic Signals at Individual Intersections."

The second phase involved development and comprehensive, closely controlled, scientific testing of several advanced concepts for operating traffic-signal systems on urban arterial streets. The results indicate that a significant degree of improvement in traffic operation is possible through application of advanced control methods. This phase final report has been published as: NCHRP Report 73, "Improved Criteria for Designing and Timing Traffic Signal Systems—Urban Arterials."

The objective of the third phase was to simulate and field test promising signal-control logic that will produce improved signal timings for a grid network of traffic signals. The final report has been published as: NCHRP Report 124, "Improved Criteria for Traffic Signal Systems in Urban Networks."

Project 3-6 FY '63, FY '64, and FY '66

Effect of Regulatory Devices on Intersectional Capacity and Operation

Research Agency:	De Leuw, Cather & Company
Principal Invest.:	Ronald Pfefer
Effective Date:	April 1, 1963
Completion Date:	August 15, 1966
Funds:	$153,175

The purpose of this research was to identify the effect of specified traffic regulatory devices on intersection capacity and operations and on systems of traffic facilities. The effects of stop and yield signs were investigated as they apply to capacity, traffic operations, safety, driver acceptance, and the traffic operations of the area of influence.

The initial phase of research has been published as: NCHRP Report 11, "Effect of Control Devices on Traffic Operation." The report examines efficient methods of intersection study and derives some preliminary relationships concerning the operations of intersections with YIELD and two-way STOP control and their street system effects.

During the second phase of research, field data were collected at STOP- and YIELD-sign locations in the areas of Chicago, San Francisco, New York, and Toronto. Analyses were made to select criteria for intersection controls and develop a method for applying them. Programs and procedures were developed to integrate and analyze the field data collected during the first phase. Detailed traffic-control-devices questionnaires were analyzed from States, cities, and counties throughout the country.

The final report has been published as: NCHRP Report 41, "Effect of Control Devices on Traffic Operations."

Project 3-7 FY '64, '65, '67, '71, and '73

Establishment of Standards for Highway Noise Levels

Research Agency:	Bolt Beranek and Newman			
Principal Invest.:	Andrew Kugler			
Effective Date:	2/1/64	10/14/68	4/1/71	9/1/72
Completion Date:	4/30/67	1/15/70	6/30/72	11/30/74
Funds:	$144,920	$69,930	$49,927	$307,486

This project was concerned with the evaluation of noise levels of the various classes of highways and the effectiveness of controlling highway noise through highway design features as well as the reduction of noise production by means of legislation and vehicle regulation. Questions relating to highway noise levels and their effect on adjacent land users frequently arise in urban highway planning and design.

The Phase I research involved the selection of the most appropriate means and units for measuring and evaluating highway noise. Its results have been published as: NCHRP Report 78, "Highway Noise-Measurement, Simulation, and Mixed Reactions."

The Phase II research objective was to prepare a highway design noise manual for the practicing highway engineer. In addition, a magnetic tape recording was produced to demonstrate basic elements of highway noise and to present examples illustrating changes in traffic noise. Loan copies of the tape recording are available on request to the TRB Audio-Visual Library (see final page of this section for ordering information). The results of the Phase II research have been published as: NCHRP Report 117, "Highway Noise—A Design Guide for Highway Engineers."

The objective of the Phase III research was to conduct a thorough measurement program on various noise reduction treatments under a variety of traffic and environmental conditions. This research developed a tie between field data and analytic approaches so that the performance of noise reduction treatments may be more accurately predicted. The results of the Phase III research have been published as: NCHRP Report 144, "Highway Noise—A Field Evaluation of Traffic Noise Reduction Measures."

The Phase IV research started with the following objectives: to summarize the present state-of-the-art for controlling the noise-producing properties of the individual mechanical components of motor vehicles that lead to the composite noise produced by motor vehicles on highways; to assess the technological and economic feasibility of reduction of traffic noise that will enable highway officials to seek federal and local legislation that might redistribute the burden of noise control; and to improve procedures for highway noise control that will allow the designer to more realistically assess the highway noise problem.

The research has been completed. Final report materials include a computer program for use with the design guide and a 17-min color film entitled "Quiet Highway Design." The film is available on a loan basis from the TRB Audio-Visual Library (see final page of this section for ordering information), and copies of the computer program can be supplied upon written request to the NCHRP. The final report on the concluding phase of this research has been published in two volumes: NCHRP Report 173, "Highway Noise—Generation and Control," and NCHRP Report 174, "Highway Noise—A Design Guide for Prediction and Control."

A report on a study task on time-varying highway noise criteria was not published, but microfiche of the report may be purchased (see final page of this section for ordering information).

Project 3-8 FY '64 and FY '65

Factors Influencing Safety at Highway-Rail Grade Crossings

Research Agency:	Alan M. Voorhees & Associates	
Principal Invest.:	David W. Schoppert	
	Dan W. Hoyt	
Effective Date:	Dec. 1, 1963	Apr. 1, 1965
Completion Date:	Dec. 31, 1964	Jan. 6, 1967
Funds:	$17,171	$74,250

This study was directed toward the interpretation and analysis of currently available highway-rail grade-crossing data in the United States.

The initial research reviewed previous work in this area and developed a mathematical model for predicting accidents, and this was tested with accident data obtained from Minnesota, Oregon, and Virginia. A warrant was developed based on the cost of providing protective devices and the cost of possible accident savings.

Later work involved the development and testing of improved grade-crossing protective devices, and several experimental devices were studied by the agency. A human factors study was completed. Several important sources of data were found that facilitated the research associated with the development of the accident predictive model as well as refinement of the proposed criteria for grade-crossing protection. Data acquired from Stanford University included 18 years of data at 617 crossings, and data acquired from the Ohio Department of Highways included all accidents occurring at 1,000 rural grade crossings. From the Interstate Commerce Commission, the investigators obtained more than 15,000 grade-crossing accident reports spanning a five-year period.

The project report has been published as: NCHRP Report 50, "Factors Influencing Safety at Highway Rail Grade Crossings."

Project 3-9 FY '66

Analysis and Projection of Research on Traffic Surveillance, Communication, and Control

Research Agency:	Roy Jorgensen and Associates
Principal Invest.:	Karl Moskowitz
Effective Date:	October 15, 1966
Completion Date:	January 14, 1968
Funds:	$23,760

The purpose of this study was to review the results of NCHRP Projects 3-2, 3-3, and 3-4, together with the

accomplishments of other recently completed research in this area in the United States and abroad, and to determine the state of the art and set forth guidelines regarding the proposed future research efforts to be conducted in this area.

The project report has been published as: NCHRP Report 84, "Analysis and Projection of Research on Traffic Surveillance, Communication, and Control."

Project 3-10 FY '66

Application of Vehicle Operating Characteristics to Geometric Design and Traffic Operations

Research Agency:	Cornell Aeronautical Laboratory
Principal Invest.:	Morton I. Weinberg Dr. Kenneth J. Tharp
Effective Date:	January 1, 1966
Completion Date:	March 10, 1967
Funds:	$41,520

This research was directed at identifying the motor vehicle characteristics that are related to highway geometric design and traffic control operations. The objective was to determine the relationships between the vehicle and its operating environment. Vehicle characteristics were reviewed; where appropriate, highway design criteria were suggested.

Elements of geometric design and traffic operations presented in the basic design and policy manuals were analyzed to determine how vehicle characteristics are being utilized. A rational approach was made to determine, expand, or modify the existing criteria. The results of the review revealed those vehicle characteristics which should be known and used in designing and operating streets and highways. For vehicle characteristics which are presently unknown or where information is outdated, methods of obtaining data and methods of using this information in geometric design and traffic operations were recommended.

The final report has been published as: NCHRP Report 68, "Application of Vehicle Operating Characteristics to Geometric Design and Traffic Conditions."

Project 3-11 FY '67

Optimizing Street Operations Through Traffic Regulations and Control

Research Agency:	Peat, Marwick, Mitchell & Co.
Principal Invest.:	James H. Kell
Effective Date:	September 1, 1966
Completion Date:	September 30, 1968
Funds:	$258,331

This research was directed to applying the best traffic regulation and control techniques to an area of typical urban streets and evaluating results. Innovations that may be expected to improve operational efficiency were explored. The cities of Sunnyvale and Redwood, Calif., were selected as the cooperating demonstration test cities. The research emphasis was placed on a quantified evaluation of the effect of traffic regulation and control techniques on the central business districts of these cities.

As this research study included the significant areas of business performance and public opinion, greater insight was gained into the political feasibility of a proposed traffic change. The study findings substantiated the theory that no major traffic improvement plan can be implemented, regardless of the extent to which it may serve the public interest, unless it meets with the support of the general public, especially that of the business community.

The final report has been published as: NCHRP Report 110, "Optimizing Street Operations Through Traffic Regulations and Control."

Project 3-12 FY '67, FY '68, and FY '71

Development of Information Requirements and Transmission Techniques for Highway Users

Research Agency:	Airborne Instruments Laboratory		
Principal Invest.:	M. A. Warskow	G. F. King	G. F. King
Effective Date:	10/1/66	3/29/71	4/1/68
Completion Date:	12/31/67	12/1/69	12/11/72
Funds:	$198,655	$100,500	$99,821

The objective of the over-all research problem was the development of a well-defined information system for the highway user. The system represents all conditions with which the driver is routinely, occasionally, and rarely confronted.

Analysis of the driving task disclosed that the operations performed by a driver can be characterized in terms of a hierarchy. It was found that a demanding priority (primacy) exists in satisfying information needs, and it was concluded that satisfying the primary of information needs is basic to the design of a highway information system. A procedure was developed for the systematic application of these principles to actual highway situations in accordance with basic information system requirements. In addition, current sign use was investigated, particularly the night legibility problem, to determine problem areas in sign application criteria. Mathematical analyses were presented on the probability of sign blockage by trucks and the effect of lateral displacement of signs. A sign design procedure to incorporate the findings with regard to sign use was outlined. The test site for the project was located in North Carolina.

The first- and second-phase research has been completed, and the project report has been published as: NCHRP Report 123, "Information Requirements and Transmission Techniques for Highway Users."

Although engineers have certain established concepts and standards regarding highway guide signing, additional research, identified as Phase III of this project, was conducted to determine whether or not these present standards provide the information required to guide motorists properly on their journeys. This research involved critical highway signing in and around urban areas and included inner-city signing, beltway signing, and junction signing for arterial routes and freeways.

The final report was not published in the NCHRP report series; however, microfiche of the report may be purchase (see final page of this section for ordering information).

Project 3-13 FY '68

Guidelines for Medial and Marginal Access Control of Major Roadways

Research Agency:	Texas A & M University Research Foundation
Principal Invest.:	Dr. Vergil G. Stover
Effective Date:	September 1, 1967
Completion Date:	November 30, 1969
Funds:	$149,293

A need existed for guides in selecting the degree of access control for a specific project and for selecting the type, location, and width of median and median openings and the design and frequency of entrances to be associated with the degree of access control.

Factors considered in this research were: accident frequency and severity; cost of physical construction and right-of-way to accomplish access control; legal considerations; traffic patterns; service to the highway user; motor vehicle operating costs; travel time and costs; land use; convenience of access to abutting property; property values; and provision for future needs for access control and for changing traffic characteristics, user requirements, or land use.

The project report has been published as: NCHRP Report 93, "Guidelines for Medial and Marginal Access Control on Major Roadways."

Project 3-14 FY '68

Optimizing Flow on Existing Street Networks

Research Agency:	Edwards & Kelcey
Principal Invest.:	Walter E. Pontier
Effective Date:	October 1, 1967
Completion Date:	January 10, 1970
Funds:	$990,000

This project investigated the benefits to traffic flow in downtown areas which can be achieved by application of traffic engineering measures. Experimentation to quantify the effect of road improvements was carried on in two study areas—the downtown portions of Louisville, Ky., and Newark, N.J. Data developed for control and analysis of these experiments were subjected to statistical evaluation to describe those controlling conditions which influence measurements in the downtown area and to develop meaningful relationships which describe the quality of traffic flow, attaining a level of service definition for downtown streets. Methods were developed for application of the results of this research to streets of other areas.

The final report has been published as: NCHRP Report 113, "Optimizing Flow on Existing Street Networks." As part of the project, a film, "Relief for Tired Streets," was produced. It demonstrates the results that can be obtained by applying sound traffic engineering practices to our nation's urban traffic problems. Loan copies of the film may be obtained through the TRB Audio-Visual Library.

Project 3-15 FY '70

Weaving Area Operations Study

Research Agency:	Polytechnic Institute of New York
Principal Invest.:	Dr. Louis J. Pignataro
Effective Date:	October 1, 1969
Completion Date:	December 31, 1973
Funds:	$300,000

The objective of this research was to analyze and evaluate the procedures recommended in Chapters 7 and 8 of the *1965 Highway Capacity Manual.* Based on the findings the agency is to develop improved techniques for the analysis and design of weaving sections.

A new algorithm has been developed and evaluated, using both field data and an available data base from FHWA sources. The design and analysis procedures have been developed in such a way that graphical, analytical, and computer solutions can be employed. These techniques have been reviewed and tested by selected State highway agencies.

The research has been completed, and the final report has been published as: NCHRP Report 159, "Weaving Areas—Design and Analysis."

Project 3-16 FY '70

Freeway Lane Drops

Research Agency:	System Development Corp.	
Principal Invest.:	Antranig V. Gafarian Diane N. Goodwin	
Effective Date:	Nov. 1, 1969	May 1, 1972
Completion Date:	Apr. 30, 1971	Oct. 31, 1973
Funds:	$99,789	$76,815

Many variables affect the operating conditions and safety of the various lane drop configurations. Sound criteria for the selection of the proper lane drop design for the objectives of Phase I were:

1. From field data, determine the effectiveness of existing mainline lane drops from the standpoint of safety and traffic operations.
2. Determine the effects of the significant parameters associated with various levels of safety and traffic service.
3. Recommend configurations for lane drops based on the findings of objectives 1 and 2. In this context "configurations" includes distance from the nearest upstream and downstream ramps.

In the first phase, three lane-drop sites with different geometric configurations were studied intensively to determine traffic operations and safety effects. The report on this initial phase was not published; however, microfiche of the report may be purchased (see final page of this section for ordering information).

The Phase II research continued with the same three objectives and the added objective of recommending remedial treatments in a set of guidelines based on analysis of descriptive data and traffic performance from many existing lane-drop sites.

The research has been completed, and the final report has been published as: NCHRP Report 175, "Freeway Lane Drops."

Project 3-17 FY '71

Improving Traffic Operations and Safety at Exit Gore Areas

Research Agency:	The Pennsylvania State University
Principal Invest.:	James I. Taylor
Effective Date:	January 1, 1971
Completion Date:	November 30, 1972
Funds:	$79,983

This research project addressed the problem of erratic maneuvers, such as backing up and stopping in the gore area, that occur with alarming frequency at freeway exit areas. Specifically, it was directed toward answering three basic questions: What factors cause motorists to make erratic maneuvers at exit gore areas? What remedial devices can be employed to reduce their occurrence at existing sites? And, what changes in design and traffic control criteria can be recommended that will minimize the problem at future sites? The results of this study provide answers to these questions, and the findings can be used by traffic and design engineers to enhance the safety and traffic operations at freeway exit facilities.

The final report has been published as: NCHRP Report 145, "Improving Traffic Operational and Safety at Exit Gore Areas." A 10-min color film, "Safety at Freeway Exits," highlighting the research findings is also available on a loan basis from the TRB Audio-Visual Library (see final page of this section for ordering information).

Project 3-18(1) FY '70

Improved Control Logic for Use with Computer-Controlled Traffic

Research Agency:	Stanford Research Institute	
Principal Invest.:	Dr. Dale W. Ross Dr. Thomas L. Humphrey	
Effective Date:	July 15, 1971	April 15, 1975
Completion Date:	May 15, 1974	June 30, 1977
Funds:	$323,998	$57,662

The objective of this research was to study traffic flow and control interaction and to develop an advance control concept, strategy, and computer program. The research has included development of an operational control program that has the capability of calculating optimal offset patterns for a network of signalized intersections and determining independent and variable signal split adjustments. The program, designed for application under all levels of network traffic volumes, including oversaturated conditions, has been tested and evaluated with actual traffic in the San Jose traffic control system.

A final report describing the research and the resulting ASCOT program package will not be published in the NCHRP report series, but copies are available on either a loan or purchase basis. A 20-min color film describing the program and its functions is also available on a loan basis for the cost of mailing and handling. The film, "Improved Control Logic for Use with Computer-Controlled Traffic," is available on a loan basis from: TRB Audio-Visual Library; the report may be purchased for $10.00 (see final page of this section for ordering information).

Project 3-18(2) FY '71

Traffic Control in Oversaturated Street Networks

Research Agency:	Polytechnic Institute of New York
Principal Invest.:	Dr. Louis J. Pignataro
Effective Date:	September 1, 1971
Completion Date:	June 30, 1975
Funds:	$200,000

The specific objectives of the first phase of the project were to:

1. Define the measures of network oversaturation and determine the existing scope and magnitude of the oversaturated street-network problem.
2. Define the root causes of the problem.
3. Evaluate the relative effectiveness of existing operations and control techniques used to combat the problem.
4. Prepare detailed operational guidelines for application of existing traffic operations and control techniques of illustrated effectiveness.

5. Describe alternative concepts of advanced traffic-control techniques for improving the efficiency of traffic operation in oversaturated networks.

6. Formulate a detailed plan and program for systematic development, testing, and application of improved traffic control in oversaturated networks.

A final report on this phase will not be published; unedited draft copies are available on loan upon request to the NCHRP Program Director. The essential findings of this report have been published as NCHRP Research Results Digest 51.

A continuation phase with the following objectives was initiated: to carry out further studies in minimal-response signal policies, nonsignal effects and remedies, and highly responsive policies and to produce a set of recommendations and guidelines for applying solutions to the problems of oversaturation. The research has been completed, and the final report covering the entire project has been published as: NCHRP Report 194, "Traffic Control in Oversaturated Street Networks."

Project 3-18(3) FY '75

Cost-Effectiveness Methodology for Evaluation of Signalized Street Network Surveillance and Control Systems

Research Agency: JHK & Associates
Principal Invest.: Thomas L. Stout
Effective Date: May 1, 1975
Completion Date: April 15, 1977
Funds: $123,267

The objectives of this research were to develop and to demonstrate a practical total-system cost-effectiveness methodology for the comparative evaluation of alternative traffic surveillance and control systems for signalized street networks. The methodology developed should take into consideration all pertinent factors bearing on the choice of the best control technique, including such factors as types of hardware components used; extent of real-time human operator interface required or desired; degree of automated traffic sensing employed for either on-line control or off-line system support purposes; physical and traffic flow characteristics of the street network being controlled; and technical skills and other resources of the operating agency.

The project's revised final report and a separate manual have been submitted. The research report, "Signal System Evaluation Methodology," will not be published in the NCHRP report series but is available on a loan basis. The manual, "An Approach for Selecting Traffic Control Systems" may be obtained on a loan basis or purchased for $11.00 (see final page of this section for ordering information).

Project 3-18(4) FY '76

Methodology for Performance Evaluation of Signalized Network Control Strategies

Research Agency: Computran Systems Corporation
Principal Invest.: Dr. H. Nathan Yagoda
Effective Date: July 21, 1977
Completion Date: November 20, 1980
Funds: $148,705

The objective of this research was to develop and demonstrate a practical methodology for the comparative performance evaluation of alternative traffic control strategies for signalized street networks. The research addressed networks of ten or more signalized intersections.

The research has been completed, and copies of the agency report are available on a loan basis or microfiche of the report may be purchased (see final page of this section for ordering information).

Project 3-19 FY '72

Grade Effects on Traffic Flow Stability and Capacity

Research Agency: Midwest Research Institute
Principal Invest.: Andrew D. St. John
Effective Date: September 1, 1971
Completion Date: August 31, 1974
Funds: $220,443

The objectives of this research were to:

1. Determine and verify methods for calculating the acceleration and speed-maintenance capabilities on grades of a wide range of motor-vehicle types, including trucks and combinations, buses, campers, housetrailers, low-performance passenger cars, and other atypical vehicles normally found on Interstate and primary highway systems.
2. Determine the factors that create instabilities in the traffic stream on grades. Particular attention is to be given to the role of low-performance and unusual-size vehicles in the creation of these instabilities.
3. Determine, through use of appropriate digital-computer traffic-simulation models and by correlated field measurements, the passenger-car equivalencies for the vehicle types enumerated in objective 1.
4. Determine the effects on safety and traffic flow with both restricted and unrestricted operations of 12- and 14-ft-wide loads on highways in varying terrain. The goal of this objective is to provide guidance for the regulation of these unusual load widths.
5. Estimate, by use of correlations between traffic flow characteristics and accident frequencies, the accident implications for the situations studied in objectives 2 and 4.

The research has been completed, and the final report has been published as: NCHRP Report 185, "Grade Effects on Traffic Flow Stability and Capacity."

Project 3-20 FY '73

Traffic Signal Warrants

Research Agency:	KLD Associates	
Principal Invest.:	Edward B. Lieberman	
Effective Date:	Sept. 1, 1972	Nov. 1, 1974
Completion Date:	Apr. 15, 1974	Dec. 31, 1976
Funds:	$120,000	$81,935

The objective of this research was to evaluate the adequacy of existing warrants, or the need for revised or additional warrants, in meeting current needs for determining whether a traffic signal should be installed.

The research has been completed, and the final report has been submitted. New warrants have been developed and are presented in the report, which also includes recommended changes for the relevant text of the *Manual on Uniform Traffic Control Devices* dealing with traffic signal warrants. Procedures for field validation of the proposed warrants have also been designed and are recommended in the report.

The report has been provided to the National Advisory Committee on Uniform Traffic Control Devices for consideration. The report was not published in the NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 3-20A FY '80

Peak-Hour Traffic Signal Warrants

Research Agency:	JHK & Associates
Principal Invest.:	R. David Henry Jay H. L. Calhoun
Effective Date:	June 23, 1980
Completion Date:	July 31, 1982
Funds:	$150,000

The objective of this research was to evaluate and verify the peak-hour warrant suggested by the Signals Subcommittee of the National Advisory Committee on Uniform Traffic Control Devices (NAC) and the peak-hour warrant developed as part of NCHRP Project 3-20. A recommendation with supporting documentation and justification was desired for adoption of a warrant, including either modifications to the above warrants or consideration of an alternative warrant.

Field studies were conducted at 190 intersections to obtain the necessary data to analyze each warrant element. Intersection delay, percent stops, traffic volume, and queue length were determined. The field studies included six urban areas and various intersection types.

A new peak-hour warrant was developed based on queue length. In general, a signal is considered to be warranted when there is an average queue of at least four vehicles for one hour on a typical day.

The project report has been published as: NCHRP Report 249, "Peak-Hour Traffic Signal Warrant."

Project 3-21 FY '74

Motorist Response to Highway Guide Signing

Research Agency:	BioTechnology, Inc.
Principal Invest.:	Fred R. Hanscom Wallace G. Berger
Effective Date:	April 1, 1974
Completion Date:	January 31, 1976
Funds:	$272,071

The first research phase under this project was directed toward identification of promising measures of driver response to guide signing and to development and validation of such measures. The research has been completed, and copies of the agency report are available on a loan basis upon written request to the NCHRP or microfiche of the report may be purchased (see final page of this section for ordering information).

The second research phase, NCHRP Project 3-21(2), extends the Phase I effort to address a specific application; i.e., use of changeable-message signs in advance of freeway lane closures.

Project 3-21(2) FY '77

Effectiveness of Changeable-Message Displays in Advance of High-Speed Freeway Lane Closures

Research Agency:	BioTechnology, Inc.
Principal Invest.:	Fred R. Hanscom
Effective Date:	December 1, 1979
Completion Date:	August 31, 1981
Funds:	$170,993

NCHRP Project 3-21, "Motorist Response to Highway Guide Signing," developed various driver response measures that can be used to determine the effectiveness of different signs. Project 3-21(2) extended the original research by applying the response measures to a specific signing problem.

The objective of this research was to determine effective advance message displays (e.g., words, symbols, and lane signals) for lane closures on high-speed freeways. This research provides, as a result of field studies at selected lane-closure sites, an objective analysis of traffic performance in response to various changeable-message displays.

Volume I of the agency's report, containing the major findings from Project 3-21(2), has been published as NCHRP Report 235, "Effectiveness of Changeable Message Displays in Advance of High-Speed Freeway Lane Closures." Volume II of the agency's report, providing greater detail on the field study and questionnaire results, is available from NCHRP for $3.50 prepaid. Microfiche

of the report is also available (see final page of this section for ordering information).

Project 3-22 FY '74

Guidelines for Design and Operation of Ramp Control Systems

Research Agency: Stanford Research Institute
Principal Invest.: Dale P. Masher
Effective Date: April 15, 1974
Completion Date: December 31, 1975
Funds: $199,030

The objectives of this project were to analyze existing ramp control techniques and to develop design procedures for freeway ramp control systems. The research considered those types of ramp control designed to keep freeways operating at or near capacity during peak periods with a minimum of manual operation. Merge control, gap-acceptance systems, and computerized control of traffic signals on surface streets in the freeway corridor may be relevant tools, but the development of design guidelines for these techniques was considered to be outside the scope of this project. Additionally, this project did not address guidelines for extensive freeway surveillance features except where these features relate to the control systems.

The final report will not be published in the regular NCHRP series; however, microfiche of the draft report, "Guidelines for Design and Operation of Ramp Control Systems," December 1975, may be purchased (see final page of this section for ordering information).

Project 3-22A FY '77

Guidelines for Design and Operation of Ramp Control Systems

Research Agency: Texas A & M University Research Foundation
Principal Invest.: Charles W. Blumentritt
Effective Date: February 1, 1977
Completion Date: March 31, 1981
Funds: $249,538

Preliminary guidelines were developed in NCHRP Project 3-22 for designing and operating ramp control systems. The objective of NCHRP Project 3-22A was to extend this research to provide more specific guidelines to evaluate the cost effectiveness of alternative ramp control system designs. The three levels of control investigated were local pretimed, traffic responsive, and systemwide.

The final report, including the guidelines, has been published as: NCHRP Report 232, "Guidelines for Selection of Ramp Control Systems."

Project 3-23 FY '74

Guidelines for Uniformity in Traffic Control Signal Design Configurations

Research Agency: KLD Associates
Principal Invest.: Gerhart F. King
Effective Date: April 8, 1974
Completion Date: July 28, 1977
Funds: $308,779

The purpose of this study was the preparation of guidelines for optimum traffic control signal design configurations at intersections and mid-block crossing locations. The research included the following objectives:

1. Preparation of an annotated bibliography of relevant literature and research in progress pertaining to traffic control signal design configurations.
2. With reference to Part IV, Sections B and D, and Part VII, Section D, of the 1971 MUTCD, a study of traffic control signal design configurations, including, but not limited to: number and arrangement of lenses in signal faces, size of signal lenses, type of signal lenses (arrows and program visibility signal), visibility and shielding of signal faces, number of signal faces, horizontal and vertical location of signal faces.
3. Identification and consideration of all factors related to the approach to signalized locations that affect or influence the observance, safety, and efficiency of traffic control signals.
4. Development and validation of a detailed set of traffic control signal design guidelines—based on field, human behavioral, and theoretical analyses—that would produce optimum traffic control signal design configurations.
5. Preparation of proposed revisions of the referenced sections of the 1971 MUTCD.
6. Identification of the areas in which further research is indicated.

The final report was not published in the NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 3-24 FY '75

Determine the Luminous Requirements for Retroreflective Highway Signing

Research Agency: University of Michigan
Principal Invest.: Dr. Paul L. Olson
Effective Date: September 1, 1974
Completion Date: April 30, 1977
Funds: $100,000

The purpose of this study was to define the relationship between sign luminance and legibility in a way that would assist in selecting optimum material choices for various

signing applications as well as aid in decisions concerning maintenance and replacement.

A laboratory study was carried out to define the effects of luminance, contrast, color, and driver visual characteristics on legibility distance. A computer model was developed to predict the legibility distance of a sign based on the laboratory data as well as geometric and photometric variables. A field study was conducted in which legibility distance predicted by the model was compared with legibility distance measured on a numbr of real and simulated signs. Data were developed that show graphically the relationship between legibility distance and the photometric properties of background and legend materials.

The final report was not published in the NCHRP report series; however, a copy of it, entitled "Determine the Luminous Requirements of Retroreflective Highway Signing," is available at a cost of $7.00 (see final page of this section for ordering information).

Project 3-25 FY '76

Cost and Safety Effectiveness of Highway Design Elements

Research Agency: Roy Jorgensen Associates, Inc.
Principal Invest.: Joseph F. Banks, Jr.
Dr. Richard L. Beatty
Dr. David B. Brown
Effective Date: July 15, 1975
Completion Date: April 16, 1978
Funds: $260,576

The objectives of this research were (1) to identify the key geometric characteristics and combinations of characteristics of road and street designs that affect accident frequency and severity; (2) to quantify the effects of varying the key characteristics and combinations of characteristics on accident frequency and severity; and (3) to develop a methodology that can be used by engineers in measuring the cost-effectiveness of the various levels of each design element.

About 50 design features were found to have some relationship to safety. Because only a limited number of design elements could be studied in depth during this research, the features of pavement width, shoulder width, and shoulder surface type for rural two-lane highways were selected for quantifying their relationship to accident and frequency and severity.

A safety cost-effectiveness methodology was developed to incorporate the quantified relationships into a practical design procedure. Utilization of the safety relationships and methodology contained in the final report will provide an optimum design for pavement width, shoulder width, and shoulder type. The methodology does not contain a rigid procedure for selection of the final design, but provides the necessary cost-effectiveness information for the designer to make an objective decision. The final design selected must also consider traffic and vehicle operating characteristics, which may override the design based on safety cost-effectiveness. However, by applying the methodology, the safety ramifications of all alternatives can be determined.

Research has been completed, and the final report has been published as: NCHRP Report 197, "Cost and Safety Effectiveness of Highway Design Elements."

Project 3-26 FY '77

Investigation of Selected Noise Barrier Acoustical Parameters

Research Agency: The Pennsylvania State University
Principal Invest.: Dr. Sabih I. Hayek
Dr. James M. Lawther
Effective Date: December 1, 1976
Completion Date: February 28, 1980
Funds: $224,494

The basic project objective was to complete an analysis of cross-section shape, surface characteristics, and the influence on ground-cover effects. The significance of these parameters was evaluated theoretically in terms of the sensitivity of barrier effectiveness to each, and the bounds of their effects were delineated in the first phase of the project.

The second phase of the project emphasized scale-model experimentation designed to verify the findings of the first phase. The tests included evaluation of insertion loss models applied to the different barrier configurations and study of the ground-effects problem and propagation characteristics related to a pavement adjoined by an impedance-covered terrain.

The agency's final report, results of the scale-model experiments, is available on a loan basis upon written request to the NCHRP or a microfiche copy may be purchased (see final page of this section for ordering information).

Project 3-27 FY '77

Guidelines for Selecting Traffic Control at Individual Intersections

Research Agency: Alan M. Voorhees & Associates, Inc.
Principal Invest.: Philip J. Tarnoff
Effective Date: November 15, 1976
Completion Date: July 31, 1979
Funds: $150,000

The objective of this research was to develop guidelines for selecting the most appropriate type of traffic signal control for an individual intersection in both urban and rural areas. Pretimed, semi-traffic-actuated, and full-traffic-actuated control types were evaluated. An annotated bibliography of previous studies was prepared, and current practices were reviewed in depth with local traffic

engineering agencies. Numerous factors affecting the choice of control type were identified.

A cost-effectiveness evaluation methodology was developed to assist in the selection of traffic signal control and addresses such items as (a) initial costs, (b) maintenance costs, (c) over-all delay, (d) percentage of traffic stopped, (e) vehicle emissions, (f) fuel consumption, and (g) other direct and indirect user costs. The incremental benefits of more sophisticated levels of control and operational reliability are fully considered. Cost and operational data are also included in the cost-effectiveness methodology to reduce the data collection requirements of future users. Adjacent intersections are addressed in the guidelines in regard to the selection of coordinated versus independent operations.

Research has been completed, and the findings have been published as: NCHRP Report 233, "Selecting Traffic Signal Control at Individual Intersections."

Project 3-28 FY '78

Development of an Improved Highway Capacity Manual

Research Agency: JHK & Associates
Principal Invest.: William R. Reilly
Effective Date: December 15, 1977
Completion Date: August 15, 1979
Funds: $161,000

Project 3-28 is a multiphase effort with the overall objective of providing the basis for a revision of the *Highway Capacity Manual* (HCM). Phase I (Project 3-28) had the threefold objective of (1) determining the current and future needs of users of the HCM, (2) assembling existing information for dissemination as an interim document prior to revision of the entire Manual, and (3) identifying gaps in the available techniques that require additional research to develop new information for inclusion in the revised Manual.

The second phase of this research includes two projects that have been initiated to satisfy the high-priority research needs identified in Phase I. Phase II research includes NCHRP Projects 3-28A and 3-28(2). The final phase will be directed to assembly of information from work sponsored by NCHRP, FHWA, and others into a form for publication as a revised Manual.

Research on Phase I has been completed. The final report presents the results of an extensive survey of user needs and a summary of related research. In addition, 15 areas of needed research are identified. Copies of the agency's report are available on a loan basis (see final page of this section for ordering information).

Interim materials were assembled and developed in Phase I for immediate distribution, as well as for eventual inclusion in the revised Manual. The Transportation Research Board has published the interim materials as TRB Circular 212 which includes capacity analysis techniques for transit, pedestrians, and unsignalized intersections.

Project 3-28A FY '80

Two-Lane, Two-Way Rural Highway Capacity

Research Agency: Texas A & M Research Foundation
Principal Invest.: Dr. Carroll J. Messer
Effective Date: May 1, 1980
Completion Date: February 28, 1983
Funds: $157,492

NCHRP has initiated a multiphase research effort with the objective of providing the basis for a revised, improved *Highway Capacity Manual* (HCM). Phase I research (Project 3-28) identified the specific needs of users of the HCM, provided interim materials for dissemination prior to development of the revised Manual, and identified additional research projects that should be conducted to provide input to the revised Manual. Project 3-28A was part of the Phase II effort, which was directed to satisfying the highest priority research needs identified in Phase I.

The procedures contained in the 1965 HCM for analysis of traffic operations on two-lane, two-way rural highways are based on the fundamental traffic flow relationships that expressed operating speed as a function of vehicular volume and capacity for various prevailing conditions. Users of the HCM procedures indicated a need for improvement in several elements of the technical analysis.

The objective of this research was to develop an analytical procedure to evaluate the capacity and level of service for two-lane, two-way rural roads in an appropriate form for inclusion in a revised HCM.

Existing simulation models were reviewed with a detailed analysis of the simulation parameters, such as truck speeds, grades, directional volumes, headways, and speed distributions. The MRI simulation model was selected for use in this research.

Field studies were conducted at selected sites in Texas, Pennsylvania, Colorado, West Virginia, and Alberta, Canada, to collect speed, volume, and related data for use in the analytical framework. These field data, combined with prior calibration data and other reported rural highway data, were used to indicate the general level of accuracy for the MRI model.

Relationships between traffic volume, levels of service, and related parameters were determined using the field data and the simulation model. These relationships were structured into an integrated procedure for calculation of directional speed (and other appropriate measures of effectiveness), volume, capacity, and level of service for a wide range of traffic and highway design conditions. A step-by-step analysis procedure was prepared.

TTI's final report includes a draft chapter for the HCM that will be finalized under Project 3-28B. Therefore, the report will not be published in the regular NCHRP series,

but is available for $3.00 from the NCHRP (see final page of this document for ordering information).

Project 3-28B FY '82

New Highway Capacity Manual

Research Agency: Polytechnic Institute of New York
Principal Invest.: Dr. Roger P. Roess and Dr. Carroll J. Messer
Effective Date: July 1, 1982
Completion Date: March 31, 1985
Funds: $283,440

NCHRP Project 3-28 is a multiphase research effort with the overall objective of providing the basis for a new *Highway Capacity Manual* (HCM). Project 3-28, the first phase of this research, identified the specific needs of users of the HCM, provided interim materials (*TRB Circular 212*) for dissemination prior to the development of the new manual, and identified additional research projects that should be conducted to provide input to the new manual. The second research phase was directed to satisfying the highest priority research needs identified in Phase I, and included NCHRP Project 3-28A, "Two-Lane, Two-Way Rural Highway Capacity," and NCHRP Project 3-28(2), "Urban Signalized Intersection Capacity."

FHWA also sponsored research for the purpose of providing resource material for the new HCM. For example, the results of an FHWA study on freeway capacity were reported in *TRB Circular 212,* and a major study on quality of flow on urban arterials was conducted. In addition to sponsored research, the TRB Committee on Highway Capacity and Level of Service (A3A10) developed draft materials for inclusion in the new HCM, and related information was obtained from other sources (e.g., capacity manuals from other countries).

The objective of the third phase, NCHRP Project 3-28B, was to assemble and review existing information related to highway capacity, determine the most appropriate material for inclusion in the new HCM, refine and reformat that material as necessary, synthesize state-of-the-art information, and prepare a complete draft of the new HCM.

The new HCM has been published in loose-leaf format as TRB Special Report 209.

Project 3-28C FY '84

Effects of Quality of Traffic Signal Progression on Delay

Research Agency: Texas A&M Research Foundation
Principal Invest.: Dr. Edmond C. Chang
Effective Date: August 1, 1986
Completion Date: July 31, 1988
Funds: $165,000

Levels of service for signalized intersection approaches in Chapter 9 of the 1985 Highway Capacity Manual (HCM), published as *TRB Special Report 209,* are based on stopped delay as computed from the cycle length, G/C ratio, v/c ratio, saturation flow, and quality of progression. Quality of signal progression has a major influence on stopped delay, as evidenced by the progression adjustment factors (PF) in Table 9-13 of Chapter 9 varying from 0.40 to 1.85. However, the adjustment factors are based on limited data. Field data, supplemented by simulation, are needed to verify the variations in delay resulting from changes in the quality of progression for a variety of conditions. These data should include the effects on stopped delay of individual factors potentially influencing quality of progression (e.g., cycle length).

The objective of this research was to evaluate the effects on stopped delay of changes in the quality of traffic signal progression. Variables to be investigated for both pretimed and semiactuated control include, but were not limited to: (1) signal offset, (2) signal spacing, (3) cycle length, (4) cycle splits, (5) bandwidth, (6) side-street entries at an upstream point, (7) v/c ratios, (8) arterial speed, and (9) platoon decay. Primary emphasis was given to through movements at pretimed signals on multilane arterials in urban and suburban areas.

The product of this research was a calibrated set of progression adjustment factors, either in the form of a revised version of Table 9-13 (TRB Special Report 209) or a *replacement* delay adjustment technique. This product is suitable for application to the general stopped delay model of Chapter 9 and to the urban arterials procedure in Chapter 11 of the HCM.

To achieve this objective, the following tasks were accomplished:

Task 1—Identify the variables that appear to have a significant influence on the quality of progression. The variables that are represented in the current HCM model shall be considered, along with additional variables that appear in the literature. For each of the identified variables, prepare an assessment of the practicality of measurement and the potential effect on stopped delay. Determine which of the variables should be considered in this project.

Task 2—Prepare an hypothetical progression-delay model utilizing these variables, for use in the design of the controlled field tests and simulation studies and for subsequent use in developing the progression-delay relationships. The model shall consider two alternatives in applying adjustment factors for quality of progression: (1) applying the adjustment factors to the entire delay equation including the overflow delay term, and (2) applying the adjustment factors to only the *first* term of the delay equation excluding the overflow delay term.

Task 3—Prepare a study design including the following: (a) Site selection: A minimum of two arterial signal systems (one urban arterial with free-flow speeds not over

30 mph and one suburban arterial with free flow speeds of not less than 40 mph) shall be studied in each of two metropolitan areas. Both pretimed and semiactuated sites shall also be studied in the pretimed mode. (b) Data collection plan: This plan will describe the proposed techniques for collecting the required data and a statistical sampling plan covering a wide variety of volume conditions, cycle lengths, splits, and offsets. The sampling plan will be based on data collection on a cycle-by-cycle basis and aggregated over nominal 15-minute periods.

Task 4—Carry out a pilot study on one of the selected links to demonstrate and refine the proposed data collection and analysis procedures. A link with heavy traffic conditions will be used. The pilot study will include photographic techniques (either film or video) to provide a permanent record of the collected data.

Prepare an interim report that describes the proposed sites and the data collection techniques and illustrates how these techniques are used in measuring the variables to be used in testing and calibrating the progression-delay model.

Task 5—When the interim report has been approved, the remainder of the field data will be collected. All data will be collected under good weather conditions and at times not hampered by nonrecurring congestion.

Task 6—Analyze the data, using the progression-delay model developed in Task 2, to identify relationships using appropriate statistical tests.

Task 7—Prepare a final report. Recommendations regarding the applicability and limitations of the proposed technique in comparison to more comprehensive analysis methods (i.e., system design and signal timing methods) will be included. Appropriate material in a format suitable for direct inclusion in the HCM will be prepared.

All tasks have been completed and the final report is being reviewed. The study recommendations will be provided to the Highway Capacity Committee for review and a decision on inclusion in the Highway Capacity Manual. The Capacity Committee is expected to act on the recommendations at their January 1989 meeting.

Project 3-28(2) FY '78 and FY '79

Urban Signalized Interaction Capacity

Research Agency: JHK & Associates
Principal Invest.: William R. Reilly
Effective Date: October 1, 1979
Completion Date: August 31, 1982
Funds: $331,000

NCHRP Project 3-28 is a multiphase research effort with the overall objective of providing the basis for a revised, improved *Highway Capacity Manual* (HCM). Project 3-28, the first phase of this research, identified the specific needs of users of the HCM, provided interim materials for dissemination prior to the development of the revised Manual, and identified additional research projects that should be conducted to provide input to the revised Manual. The second research phase, including Projects 3-28A and 3-28(2), was directed to satisfying the highest priority research needs identified in Phase I.

The objective of Project 3-28(2) was to develop procedures for capacity analysis of the intersection as a complete unit and of each individual intersection approach. This research on urban intersections and a current FHWA project, "Quality of Flow on Urban Arterials," will provide a comprehensive set of capacity analysis procedures for inclusion in the HCM.

Previous research efforts related to intersection capacity analysis were reviewed to determine the adequacy and applicability of existing techniques and simulation models for use in this study. Models and empirical techniques that can be used to relate delay, capacity, level of service, and physical and traffic variables were evaluated. An evaluation of the most promising procedures through illustrative case studies was also completed.

Traffic service measures such as delay, stops, and saturation flow were collected at intersections in Alexandria, VA; Atlanta, GA; and Tucson, AZ. Additional field data were collected in San Francisco, Chicago, and Tucson for validation purposes. In cooperation with the FHWA, the NETSIM computer simulation model was modified for use in this project. The field and simulation data were further supplemented with existing time lapse film data from a previous FHWA intersection delay study for use in the development of the capacity analysis procedure.

Computational procedures to determine the capacity, level of service, and operational features of signalized intersections were developed. The effects of traffic signal timing and phasing are included in the procedures. A draft chapter for the next HCM and a research report were prepared. Copies are available for loan upon written request to the NCHRP or microfiche of the report may be purchased (see final page of this section for ordering information).

Project 3-29 FY '83

Traffic Signal Display Complexity

Research Agency: Systems Technology, Inc.
Principal Invest.: R. Wade Allen
Effective Date: July 1, 1983
Completion Date: March 31, 1986
Funds: $196,284

The objectives of this research were to: (1) determine drivers' abilities to deal with complex signal displays and identify the associated response factors; (2) assess the effectiveness of various complex signal display treatments currently in use; and (3) identify potential, future changes.

For purposes of this research, complex signal displays were defined as those where misinterpretation by the driver may result from simultaneously viewing two or more signal and sign messages. Research included inter-

section signal displays and combinations specified in Section IV-B of the MUTCD. Guidelines were developed for providing effective and uniform traffic signal displays for complex situations, and recommended changes to the MUTCD were identified.

The findings of previous work relevant to the effectiveness of complex signal displays were reviewed to identify applicable information for use in this research. Two hundred state, county, and city traffic engineers were contacted to determine (1) the intersection types and geometric designs that cause the most significant problems, (2) the signal configurations (MUTCD and/or other) currently used, and (3) specific display complexity problems. Left-turn movements and skewed and off-set intersections were considered to warrant primary emphasis.

Laboratory studies were conducted to determine the drivers' abilities to deal with complex signal displays and to assess the effectiveness of various complex signal displays currently in use. These studies determined the specific driver related factors, such as ambiguity, information overload, etc., that cause delayed and/or faulty responses. A limited field study was conducted to validate the most promising alternatives. The operational and safety aspects were evaluated in addition to verifying driver behavior and understanding, mostly for left-turn situation.

The final report will not be published but is available on a loan basis from the NCHRP. Copies have been provided to the National Committee on Uniform Traffic Control Devices for consideration in future changes to the MUTCD.

Project 3-30 FY '83

Intersection Channelization

Research Agency: Jack Leisch Associates
Principal Invest.: Timothy Neuman
Effective Date: July 1, 1983
Completion Date: May 15, 1985
Funds: $130,000

The objective of this research was to prepare a publication updating the information in *HRB Special Report 74* and incorporating information, illustrations, and guidelines on the current state of the art for channelization. This research covered channelization of both new and reconstructed intersections in urban and rural environments. The research included typical intersection types such as 4-way, Y, T, oblique, and multileg intersections, as well as freeway ramp intersections with surface streets.

A mail survey was conducted of all 50 state highway departments/DOTs and 90 local agencies to determine the current practice for channelization of different types of intersections. Information on operational and design characteristics was obtained as well as examples and photographs of typical intersection designs and special treatments. Standards and guides used by the agencies in the design and implementation of channelization and the findings from studies of the effectiveness of various treatments were assembled. Highway agencies with differing philosophies on channelization and/or with novel channelization treatments were visited to obtain the supplementary information, documentation, and photographs needed to cover the full range of applications, designs, and performance characteristics.

Various channelizing techniques and geometric design elements were evaluated in terms of intersection performance, safety impact, energy savings, maintenance problems, costs, and the effects on pedestrians, bicyclists, and the handicapped. The geometric design elements include island size, island type (raised, painted, or depressed), lateral clearance, and tapers approaching and leaving the island.

Channelization guidelines were developed, providing specific principles and criteria (e.g., minimum island size as a function of traffic parameters) on the applicability of channelization techniques. Typical examples of good current practice were documented including fully dimensioned plan views, photographs, and agency insights to the specific applications.

The channelization guidelines have been published with removable inserts for the design drawings as: NCHRP Report 279, "Intersection Channelization Design Guide."

Project 3-31 FY '83

Guidelines for Evaluating Alternatives for Replacing a Grade-Separated Rail/Highway Crossing

Research Agency: Ernst & Whinney
Principal Invest.: Robert Taggart
Effective Date: September 4, 1984
Completion Date: February 28, 1987
Funds: $200,000

The objective of this research was to provide a comprehensive framework for use in evaluating alternatives and developing recommendations on whether to replace a grade separation with an at-grade crossing. The framework is applicable for determining the best alternatives for new crossings and for changes to existing at-grade crossings. Widely applicable techniques, including guidelines for both quantifiable and nonquantifiable factors, are described to assist in the decision-making process.

A list of the research tasks follows:

1. Determine the current practices of selected government agencies and railroads. A survey of a representative number of government agencies and railroads was conducted to obtain information on design standards as well as policy and legal positions.

2. Identify and rank factors to be considered and provide detailed documentation of how the relative importance of the factors was established. In addition to cost and safety considerations, factors include: (1) volume and nature of traffic using the intersecting highway and rail-

road, (2) proximate land use, (3) potential use by emergency vehicles, (4) potential environmental impact, (5) energy consumption, (6) maintenance, (7) liability, and (8) societal implications.

3. Identify sources and methods of obtaining data necessary to support the application of factors. The types of data include: (1) accident data, (2) inventory data, (3) cost information, (4) liability issues, (5) maintenance agreements, and (6) operational and mobility considerations, especially passenger trains, buses, and hazardous materials vehicles.

4. Develop a framework of procedures utilizing the factors identified in Task 2 to assist in selecting one of the four alternatives described above. Detailed analysis guidelines and a recommended format for presenting the evaluation results are included.

5. The framework of procedures developed in Task 4 were applied to two case studies.

6. Prepare a final research report that documents the rationale used to select the framework and that describes its application. Prepare a separate user's guide, including examples, on the use of the framework.

Research has been completed and the final report and user's guide have been published in the regular NCHRP report series as NCHRP Report 288.

Project 3-32 FY '85

Temporary Pavement Markings for Work Zones

Research Agency: Texas A & M Research Foundation
Principal Invest.: Dr. Conrad L. Dudek
Effective Date: May 1, 1985
Completion Date: February 28, 1987
Funds: $164,990

Temporary traffic control has become a larger percentage of the costs on many construction, maintenance, or utility projects. With the prospects of continued inflation, limited resources, and high interest rates, it is imperative that all aspects of temporary traffic control be evaluated for economy in application and benefits to the public.

FHWA has issued guidelines and proposed changes in the *Manual on Uniform Traffic Control Devices* (MUTCD) regarding Temporary Markings for Construction and Maintenance Areas. The proposed changes would require as a minimum 4-ft broken lines as temporary markings on most projects, which is more than double what many states now specify. If adopted as the national standard, 4-ft markings would increase project costs.

Research was needed to determine if the proposed 4-ft markings would actually result in significant safety and operational improvements in comparison to current practice.

The specific objective of this research was to compare the safety and operational effectiveness of 1-ft, 2-ft, and 4-ft temporary broken line pavement markings in work zones. The scope and test conditions studied were: (1) surfacing operation on a two-lane, two-way facility; (2) data collection during hours of darkness; (3) dry roadway conditions; (4) tangent and curve sections; (5) use of the test state(s) typical pavement marking cycle (40 to 50 ft); and (6) field tests in real or staged work zones that are open to traffic. In order to meet this objective, the following tasks were performed:

Task 1. A critical review of the literature on safety and operational effects of pavement marking in work zones was conducted

Task 2. A detailed data collection and analysis plan along with a proposed schedule was developed. The plan included (1) experimental design and analysis plan, including the rationale for selecting the recommended approach and proposed sample sizes; (2) measures of effectiveness (MOE's) to be used to evaluate the three different stripe lengths; and (3) methods and location of field measurements.

Task 3. Data collection and analysis at six sites were performed.

Task 4. A research report including a discussion of the traffic engineering and human factors implications of the research findings to current practice and to the proposed change was prepared.

All research has been completed, and the final report has been provided to the National Committee on Uniform Traffic Control Devices and to FHWA. On the basis of the limited conditions studied and the project findings, further research is deemed necessary before any further changes in the MUTCD are contemplated.

The findings of this research project were presented by the principal investigator at the TRB Annual Meeting in January, 1988. A paper, "Field Studies of Temporary Pavement Markings at Overlay Project Work Zones on Two-Lane, Two-Way Rural Highways," by Conrad L. Dudek, R. Dale Huchingson, F. Thomas Creasey, and Olga Pendleton, has been published in Transportation Research Record 1160, **Traffic Control Devices 1988.** The Record also includes a discussion by Anita W. Ward and an author's closure. A decision on publication of the final report is pending. Loan copies are available from NCHRP.

Project 3-33 FY '85

Capacity and Level-of-Service Procedures for Multilane Rural and Suburban Highways

Research Agency: JHK & Associates
Principal Invest.: William R. Reilly
Effective Date: June 1, 1985
Completion Date: May 31, 1989
Funds: $475,132

Chapter 7, "Multilane Highways," of the new *Highway Capacity Manual* (HCM) published in 1985, is predicated

largely on the limited research used for the 1965 edition and on extrapolation from recent studies of other highway types, especially freeways. In the absence of an adequate data base concerning the operating and capacity characteristics of the multilane highway, research is needed to develop this information and to prepare an improved chapter on multilane highways.

The objective of this research was to confirm and/or develop operational, design, and planning procedures for determining the capacity and levels of service of multilane highways, both rural and suburban. This research will: (1) review the current state of the art, (2) develop an adequate data base and, (3) validate, revise, or develop new analytic procedures. Items to be considered include separation of traffic directions, access characteristics, roadside development, presence of signalized and unsignalized intersections, lane widths, lateral obstructions, geometrics, and other variables that may impede smooth traffic flow. The proposed procedures will replace Chapter 7 of the 1985 HCM.

The major thrust of this effort was focused on multilane highway facilities having four or more lanes. The research, however, also considered special multilane configurations such as three-lane, two-way operation (2-1 split) and the provision of a continuous left-turn lane. New material developed for these special configurations will be incorporated into the appropriate HCM chapter.

To accomplish this objective the following tasks was performed in two phases:

Phase I:

Task 1. Conduct a review of the pertinent literature and current research.

Task 2. Evaluate the adequacy of the current state-of-the-art procedures used in analyzing multilane highway capacity and level of service.

Task 3. Prepare preliminary capacity analysis procedures to serve as the basis for a data collection plan. The proposed capacity analysis method may be a refinement or revision of the existing procedures or may require an entirely new concept of multilane capacity analysis.

Task 4. Prepare a field data collection plan to quantify the traffic flow relationships.

Task 5. Prepare a Phase I report, including the proposed data collection plan and a revised, detailed budget for Phase II.

Phase II:

Task 6. Collect field data according to the approved plan.

Task 7. Reduce and analyze the data collected under Task 6 to obtain values for the appropriate traffic flow relationships.

Task 8. Prepare a report describing the proposed final form and content of the capacity and level-of-service analysis procedures.

Task 9. Write a new version of Chapter 7, "Multilane Highways," containing the new analysis procedures.

All tasks have been completed and the final report has been drafted. The study recommendations and a draft Chapter 7 will be provided to the Highway Capacity Committee for review and a decision on inclusion in the Highway Capacity Manual. The Capacity Committee is expected to act on the recommendations at their January 1989 meeting.

Project 3-34 FY '86

The Feasibility of a National Heavy-Vehicle Monitoring System

Research Agency:	Arthur D. Little, Inc.
Principal Invest.:	Ashok B. Boghani
Effective Date:	November 1, 1985
Completion Date:	September 30, 1988
Funds:	$499,791

Various types of information on heavy vehicles are collected by federal, state, and local governments to support highway planning and design activities, as well as to carry out weight enforcement programs and tax administration. Collecting and processing this information is extremely costly from the viewpoint of both government and private industry, and in many cases the data are not as complete or as accurate as desired for the intended purpose. In addition to actual dollar costs, the present system suffers from burdensome paperwork, operator inconvenience and potential hazard, lack of enforcement uniformity, and inconsistency among the individual states. International inconsistency is also a concern. The potential use of the collected information for other purposes (e.g., by private industry in fleet and operations management, and by enforcement agencies in locating stolen equipment) has also not been fully explored.

New technologies in automatic vehicle identification (AVI), automatic vehicle classification (AVC), and weigh-in-motion (WIM) are considered to potentially offer a more cost-effective approach to the collection of heavy-vehicle data. The interest in AVI systems, integrated with AVC and/or WIM, is so great that a group of western states and Canadian provinces is embarking on a multi-jurisdictional project to demonstrate the utility of an integrated electronic heavy-vehicle monitoring system. This project, called the Crescent Demonstration Project, is limited in scope and is not designed to address all of the questions and problems involved in the implementation of a multijurisdictional, national or international system.

Therefore, there is a need to evaluate the feasibility of applying these relatively new technologies at the national and/or regional levels and to build on the existing knowledge from the Crescent Project and other related studies. Institutional issues such as privacy, access to competitive information, and potential for manipulation and evasion of the system will be major determinants of feasibility and acceptability. These issues will therefore play a prominent part in the evaluation.

The objective of this research was to identify and evaluate the needs, issues, requirements, and feasibility of using an automated system (AVI/AVC/WIM) as a cost-effective, statistically sound replacement and/or supplement to existing heavy-vehicle data collection systems. This research will encompass: (1) the identification of different system-design configurations for the integration of AVI, AVC, and WIM to provide appropriate levels of monitoring and related confidence levels; (2) amount of equipment/automation to achieve different objectives; (3) site location criteria on a state, regional, and nationwide scale; (4) an economic analysis of the alternative levels of monitoring; and (5) the full range of issues associated with implementation and operation.

The following tasks will be completed:

Task 1—Identify the types and range of existing and potential national, state, and private industry functions (activities) that are or could be supported by heavy-vehicle data.

Task 2—Determine the required deployment density of an automated data collection system to provide an acceptable statistically based level of accuracy for each function.

On the basis of the identified deployment requirements, group functions with similar needs that can be satisfied with a common system configuration of deployment density and level of sophistication (i.e., number of sites, number of vehicles equipped, type of data collection equipment, national/regional area, etc.). Approximately 3 to 5 configurations are anticipated to cover the range of functions, data requirements, and needed levels of accuracy.

Task 3—Examine each system configuration against the issues and related considerations identified in Task 1.

Task 4—Submit an interim report presenting the findings of Tasks 1 through 3.

Task 5—Conduct a cost-benefit analysis for each approved system configuration (including the incremental cost/benefit associated with each function). The advantages and/or disadvantages of automated systems will be compared to existing data collection and processing systems; and the impact on other data collection, processing, and reporting procedures that would be affected by the use of an automated system will be identified.

Task 6—Describe implementation considerations for each recommended system configuration. These considerations will include the technical, operational, institutional, cost, financial, and legislative issues, the data base management system requirements, and any other considerations identified during the course of the research.

Task 7—Prepare a final report.

Research has been completed and the final report will be published as: NCHRP Report 303, "Feasibility of a National Heavy Vehicle Monitoring System."

Project 3-35 FY '86

Speed-Change Lanes

Research Agency: JHK & Associates
Principal Invest.: William R. Reilly
Effective Date: June 1, 1986
Completion Date: March 30, 1989
Funds: $250,000

Changing vehicle and driver population characteristics makes it necessary to periodically reexamine highway design criteria. The speed-change lane is one of the most common highway features because it can be either a permanent feature (terminals, lane drops, etc.) or a temporary feature (construction and maintenance zones).

The more diverse vehicle population on the highways today, ranging from light low-powered automobiles to heavy trucks, makes a reexamination of speed-change lane criteria necessary to keep design parameters current.

The objective of this research is to examine the current design parameters which establish speed-change lane length. Based on a review of current practice, updated vehicle performance characteristics, and new driver-behavioral data, recommended design procedures will be developed for specific applications taking into account the type of facility, geometrics, and other relevant considerations. This research will address existing and new acceleration and deceleration lanes on freeways. The scope of this research does not include (a) the design of weaving sections, (b) work zone applications, (c) ramp metering, and (d) new accident studies.

To accomplish this objective, the following tasks will be conducted:

Task 1—Review literature and operational experience through a limited survey of state highway officials.

Task 2—Update vehicle mix and performance data. Using available data to the maximum extent possible, update the vehicle parameters used in speed-change lane criteria. Gaps in the published data will be filled by contacting manufacturers and others and, if necessary, by conducting limited operational tests. Changes in vehicle mix and selection of a new design vehicle(s) will be considered.

Task 3—Determine behavioral characteristics of the driver/vehicle unit in speed-change lanes. Conduct driver information or task analyses to identify the driving tasks required to negotiate a speed-change lane. If necessary conduct laboratory, closed field, or field studies to verify the analyses or to fill gaps in available data.

Task 4—Develop a conceptual framework for design of freeway speed-change lanes. This framework will include revised or new design criteria applicable to specific conditions (e.g., facility type, grade, curvature, terminals, volume).

Task 5—Develop a plan to field test the proposed design criteria.

Task 6—Conduct field test studies.

Task 7—Analyze the field study data to confirm the design criteria developed in Task 4

Task 8—Develop application procedures. A range of typical projects and conditions will be described including reconstruction and new construction. Guidance on extreme applications (e.g., steep grades, high truck volumes) will also be provided.

Task 9—Prepare a draft final report. One appendix to the report will be a stand-alone design guide tailored to state/local designers.

Tasks 1 through 7 have been completed and work is nearing completion on the user application procedures and the final report. Panel review and revision of all materials will require a time extension until about March of 1989.

Project 3-36 FY '87

Development of a Low-Cost Bridge Weigh-In-Motion System

Research Agency: Bridge Weighing Systems, Inc.
Principal Invest.: Richard E. Snyder
Effective Date: February 16, 1987
Completion Date: August 16, 1989
Funds: $400,000

Truck weight, dimension, and speed data are required for a wide variety of purposes, including maintenance management programs, pavement and bridge management systems, pavement and bridge design, cost allocation studies, and for compliance with FHWA-mandated vehicle weight and speed monitoring programs. Current methods for collecting these data are very costly to both the states and the trucking industry and are often ineffective. A technique is needed to economically acquire information on the characteristics of heavy vehicles and to provide a data base that can be used for improved planning, design, and maintenance of highways and bridges.

At present, most truck weight data are obtained from conventional off-road weigh stations at fixed locations on major highways. However, there are well known disadvantages associated with the operation of these facilities: they occupy valuable real estate, require expensive equipment, and need costly operating personnel. The stations often become over-used, increasing delays to trucking firms. Further, these stations are often easily evaded by overloaded vehicles or by those who wish to avoid delays. A number of states have been investigating bridge weigh-in-motion (WIM) systems, but the cost of equipment and manpower has prevented widespread implementation.

There is a need to develop a low-cost system, suitable for widespread application, that can combine load measurement with vehicle classification. One approach to this problem is the further development of current bridge weigh-in-motion technology, using low-cost, low-power electronics and transducers.

The objective of this research is to develop a low-cost bridge weigh-in-motion (WIM) system capable of providing the traffic data used in the design and maintenance of highways and bridges. This system will be able to record gross vehicle weights and classify vehicles, at a minimum, and also be able to record individual axle weights within the limits of the specific bridge and site characteristics. Further, the system will use state-of-the-art technology, have a target purchase price of $5,000 to $10,000 per unit, have a low life-cycle cost, be capable of interfacing with automatic vehicle identification (AVI) equipment, and be deployable on both bridges and large culverts. This research will include the development, testing, and demonstration of a "turnkey" prototype system.

The research will include the following tasks:

Task 1—Review existing bridge WIM/AVC systems including the technical design, practical considerations, costs, hardware and software requirements, operational and maintenance problems, reliability, and accuracy. This review will also consider other technology that may be transferable to components of a WIM/AVC system.

Task 2—Develop a conceptual system design defining the data requirements, equipment performance criteria, hardware and software requirements, and estimated purchase price. At a minimum, the system will be able to collect the following data:

- Gross vehicle weight for vehicles over 12,000 pounds.
- Number of axles and spacing.
- Traffic counts of all vehicles.
- Speed.
- Vehicle classification.

In addition to these minimum requirements, individual axle weights are also desired if the system can obtain this information with reasonable accuracy.

Task 3—Develop an operational model for laboratory testing. This model will include the necessary software for data recording and transmission, the signal processing algorithms, the interface between the WIM and AVC hardware, and, to the extent possible, the provision for interfacing with AVI hardware. The model will also include complete fabrication of the hardware components for testing and modification under controlled laboratory conditions.

Task 4—Conduct laboratory tests to evaluate the system performance and capabilities.

Task 5—Build prototype(s) of the WIM/AVC system for field testing. Special considerations include the different types of bridges and culverts on which the system will be used, environmental factors, installation and maintenance requirements, vandal resistance, among others.

Task 6—Field test the prototype(s).

Task 7—Evaluate the field test results and modify the system design and prototype(s) as necessary.

Task 8—Build a prototype of the final system design for delivery to the NCHRP, along with complete documentation to support subsequent manufacture and pro-

curement. This documentation will include detailed reproducible production drawings, software with a properly annotated source listing, and installation and operating instructions. The research product will be in the public domain for use by states and others in procuring low-cost bridge WIM equipment.

Task 9—Prepare a final report.

Tasks 1 through 4 have been completed.

Project 3-37 FY '90

Capacity of Ramp-Freeway Junctions

Research Agency:	In developmental stage
Principal Invest.:	
Effective Date:	(36 months)
Completion Date:	
Funds:	$500,000

When the *Highway Capacity Manual* (HCM) was revised in 1985, the required data and understanding for many traffic situations were found not to exist. For expediency, "reasonable" judgments were made about how to analyze such situations, but it was understood that such material was unreliable and was to be revised as soon as possible. The Transportation Research Board subsequently published a prioritized list of subjects about which the HCM is unreliable and research is needed (Circular 319). Number one on that list of priorities is the capacity of ramp-freeway junctions. A theory which accounts for the impact of geometric and traffic variables must be developed and calibrated with a nationwide survey. The objective of this research shall be to: (1) Develop a theory or algorithm that can calculate the capacity and level of service of ramp-freeway junctions as functions of geometric and traffic variables. (2) Calibrate that theory or algorithm with a nationwide data sample. The geometric variables considered should include merge/diverge angle, length and type of acceleration/deceleration lane, grades, design speeds, and number of lanes on the ramp and on the mainline. The traffic variables considered should include traffic volume on the ramp and on the mainline, percent trucks, and arrival pattern (random/ramp-metered/platoon). The research can be divided into six major tasks:—*Task 1.* Ascertain the state-of-the-art in ramp-freeway capacity analysis. This task includes a literature survey but it also includes coordination and consultation with other, related research. *Task 2.* Select 80 experimental sites. Experimental sites must cover the full range of traffic, geometric, and geometric, and geographical variables. *Task 3.* Formulate a model of the capacity of ramp-freeway junctions. This model may take form of a theoretical relationship or of an algorithm. The critical issue is that the model be able to predict the level of service and capacity of ramp-freeway junctions. Operating speed is a desirable, but not essential, measure of effectiveness. *Task 4.* Conduct a pilot study at four of the experimental sites. Calibrate the model. *Task 5.* Revise the model and data collection procedures, prepare an interim report, and confer with the NCHRP Advisory Panel before embarking on the full data collection. The purpose of this task is to ensure that both the researchers and the NCHRP panel understand the state-of-the-art and agree as to what the most promising model and data collection methodologies are. *Task 6.* Perform a full data collection at 76 experimental sites. Calibrate the revised model.

Project 3-38(1) FY '87

Assessment of Advanced Technologies for Relieving Urban Traffic Congestion

Research Agency:	Castle Rock Consultants, Inc.
Principal Invest.:	Peter Davies
Effective Date:	July 1, 1987
Completion Date:	June 30, 1989
Funds:	$199,752

Traffic congestion is rapidly becoming one of the most serious problems affecting urban areas. Traffic operations techniques and systems are needed that can substantially increase capacity and improve traffic flow efficiency. While it is essential that "best practices," new construction, and traditional traffic engineering approaches in dealing with traffic demand be vigorously used, innovative and advanced technology needs to be incorporated into the highway system if significant relief for urban traffic congestion is to be realized at economic and social costs below the cost of constructing extensive new conventional facilities.

Application of advanced technologies in areas such as motorist communication, information and navigation systems, vehicle guidance, control systems, and others has the potential for relieving traffic congestion. Issues related to applying such systems to help alleviate traffic and transportation problems have yet to be fully explored.

The objectives of this research are to: (1) identify and assess the most promising advanced technologies and systems that can improve urban highway traffic operations by achieving significant increases in capacity and traffic flow; and (2) for the most promising of these technologies and systems, formulate a plan for research, development, testing, and demonstration.

The following two research phases are to be accomplished:

Phase 1—Preliminary Assessment of Advanced Technologies

Task 1—Identify advanced and innovative technologies and systems that offer significant promise of improving urban highway traffic operations. These improvements may include increased capacity, enhanced traffic flow, or improved system operational efficiency.

Task 2—Conduct a preliminary quantitative assessment of each technology with respect to costs and benefits. This assessment will relate each technology to the type of urban congestion problems that can be alleviated (e.g., freeway incidents, recurring congestion on freeways and arterials).

Task 3—Conduct a preliminary assessment of the institutional and organizational issues, public/private sector roles, funding mechanisms, and potential economic benefits of widescale use related to the implementation aspects of these technologies.

Task 4—Prepare an interim report including a list of the most promising technologies in order of their potential for reducing congestion and in terms of the chance of successful implementation.

Phase 2—Detailed Assessment and Program Development

Task 5—Perform a detailed assessment of each of the technologies selected in Task 4. This assessment will include a more detailed analysis of the factors covered in Phase 1. In addition, it will examine such issues as environmental considerations, social impacts, developmental risks, and implementation risks.

Task 6—On the completion of Task 5, prepare and present an executive level briefing to a limited number of top highway officials on the results and recommendations to date. The purpose will be to exchange information and to obtain input to assist the contractor in formulating research, development, and demonstration (RD&D) program plans.

Task 7—Develop a detailed RD&D program plan for each technology assessed in Task 5, describing the next stage of research, planning, and program development. The research and development element of the plan will define the specific new research requirements to advance these technologies to a demonstration stage by the mid-1990's. The demonstration element of the plan will describe the scale and application of the demonstrations to be developed. It will also address commercialization considerations, institutional and organizational issues, public/private sector roles, educational needs, and demonstration risks. RD&D program costs will be estimated for each plan formulated.

Task 8—Prepare and present an executive level briefing to the same participants who were involved in Task 6. This briefing should cover the recommended RD&D program with emphasis on implementation considerations.

Task 9—Prepare a final report.

Tasks 1 through 4 have been completed and the interim report was reviewed at a panel meeting in April, 1989. Subsequently TRB, with the concurrence of AASHTO and FHWA, has proposed a broader, policy study of the issues being addressed in project 3-38(1). Following initiation of the TRB policy study, to be designated as a continuation of this project, the research agency will pursue the original objectives in a way that will complement the new TRB policy study. Further details are provided in the project description immediately following.

Project 3-38(1)A FY '90

A Study to Assess Advanced Vehicle and Highway Technologies

Research Agency:	Transportation Research Board
Principal Invest.:	Robert E. Skinner, Jr.
Effective Date:	
Completion Date:	(18 months)
Funds:	$42,500 (additional funding is expected to be provided by other Federal agencies and industry sponsors).

Traffic congestion is rapidly becoming one of the most serious problems affecting urban areas. Urban travel in general is increasing at a rate of 4 percent per year, but construction of new facilities is expected to accommodate less than one-fourth of this additional demand. Therefore, a continued loss in mobility is expected. Against this backdrop of serious existing and growing congestion, traffic operations' techniques and systems are needed that can substantially increase capacity and improve traffic-flow efficiency. Innovative and advanced technology needs to be incorporated into the highway system if significant relief for urban traffic congestion is to be realized at economic and social costs below the cost of constructing extensive new conventional facilities. Application of advanced technologies in areas such as motorist communication, information and navigation systems, vehicle guidance, control systems, and others has the potential for relieving traffic congestion. To date Project 3-38(1) has identified and assessed the most promising advanced technologies and systems that can improve urban highway traffic operations, and a comprehensive report on the state-of-the art in these technologies has been prepared. In the continuation of Project 3-38(1), funding of $42,500 will be provided towards a broad new TRB/NCR policy study. Building on the state of the art developed under 3-38(1), the TRB/NRC study (Project 3-38(1)A will develop recommendations on the appropriate staging of new systems and the necessary research and development activities required to bring about their implementation. The systems to be considered range from variable-message signs and computer-controlled traffic signals, already in selected use, to automated highways and automatic vehicle-chauffeuring systems that are in early stages of development. The results anticipated from the study will include an assessment of the extent to which advanced systems could be applied to maintain and improve highway transportation in the United States over the next 50 years. The likely benefits and costs of specific technology

applications, as well as options that do not involve new technology will be estimated. Finally, a desirable schedule for introducing stages of advanced technology, specific research and development activities, and a funding program will be outlined.

Project 3-38(2) FY '87

Travel Characteristics of Large-Scale Suburban Activity Centers

Research Agency: JHK and Associates, Inc.
Principal Invest.: Kevin G. Hooper
Effective Date: June 1, 1987
Completion Date: February 28, 1989
Funds: $300,000

There is a lack of up-to-date information on travel characteristics of activity centers, particularly the large-scale, multi-use suburban centers that have been developed recently. These data include trip generation rates, travel modes, trip purpose, trip length, parking characteristics, pedestrian activity, capture rate (i.e., proportion of trips attracted to the development from traffic normally passing by the site), intra-site vehicle movements, hourly variations, and vehicle occupancy.

The objective of this project is to develop a comprehensive data base on travel characteristics for various types of large-scale, multi-use suburban activity centers. Representative trip generation rates and other travel characteristics will be determined for use by others in analyzing the traffic impacts of such activity centers on the transportation system. This research will be limited to activity centers with over 5 million square feet of existing floor space and that lie outside of the CBD.

The following tasks will be accomplished.

Task 1—Review existing data for purposes of identifying candidate sites.

Task 2—Select activity centers. At least six sites are to be identified for primary data collection purposes covering several different geographic areas. Travel characteristics of such activity centers are believed to vary depending on whether the center: (1) is a planned activity center or is an assemblage of individual developments, (2) has or does not have a regional shopping center, (3) is located in an already built-up area within the "inner ring" of the suburbs or is located further out where development is still evolving, and (4) has or does not have a significant housing component.

Accordingly, the site-selection classification scheme will cover these factors at a minimum, as well as others (e.g., presence of mass transit service, location on circumferential vs. radial highway, etc.) that are considered to cause significant variations in travel characteristics.

Task 3—Develop a detailed data collection plan, identifying the data items considered to be important and including a description of the data collection techniques, a cost and time schedule for each center, any special considerations for each selected center, and the data summary/presentation formats. Direct assistance in the data collection effort from local sources will be pursued, and identified in the plan.

Task 4—Collect data.

Task 5—Summarize data. Summaries of the data will be designed to permit analyses of: (1) the characteristics of the centers, (2) the intra-site trips generated by these centers, (3) the captured trips (i.e., traffic passing by the center with some other primary destination that stops off for a secondary trip purpose), (4) travel characteristic differences among multi-use centers, and (5) travel characteristic differences of individual land uses within a multi-use center relative to the same land uses when they exist as single-use developments.

Task 6—Prepare final report. The final report will include data base summaries and an illustrative case study to describe the application of the data to site-impact analysis.

Tasks 1 through 5 have been completed and the final report is in preparation: Panel review and revision will require a time extension.

Project 3-38(3) FY '87

Traffic Adaptive Control (Phase 1)—Critical Intersection Control Strategies

Research Agency: Farradyne Systems, Inc.
Principal Invest.: R. David Henry
Effective Date: September 1, 1988
Completion Date: June 30, 1989
Funds: $149,951

The inability of traditional fixed-time traffic signal control systems to automatically modify their timing plans, in response to both long-term and short-term changes in traffic demand, results in excessive delay and congestion. Of particular concern is the fact that correctable delay at poorly timed signals increases dramatically as demand approaches capacity.

At present, there is no consensus as to the best approach to providing traffic adaptive control in signalized networks. Although considerable research has been done on strategies that periodically recompute and change system-wide timing plans, very little research has been done with regard to the critical intersection control (CIC) strategy included in FHWA's UTCS software and other packages. Preliminary results from implementation of CIC, such as in the UTCS-enhanced-type system in Los Angeles, have suggested its potential as an effective adaptive control measure. However, further validation is needed. Recommendations and guidelines are needed regarding the proper application of CIC in different types of signalized network configurations and operating conditions.

The objectives of this research are to: (1) determine the effectiveness of a selected CIC strategy currently used in a first-generation computer-controlled signal system; (2) if the CIC strategy is shown to be effective, develop comprehensive guidelines and a user manual for its application; and (3) develop detailed recommendations for improvements to the CIC strategy for future implementation and evaluation.

To accomplish these objectives, the following tasks will be conducted:

Task 1—A thorough review of existing CIC strategies will be conducted. Based on this review, a CIC strategy and potential test site(s) suitable for a comprehensive field evaluation will be recommended.

Task 2—A field evaluation plan to determine the effectiveness of the CIC strategy selected will be developed. This evaluation will be based on a variety of geometric configurations, intersection spacings, traffic signal timing and phasing, demand/capacity levels, and operational conditions (e.g., effects on downstream intersections). Additionally, the evaluation will determine the sensitivity of parameters and coefficients used in the detector smoothing algorithms and demand equations in terms of traffic performance. At the completion of Task 2, an interim report containing the results of Task 1 and the field evaluation plan will be submitted.

Task 3—Following a decision to proceed, the field evaluation for the strategy selected will be performed. A report documenting the results will be submitted.

Task 4—Detailed recommendations for potential improvements to the CIC strategy evaluated will be developed. Examples of possible CIC improvements are (1) ability to assign individual coefficients to specific detectors, (2) ability to modify cycle length, and (3) ability to consider congestion at downstream intersections. These recommendations will include time and cost estimates for implementation and evaluation in a subsequent phase of this project.

Task 5—Following the authorization to proceed, comprehensive guidelines for the use of the CIC strategy evaluated in Task 3 will be developed. These guidelines will address issues relative to CIC applicability, constraints and limitations, selection of parameters and coefficients used in the smoothing algorithms and demand equations, and traffic conditions under which CIC should be activated by the system. A user manual that documents the guidelines in a format and style suitable for use by operators of computerized signal systems will be prepared.

Task 6—A final report documenting all methodology and results will be prepared.

Tasks 1 through 3 have been completed and the project panel has met and approved a plan to conduct field tests in the City of Los Angeles' UTCS Enhanced system. Some computer hardware installation problems are delaying the project, necessitating a six-month extension.

Project 3-38(4) FY '87 and FY '88

Traffic Signal Control for Saturated Conditions

Research Agency: KLD Associates, Inc.
Principal Invest.: Edward B. Lieberman
Effective Date: October 1, 1987
Completion Date: March 31, 1989
Funds: $270,000

Medium- and large-sized urban areas throughout the United States experience saturated traffic flow conditions on almost a daily basis. Saturated operating conditions are characterized by the existence of queues that are not able to discharge within a reasonable period of time at a given signalized intersection. Signal-timing strategies based on progression are not optimal in these situations. Latent queues that were not able to clear during previous cycles may cause the progression scheme to break down. In fact, progression schemes that allow the arrival of platoons at the rear of a latent queue may worsen the problem by effectively lengthening the queue. These queues may grow to sufficient length to adversely affect upstream intersection operations. These conditions are true during peak period (recurring) congestion and also in nonrecurring congestion caused by special events or incidents.

The objectives of this research are to: (1) develop a user manual containing procedures and guidelines for applying appropriate signal-timing strategies to minimize the impact of recurring saturated traffic conditions under a wide range of network geometry, traffic flow patterns, and operating conditions; and (2) develop procedures that can be used in computerized signal systems for real-time response to both recurring and nonrecurring saturated conditions.

To accomplish the first objective, the following tasks will be conducted:

Task 1—A number of scenarios that describe saturated conditions for a wide range of network geometry, traffic demand, and operating conditions will be defined. Consideration will be given to approach length, number of approach lanes and their usage, pedestrian crossing requirements and interference with turning traffic, actuated and fixed-time control, upstream turning movements, and downstream bottlenecks (e.g., bridge, tunnel, lane reductions, etc.).

Task 2—A set of signal-timing strategies that can be used to minimize the impact of saturated traffic flow conditions will be prepared. Consideration will be given to strategies that include simultaneous and reverse progression schemes and metering of upstream or side-street traffic flow.

Task 3—For each scenario defined in Task 1, alternative signal-timing strategies from the set of strategies developed in Task 2 for evaluation will be selected. Appropriate signal-timing parameters (e.g., cycle length,

phase sequencing and timing, and offsets) for each alternative to be evaluated will be developed. An interim report documenting the results of Tasks 1 through 3 will be submitted before proceeding further.

Task 4—Using the NETSIM model, the effectiveness of the alternative signal-timing strategies developed in Task 3 for each scenario will be evaluated. From the analysis of these results, procedures and guidelines that can be used by practicing engineers to select the appropriate timing strategy for a given set of geometric, signal-timing, and traffic demand parameters will be developed.

Task 5—A user manual that describes the timing strategies developed in Task 2 and contains the procedures and guidelines developed in Task 4 will be developed. Full documentation of the simulations and analysis conducted in Task 4 will be included as an appendix in the manual.

To accomplish the second objective, the following tasks will be conducted:

Task 6—Procedures that can be used in computerized signal systems for real-time response to both recurring and nonrecurring congestion will be developed. These procedures will include algorithms and detector placement guidelines for determining the onset and termination of saturation. They will also include signal-timing strategies that can respond in real-time to the detection of saturation. (The signal-timing strategies to be investigated will not be limited to those studied in the previous tasks). Cost and time estimates to (1) install the detectors; (2) develop, test, and install the necessary software; and (3) conduct before-after field evaluations at several test sites will be prepared. These estimates will provide the basis for a subsequent research project.

Task 7—A final report will be prepared.

Tasks 1 through 3 have been completed and the project panel has reviewed a plan for the Task 4 scenario testing. The research agency is revising the plan and, following panel review and approval, work on the remaining tasks will proceed.

Project 3-38(5) FY '88

Effective Utilization of Street Width

Research Agency:	Midwest Research Institute
Principal Invest.:	Douglas W. Harwood
Effective Date:	April 1, 1988
Completion Date:	April 1, 1990
Funds:	$160,000

New development and changing land use in many urban areas call for increases in street capacity. Frequently, the additional capacity must be provided without an increase in curb-to-curb street width. Lane-width reductions through restriping to provide more lanes, used either alone or in combination with parking prohibitions, median removal, and intersection improvements are among the strategies used to provide additional capacity. Research is needed to document the operational effects of narrower lane widths on congestion reduction and related accident impacts.

The objective of this project is to determine the relationship between capacity and safety for various lane widths and allocations for a given street width. This relationship will be quantified for both street segments and intersections. Such factors as volume-to-capacity ratios, prevailing speeds, vehicle type and volume, alignment quality, service to adjacent property, classification of streets, and environmental factors are among the important operational considerations.

To meet this objective the following tasks will be accomplished:

Task 1—Conduct a literature search and identify related literature on the effects of operational-type improvements involving lane width on capacity and/or safety.

Task 2—Design and conduct a survey to determine current use of narrow lane widths in urban areas. The survey should include the rationale for or the purpose of such use, and operating experience. The results of this survey should identify typical types of lane-width-reduction strategies and the resulting lane configuration and use. In addition the survey must determine data availability and quality as it relates to the selection of key capacity and safety parameters to be studied. Finally, the survey should identify key measures-of-effectiveness that have been or can be used to evaluate alternative strategies.

Task 3—Develop a methodology for determining operational and safety effects of narrow lane widths. The methodology may include but need not be limited to such techniques as: (1) field operational studies of speeds, vehicle placement, and traffic conflicts, (2) traditional accident data collection and analysis, and (3) syntheses of previous research. The overall research plan should enable quantification of traffic performance and safety effects over the full range of street conditions. Submit an interim report that (1) provides a synopsis of the survey, (2) recommends the scope of strategies to be studied, data to be obtained, and measures-of-effectiveness, and (3) presents the methodology to further quantify the capacity and safety effects of narrow lane widths.

Task 4—Perform studies to determine capacity and safety effects of narrow lane widths using the methodology developed in Task 3. Studies should include lane use (e.g., left-turn lane, through lane, right-turn lane), lane width, street classification, volume-to-capacity ratio, speed, and adjacent land use.

Task 5—Quantify the traffic performance and safety effects of the range of lane widths for the various street types and traffic conditions studied. Specify expected accident rates and severity along with changes in capacity and vehicular delay.

Task 6—Prepare a final report to include an executive summary and detailed procedures that can be used to implement the research results. These procedures should

include and address the following safety and operational factors: (1) relative accident experience, (2) traffic volume and mix, (3) relative speeds, (4) lane mix and type, (5) street classification, and (6) relative capacity.

Tasks 1 and 2 have been completed and work is underway on Task 3.

Project 3-38(6) FY '88

Cost Sharing for Transportation Improvements Near Major Suburban Employment Centers

Research Agency: Indiana University
Principal Invest: Thomas Snyder
Effective Date: May 15, 1988
Completion Date: August 31, 1989
Funds: $125,000

Major employment centers in suburban areas, by their nature, generate vehicle trips that impact surrounding road and signal facilities. Transportation improvements are often required to mitigate impacts, sometimes at considerable distance from the centers. Public agencies are using a variety of cost-sharing approaches that in certain cases may result in inequities, both among developers and between the developer and the public agency. For instance, a developer who triggers a threshold level for capacity improvements may be burdened with the entire cost. Other developers obtaining approvals before or after the improvement costs have been allocated may not be faced with any of these costs. Inasmuch as an equitable agreement is in the broad public interest, it is important that agencies and developers formulate rational positions and derive fair-share options.

The objective of this research is to provide information to state and local agencies, as well as developers, on (1) how to select the most appropriate cost-sharing approach, (2) specific factors to be considered in allocating costs in each approach, (3) detailed cost-allocation methodologies, and (4) application guidelines. This research will focus on the equitable allocation of the private sector share of transportation improvement costs among individual properties at new or expanding major suburban employment centers.

To meet this objective the following tasks will be accomplished.

Task 1—Review Alternative Cost-Sharing Approaches. Existing approaches to allocating private sector costs will be reviewed, primarily through a literature review.

Task 2—Review Basic Economic Theory. General economic theory and principles will be reviewed for applicability to the equity considerations in determining cost-sharing allocations.

Task 3—Evaluate and Select Alternative Approaches. Based on the results of Tasks 1 and 2, appropriate cost-sharing approaches (e.g., impact fees, assessment districts, negotiated agreements) will be evaluated for application to new or expanding major employment centers and the factors that must be accounted for in implementing each will be identified.

Task 4—Develop Cost-Allocation Methods. For each approach selected in Task 3, an appropriate cost-allocation method will be developed using existing methods to the maximum extent possible. Of particular interest is the use of sound economic theory that provides for the appropriate treatment of costs (i.e., average unit costs, incremental costs, marginal costs, short-term vs. long-term, etc.). Step-by-step procedures for direct application are desired, based on empirical data to the extent possible.

Task 5—Illustrate Alternative Approaches. Use of the alternative cost-sharing approaches and the cost-allocation methods will be illustrated by applying them to at least three representative types of major employment centers (real or hypothetical). The same centers will be used in each case to provide cross comparisons.

Task 6—Develop Guidelines. These guidelines should cover (1) considerations and rationale for the selection of cost-sharing approaches and cost-allocation methods, (2) typical applications, and (3) limitations. The primary audience for the guidelines is at the decision-making level; whereas, the documentation of the approaches and methods should be directed to the analyst.

Research is underway on Tasks 1, 2, and 3.

Project 3-38(7) FY '89

Access Management Policies and Guidelines for Activity Centers

Research Agency: In developmental stage
Principal Invest.:
Effective Date: (18 months)
Completion Date:
Funds: $125,000

Streets and highways constitute a major public investment, and it is essential to operate them safely and efficiently. Inadequate access management is an important factor behind the operational deterioration of many of our streets and highways. There is a need to identify better methods for applying access management practices to different classes of highways within the vicinity of activity centers, and for implementing such practices on highways experiencing access management problems.

The objective of this research is to develop policies and guidelines to preserve and improve the capacity and safety of the overall highway system within the vicinity of activity centers through better management of access control. These guidelines would apply to (1) modification of

access control on streets and highways where activity-center development has already occurred, (2) planning access control in newly developed areas or for new highways being constructed in existing developed areas, and (3) management of access control within activity centers.

To meet this objective, the following tasks shall be accomplished:

Task 1. Conduct a detailed review of literature, a survey of State and local governments, and a survey of activity center developers and managers. The purpose of these activities in two-fold: (1) to identify problems currently being experienced on highways and streets in the vicinity of activity centers and (2) to identify current successful practices for management of access to activity centers along major streets and highways. As a minimum the following information shall be collected:

- What access management policy(s) are in place?
- Are these policies backed by legislation?
- Do the policies or legislation authorize the retrofit of access management on existing streets and highways within the vicinity of activity centers?
- Do existing policies include access design standards?
- Do access design standards vary by highway functional class?
- How is enforcement of the policy handled?
- Are standards and policy administered by State, regional, or local government? How is coordination handled? How are conflicts between standards of different jurisdictions handled?
- What is the typical design year used for analysis of access adequacy for activity centers?
- What are the typical problems with current policies, guidelines, and standards? For example, what existing components should be eliminated? What existing components should be changed? What components should be added?
- If there were no constraints (political, funding, or personnel), what would the ideal access management policy for activity centers include?

Task 2. Prepare a report summarizing the material gathered during Task 1. This report shall be appropriate for publication as a synthesis and evaluation of current practices in access management for activity centers.

Task 3. Prepare a draft report recommending policies and guidelines that can be used for managing access on streets and highways in the vicinity of activity centers. This draft report shall be circulated for review and comment to a representative sample of the Task 1 survey respondents.

Task 4. At a meeting of the NCHRP project panel, present a summary of the responses to the Task 3 draft report and make recommendations regarding whether or not additional research is required.

Task 5. Prepare a final report on Recommended Access Management Policy and Guidelines for Activity Centers.

Project 3-39 FY '88

Evaluation and Calibration Procedures for Weigh-In-Motion Systems

Research Agency: Texas A&M Research Foundation
Principal Invest: Dr. Wiley Cunagain
Effective Date: March 1, 1988
Completion Date: November 30, 1990
Funds: $265,000

State highway agencies need accurate truck-weight data for use in planning, design, operations, and maintenance activities related to both highway pavements and bridges. A considerable amount of data is needed to support these activities, as well as for enforcement and highway finance purposes. Further, states are faced with an increasing need for this type of information to implement pavement management systems and to meet the data requirements of the Strategic Highway Research Program.

Various weigh-in-motion systems are available to collect truck data in a more efficient manner than by using conventional weighing methods. A number of states are currently installing these systems and are specifying and conducting independent acceptance and validation procedures. However, nationally recognized procedures for acceptance testing and for on-site calibration of WIM systems do not exist. Such procedures need to be developed and validated by statistically designed field experiments so that WIM users can be confident that WIM-estimated weights will meet specified tolerances for various applications. Widely accepted procedures will also benefit the manufacturers by providing more consistent testing requirements among their customers.

The objective of this research is to develop a procedure(s), covering all WIM system applications, for (1) acceptance testing, (2) on-site calibration, and (3) periodic verification of system performance.

To accomplish this objective, the following tasks will be conducted:

Task 1—Review and summarize the past experience and technical information relating to the evaluation and calibration of WIM systems. Prepare a task report summarizing the existing information's applicability to the objectives of this research and proposing specific procedures for further development in Task 2. Each procedure will include testing under actual traffic conditions; the feasibility of procedures based on simulation of the traffic-induced forces on the transducers will also be specifically addressed, including recommendations for incorporating this simulation into subsequent tasks.

Task 2—Develop recommended procedures for evaluation and calibration of WIM systems. Separate procedures may be needed for acceptance testing, calibration at time of installation at each site, and periodic verification. Factors to be considered include (1) types and applications of WIM equipment, (2) site conditions, (3) traffic mixes, and (4) a statistically valid traffic sample

for each site. Provide an interim report including a description of the detailed procedures, a statistically valid experiment design for field testing the procedures, and a design for a pilot test.

Task 3—Pilot test the approved procedures and experiment design through field studies at one or two sites, and makes any needed modifications.

Task 4—Following approval of the revised procedures and experiment design, validate the procedures through field tests.

Task 5—Prepare the final report, including documentation that can provide the basis for a nationally accepted test for use by all states.

Tasks 1 and 2 have been completed.

Project 3-40 FY '89

Single Point Urban Interchange Design and Operations Analysis

Research Agency: In developmental stage
Principal Invest.:
Effective Date: (21 months)
Completion Date:
Funds: $250,000

The Single Point Urban Interchange (SPUI) essentially combines two separate diamond ramp intersections into one large at-grade intersection which accommodates all interchanging vehicular movements and the through traffic. Signalization of the one major intersection simplifies coordination on the arterial. It has been reported that SPUIs can significantly increase traffic-carrying capability compared with the conventional diamond interchange.

There are currently numerous uncertainties about the design and operation of SPUIs. These include: wrong-way movement potential; traffic signal, signing, and delineation requirements; sight distance; cost-effectiveness; increased capability to accommodate heavy traffic movements; safety problems; and driver behavior.

The objectives of the research are (1) to document current practice in design and traffic operations at existing SPUIs and (2) to develop and document guidelines for the design, operation, analysis, and cost effectiveness of SPUIs.

Accomplishment of the objectives will require, as a minimum, the following tasks:

Task 1—Determine the state of the art and current practice through a review of the literature and contacts with highway agenices planning, designing, constructing, operating, and maintaining SPUIs.

Task 2—Prepare an interim report which documents the results of Task 1, describes and illustrates key factors in the design of SPUIs, and lists key strengths and weaknesses experienced to date. The report shall also include recommended refinements of the research plan for the remainder of the project.

Task 3—Develop guidelines to assess the cost effectiveness of SPUIs in comparison with alternative design solutions on a life-cycle basis (right-of-way, pavement, structures, drainage, and function), including first costs, continuing agency costs, user costs, and environmental costs.

Task 4—Develop guidelines for geometric design for use with the AASHTO "Green Book." Guidelines should consider, but not be limited to, the following: turning radii, design speed, free flow movements, channelization design including provision for U-Turns, pedestrian and bicycle accommodations, horizontal and vertical sight distance, capacity, frontage and service roads, and access control.

Task 5—Develop guidelines to analyze the functional performance of SPUI traffic operations throughout its design life (these may be based on existing computer programs). Develop criteria for the optimum placement and operation of traffic control devices. Define safety considerations, including pedestrian and bicycle traffic, and develop recommendations for dealing with the impact of these factors.

Task 6—Prepare a final report, documenting the research and presenting the findings, with emphasis on the user guidelines for those highway agencies contemplating selection, design, construction, operations, and maintenance of SPUIs.

Tasks 1 and 2 have been completed.

AREA 4: GENERAL MATERIALS

Project 4-1 FY '63 and FY '64

Development of Appropriate Methods for Evaluating the Effectiveness of Stabilizing Agents

Research Agency: University of Illinois
Principal Invest.: Dr. E. J. Barenberg
Effective Date: June 1, 1963
Completion Date: October 31, 1966
Funds: $114,991

This study was directed toward the further improvement of existing methods or the development of new methods of tests which will lead to a way of measuring the effectiveness of various stabilizing agents. The methods are expected to provide definitive data to predict performance under in-service conditions and provide criteria for the design and construction of pavement components involving stabilized materials.

This research was conducted principally by means of laboratory experiments to investigate the effectiveness of viscous and nonviscous materials as stabilizing agents. Type I portland cement and a penetration-grade asphalt

were chosen for the study because of their popularity as reflected in current usage, and limited tests of model pavements stabilized with both these materials were conducted in the research agency's test track for the purpose of correlating the results obtained in the laboratory with the behavior of the model pavements.

The project report was not published in the regular NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 4-2 FY '63 and FY '64

A Study of Degrading Aggregates in Bases and Subbases with Production of Excessive Amounts of and/or Harmful Types of Fines

Research Agency:	Purdue University
Principal Invest.:	Dr. R. B. Johnson
	Dr. N. B. Aughenbaugh
	Dr. N. M. Smith
	Dr. T. R. West
Effective Date:	February 15, 1963
Completion Date:	November 30, 1966
Funds:	$63,990

This study was directed toward the development of tests or procedures for predicting the amount and effects of aggregate degradation and the development of techniques for upgrading such aggregates for economic use in highway pavement structures.

The research has been completed, and the project report has been published as: NCHRP Report 98, "Tests for Evaluating Degradation of Base Course Aggregates."

Project 4-3(1) FY '63 and FY '66

Development of Methods to Identify Aggregate Particles Which Undergo Destructive Volume Changes When Frozen in Concrete

Research Agency:	Virginia Polytechnic Institute	
Principal Invest.:	Dr. R. D. Walker	
Effective Date:	Mar. 1, 1963	July 1, 1965
Completion Date:	Sept. 30, 1964	Mar. 31, 1967
Funds:	$20,000	$23,337

Research conducted under this study related to the development of a rapid method of test(s) to distinguish deleterious particles in aggregates and to predict their behavior under various degrees of exposure in concrete subjected to freezing and thawing. The work was similar to that conducted under Project 4-3(2) at Pennsylvania State University (the same objectives apply) but different in approach. Certain aggregates investigated were common to both studies.

The initial research phase has been completed, and the project report for this phase has been published as: NCHRP Report 12, "Identification of Aggregates Causing Poor Concrete Performance When Frozen."

The final research phase has been completed, and the project report has been published as: NCHRP Report 65, "One-Cycle Slow-Freeze Test for Evaluating Aggregate Performance in Frozen Concrete."

Project 4-3(2) FY '63 and FY '66

Development of Methods to Identify Aggregate Particles Which Undergo Destructive Volume Changes When Frozen in Concrete

Research Agency:	The Pennsylvania State University	
Principal Invest.:	Dr. T. D. Larson	
Effective Date:	Mar. 25, 1963	July 1, 1965
Completion Date:	Jan. 31, 1965	Aug. 31, 1967
Funds:	$56,457	$49,756

This project involved the development of a rapid test(s) to distinguish deleterious particles in aggregates and thereby predict their behavior under various degrees of exposure in concrete subjected to freezing and thawing. The study was similar to that conducted under Project 4-3(1) at Virginia Polytechnic Institute (the same objectives apply) but different in approach. A number of aggregates investigated were common to both studies.

The initial research phase has been completed, and the project reports for this phase have been published as: HRB Special Report 80, "A Critical Review of Literature Treating Methods of Identifying Aggregates Subject to Destructive Volume Change When Frozen in Concrete and a Proposed Program of Research," and NCHRP Report 15, "Identification of Concrete Aggregates Exhibiting Frost Susceptibility."

The final research phase has been completed, and the project report has been published as: NCHRP Report 66, "Identification of Frost-Susceptible Particles in Concrete Aggregates."

Project 4-4 FY '63

Synthetic Aggregates for Highway Uses

Research Agency:	Battelle Memorial Institute
Principal Invest.:	M. J. Snyder
	F. F. Fondriest
Effective Date:	March 1, 1963
Completion Date:	April 15, 1964
Funds:	$14,790

In an effort to determine potential sources of aggregates, this study was authorized to explore the feasibility of utilizing artificial aggregates in highway construction.

Research has been completed, and the project report has been published as: NCHRP Report 8, "Synthetic Aggregates for Highway Construction."

Project 4-5 FY '63

A Study of the Mechanism Whereby the Strength of Bases and Subbases Is Affected by Frost and Moisture

Research Agency: Michigan Technological University
Principal Invest.: Dr. W. M. Haas
Effective Date: February 15, 1963
Completion Date: August 31, 1965
Funds: $64,105

This project involved an extension of present knowledge and understanding of the phenomena of the action of frost and moisture in bases and subbases. Initially, laboratory models were developed which incorporated significant variables as an aid in analyzing the mechanism of frost action and its relation to strength. Hypotheses evolving from the laboratory were checked in the field.

The project report was not published in the regular NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 4-6 FY '65

Projective Coatings for Highway Structural Steel

Research Agency: Steel Structures Painting Council
Principal Invest.: John D. Keane
Effective Date: March 1, 1965
Completion Date: November 30, 1966
Funds: $25,000

This research involved a state-of-the-art review, field exposure testing on which definitive rankings may be based, and the development of plans for research to acquire needed information where adequate coatings are not available.

Research has been completed, and the final report has been published as: NCHRP Report 74, "Protective Coatings for Highway Structural Steel." In addition, the following documents have been published in extremely limited quantities: NCHRP Report 74A, "Protective Coatings for Highway Structural Steel—Literature Survey," and NCHRP Report 74B, "Protective Coatings for Highway Structural Steel—Current Highway Practices."

Project 4-7 FY '68 and FY '69

Fatigue Strength of High-Yield Reinforcing Bars

Research Agency:	Portland Cement Association	
Principal Invest.:	Dr. John M. Hanson Dr. Thorsteinn Helgason	
Effective Date:	Oct. 1, 1967	Feb. 1, 1971
Completion Date:	Feb. 28, 1970	Aug. 31, 1973
Funds:	$100,000	$50,000

The principal objective of this study was to obtain fatigue strength test data on ASTM A432 steel bars (generally Grades 60 and 75) to support realistic design criteria. This was approached through the design and execution of a statistically valid experiment.

Phase I experimental work consisted of repeated-load tests on rectangular and T-shaped concrete beams reinforced with a single longitudinal bar. These specimens contained bars ranging in size from No. 5 to No. 11 and having nominal yield stresses from 40 to 75 ksi. Major emphasis in the Phase I study was on stress range, minimum stress, bar diameter, type of specimen, and grade of bar.

Phase II had the objectives of (1) determining the effect of surface geometry (deformation pattern and details) and (2) incorporating the results of Phases I and II into a single final report. A total of 353 fatigue tests was conducted in the two phases of work.

On the basis of the observed behavior, a fatigue design provision was developed for deformed reinforcing bars suggesting a limitation on the service load stress range.

Research has been completed, and the project report published as: NCHRP Report 164, "Fatigue Strength of High-Yield Reinforcing Bars."

Project 4-8 FY '68

Research Needs Relating to Performance of Aggregates in Highway Construction

Research Agency: Virginia Polytechnic Institute
Principal Invest.: Dr. R. D. Walker
Effective Date: January 1, 1968
Completion Date: April 30, 1969
Funds: $55,254

The objective of this research was to formulate a comprehensive series of statements of research problems and recommended studies (including estimates of time, cost, and priority) which have as their objective the development of procedures by the use of which a highway materials engineer may evaluate quantitatively the relevant properties of aggregates to be selected for a given class of use in a given environment of service for a given level of performance.

Research has been completed, and the project report has been published as: NCHRP Report 100, "Research Needs Relating to Performance of Aggregates in Highway Construction."

Project 4-8(2) FY '71

Density Standards for Field Compaction of Granular Bases and Subbases

Research Agency: Clemson University
Principal Invest.: J. P. Rostron
Effective Date: April 1, 1971
Completion Date: June 30, 1973
Funds: $95,248

The objectives of this project were:

1. To evaluate current and proposed procedures and criteria for the setting of density standards.

2. To illustrate examples of inadequate standards and the consequences of such inadequacy.

3. To develop new or revised procedures and criteria for more appropriate density standards.

4. To illustrate that the new or revised procedures and criteria would yield adequate density standards.

5. To draft, in a form suitable for adoption or adaptation by highway departments, proposed new or revised procedures and criteria for the setting of density standards to control compaction during the construction of granular bases and subbases.

Research has been completed, and the project report has been published as: NCHRP Report 172, "Density Standards for Field Compaction of Granular Bases and Subbases."

Project 4-8(3) FY '72 and FY '76

Predicting Moisture-Induced Damage to Asphaltic Concrete

Research Agency:	University of Idaho	
Principal Invest.:	Dr. Robert P. Lottman	
Effective Date:	Sept. 1, 1971	Aug. 1, 1975
Completion Date:	Mar. 31, 1974	Jan. 31, 1982
Funds:	$190,177	$70,860

The objective of this project was to meet the need for a laboratory testing system that will quantitatively predict the ability of asphaltic concrete to resist the detrimental effects of moisture under field conditions.

Research on Phase I included sampling and laboratory testing of mixtures composed of materials from many pavements in service, some of which were experiencing moisture damage and some not. Effort was made to reproduce in the laboratory the observed response to moisture in the field. The study produced a tentatively proposed system of tests for determining the moisture susceptibility of asphaltic concrete mixtures and a detailed work plan for a field evaluation of the system. The primary research program was conducted by the University of Idaho, with assistance by Battelle-Northwest and the University of Washington. The final report for Phase I has been published as: NCHRP Report 192, "Predicting Moisture-Induced Damage to Asphaltic Concrete."

Research on Phase II has been completed. The predicted and observed performance over a 5-year period of 8 asphaltic concrete pavements in various climatic regions provided substantial verification of the tentative system of tests developed under Phase I. The American Association of State Highway and Transportation Officials (AASHTO) has adopted the test procedure as T283-85, "Resistance of Compacted Bituminous Mixtures to Moisture-Induced Damage." The project report for Phase II has been published as: NCHRP Report 246, "Predicting Moisture-Induced Damage to Asphaltic Concrete—Field Evaluation."

Project: 4-8(4) FY '84

Predicting Moisture-Induced Damage to Asphaltic Concrete—10 Year Field Evaluation

Research Agency:	University of Idaho
Principal Invest.:	Dr. Robert P. Lottman
Effective Date:	June 1, 1985
Completion Date:	January 31, 1987
Funds:	$24,402

Under Project 4-8(3), a laboratory test was developed for predicting moisture-induced damage and the test was used to predict the performance of asphaltic concrete pavements on eight construction jobs. After 5 years of service, ranking of the pavement sections in terms of visual evidence of stripping and strength ratios of cores removed from the pavements was very similar to the predicted ranking produced by the laboratory tests.

The objective of this project was to further verify the ability of the previously developed test methods to predict moisture-induced damage in terms of distress in the asphaltic concrete layer and performance of the pavement surface courses by the collection and analysis of additional data from the eight pavement test sections after 10 years of service.

Research has been completed and the preliminary draft final report has been reviewed and approved by the project panel. The agency report has been distributed to the Program sponsors and other interested persons. It will not be published in the regular NCHRP report series, but loan copies are available upon written request to the NCHRP or a microfiche may be purchased (see final page of this section for ordering information).

Project 4-9 FY '69

Evaluation of Preformed Elastomeric Pavement Joint Sealing Systems and Practices

Research Agency:	Utah Department of Transportation	
Principal Invest.:	Dale E. Peterson	
Effective Date:	Oct. 1, 1968	Oct. 1, 1972
Completion Date:	June 30, 1971	Dec. 31, 1979
Funds:	$93,494	$144,837

The objective of this project was the development of guide specifications for use of preformed elastomeric joint seals in portland cement concrete pavements. The research involved (1) a review and analysis of existing information, (2) an extensive laboratory testing program, and (3) a field evaluation phase.

Research has been completed with successful development and field verification of guide specifications. A major finding of the study is that the ability of elastomeric sealing systems to prevent intrusion of moisture and foreign material is more dependent on the adhesion between the seal and the pavement joint surface than on the pres-

sure exerted by the compression of the seal. Consequently, selection of and specifications for the lubricant-adhesive used during installation is a very important factor in long-term performance of the system.

The essential findings of the study have been published as NCHRP Research Results Digest 123. The agency report has been distributed to program sponsors. It will not be published in the regular series.

Project 4-10 FY '70

Promising Replacements for Conventional Aggregates for Highway Use

Research Agency: University of Illinois
Principal Invest.: Dr. C. R. Marek
Effective Date: October 15, 1969
Completion Date: March 31, 1971
Funds: $50,000

The purpose of this project was to study the utilization of modern technology as it might apply to the development of substitute materials and/or new procedures for upgrading existing unsuitable materials for use as aggregates in portland cement concrete, bituminous mixes, and base courses.

This research has been completed, and the project report has been published as: NCHRP Report 135, "Promising Replacements for Conventional Aggregates for Highway Use."

Project 4-10A FY '70

Waste Materials as Potential Replacements for Highway Aggregates

Research Agency: Valley Forge Laboratories
Principal Invest.: Richard H. Miller
Effective Date: September 1, 1972
Completion Date: November 30, 1973
Funds: $53,663

NCHRP Project 4-10, "Promising Replacements for Conventional Aggregates for Highway Use," identified the potential for using waste materials as aggregate in highway construction. The objectives for Project 4-10A, as developed from the prior effort, were to:

1. Provide an inventory of the types, sources, and quantities of waste materials potentially suitable for the production of synthetic aggregates or for otherwise replacing conventional aggregates in highway construction.
2. Provide an assessment of the prospects for practical use of specific waste materials for production of synthetic aggregates or otherwise replacing the need for conventional aggregates in highway construction, particularly where aggregate supplies are scarce.

Based on technical, economic, and environmental evaluations, 30 waste materials were found to have some potential for use as highway aggregates. The basic technology was judged to exist for converting any one of the materials into aggregate, but in most instances much experimentation remains to be done.

Research has been completed, and the project report has been published as NCHRP Report 166, "Waste Materials as Potential Replacements for Highway Aggregates."

Project 4-11 FY '75

Buried Plastic Pipe for Drainage of Transportation Facilities

Research Agency: Simpson Gumpertz & Heger
Principal Invest.: Frank J. Heger
R. E. Chambers
Effective Date: September 16, 1974
Completion Date: January 26, 1979
Funds: $200,000

At the time the research problem was conceived, a number of plastic pipe products were available to the transportation industry that appeared to have good potential for economical use as underdrains, storm sewers, culverts, and other drainage structures. However, because of the lack of experience with these products in transportation facilities, their use was limited in these applications. Understandably, there was a reluctance to use them in place of, or as alternates to, more conventional pipe products whose in-service behavior had been established by many years of experience. Accordingly, a need existed for an evaluation of the theoretical considerations and field performance of buried plastic pipe to determine under what conditions they could be used in transportation facilities.

Several piping systems were found to be appropriate for transportation drainage applications. Perforated corrugated polyethylene (PE) tubing, perforated polyvinyl chloride (PVC), and acrylonitrile-butadiene-styrene (ABS) pipe were selected for underdrains. PVC pipe and ABS composite pipe were selected for storm drains and small culverts. Advantages and possible limitations, are presented. In addition, guidelines for selecting, designing, and installing plastic pipe were developed including sample design problems, recommended specifications for two types of plastic pipe products (corrugated polyethylene tubing and polyvinyl chloride piping), and a recommended standard for field installation practices.

Research has been completed, and the project report has been published as: NCHRP Report 225, "Plastic Pipe for Subsurface Drainage of Transportation Facilities."

Project 4-12 FY '77

Upgrading of Poor or Marginal Aggregates For PCC and Bituminous Pavements

Research Agency: The Pennsylvania State University
Principal Invest.: Dr. Philip D. Cady
Effective Date: December 1, 1976
Completion Date: May 31, 1979
Funds: $149,941

The over-all objective of this study was to advance methods of upgrading poor or marginal-quality coarse aggregates to acceptable durability and structural levels for use in high-type bituminous and PCC pavement mixtures. The procedures for upgrading aggregates in this study were limited to the use of different types of coatings, chemical treatments, or impregnation with plastics or other materials.

The beneficiation addressed recognized problems such as freeze-thaw damage, stripping, degradation, inadequate soundness, alkali-aggregate reactions, destructive volume changes, and objectionable coatings.

This study did not address itself to pavement surface characteristics, such as skid properties, texture and roughness, or mixtures applied as seal coats or thin surface treatments.

Research has been completed, and the final report has been published as: NCHRP Report 207, "Upgrading of Low-Quality Aggregates for PCC and Bituminous Pavements."

Project 4-13 FY '77

Temporary Pavement Marking Systems

Research Agency: Southwest Research Institute
Principal Invest.: John M. Dale
Effective Date: November 1, 1976
Completion Date: February 28, 1978
Funds: $49,500

The specific objectives of this research were: (1) To examine one or more concepts, existing or new, that offer promise for development into workable temporary pavement marking systems. The desired characteristics of these systems include delineation quality, ease of installation and removal, absence of adverse environmental effects, ease of implementation, and cost-effectiveness. (2) To analyze the feasibility of the concept or concepts in comparison with existing practice with reference to, but not limited to: (a) manpower, equipment, and material costs (application and removal), (b) effect on traffic during application and removal, (c) traffic control effectiveness, (d) system durability, (e) material and process availability, and (f) hazards to workmen during application and removal.

The concept of this research was to develop and evaluate additives to be used with existing traffic paints. Research began with lab tests of candidate additives of four types: those with water of hydration, blowing agents, fuels, and oxidizers. No practicable material was found to meet the requirements of the project. A final report has been submitted and is available on a loan basis upon written request to the NCHRP.

Further research of temporary marking materials, pursuing other approaches, has been resumed under Project 4-13A.

Project 4-13A FY '77

Temporary Pavement Marking Paint Systems

Research Agency: Georgia Institute of Technology
Principal Invest.: Dr. Charles J. Ray
Effective Date: April 1, 1978
Completion Date: September 30, 1979
Funds: $69,971

The specific objectives of this research were: (1) to examine new paint formulations, primer materials, and related combinations that offer promise for development into workable temporary pavement marking systems; and (2) to analyze the feasibility of the concept or concepts in comparison with existing practice.

A wide range of materials and removal processes was investigated. Coatings based on vinyl chloride copolymers, chlorinated rubber, and acrylic resins were tested. Removal techniques included photolysis, biodegradation, thermal degradation, and chemical degradation. The removal tests were inconclusive.

Research has been completed. The agency's final report will not be published but is available on a loan basis upon written request to the NCHRP.

Project 4-14 FY '78

Coating Systems for Painting Old and New Structural Steel

Research Agency: Georgia Tech Research Corporation
Principal Invest.: Dr. D. J. O'Neil
F. A. Rideout
Dr. Charles Ray
Effective Date: January 1, 1978
Completion Date: December 31, 1981
Funds: $199,302

The objective of this research was the preparation of tentative guidelines for the use of existing and recently developed nonproprietary coating systems for the painting of structural steel with emphasis on such considerations as (a) health and environment, (b) exposure conditions, (c) application requirements, and (d) economics.

Research has been completed with partial accomplishment of objectives. Tentative guidelines for selection of new coating systems have been developed but additional field testing is needed for verification.

Copies of the agency report were distributed to program sponsors and will not be published in the regular NCHRP report series. Loan copies are available or microfiche of the report may be purchased (see final page of this section for ordering information).

Project 4-15 FY '82

Corrosion Protection of Prestressing Systems in Concrete Bridges

Research Agency:	Wiss, Janney, Elstner Associates, Inc.
Principal Invest.:	William F. Perenchio
Effective Date:	July 1, 1982
Completion Date:	November 30, 1985
Funds:	$250,000

The objectives of this research are (1) to prepare a summary report of available technology for the corrosion protection of prestressing steel, (2) to develop and demonstrate a coating or duct system of corrosion protection for bonded post-tensioning steel, and (3) to identify a feasible system for corrosion protection of pretensioning strands. Attainment of the project objectives necessitates the following tasks.

Task 1. Identify those techniques that have been used specifically to protect pretensioning and post-tensioning steel, ducts, and anchorages from corrosion; evaluate their effectiveness based on available research and field experience; and forecast their long-term (50 to 100 years) performance. Write a report summarizing the results and identifying promising corrosion protection systems. Specifically recommend a system for the corrosion protection of post-tensioning wires, strands, and bars to be further evaluated under Task 2.

Task 2. Perform mechanical and other tests to demonstrate the practical use of the selected post-tensioning corrosion protecting system in situations encountered in the field, particularly in segmental bridge applications. Such testing should include, but not be limited to: (1) friction, (2) bond, (3) mechanical abrasion and damage, (4) continuity of protection at anchors, (5) compatibility with the portland cement concrete and grout environment, and (6) effectiveness of the system in protecting the prestressing steel from corrosion. Based on the test results, write a recommended practice for the design and construction of a corrosion protection system for post-tensioning.

Task 3. Determine performance requirements for nonmetallic coating of 7-wire strands used for pretensioning, including but not limited to the following: (1) chemical and physical compatibility with base metal, (2) effectiveness in controlling corrosion, (3) bond with steel and with concrete, (4) resistance to injury during handling, (5) problems associated with coiling and flexure of the strand, (6) effects of anchorage devices, (7) strain compatibility, and (8) quality control (especially the control of "holidays"). Identify and evaluate candidate coating materials, and determine the feasibility of applying the coatings through direct contact with strand and coating manufacturers and coating applicators. Based on the research done, report on the technical and economic feasibility of a nonmetallic coating system for strands.

Task 4. Prepare final report documenting all research.

The Task 1 agency interim report has been submitted, reviewed, and distributed to all NCHRP sponsors. It is available to others on a loan basis or for purchase of Xerox copies (see final page of this section for ordering information).

Based on recommendations from the Task 1 interim report, an updated research plan was submitted and approved for accomplishing the remaining tasks. Under Task 2, tests for mechanical behavior and corrosion resistance in posttensioning applications include various combinations of plastic, galvanized metal, epoxy coated metal, and bare metal ducts; uncoated and epoxy-coated anchorage hardware and 7-wire strands; and corrosion inhibiting admixtures for grouts. The testing procedures for Task 2 have not changed dramatically from those originally proposed; however, those under Task 3 have.

Task 3 was originally conceived as a feasibility study for epoxy coating 7-wire strand most likely to be used in pretensioning applications. Since the original conception of the project, an epoxy-coated 7-wire strand is now commercially available and is being used in some limited applications. Consequently, work under the updated research plan for Task 3 no longer focuses on feasibility, but on actual tests for mechanical behavior and corrosion resistance.

The research project is complete. After experiencing extreme delays in analyzing and documenting the research, the agency has submitted a revised final report which is now in the publication process.

Project 4-16 FY '84

Cost and Service Life of Pavement Markings

Research Agency:	Pennsylvania State University
Principal Invest.:	Dr. John J. Henry
Effective Date:	October 1, 1984
Completion Date:	September 30, 1988
Funds:	$340,327

A wide variety of materials is available for the marking of streets and highways. Traffic paints have been the mainstay of marking materials for the past 60 years, but the recognition that such paints have severely limited serviceability in locations of high traffic volumes and/or extreme climate has led in the past 20 years to the increasing use of "durable" marking materials.

Traffic paints are either latex-based or solvent-based comprised of alkyd, chlorinated rubber, or epoxy resins.

In severe service conditions such materials may provide 6 months or less useful life. Durable marking materials generally are solventless systems and can be epoxy, polyester, or either hydrocarbon or alkyd thermoplastic materials. Their service life when properly applied can approach 3 or more years. Traffic paints traditionally have been applied by state and municipal forces, whereas durable marking materials are generally applied by private firms under contract.

At present, applied traffic paints can cost from $0.025 to $0.06 per lineal foot (4-inch line), while durable markings can cost from $0.055 to $1.25 per lineal foot. Cost disparities also exist for special markings, such as crosswalks, turn arrows, and other in-lane markings. A higher initial cost may be justified if the effective service life of the durable material exceeds that of traffic paint in the same location. Higher costs may also be justified by the more intangible benefits of continuous, year-round delineation and reduced exposure of striping personnel and the public to hazardous striping operations. Such benefits are particularly important for special markings. In some cases, environmental restrictions may dictate the selection of marking materials.

The judgment of whether the cost of a material is reasonable for a particular set of circumstances (climate, traffic volume, condition of previous markings, pavement type, highway geometry, etc.) should be made on the basis of its probable service life. However, factual data on which to base such judgments are scarce. Some general information is available from field tests and operational use of various types of pavement marking materials, but there has been little to no specific treatment of the problem of how to select a cost-effective marking material for a particular set of circumstances. In addition, the influence of width (4, 6, and 8 inches) on the effective service life of traffic lines has not been established. This lack of comprehensive data is disturbing in light of stringent budgets.

The objective of this research is to determine the typical "on-road" service life and cost of various types of pavement marking materials and to quantify how major external factors affect service life. In addition, the effect of traffic line width on service life will be determined. Maximum use will be made of existing information from field tests and operational installations, and a limited amount of new field testing will be conducted. Guidelines will be developed for the use of commercially available pavement marking materials, including selection criteria affecting the optimum balance between cost and service life. The materials to be evaluated include: paint, epoxy, epoxy paint, alkyd and hydrocarbon thermoplastics, polyester paints, epoxy thermoplastic, and preformed materials. A list of the research tasks follows:

1. Compile comparative data on the performance and total cost installed of commercially available traffic paint and durable marking materials through a critical review of published results, a survey of selected state and large municipal highway agencies, and personal follow-up where appropriate.

2. Critically analyze the data to develop comparative estimates of the service life of traffic paint and durable marking materials within the ranges of external factors, such as climate, traffic volume, traffic mix, highway geometry, and type and condition of pavement and previous markings. Develop estimated installed costs per foot for each material type.

3. Prepare an interim report with a detailed test plan for Task 4. Prepare a priority listing of *all* tests needed to provide information covering the full range of materials and conditions. From this list, select specific materials and conditions for field testing within the limited funds of this project.

4. Conduct tests according to the approved test plan.

5. Prepare guidelines for selection of the appropriate pavement marking materials identifying the effects of major external factors. The intent of these guidelines is to allow users to determine life-cycle costs for various marking materials.

The final report is being prepared.

Project 4-17 FY '85

Environmental Monitoring and Evaluation of Calcium Magnesium Acetate (CMA)

Research Agency:	University of Washington
Principal Invest.:	Dr. Richard R. Horner
Effective Date:	January 7, 1985
Completion Date:	October 31, 1987
Funds:	$199,943

Because of the environmental deficiencies of conventional deicers, sodium and calcium chloride, the Federal Highway Administration (FHWA) initiated research to find a suitable alternative. As a result, calcium magnesium acetate (CMA) had been identified as a possible alternative deicing chemical.

To determine potentially undesirable environmental impacts, a chemically pure CMA had been evaluated. Laboratory investigations by Caltrans included impacts to terrestrial vegetation, impacts to aquatic ecosystems, leaching characteristics in the soil, potential atmospheric effects, occupational exposure, impacts to ground and surface water supplies, and public health implications. Results of this preliminary laboratory research indicated that pure CMA has no significant detrimental effects to the environment. However, the manufacture of pure CMA was an expensive process. Efforts to develop a more economical method for production of CMA were underway.

Research conducted by SRI International had identified a process to manufacture CMA in large quantities by fermentation of corn grain sugars with bacterium, *Clostridium thermoaceticum.* Based on this preferred process, an FHWA research contract to develop a mutant bacterial

strain for large scale production of CMA was conducted at the University of Georgia. However, the product of this research was not chemically pure CMA. Its calcium and magnesium content and its purity varied from that previously tested in the laboratory. Consequently, the environmental impacts of CMA produced by this method for economical, large scale production may not have been comparable to the results of the previous laboratory studies done by Caltrans.

Research was needed on a regional and geographic basis to determine any long-term (multiyear) environmental impacts of CMA produced by the preferred process. Additional laboratory, as well as control plot, studies were necessary to address the environmental aspects of this new material. Field studies to investigate the transport and environmental fate of CMA as a highway deicer were needed to identify and document field effects.

The objective of this study was to evaluate the transport and environmental fate of CMA as a highway deicing chemical. Research is complete; the results of laboratory and controlled field plot studies are documented in NCHRP Report 305, "Environmental Monitoring and Evaluation of Calcium Magnesium Acetate (CMA)." This published report also contains recommended procedures for field monitoring that can be performed by potential users of CMA.

AREA 5: ILLUMINATION AND VISIBILITY

Project 5-2(1) FY '63

Effects of Illumination on Operating Characteristics of Freeways—Traffic Flow, Driver Behavior, and Accidents

Research Agency:	Yale University, Bureau of Highway Traffic	
Principal Invest.:	Fred W. Hurd	
Effective Date:	Feb. 15, 1963	Feb. 1, 1967
Completion Date:	May 31, 1966	July 31, 1967
Funds:	$124,319	$21,530

Because of insufficient information on the requirements in freeway illumination, thorough research needs to be performed. A scientific basis for warrants and design criteria for use in installing continuous and localized lighting on freeways is needed, as is evaluation in terms of benefits and costs.

A 5-mile segment of the Connecticut Turnpike in the Bridgeport area was selected for the study site. The light intensity was changed to reflect illumination at both the 0.2 and 0.6 average horizontal footcandle levels. The same study area has been used for Projects 5-2(2) and 5-2(3).

Yale University has evaluated the day and night operating characteristics of traffic flow, driver behavior, and accidents. Traffic characteristic data from more than 400,000 picture frames were transferred to punched cards and analyzed by an electronic computer. Information was obtained on lane use, variation of placement and velocity, headway distributions, vehicle clustering by type, and use of the on-ramp. Evaluations of day and night accident data and traffic volume data have been made.

The project report has been published as: NCHRP Report 60, "Effects of Illumination on Operating Characteristics of Freeways."

Project 5-2(2) FY '63

Effects of Illumination on Operating Characteristics of Freeways—Driver Response, Visibility, and Visual Discomfort

Research Agency:	The Ohio State University
Principal Invest.:	Dr. Thomas H. Rockwell Dr. H. Richard Blackwell
Effective Date:	February 15, 1963
Completion Date:	August 31, 1965
Funds:	$81,187

The objectives of this research supplemented Project 5-2(1), the accent in this contract being on the characteristics of driver response, visibility, and visual discomfort.

The results presented in the project report have been combined with the results of Project 5-2(1) and have been published as: NCHRP Report 60, "Effects of Illumination on Operating Characteristics of Freeways."

Project 5-2(3) FY '63

Effects of Illumination on Operating Characteristics of Freeways—Driver Discomfort

Research Agency:	The Institute for Research at State College, Pennsylvania
Principal Invest.:	Dr. Paul M. Hurst
Effective Date:	February 20, 1963
Completion Date:	February 28, 1966
Funds:	$37,460

As with Project 5-2(2), this research complemented that of Project 5-2(1). This study was concerned with only one aspect, that of driver comfort as related to anxiety as measured under various lighting conditions.

The results presented in the project report have been combined with the results of Project 5-2(1) and have been published as: NCHRP Report 60, "Effects of Illumination on Operating Characteristics of Freeways."

Project 5-3 FY '64

Visual Information Needed by the Driver at Night

Research Agency: The Ohio State University
Principal Invest.: Dr. Thomas H. Rockwell
Dr. Ronald L. Ernst
Effective Date: September 1, 1964
Completion Date: March 31, 1967
Funds: $100,940

This research was designed to determine minimum information necessary to maintain control stability and identify the information which is normally used.

The project report has been published as: NCHRP Report 99, "Visual Information Needed by the Driver at Night."

Project 5-4 FY '64

Economic Study of Roadway Lighting

Research Agency: The Franklin Institute
Principal Invest.: Arno Cassel
Effective Date: July 20, 1964
Completion Date: August 31, 1965
Funds: $19,412

The purpose of this project was to determine capital cost ranges and operating costs for prevailing light sources in relation to type of luminaire distribution system and light intensity on the pavement.

The project report has been published as: NCHRP Report 20, "Economic Study of Roadway Lighting."

Project 5-5 FY '65

Nighttime Use of Highway Pavement Delineation Materials

Research Agency:	Southwest Research Institute	
Principal Invest.:	John M. Dale	
Effective Date:	Mar. 1, 1965	July 15, 1967
Completion Date:	Dec. 31, 1966	Sept. 15, 1969
Funds:	$50,000	$100,000

In this study, ways of improving delineation of roadways under wet and dry conditions by either improving techniques utilizing existing materials or developing new materials and techniques were investigated.

The project report on the laboratory phase of the research has been published as: NCHRP Report 45, "Development of Improved Pavement Marking Materials—Laboratory Phase."

The purpose of the continuation phase was to further develop, optimize, and field test the new marking system that emerged from the initial research effort. The project report on the field phase of the research has been published as: NCHRP Report 85, "Development of Formed-in-Place Wet Reflective Markers."

In addition to the final report, a motion picture film, "Pavement Marking Materials," was produced describing the results of the research. Loan copies of the film are available from the TRB Audio-Visual Library (see final page of this section for ordering information).

Project 5-5A FY '71

Development of Optimum Specifications for Glass Beads in Pavement Markings

Research Agency: The Pennsylvania State University
Principal Invest.: Dr. Luke M. Shuler
Effective Date: May. 1, 1971
Completion Date: June 30, 1973
Funds: $99,350

This study was a continuation of recommended research based on the findings of Project 5-5 as reported in NCHRP Report 45.

Specific objectives were to:

1. Review and analyze world-wide research and practices involving the use and manufacture of traffic marking beads.
2. Identify those variables that markedly influence the effective utilization of glass beads in pavement markings. Evaluate these variables by laboratory and field tests as required in order to rate them in terms of their influence on the effectiveness and serviceability of delineation under actual traffic conditions. Field tests are to include measurements of wet-nighttime reflectivity.
3. Determine the capability and economics of producing glass beads of specified gradation, composition, shape, flow properties, color, etc.
4. Develop practical specifications and criteria for the selection and use of beads for reflectorizing traffic paint markings.
5. Evaluate for one or more states the probable benefits that would accrue should the proposed specifications be adopted in place of current specifications.

The research included a survey of current practice and field applications of test lines using a variety of paint film thicknesses and glass bead samples. A quantitative study was also undertaken of the retroreflective characteristics of glass beads in horizontal markings by calculations based on general mathematical optical theory.

The final report was not published in the NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 5-5B FY '72

Pavement Marking Systems for Improved Wet-Night Visibility Where Snowplowing is Prevalent

Research Agency:	Texas A & M University Research Foundation
Principal Invest.:	Dr. William M. Moore
Effective Date:	September 1, 1971
Completion Date:	December 31, 1974
Funds:	$200,000

The objectives of this research were:

1. Develop one or more innovative concepts for pavement marking systems that are practical, economical, and effective under nighttime wet-pavement conditions and compatible with snowplowing.
2. Conduct a laboratory and controlled field evaluation of the system(s) developed in objective 1 and demonstrate its (their) practical and economic feasibility.

Interim reports submitted in September 1972 and October 1973 described the development and testing of the "first generation" markers and the development of the "second generation" markers modified in accordance with the findings from the first winter field tests. The second generation marking systems were tested at sites in Colorado, New York, Pennsylvania, Virginia, and Texas.

The research has been completed, and the final report will not be published; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 5-6 FY '68

Highway Fog

Research Agency:	Cornell Aeronautical Laboratory
Principal Invest.:	W. C. Kocmond K. Perchonok
Effective Date:	October 2, 1967
Completion Date:	April 30, 1969
Funds:	$99,955

The objectives of this research were: (1) to review past and current research of warm and cold fog as it affects highway operation; (2) to prepare a state-of-the-art summary of the review to include, but not be limited to, fog abatement, guidance systems, measures of visibility, and effect on traffic operations; (3) to determine the day and night fog levels (standards of visibility) that produce significant detrimental effects on driver performance and traffic operations; (4) to explore the feasibility of warm and cold fog abatement and vehicular guidance systems under highway conditions; and (5) to suggest ways and means of obtaining maximum effectiveness of systems to combat reduced visibility due to fog.

The research has been completed, and the final report has been published as: NCHRP Report 95, "Highway Fog."

Project 5-6A FY '70

Highway Fog

Research Agency:	Sperry Rand Corporation
Principal Invest.:	James O. Dyal Richard T. Brown William H. Heiss
Effective Date:	September 1, 1970
Completion Date:	May 31, 1973
Funds:	$93,540

This research was a continuation of NCHRP research in the general area of highway fog. The major objectives of the research were to:

1. Analyze the highway fog problem and determine the day and night fog levels (standards of visibility) that produce significant detrimental effects on driver performance and traffic operations.
2. Explore the feasibility of active and passive guidance systems for freeways and expressways that will inform and warn the motorist of prevailing roadway fog and traffic conditions ahead, and guide and control traffic more safely and conveniently through the fog area.

The research was addressed principally to the first objective and developed a measurable fog visibility index and related this index to potential actions that can be taken to eliminate or minimize the detrimental effects of fog.

The research has been completed, and the final report has been published as: NCHRP Report 171, "Highway Fog—Visibility Measures and Guidance Systems."

Project 5-7 FY '69

Roadway Delineation Systems

Research Agency:	The Pennsylvania State University
Principal Invest.:	Dr. J. I. Taylor
Effective Date:	October 1, 1968
Completion Date:	June 30, 1971
Funds:	$469,526

The objectives of this research were: (1) to review past and current research pertaining to roadway delineation; (2) to prepare a state-of-the-art summary of the review; (3) to determine the driver's delineation requirements during various conditions, such as traffic, weather, highway geometry, and illumination; (4) to establish rational technique(s) for determining the effectiveness and any detrimental side effects of delineation treatments and, using the technique(s) established, evaluate existing and proposed delineation systems; (5) to test the more promising delineation systems; (6) to develop practical criteria for the selection of delineation treatments, including factors of cost effectiveness and maintenance problems; and (7) to compare the physical characteristics and performance of colored pavements with those of conventional asphalt and portland cement pavements.

The research has been completed, and the final report has been published as: NCHRP Report 130, "Roadway Delineation Systems."

Project 5-8 FY '70

Warrants for Highway Lighting

Research Agency:	Texas A & M University Research Foundation
Principal Invest.:	Neilon J. Rowan Ned Walton
Effective Date:	March 16, 1970
Completion Date:	February 15, 1973
Funds:	$198,875

The specific objectives of this project were to:

1. Review and analyze world-wide research and practice in roadway lighting. Prepare a state-of-the-art summary of the review.
2. Develop requirements for a suitable visual environment to be obtained by fixed roadway lighting for safe and efficient traffic operations. Provide guidelines for the design of fixed roadway lighting to obtain this environment.
3. Evaluate the possible benefits derived when a suitable visual environment is provided by fixed roadway lighting.
4. Determine warrants (the minimum conditions) for where fixed roadway lighting systems should be installed for continuous lighting and at specific locations including, but not limited to, interchanges and intersections.
5. Analyze the role of cost-effectiveness and other evaluation techniques in (a) establishing the need for fixed roadway lighting, (b) setting priorities for fixed lighting projects, and (c) evaluating alternative designs of lighting.
6. Recommend a method of setting priorities for the installation of fixed lighting.
7. Provide typical example(s) of where lighting is warranted and demonstrate the practical application of objectives 1 through 6.

The research has been completed, and the final report has been published as: NCHRP Report 152, "Warrants for Highway Lighting."

Project 5-9 FY '81

Partial Lighting of Interchanges

Research Agency:	KETRON, Inc.
Principal Invest.:	Michael S. Janoff
Effective Date:	December 1, 1980
Completion Date:	January 31, 1983
Funds:	$199,999

The objective of this research was to determine the effectiveness of partial lighting of interchanges and to develop recommendations for its use. A methodology was developed for evaluating the effectiveness of partial lighting relative to no lighting and to complete lighting of interchanges. The methodology is based on measures of visibility (e.g., illumination, roadway luminance, and a visibility index), and traffic characteristics (e.g., ramp speed, acceleration, and erratic maneuvers). The dual function that lighting serves in alerting drivers to an upcoming situation and in providing adequate visibility to execute the required driver maneuvers was investigated. The boundary conditions for roadway and traffic characteristics for which no lighting, partial lighting, or complete lighting is appropriate were determined through field studies at freeway interchanges. A small pilot study to test the field data collection was completed followed by the main field study at a site on the Baltimore Beltway.

The project report has been published as: NCHRP Report 256, "Partial Lighting of Interchanges."

Project 5-10 FY '88

A Mobile System for Measuring Retroreflectance of Traffic Signs

Research Agency:	EKTRON Applied Imaging
Principal Invest.:	John Lumia
Effective Date:	September 7, 1987
Completion Date:	March 7, 1989
Funds:	$199,094

Traffic signs are very important components of streets and highways. Ideally, they help motorists find their way in a safe manner by providing for the orderly and predictable movement of traffic. In order for signs to accomplish their intended purposes, they must be visible to the motorists at all times. While sign visibility is generally not a problem during daylight, at night signs with inadequate retroreflectance may not be sufficiently visible and can contribute to accidents.

Most signs are made from retroreflective materials that tend to deteriorate over time leading to ineffective performance at night. Consequently, there is a serious need to establish requirements for sign visibility and to devise a practical system for evaluating the condition of existing signs and providing data for decisions on sign replacement or refurbishment. At the present time, there are laboratory methods and portable instruments available for measuring retroreflectance, but easy-to-use mobile systems are not available. Practical, safe, and cost-effective methods to measure the retroreflective characteristics of in-situ signs from a mobile highway unit need to be investigated. The research requested in this proposal will determine the feasibility of developing such a system.

The objectives of this project are (1) to develop a system concept for the rapid assessment of retroreflective effectiveness of signs, and (2) to demonstrate the feasibility of the system concept by devising and testing a proof-of-concept model.

The system is to be useful in determining the need for sign replacement or refurbishing. The system is to be

capable of measuring the retroreflectance of sign legends and backgrounds irrespective of color, size, and placement. For safety and economic reasons, it is preferable that the system be operational during daylight from a moving vehicle.

To accomplish the objectives, the following tasks will be conducted:

Task 1—Review the literature dealing with retroreflective signs used on streets and highways. This review shall investigate the various types of retroreflective materials used, the range of sizes of the various signs, as well as their locations relative to the roadway. Also, past and current research on the measurement of retroreflectance and instrumentation used for such measurements shall be included.

Task 2—Develop a concept for a system of equipment and procedures for the rapid assessment of retroreflective effectiveness of signs. The system concept should accommodate the impact of changes in daylight, speed, and geometrics during in-motion measurements.

The system shall be designed to:

- Produce sign retroreflectance readings at a low unit cost (capital and operating), per sign.
- Evaluate signs of various sizes, colors, and positioning.
- Operate in a manner that does not pose a danger to the operator or the passing motorist.
- Be sufficiently reliable to allow highway agencies to comply with existing and/or pending reflectance regulation.
- Produce retroreflectance output in units of candelas per foot-candle per square foot.
- Be capable of being operated by highway maintenance technicians during daylight with a minimum amount of calibration needed.

Prepare and submit for approval an interim report describing the conceptual system design and a plan for the laboratory to be used in Task 3. The interim report shall be submitted within 4 months after the research begins.

Task 3—Select a suitable system components and design a system, including required computer software for data collection and reduction. Build a breadboard model for proof-of-concept testing.

Task 4—Conduct laboratory tests to evaluate the system's performance and capabilities, modifying the system design and model as necessary. Perform measurements on representative signs under day and night conditions at varying distances and orientations. Compare these measurements with those obtained using conventional methods (Federal Test Method Standard 370, ASTM E-810, FP-85).

Task 5—Develop an implementation plan for producing an operational prototype system capable of measuring retroreflectance of in-situ signs from a moving vehicle during daylight. This plan shall include:

- Statement of work including the tasks to be performed.
- Proposed budget.
- A list of required system performance specifications.
- Estimate of the final (production) system capital and operating cost.

Task 6—Prepare a Final Report

Tasks 1 through 3 have been completed, and work is underway on Task 4. The project panel met to review the interim report and has approved additional funds to evaluate a laser range finder at the breadboard stage.

Project 5-11 FY '89

Implementation Strategies for Sign Retroreflectivity Standards

Research Agency:	In developmental stage
Principal Invest.:	
Effective Date:	(27 months)
Completion Date:	
Funds:	$200,000

Traffic signs are very important components of streets and highways. Ideally, they help motorists find their way in a safe manner by providing for the orderly and predictable movement of traffic. For signs to accomplish their intended purposes, they must be visible to the motorists. Although sign visibility is generally not a problem during daylight, signs with inadequate retroreflectivity may not be sufficiently visible at night and can contribute to accidents. In the context of this research, retroreflectivity is intended to encompass the characteristics of legibility, visibility, and conspicuity.

On April 26, 1985, the Federal Highway Administration published an Advance Notice of Proposed Amendment to the *Manual on Uniform Traffic Control Devices* as the initial step in developing performance standards for in-service, retroreflective, traffic-control devices. Since then, research has been initiated to determine minimum visibility requirements for traffic signs that will satisfy the needs of the nighttime driving population. In addition, research is underway to develop field measurement tools to determine whether a specific in-service traffic sign meets given retroreflectivity levels.

However, before retroreflectivity standards can be implemented, their potential economic impact must be assessed. Further, any adverse effects of such standards should be mitigated. The results of this project will provide alternative strategies for economical ways to improve the effectiveness of signs within available resources.

The objective of this project is to determine the economic consequences of alternative standards for retroreflective traffic signs. Accomplishment of the objective will involve collection of retroreflectivity data on representative traffic signs in diverse geographic regions. Study areas will include both urban and rural roadways and will be large enough to adequately represent a range of

maintenance conditions and classes of roadways. This study shall not include construction and maintenance signs.

To accomplish the objectives, the following tasks shall be conducted:

Task 1. Evaluate the literature and other informational sources pertaining to retroreflectivity of traffic signs. The various types of sign inventory systems in use and current maintenance practices shall be investigated.

Task 2. Review the references noted below and summarize information pertinent to establishing the feasibility of retroreflectivity standards.

Task 3. Use, where appropriate, the latest results and findings from the following research projects:

(a) NCHRP Project 5-10, "A Mobile System for Measuring Retroreflectance of Traffic Signs."

(b) FHWA Contract No. DTFH61-87-R-00008, "Minimum Visibility Requirements for Traffic Control Devices."

(c) FHWA Contract No. DTFH61-88-R-00060, "Service Life of Retroreflective Traffic Signs."

Task 4. Develop a data collection plan to include, as a minimum, the following:

(a) Identify the study areas and the sign and roadway categories to be sampled.

(b) Select the locations for sampling. These should be diverse not only by region, but also by governmental level (e.g., federal, state, city, county) and maintenance policy. The sample size should be sufficient to allow statistically valid estimates of the retroreflective conditions and the distribution of signs by class of roadways.

(c) Prepare a detailed data collection plan.

Task 5. Submit an interim report to include the results of Tasks 1 to 4 and meet with NCHRP Project Panel for approval of the data collection plan.

Task 6. Collect existing data on in-service sign retroreflectivity, replacement costs (e.g., labor and material), and other information utilized by sign management programs.

Task 7. Analyze the data:

(a) For different categories of signs, develop relationships that indicate how various retroreflectivity standards would affect, nationally and at state and local levels: (i) the number of signs to be replaced, (ii) the replacement costs, and (iii) any other economic or management considerations.

(b) Describe the modeling techniques used and segregate data so they can be applied readily to any jurisdiction's sign replacement and maintenance programs.

Task 8. Develop economic-based implementation strategies for alternative sign-retroreflectivity standards across different categories of signs, roadways, and jurisdictions.

Task 9. Recommend several options for system-wide implementation that:

(a) Provide guidelines for phasing in the implementation of retroreflectivity standards.

(b) Indicate the expected economic consequences of adoption of these standards.

Task 10. Prepare the final report.

Research should be initiated in early 1989.

AREA 6: SNOW AND ICE CONTROL

Project 6-1 FY '63

Development of Economical and Effective Chemical Deicing Agents to Minimize Injury to Highway Structures and Vehicles

Research Agency:	IIT Research Institute
Principal Invest.:	D. B. Boies
Effective Date:	February 15, 1963
Completion Date:	September 30, 1964
Funds:	$40,000

Research was directed to the development of chemical agents that are not only economical and effective when used as deicing agents but also have minimal harmful effects on metals and concrete. Consideration was given to the relationship of laboratory tests to field conditions.

The project report has been published as: NCHRP Report 19, "Economical and Effective Deicing Agents for Use on Highway Structures."

Project 6-2 FY '63

Nonchemical Methods for Preventing or Removing Snow and Ice Accumulations on Highway Structures

Research Agency:	Roy Jorgensen and Associates
Principal Invest.:	R. E. Jorgensen R. D. Johnson
Effective Date:	Feburary 15, 1963
Completion Date:	February 29, 1964
Funds:	$25,000

This study was primarily one of searching the literature and appraising the current status of knowledge of the subject. In addition to a literature survey, contacts were made with highway departments and other agencies that have been confronted with the problem. Designs for structure heating systems as used in the U.S. and other countries have been evaluated, as have other nonchemical methods. The researchers have included in their studies the effectiveness of nonchemical methods and economic losses due to structure deterioration.

The project report has been published as: NCHRP Report 4, "Non-Chemical Methods of Snow and Ice Control on Highway Structures."

Project 6-3 FY '63

Development and Evaluation of Protective Coatings to Prevent Deterioration of Concrete Structures by Deicing Agents

Research Agency: Battelle Memorial Institute
Principal Invest.: M. J. Snyder
Effective Date: March 1, 1963
Completion Date: February 28, 1965
Funds: $58,557

Investigations on this project were oriented toward developing new and evaluating existing materials to be applied to concrete surfaces to inhibit concrete deteriorations from deicing agents. Consideration was given to fresh as well as hardened concrete.

The project report has been published as: NCHRP Report 16, "Protective Coatings to Prevent Deterioration of Concrete by Deicing Chemicals."

Project 6-4 FY '63

Evaluation and Development of Methods for Reducing Corrosion and Reinforcing Steel

Research Agency: Battelle Memorial Institute
Principal Invest.: A. B. Tripler, Jr.
Effective Date: March 1, 1963
Completion Date: April 30, 1965
Funds: $39,330

Research investigations for this project related to an appraisal of existing methods for inhibiting corrosion of reinforcing steel in concrete. Consideration was given to such methods as (1) coatings on reinforcing bars, (2) inhibitors in concrete mixtures, (3) inhibitors in deicing chemicals, and (4) cathodic protection.

The project report has been published as: NCHRP Report 23, "Methods for Reducing Corrosion of Reinforcing Steel."

Project 6-5 FY '63

Study of Physical Factors Influencing Resistance of Concrete to Deicing Agents

Research Agency: University of Illinois
Principal Invest.: Prof. C. E. Kesler
Effective Date: March 1, 1963
Completion Date: August 31, 1965
Funds: $72,500

This research concerned the relationships between the physical characteristics of concrete and the susceptibility of concrete to damage from freezing and thawing in the presence of free moisture and deicing agents. Studies were made of the effects of varying concrete production methods on potentially durable concrete. Variations in the surface porosity, strength, and air-void system produced by differing finishing techniques were evaluated for typical air-entrained concretes. Large- and small-scale specimens were cast, and effects of period and time of finishing, environmental conditions, and additions of water during finishing were evaluated using surface scaling tests, surface tensile strength tests, and microscopical determination of surface air-void parameters.

This project has been completed, and the report has been published as: NCHRP Report 27, "Physical Factors Influencing Resistance of Concrete to Deicing Agents."

Project 6-6 FY '63

To Evaluate Existing Methods and/or Develop Improved Methods for the Measurement of Certain Properties of Concrete

Research Agency: The Ohio State University
Principal Invest.: Prof. R. W. Bletzacker
Effective Date: March 1, 1963
Completion Date: February 28, 1966
Funds: $69,393

In order to insure that finished concrete will conform to those specifications selected to produce adequate resistance to deicing agents, this study was initiated to evaluate and/or develop methods for securing pertinent quality control information at the earliest desirable or feasible age in order that any necessary corrective measures can be applied to the work in progress. Specifically, the study concerned the factors of (1) air content and uniformity of distribution, (2) cement content and uniformity of distribution, (3) water content and uniformity of distribution, and (4) thickness of cover over reinforcement.

The project report was not published in the regular NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 6-7 FY '63

Estimation of Disintegration in Concrete Structures

Research Agency: Geotechnics
Principal Invest.: Floyd O. Slate
Effective Date: March 1, 1963
Completion Date: August 31, 1964
Funds: $8,547

This study involved the development of instruments and method(s) for field use to detect and determine the extent of disintegration of structural concrete. The method(s) should be able to delineate area and depth within an accuracy of approximately 10 percent.

The contract was terminated with no project report. Research was resumed under Project 6-7A.

Project 6-7A FY '63

Estimation of Disintegration in Concrete Structures

Research Agency: IIT Research Institute
Principal Invest.: Dr. W. J. McGonnagle
Effective Date: February 1, 1965
Completion Date: July 31, 1966
Funds: $44,614

This research study involved the development of instruments and method(s) for field use to detect and determine the extent of disintegration of structural concrete. The method(s) should be able to delineate area and depth within an accuracy of approximately 10 percent.

The project report was not published in the regular NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 6-8 FY '63

Evaluation of Methods of Replacement of Deteriorated Concrete in Structures

Research Agency: Bertram D. Tallamy Associates
Principal Invest.: Dr. B. D. Tallamy
Effective Date: February 15, 1963
Completion Date: February 29, 1964
Funds: $25,000

This study was directed toward a search of available literature and a canvass of agencies that have been known to employ methods of repair of structural concrete. The researchers attempted an evaluation of the economics and adequacy of the various methods to accomplish the job. Recommendations were made of areas requiring further study.

The project report has been published as: NCHRP Report 1, "Evaluation of Methods of Replacement of Deteriorated Concrete in Structures."

Project 6-9 FY '64

Potential Accelerating Effects of Chemical Deicing Damage by Traffic and Other Environmental-Induced Stresses in Concrete Bridge Decks

Research Agency: University of Illinois
Principal Invest.: Prof. Clyde E. Kesler
Effective Date: January 1, 1965
Completion Date: June 15, 1968
Funds: $200,000

The objectives of this research were to establish by laboratory studies the relationships between performance and displacement in bridge-deck slabs. Air-entrained reinforced concrete deck slabs with restraints similar to those experienced by slabs on structural steel and reinforced concrete beam-type bridges were investigated, and tests were conducted on replicas of actual bridge-deck slabs. Loading and environmental conditions in these tests simulated those encountered in the field.

The final report has been published as: NCHRP Report 101, "Effect of Stress on Freeze-Thaw Durability of Concrete Bridge Decks."

Project 6-10 FY '68 and FY '69

Develop Improved Snow Removal and Ice Control Techniques at Interchanges

Research Agency: Bertram D. Tallamy Associates
Principal Invest.: L. G. Byrd
Effective Date: September 1, 1967
Completion Date: September 30, 1970
Funds: $95,000

The purpose of this study was to identify and evaluate the specific problems associated with snow removal and ice control operations at interchanges and to recommend methods for alleviating the problems. The investigation has been completed, and both physical and operational factors that influence winter maintenance operations at interchanges have been listed in the project report. Design considerations and operational procedures aimed at alleviating the problem have been described in a manual submitted as part of the final report.

The project report has been published as: NCHRP Report 127, "Snow Removal and Ice Control Techniques at Interchanges."

Project 6-11 FY '71

Economic Evaluation of the Effects of Ice and Frost on Bridge Decks

Research Agency:	Midwest Research Institute	
Principal Invest.:	Robert R. Blackburn	
Effective Date:	Sept. 1, 1970	Sept. 12, 1972
Completion Date:	Nov. 30, 1971	Sept. 11, 1974
Funds:	$50,000	$50,000

Ice or frost on bridge decks while the approach pavements remain ice- or frost-free is a known safety hazard. Although little hard evidence has been presented to indicate the extent of the problem, maintenance practice and research on various preventive or remedial techniques often assumes it to be significant. This project was undertaken to fill a need to quantify the problem as a basis for rational decisions concerning the economics of design and maintenance practices.

Phase I of the project consisted of a literature search, a survey of selected State highway departments, the formulation of a cost-benefit methodology, a preliminary model parametric analysis, the collection of cost data on preventive and remedial techniques in current use, the development of a subsidiary net cost model, the formulation and evaluation of a bridge classification model, and

the computation of illustrative examples of the cost-benefit methodology.

The application of the methodology developed in Phase I to sample cases identified data that were lacking. Furthermore, the resulting models were found not to be in a convenient form for ready implementation. Phase II of the project was designed to overcome the deficiencies. The continued research was directed at evaluating and implementing the methodology developed so that it could be used more readily by a highway administrator to determine the added design or extra maintenance cost justified to prevent or remedy ice or frost on bridge decks. The cost-benefit methodology developed consists of a cost model and a benefit model. A bridge characterization model was also developed for predicting the annual number of ice and snow accidents to be expected on a bridge, given various characteristics of the bridge. The use of the methodology and bridge model appears promising; however, anyone wishing to apply the process will need to develop a more precise accident data base with regard to bridge and road surface conditions (frost, localized ice, etc.) for the particular area of interest beyond that now being collected. The data base can be generated using data collection procedures developed in the study.

Research has been completed, and the final report has been published as: NCHRP Report 182, "Economic Evaluation of Ice and Frost on Bridge Decks."

AREA 7: TRAFFIC PLANNING

Project 7-1 FY '64 and FY '65

The Influence of Land Use on Urban Travel Patterns

Research Agency:	Louis E. Keefer	
Principal Invest.:	Louis E. Keefer David K. Witheford	
Effective Date:	Feb. 1, 1964	Apr. 1, 1966
Completion Date:	Jan. 31, 1966	Sept. 30, 1967
Funds:	$62,674	$66,894

This project sought to determine the criteria or values concerning travel patterns created by major traffic generators. Such information is useful in forecasting the effect of various land uses on street networks and in providing a better basis for facility design, as well as for the control of various land uses. The nature of relationship between travel patterns and influencing factors (i.e., travel time, traffic generator characteristics such as location, size, type and intensity of land use, modes of travel, and other pertinent variables) were evaluated.

A report on the initial research has been published as: NCHRP Report 24, "Urban Travel Patterns for Airports, Shopping Centers, and Industrial Plants."

A report on the continuing phase of the research has been published as: NCHRP Report 62, "Urban Travel Patterns for Hospitals, Universities, Office Buildings, and Capitols." This report presents trip characteristics for four specific uses of land. The travel information on hospitals has been derived from the study of data for 77 hospitals located in 16 different metropolitan areas. The findings for college and university travel were developed from 38 institutions located in 16 metropolitan areas. Travel patterns for six State capitol complexes are presented. The trip characteristics for 20 office buildings located in 9 cities comprise the fourth type of land use studied and reported in the continuation research phase.

Project 7-2 FY '64 and FY '65

Traffic Attraction of Rural Outdoor Recreational Areas

Research Agency:	IIT Research Institute	
Principal Invest.:	Andrew Ungar	
Effective Date:	Feb. 1, 1964	May 1, 1965
Completion Date:	Mar. 15, 1965	May 31, 1966
Funds:	$24,652	$24,844

This research was concerned with determining the traffic attraction and generation of rural outdoor recreational areas, such as those created in many places by the creation of artifical lakes. Knowledge of the traffic patterns generated by such recreational areas would enable rational planning of highway access and parking facilities.

The final report evaluates the attractiveness characteristics and location of 18 Indiana state parks and compares the results to a similar study of reservoir recreational areas in Kansas. A predictive model suitable for application to the planning of new recreational areas is described utilizing trip distribution, a socio-economic activity index of the contributing area, and an estimate of the attractiveness based on the facilities to be provided.

The project report has been published as: NCHRP Report 44, "Traffic Attraction of Rural Outdoor Recreational Areas."

Project 7-3 FY '64 and FY '65

Weighing Vehicles in Motion

Research Agency:	The Franklin Institute
Principal Invest.:	R. Cyde Herrick
Effective Date:	Feburary 1, 1964
Completion Date:	August 31, 1967
Funds:	$73,391

The purpose of this research was to develop new or improved methodology for weighing vehicles in motion with review and study of existing or new equipment. The ultimate aim was to obtain load magnitudes automatically in a way similar to obtaining traffic volumes by traffic counters.

Franklin Institute's approach to this problem served to complement the studies performed by others rather than to duplicate existing research. The data processing system in block form only was developed on the project. It was planned that no full-scale or field testing would be performed under this contract. Study was primarily given to methods that will allow static weights of the axle to be calculated from a limited number of dynamic load observations.

The methods for estimating the static axle weight from sampled force studied include averaging, dynamic models, the interlacing polynomials, and regression analysis. A preliminary system for the detection and the analysis of weighing vehicles in motion was synthesized.

The project report has been published as: NCHRP Report 71, "Analytical Study of Weighing Methods for Highway Vehicles in Motion."

Project 7-4 FY '64, FY '65, and FY '67

Factors and Trends in Trip Lengths

Research Agency:	Alan M. Voorhees & Associates	
Principal Invest.:	Alan M. Voorhees Salvatore Bellomo	
Effective Date:	Feb. 1, 1964	Oct. 23, 1967
Completion Date:	Oct. 31, 1966	Jan. 10, 1969
Funds:	$89,250	$61,730

This research involved the establishment of the characteristics of trends in trip lengths. Knowledge of such trends is needed to determine future urban travel demands. It was expected that characteristics of trip lengths will be influenced by factors such as trip purpose, level of service, size and spatial characteristics of urban areas, socioeconomic characteristics, and trip-generating activity location.

The results of the first two years of this research have been published as: NCHRP Report 48, "Factors and Trends in Trip Length." This report provides empirical and theoretical analyses from data collected from several transportation studies. Trip length guidelines have been developed to provide transportation planners with tests of reasonableness for travel forecasts.

The project was continued to enable the study of trip length in subareas within metropolitan areas. The objectives of the second phase were to establish various relationships to assist planners in minimizing trip length on a subarea basis and to provide guidelines for checking metropolitan trip length forecasts.

The final report provides results of hypotheses formulated and tested to state the relationship over time between trip length and influencing factors. Simulation studies are reported of home-based work-trip analyses for certain hypothetical urban forms and transportation systems.

The results of the continuation phase of the project have been published as: NCHRP Report 89, "Factors, Trends, and Guidelines Related to Trip Length."

Project 7-5 FY '64 and FY '65

Predicted Traffic Usage of a Major Highway Facility Versus Actual Usage

Research Agency:	Yale University, Bureau of Highway Traffic
Principal Invest.:	M. J. Huber H. B. Boutwell
Effective Date:	Feburary 1, 1964
Completion Date:	November 30, 1966
Funds:	$99,675

This project involved the development of better methods for forecasting and assignment of traffic. Various methods in current use were investigated. Methods were developed to determine the effects a new facility has on the traffic pattern of existing facilities. A major emphasis of the research was to determine the accuracy of the predicted use as compared to the actual use of highway facility.

The project report describes various electronic computer traffic assignment methods with test results compared to actual survey data obtained along the Connecticut River, Pittsburgh Area Transportation Study data and network assignments were obtained to study several forecasts made in the late 1940s. A computer program was assembled to assign traffic to a network using four different capacity restraint methods. An analysis of statistical inferences from different network loadings was conducted.

The project report has been published as: NCHRP Report 58, "Comparative Analysis of Traffic Assignment Techniques with Actual Highway Use."

Project 7-6 FY '66

Multiple Use of Lands Within Highway Rights-of-Way

Research Agency:	Barton-Aschman Associates
Principal Invest.:	Harvey R. Joyner
Effective Date:	February 1, 1966
Completion Date:	February 28, 1967
Funds:	$24,220

Controlled-access highways in urban and rural areas include land which was necessarily acquired to provide space for the present and future safe design and operation of the facility but which is not now used. This project assembled information that illustrates what has been and what might be accomplished with these plots of land in the interest of both the highway user and the adjacent community.

The project report has been published as: NCHRP Report 53, "Multiple Use of Lands Within Highway Rights-of-Way."

Project 7-7 FY '66

Motorists' Needs and Services on Interstate Highways

Research Agency: Airborne Instruments Laboratory
Principal Invest.: Martin A. Warskow
Effective Date: January 1, 1966
Completion Date: December 31, 1967
Funds: $99,267

This project was concerned with the needs and desires of motorists traveling on the Interstate Highway System, how these needs and desires are being satisfied, and what additional service provisions should be made. Legal and financial implications for providing various services were studied.

The project report has been published as: NCHRP Report 64, "Motorists' Needs and Services on Interstate Highways."

Project 7-8 FY '66

User Cost and Related Consequences of Alternative Levels of Highway Service

Research Agency: Stanford Research Institute
Principal Invest.: David A. Curry
Effective Date: September 1, 1970
Completion Date: April 15, 1972
Funds: $99,070

The objectives of this project were to evaluate data related to user costs on various highway facilities under different levels of service, volumes, and other conditions, and to develop a methodology that will relate these variables to user costs. Through the means of sensitivity analyses, highway design and situation variables were identified that have major impact on output variables that can be of use to highway decision-makers.

Motor vehicle running cost data were compiled and updated for use in calculating relative road user costs at different levels of highway service and as affected by details of geometric design and traffic performance. By use of Appendix A of the *Highway Capacity Manual,* relationships were derived for peak-hour volume per lane in conjunction with AADT per lane pair. Queuing was analyzed based on the shock-wave method for uninterrupted flow and the deterministic method for interrupted flow. A methodology for estimating vehicle emissions was developed based on a "typical" vehicle configuration.

The research has been completed, and the project report has been published as: NCHRP Report 133, "Procedures for Estimating Highway User Costs, Air Pollution, and Noise Effects."

Project 7-9 FY '73

Development of Models for Predicting Weekend Recreational Traffic

Research Agency: Midwest Research Institute
Principal Invest.: Walter R. Benson
Effective Date: September 1, 1972
Completion Date: May 15, 1974
Funds: $74,983

The objective of this research was to develop techniques for the prediction of weekend recreational traffic capable of responding to changes in recreation demand, recreation supply, and transportation supply.

The principal development was a computer program RTPM (Recreational Traffic Prediction Model). RTPM operates in conjunction with the Urban Planning Battery in a three-stage process as follows:

1. Urban Planning Battery programs are employed to create a highway network representing the primary roads in an area selected for study and to determine travel times between all zones in the network.
2. RTPM generates a trip file consisting of all origin-destination weekend recreational travel for which either the origin or the destination point is within the area selected.
3. These trips, within a user-specified time-of-weekend period, are loaded onto the highway network by Urban Planning Battery programs to provide estimates of traffic on any one or more individual highway segments.

The project report was not published in the NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 7-10 FY '74 and FY '75

Peak-Period Traffic Congestion

Research Agency: Remak-Rosenbloom
Principal Invest.: Sandra Rosenbloom
Roberta Remak
Effective Date: April 1, 1974
Completion Date: March 31, 1975
Funds: $49,624

The objectives of this project were to (1) conduct a state-of-the-art survey to identify methods currently used or envisioned to alleviate the problem, (2) evaluate methods to ameliorate peak-period traffic congestion and to combine promising mutually supportive approaches into packages, and (3) develop research problem statements in the areas of institutional, energy, and social impacts associated with potentially effective congestion reduction packages.

Techniques to ameliorate peak-period traffic congestion were classified as social, socioeconomic, sociotechnical, and technical. They have been summarized in a state-of-

the-art report. Experience with each technique has been described under the following categories: concepts, costs, time frame, funding source, political feasibility, and impact.

Mutually supportive techniques and incompatible techniques were identified. As a result, eight recommended packages of techniques to ameliorate peak-period traffic congestion were developed. These packages carry the following titles: (1) Work Hour Changes, (2) Pricing Techniques, (3) Restricting Access, (4) Changing Land Uses, (5) Prearranged Ride Sharing, (6) Communications Substitutes for Travel, (7) Traffic Engineering Techniques, and (8) Transit Treatments.

To highlight existing deficiencies and knowledge, ten problem statements were developed.

Two reports describe the findings from this project. Volume 1, entitled "Peak-Period Traffic Congestion: State of the Art and Recommended Research," is available either on loan from the NCHRP or in microfiche (see final page of this section for ordering information). Volume 2, entitled "Peak-Period Traffic Congestion—Options for Current Programs," has been published as: NCHRP Report 169, "Peak-Period Traffic Congestion—Options for Current Programs."

Research was continued under NCHRP Project 7-10(2).

Project 7-10(2) FY '75

The Institutional Aspects of Implementing Congestion-Reducing Techniques

Research Agency:	Remak-Rosenbloom
Principal Invest.:	Roberta Remak Sandra Rosenbloom
Effective Date:	April 1, 1975
Completion Date:	November 30, 1978
Funds:	$74,703

The general objective of Project 7-10(2) was to develop strategies for assuring that congestion-reduction packages are considered rationally within today's institutional framework.

The research found that institutional problems can best be anticipated by recognizing that they derive from three sources. Some are inherent in the individual techniques selected. Others result from needs to coordinate activities of several essentially independent institutions. Still others derive from the character of the community in which the program is being carried out.

The congestion-reducing techniques recommended in NCHRP Project 7-10 were grouped according to common institutional problems they presented and strategies that could be used to overcome them. These groups were: (1) traffic engineering techniques; (2) transit improvement techniques; (3) techniques for restricting automobile use; (4) techniques for changing land use; and (5) techniques relying on employer initiative.

The research has been completed, and the project report has been published as: NCHRP Report 205, "Implementing Packages of Congestion-Reducing Techniques—Strategies for Dealing with Institutional Problems of Cooperative Programs." The report discusses the major problems for each group and recommends strategies to overcome opposition and enlist cooperation. Guidance is given, where appropriate, for federal, state, and local levels of government.

Joint implementation, requiring agency coordination, was found to generate institutional problems independent of the particular techniques involved in the congestion-reduction program. The research leads to the conclusion that metropolitan planning organizations (MPO) must integrate local and areawide transportation needs, resolve conflicts in plans of individual agencies, and at the same time ensure that federal and state program requirements are met. Strategies are recommended to assist an MPO or other central authority to effect necessary coordination.

The important institutional factors determined by the character of the community are the unofficial power structure, special-interest organizations, and community attitudes. Because these factors will be unique in each community, only broad strategies were recommended.

Project 7-11 FY '81

Low-Cost TSM Projects—Simplified Procedure for Evaluation and Setting Priorities

Research Agency:	Multiplications, Inc.
Principal Invest.:	J. H. Batchelder, H. S. Levinson, M. Golenberg
Effective Date:	April 6, 1981
Completion Date:	November 30, 1983
Funds:	$199,988

The general objective of this research was to improve the capability of transportation agencies to estimate quickly the impacts of, and to determine priorities for, proposed low-cost transportation actions so that programming decisions can be made on better information.

The research conducted under this project has defined a rational, structured framework for planning and programming TSM actions. TSM is treated as a means of solving near-term, identifiable problems or well-defined policy objectives through the implementation of low-cost, workable and publicly acceptable projects. The key features of the process are:

- A consistent assessment of problems and understanding their causes.
- The establishment of realistic objectives for TSM actions designed to solve the problems.
- The setting of fiscal and other guidelines for design and development of actions.
- The identification of potential actions that are appropriate and feasible in the problem setting.

- The systematic design of an implementable project that combines or "packages" actions as necessary to meet the objectives established for problem solution.

On the basis of the research results, a three part user's manual was developed to assist practitioners. Part I of the manual describes a structured and responsive framework recommended for planning and programming TSM actions. Part II of the manual is a Reference Handbook designed to support transportation agencies in planning, evaluation, and programming of low-cost transportation actions. Part III of the manual contains example applications that illustrate use of: (1) the TSM planning framework, and (2) the reference handbook material to support the planning and programming of TSM solutions.

The manual has been published as: NCHRP Report 263, "Procedures for Evaluating Low-Cost TSM Projects—User's Manual." The project research report, however, has not been published but a limited number of copies are available at a cost of $6.00 each or microfiche may be purchased (see final page of this section for ordering information).

Additional efforts to facilitate the wider application of NCHRP Report 263 are explained in the 7-11A project description.

Project 7-11A FY '81

Low-Cost TSM Projects—Simplified Procedures for Evaluation, Phase II

Research Agency:	Texas A&M University Research Foundation
Principal Invest.:	John M. Mason, Jr.
Effective Date:	March 4, 1985
Completion Date:	August 3, 1986
Funds:	$150,000

Transportation agencies have been implementing low-cost TSM actions in order to obtain maximum benefits from the transportation dollar. To assist in implementation, *NCHRP Report 263,* "Simplified Procedures for Evaluating Low-Cost TSM Projects—User's Manual," provides a procedure to identify appropriate TSM actions and to identify techniques to estimate their various impacts. Furthermore, the manual provides guidance on combining TSM actions to provide cost-effective packages. Inasmuch as *NCHRP Report 263* represents a comprehensive compilation of the best available technology for planning and implementing TSM actions, it is highly desirable to increase its use by practitioners. FHWA has programmed funds for the development of arterial planning workshop materials, based on *NCHRP Report 263* and other reports, for the National Highway Institute to sponsor workshops throughout FHWA regions. These workshops served to introduce the manual only to a limited audience from most agencies. For the critical masses within agencies to gain use of the manual, a need exists to develop materials that will introduce Report 263 in a day, or less, to practitioners in small and medium-sized agencies. Additionally, self-training materials are needed to supplement the introduction to serve those requiring hands-on experience with the manual. Furthermore, in support of TSM action implementation, audiovisual materials need to be developed to increase awareness of TSM action effectiveness among appointed and elected decision-makers.

The first objective of this project was to disseminate and promote the use of material in *NCHRP Report 263* primarily to technical staffs of states, MPOs, and local governments by developing modular audiovisual (A/V) and computer disks to illustrate use of the Report. The second objective was to describe for decision-making TSM actions and their benefits as alternatives to major capital improvements by developing 35-mm slide presentations.

Progress to December 31, 1985 included development of the following products to meet the needs of the two objectives. For objective 1, the products are:

1. The Programmed Learning Text intended to present in a simplified manner the detailed technical guidelines for the implementation of TSM.
2. Computer-aided instruction modules:

I. Tutorial
II. TSM Screening Aids
III. Impact Estimation and Analysis Aids
IV. Accident Reduction Factors
V. Cost Indices

3. Audio-visual, slide-tape show developed in six modules to cover the content of Report 263.

For objective 2, two 35-mm slide presentations have been developed: (1) for medium to large urban areas and (2) for urban areas under 250,000 population. Both are accompanied by written scripts and audio tapes. The project report has been published as NCHRP Report 283, "Training Aid for Applying NCHRP Report 263, Simplified Procedures for Evaluating Low-Cost TSM Projects."

Project 7-12 FY '89

Microcomputer Evaluation of Highway User Benefit

Research Agency:	In developmental stage
Principal Invest.:	
Effective Date:	(24 months)
Completion Date:	
Funds:	$200,000

The objective of this study is to develop a comprehensive, user-friendly, portable microcomputer program capable of using new and updatable support data and the best practical procedures for conducting highway user benefit-cost analysis and related noise and air pollution emission analyses.

Benefit-cost analysis can be used over a broad spectrum of projects and at different levels of detail. The scope of this study should cover highway projects ranging from individual intersection improvements and Transportation Systems Management (TSM) projects to major road upgradings and construction of new roads connecting to the interstate or other major facilities. Comprehensive life-cycle cost evaluation techniques should also be included. The focus of the effort will be directed to analyses at the project level and its immediate area impacts rather than at a highway system level.

Task 1. Review the literature for procedures used in highway user benefit-cost and related noise and air pollution emission analyses and identify sources of support data for use in the determination of vehicle operating costs, accident reduction benefits, travel-time values, and any other appropriate factors.

Task 2. Assess the support data and procedures identified in Task 1 and select for inclusion in the computer program those most appropriate in terms of their currency, completeness, general use, and ease of updating. In addition, provide a comparative analysis of the selected procedures with those found in the 1977 AASHTO *Manual on User Benefit Analysis of Highway and Bus Transit Improvements.*

Task 3. Develop procedures for updating support data to the current analysis year, and propose default values where appropriate.

Task 4. Develop a preliminary design for the microcomputer program that accurately reflects the anticipated context and degree of user friendliness. The design should address at least the following: screen layouts, menus, input requirements and procedures from the user and from support data sources, modular structure, process flow diagrams, and output formats and compatibility. In addition, develop a preliminary design for a program validation plan, a user's manual, and program documentation report.

Task 5. Prepare and submit to NCHRP an interim report on Tasks 1 through 4. NCHRP approval is required before subsequent tasks are initiated.

Task 6. Develop the comprehensive user friendly software, adapting the selected techniques to microcomputer use. The program should contain at least the following features:

a. Capability to conduct life-cycle cost analysis.
b. Both default values and user-provided data input capability.
c. Procedures for updating support data and parameter values to the analysis year.
d. Informative error messages.
e. Capability to operate on a fully IBM-compatible microcomputer at a reasonable speed, in a portable and commonly available language that does not require additional end user hardware or software acquisition.

Task 7. Validate the software using the validation plan identified in Task 4. The purpose of the validation plan is to ensure that all calculations are performed correctly with adequate checking of data, parameter values, and ranges. Prepare a program validation report that: (a) describes the methodology used in developing the validation plan, (b) provides a description of the test data sets used to validate the computer program, and (c) documents the results obtained by "hand" and by the computer program.

Task 8. Prepare a user's manual, a program documentation report, and a brief, applications-oriented primer on benefit-cost analysis and economic evaluation of highway user benefits.

Task 9. Provide to five states selected by the NCHRP copies of the software, documentation developed in Tasks 7 and 8, and all other necessary materials to test the implementation capabilities of the software. These states will critique the materials provided and transmit written evaluations to the contractor who will make necessary modifications to the program and documentation.

Task 10. Prepare a final report documenting the research effort. It should contain the modified applications-oriented primer; a description of the computer program and its application, including examples; the user's manual; and the program documentation report including the executable program and its source code.

AREA 8: FORECASTING

Project 8-1 FY '64

Social and Economic Factors Affecting Travel

Research Agency: Vogt, Ivers and Associates
Principal Invest.: Robert S. Vogt
Effective Date: February 1, 1964
Completion Date: September 23, 1966
Funds: $94,558

The purpose of this research was to develop means of estimating intercity travel using known traffic volumes and available economic and social data between selected cities and testing it by application to other pairs of cities between which travel is also known.

Knowledge gained by this research is useful to transportation planners and design engineers. Extensive use of electronic computers and existing computer programs to extract and classify summarized pertinent origin-destination data from existing studies has been accomplished. A nationwide network has been produced for trip distribution purposes. More than 3,000 centroids representing each county or county equivalent with basic population, employment, income, bank deposit, and other social-economic information have been assigned. The centroids are connected by links representing the highway system. External O-D data were acquired and processed for 22 cities

in Tennessee, Wisconsin, and Missouri. From these data, regression analyses were run to test various equation forms and the correlation between variables, combination of variables, and transformation of variables for total trips and for trips by purpose. The trips predicted from the regression equations have been compared to actual survey trips.

The project report has been published as: NCHRP Report 70, "Social and Economic Factors Affecting Travel."

Project 8-2 FY '64 and FY '65

Factors Influencing Modal Trip Assignment

Research Agency: IIT Research Institute
Principal Invest.: Dr. F. C. Bock
Effective Date: February 1, 1964
Completion Date: August 31, 1966
Funds: $298,033

The intent of this research was to improve methods of assigning urban area traffic to the various modes of travel. It involved the identifying of factors underlying choice of travel mode, the determination of the relationships of these factors, and also the development of a method of analysis and forecasting. Methods were tested and found to be practicable for use under real-life conditions. Such methods would be applicable in making better trip assignments in urban transportation systems.

The project report contains a survey of existing modal split models, and analysis of five metropolitan areas having rail rapid transit, a study of factors influencing choice in travel mode, and prediction models for modal choice based on discriminant functions with a comparison of reported trips and computed paths.

The project report has been published as: NCHRP Report 57, "Factors Influencing Modal Trip Assignment."

Project 8-3 FY '64

Individual Preferences for Various Means of Transportation

Research Agency: University of Pennsylvania
Principal Invest.: Dr. Russell L. Ackoff
Effective Date: February 1, 1964
Completion Date: March 31, 1965
Funds: $63,282

This project was designed to probe individuals' transportation preferences as contrasted to the more objective studies that Project 8-2 is concerned with. It was expected that the research would develop additional knowledge as to why and under what conditions persons will use or shift from one form of transportation to another. Better information and estimating bases are needed in order to obtain broad community agreement on plans for transit and highway improvement.

The final report was not published; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 8-4 FY '65

Criteria for Evaluating Alternative Transportation Plans

Research Agency: Northwestern University
Principal Invest.: Dr. Edwin N. Thomas
Dr. Joseph L. Schofer
Effective Date: February 1, 1965
Completion Date: August 1, 1967
Funds: $89,900

This project was intended to identify and evaluate the broad array of factors which should be considered in making an intelligent choice among alternative transportation plans. A system for using these factors should be devised.

The multi-volume report consists of a section in three parts entitled "Strategies for the Evaluation of Alternative Transportation Plans," and a section entitled "Evaluation of Engineering Projects Using Perceptions of and Preferences for Project Characteristics."

In response to comments of the project panel, some additional material was found to be desirable to be added to the final report. Certain modifications were deemed necessary to relate the findings of the research more closely to the immediate needs of transportation planners.

A continuation contract was executed under NCHRP Project 8-4A for the purpose of modifying the final report for publication.

Project 8-4A FY '65

Criteria for Evaluating Alternative Transportation Plans

Research Agency: University of Illinois
Principal Invest.: Dr. Joseph L. Schofer
Effective Date: October 14, 1968
Completion Date: January 10, 1969
Funds: $5,000

See Project 8-4 for objective of the research.

To improve the flow of ideas throughout the document, the final report of Project 8-4 was modified. In addition, more extensive descriptions of strategies for treating streams of cost and effectiveness indicators were prepared and integrated into the text. Also, several illustrative examples of the application of cost-effectiveness analysis to transportation-plan evaluation were prepared to demonstrate the use of the methodology, as well as to support some of the broader concepts described in the final report.

The project report has been published as: NCHRP Report 96, "Strategies for the Evaluation of Alternative Transportation Plans."

Project 8-5 FY '65 and FY '68

Transportation Aspects of Land-Use Controls

Research Agency:	Victor Gruen Associates	
Principal Invest.:	Harold Marks	
Effective Date:	April 1, 1965	Aug. 7, 1967
Completion Date:	May 31, 1966	Jan. 15, 1970
Funds:	$25,967	$99,571

The objective of this research was to provide a better understanding of the effectiveness of existing land-use controls on the continuing utility of transportation systems.

A first technical report has been published as: NCHRP Report 31, "A Review of Transportation Aspects of Land-Use Control."

This project was continued to establish principles or guidelines for developing land-use controls and other techniques that will be stable and effective in the protection of highway utility. The research effort was conceptual in nature and presented a variety of ideas and proposals by which the highway investment can be protected. Some of the guidelines were developed in considerable detail. These can be incorporated into the procedures and practices of land-use and highway administrators. Other principles were developed as a base from which more detailed analyses can be undertaken.

The project report discusses basic interrelationships between transportation facilities and land use and how such relationships can cause transportation facility breakdowns. The effects of changing land-use controls on the utility of highways are discussed, with special attention being given to large traffic generators located near freeway interchanges.

The continuation research has been completed, and the project report has been published as: NCHRP Report 121, "Protection of Highway Utility."

Project 8-6 FY '66

Individual Preferences for Alternative Dwelling Types and Environments

Research Agency:	University of North Carolina
Principal Invest.:	F. Stuart Chapin, Jr.
Effective Date:	February 14, 1966
Completion Date:	March 13, 1968
Funds:	$99,897

In predicting the future demand for transportation, it is imperative that future densities of residential areas be projected. In order that this may be done with confidence, a better understanding must be acquired for the preferences of various housing types and environments.

The project report deals with a summary of findings on housing choice of the households interviewed; an analysis of the residential mobility process; an analysis of the housing-choice process; and, drawing on these analyses, a discussion of the elements needed for a model of moving behavior which will have the capability of dealing with both the mobility and choice processes as components of residential changes.

The project report has been published as: NCHRP Report 81, "Moving Behavior and Residential Choice—A National Survey."

Project 8-7 FY '69

Evaluation of Data Requirements and Collection Techniques for Transportation Planning

Research Agency:	Creighton-Hamburg
Principal Invest.:	Roger L. Creighton
Effective Date:	September 13, 1968
Completion Date:	August 28, 1970
Funds:	$190,000

The purpose of the research project was to see what data were needed, first, for the basic transportation planning process such as was required to be undertaken for metropolitan areas by the Highway Act of 1962, and, second, for new kinds of transportation planning that are developing. A very limited number of transportation studies were selected for careful and detailed data analysis to establish recommendations on guidelines for data requirements and collection techniques. The project defined data requirements for both basic and continuing urban transportation studies with regard to travel, transportation facility, land-use, and socioeconomic data. Sensitivity analysis was performed to examine variations of the transportation data for assessing the impact that data errors have on the output of the transportation planning process.

The research included a comprehensive study of the transportation planning process in five cities to determine data collected, how they were used for planning and research, and their times and costs. Sensitivity tests of these data were conducted. Studies of data needs for new types of transportation-planning processes and alternate means of collecting data were also undertaken. Research was conducted on data needs of related planning processes, such as TOPICS Planning and Transit Planning.

The project report has been published as: NCHRP Report 120, "Data Requirements for Metropolitan Transportation Planning."

Project 8-7A FY '71

Data Requirements and Transportation Planning Procedures in Small Urban Areas

Research Agency:	University of Tennessee
Principal Invest.:	Dr. William L. Grecco
Effective Date:	June 1, 1973
Completion Date:	June 14, 1975
Funds:	$98,005

The initial focus of this research was to develop a simplified transportation planning process for small urban

areas of less than 250,000 population that is sufficiently flexible so that travel forecasts can be based on a small-sample home-interview survey or simulation. It was found that the existing standardized procedures were incompatible with the possible variations in the nature of the problems, available resources, and expectations of the participants. The digest of responses from the small urban areas examined typifies the difficulty faced when attempting to adapt the planning problem to the planning process, rather than fitting the process to the specific problem. The need for a customization of planning procedures was established, and the current organizational framework and technical practices in both land-use and transportation planning were evaluated from that standpoint.

Land-use planning in small communities was found to be highly standardized in format and content, but not in procedures, which varied significantly in terms of sophistication. It was found to be appropriate for planners to forego elaborate procedures in favor of various hand methods that are heavily dependent on the planner's knowledge of the community and the exercise of professional judgment in an ad hoc, or opportunistic, fashion. The transportation planning procedures appeared to be relatively more standardized.

The research identified and presented four types of transportation planning techniques for application in small urban areas: (a) network simulation based on synthetic models and a small-sample household survey, (b) consumer-oriented transit planning procedure, (c) simple techniques for corridor analysis, and (d) hand-computation-oriented procedure for estimating localized impacts of major traffic generators. Existing techniques were reviewed and tested (to varying levels) within each category. Examples include cross-classification and synthetic models, corridor-growth traffic-forecasting models, use of work-trip data from employers to update continuing transportation studies, development of a consumer-oriented approach to determining local transit needs and providing activity-center traffic estimates to assist in assessing the localized impact of land-use changes on the transportation system.

Research has been completed, and the project has been published as: NCHRP Report 167, "Transportation Planning for Small Urban Areas."

Project 8-8(1) FY '69

The Impact of Highways upon Environmental Values (Study Design)

Research Agency:	Massachusetts Institute of Technology
Principal Invest.:	Dr. Marvin L. Manheim
Effective Date:	September 16, 1968
Completion Date:	March 14, 1969
Funds:	$29,654

The increased emphasis on social and esthetic values has focused attention on the need for improving integration of the highway with the community.

The scope of this project was to develop an independent study design to be used as the research plan for the second-phase work. The study design was completed, and the report received but not published.

Refer to Project 8-8(3) for description of the over-all project objectives and details of the second phase of this study.

Project 8-8(2) FY '69

The Impact of Highways upon Environmental Values (Study Design)

Research Agency:	Daniel, Mann, Johnson & Mendenhall
Principal Invest.:	S. R. Sludikoff
Effective Date:	September 9, 1968
Completion Date:	March 7, 1969
Funds:	$28,950

The increased emphasis on social and esthetic values has focused attention on the need for improving integration of the highway with the community.

The scope of this project was to develop an independent study design to be used as the research plan for the second-phase work. The study design was completed, and the report received but not published.

Refer to Project 8-8(3) for description of the over-all project objectives and details of the second phase of this study.

Project 8-8(3) FY '69

The Impact of Highways upon Environmental Values

Research Agency:	Massachusetts Institute of Technology
Principal Invest.:	Dr. Marvin L. Manheim
Effective Date:	September 15, 1969
Completion Date:	July 31, 1974
Funds:	$470,000

The increasing emphasis on social and environmental values has focused attention on the need for improving integration of a transportation facility with both the natural and the human environment. To achieve desirable levels of integration, research was programmed by AASHTO to (a) develop a practical method for evaluating the immediate and long-term effects of highways on the social and environmental considerations of communities and (b) test, evaluate, and refine the method by applying it to specific cases covering a range of situations. Because the design process must maximize the probability that significant community values will be considered, even if the state of the art does not allow all of these values to be measured quantitatively or precisely, the research emphasizes development of an approach in the context of

the location process. Although the scope encompasses all types of highways, the study findings are applicable to all types of transportation facilities, many other public works projects, and all phases of planning.

In the initial phase, funded in 1969, MIT prepared a study design that served as the working plan to develop a pragmatic approach to the problem. The conclusion to the first phase was an unpublished draft report, "Community Values in Highway Location and Design: A Procedural Guide."

The second and final phase included (1) working with selected State highway departments to implement the proposed approach and adapt it to specific situations; (2) extending the approach for use in metropolitan area and statewide multimodal, systems-level planning; (3) extending, testing, and refining the techniques set forth in the draft Procedural Guide; and (4) revising the Procedural Guide to reflect the additional knowledge.

The approach developed recognizes and considers ten elements basic to the consideration of environmental and social values in transportation planning. They are:

(1) Differential effects.
(2) Community values.
(3) Community interaction.
(4) Evaluation and reporting.
(5) Consideration of alternatives.
(6) Identification of impacts and affected interests.
(7) Process management.
(8) Interrelation of system and process planning.
(9) Institutional arrangements and decision making.
(10) Implementation of the approach.

These elements are described in an overview and discussed individually in detail. To assist in incorporating these elements into the transportation planning process, specific immediately implementable techniques that can be used by transportation agencies are described. Most of the techniques can be adopted individually without difficulty. (They are intended for use in developing and evaluating alternative transportation plans with the participation of other state and federal agencies and local citizens and officials.) Some of these techniques are already current practice in some agencies. Several have been tried in other professions; others have been recommended in the published literature or were suggested in discussions with federal and State highway officials. Many more stemmed from direct observation of the problems transportation agencies are facing.

Research has been completed, and the project report has been published as: NCHRP Report 156, "Transportation Decision-Making—A Guide to Social and Environmental Considerations."

The report is closely related to the requirements of the Process Guidelines for the development of Environmental Action Plans as specified in Volume 7, Chapter 1, Section 1 of the Federal Highway Administration's *Federal-Aid Highway Program Manual.* It is structured to assist in the revision and implementation of Action Plans. The overview discussion of the ten elements is roughly analogous in scope and level of detail to the FHWA Process Guidelines. The remaining sections of the report correspond in many ways to the content of an Action Plan.

Project 8-9 FY '72

Comparative Economic Analysis of Alternative Multimodal Passenger Transportation Systems

Research Agency: Creighton-Hamburg
Principal Invest.: F. F. Frye
Effective Date: September 1, 1971
Completion Date: January 31, 1973
Funds: $100,000

The objective of this research was to develop improvements and expansion of existing processes that evaluate alternative multimodal transportation system plans. These improvements were sought on the basis of increasing the number of relevant criteria used in the evaluation framework and ensuring that the measuring techniques (economic evaluation criteria) developed represented accurately the impacts of alternative transportation plans.

Research has been completed, and the project report has been published as: NCHRP Report 146, "Alternative Multimodal Passenger Transportation Systems—Comparative Economic Analysis."

Project 8-10 FY '72

Planning and Design Guidelines for Efficient Bus Utilization of Highway Facilities

Research Agency: Wilbur Smith and Associates
Principal Invest.: Herbert S. Levinson
Effective Date: September 1, 1971
Completion Date: July 31, 1973
Funds: $149,907

This research was designed to develop a single reference source of bus priority measures to increase the person-carrying capacity of urban highways.

The interim report, "Bus Use of Highways—State of the Art," published as NCHRP Report 143, contains a literature search and correlative analysis of more than 200 bus priority treatments throughout the world.

The final report, "Bus Use of Highways—Planning and Design Guidelines," published as NCHRP Report 155, contains planning and design guidelines for efficient bus use of highways based on the experience gained from the literature search and state-of-the-art survey. It identifies significant policy implications, contains relevant planning criteria and warrants for various bus priority treatments, suggests measures of effectiveness, presents bus design parameters, and sets forth detailed planning and design guidelines for both freeway-related and arterial-related

bus priority treatments and for terminals. For measuring effectiveness, it was found that the variance of bus times is an important descriptor of bus reliability.

To aid the designer, vehicle design and performance characteristics are given, together with bus capacity considerations. These include queue behavior parameters, bus unloading and loading times, and bus capacity ranges.

Bus priority treatments should be complemented by appropriate policies that encourage and reinforce transit use, such as low bus fares, downtown commuter parking supply and rate adjustments, and strict enforcement of bus priority treatments. Within this policy framework, that recognizes public transport as an essential community service, various types of bus preferential treatments can be applied to specific urban situations.

Project 8-11 FY '73, FY '76, and FY '77

Social, Economic, Environmental Consequences of Not Constructing a Transportation Facility

Research Agency:	DACP, Inc.
Principal Invest.:	Jonathan S. Lane Lance R. Grenzebach
Effective Date:	September 16, 1974
Completion Date:	November 30, 1979
Funds:	$364,363

This project had as its general objective the strengthening of transportation impact assessment and evaluation procedures; the mechanism for this was the no-action alternative. The research was to define the no-action alternative, determine its role in project evaluation and impact assessment, and review techniques available for assessing the impacts of no-action and other project alternatives.

It was found that existing agency procedures regarding the no-action alternative were inconsistent and confusing. Definitions and role of the no-action alternative varied widely. Reports on a plethora of impact assessment methods were scattered throughout the literature. From these findings came the strong recommendation that the no-action alternative be defined as the maintenance of existing facilities and services in the study corridor and region and that the role of the no-action alternative be that of a benchmark against which all other alternatives be evaluated and assessed.

A December 1975 two-volume interim report is available in microfiche and covers the then existing state of the art: (a) illustrations of alternative definitions; (b) expanded discussion and illustration of alternative methods of plan evaluation and of techniques in current use for social, economic, and environmental impact assessment; and (c) reporting of the four case studies of facilities where no-build decisions had been made (see final page of this section for ordering information).

Research has been completed, and the project report has been published in two volumes, as follows: NCHRP Report 216, "The No-Action Alternative: Research Report," highlights the findings of the research and documents the research activities, including summary reports of case studies, surveys, and pilot program activities undertaken with nine state agencies.

NCHRP Report 217, "The No-Action Alternative: Impact Assessment Guidelines," details how the research findings may be applied and provides recommended policy and procedural changes to strengthen both assessment and evaluation of all alternatives, presents the recommended approach for the definition and use of the no-action alternative, and includes methods for assessing 13 categories of impacts and evaluating the results. Although the recommendations may require adjustment and "tailoring" by each user agency, the net effect of the Guidelines should be to encourage standardization of practice and more effective use of the no-action alternative.

Project 8-12 FY '75

Travel Estimation Procedures for Quick Response to Urban Policy Issues

Research Agency:	Metropolitan Washington Council of Governments
Principal Invest.:	George V. Wickstrom Arthur B. Sosslau
Effective Date:	September 3, 1974
Completion Date:	December 31, 1975
Funds:	$39,895

Most techniques for estimating urban travel demand were developed to evaluate alternative transportation systems for an entire region. Application of these comprehensive techniques to provide timely answers to current policy questions has proven very difficult. This research effort was initiated to assemble and modify existing techniques, as well as to develop new approaches, for use by transportation planners faced with the need to be more responsive to current issues.

Research has been completed, and the major findings have been incorporated into the research report emanating from Project 8-12A and published as: NCHRP Report 186, "Travel Estimation Procedures for Quick Response to Urban Policy Issues."

Project 8-12A FY '75 and FY '76

Travel Estimation Procedures for Quick Response to Urban Policy Issues

Research Agency:	Comsis Corporation
Principal Invest.:	Arthur B. Sosslau George V. Wickstrom
Effective Date:	November 1, 1975
Completion Date:	October 31, 1978
Funds:	$239,331

This continuation of Project 8-12 has provided a user's guide of travel estimation techniques having quick response capabilities. The techniques are applicable for use by transportation and land-use planners, giving emphasis to the impacts of land-use changes on transportation alternatives and the magnitude of urban activities consistent with differing levels of transportation service. Problems of scale are addressed; e.g., the applicability of techniques to regions, subregions, and corridors.

Detailed descriptions of manual techniques for use in each aspect of travel demand estimation (i.e., trip generation, trip distribution, modal choice, auto occupancy, time-of-day distribution, traffic assignment, capacity analysis, and development density versus highway spacing relationships) were developed in this research. Numerous charts, tales, and nomographs were prepared to simplify each analysis step. Data requirements were also reduced by making maximum use of transferable parameters developed from other studies and urban areas. Three scenario applications of the manual techniques were conducted to illustrate the potential usefulness of the various analysis techniques. The presentation of the procedures in the final report is structured to allow their utilization by transportation planners with various levels of experience.

Instructional materials for use in training sessions or workshops were developed based on the manual techniques described in the user's guide. These materials include more than 400 slides, 50 transparencies, an instructor's notebook, and a student's notebook. The training package is available from NCHRP on loan upon written request or may be purchased. Requests should be directed to NCHRP.

The research report and user's guide have been published, respectively, as: NCHRP Report 186, "Travel Estimation Procedures for Quick Response to Urban Policy Issues," and NCHRP Report 187, "Quick-Response Urban Travel Estimation Techniques and Transferable Parameters—User's Guide."

Project 8-13 FY '75

Disaggregate Travel Demand Models

Research Agency: Charles River Associates
Principal Invest.: William B. Tye
Effective Date: September 15, 1974
Completion Date: January 31, 1976
Funds: $100,000

The over-all objective of this research was to develop, in separately funded phases extending over several years, operational travel demand forecasting models consistent with travel choice behavior and with coefficients estimated by use of data at the level of households or individual travelers. It was anticipated that such models will form the basis of improved travel demand estimation procedures.

Models were developed in Phase I using Pittsburgh and Minneapolis/St. Paul data bases. Binary logit models were estimated for (1) the mode choice for work, (2) the mode choice for shopping, (3) the destination choice for shopping, and (4) the trip frequency choice for shopping. A report, "Disaggregate Travel Demand Models: Phase I Report," presents the major findings and is available in microfiche (see final page of this section for ordering information). In the report, the models are appraised in terms of their advantages in travel demand analysis, their low data collection costs, their transferability, and their flexibility in application. Several hypothetical applications are provided.

Research was continued as Project 8-13(2).

Project 8-13(2) FY '77

Disaggregate Travel Demand Models

Research Agency: Charles River Associates, Inc.
Principal Invest.: William B. Tye
Effective Date: May 1, 1976
Completion Date: December 31, 1980
Funds: $200,000

This project was a continuation of Project 8-13. The overall objective of the research was to develop operational travel demand forecasting models consistent with travel choice behavior and with coefficients estimated by use of data at the level of households or individual travelers.

Phase II extended the Project 8-13 research program: (1) to conduct one or more demonstrations of the disaggregate models applied to policy issues at a state or local planning agency; and (2) to determine an approach to be used in solving problems that will be incurred in application (such as application of disaggregate models to aggregate data and aggregate forecasting). A worktrip mode-choice model, developed with Pittsburgh, Pa., data was used to predict the share of trips attracted to a new park-and-express-ride bus service in Baltimore. The predicted ridership was approximately one-half of the observed trips. The application uncovered potential pitfalls in the application of disaggregate models, particularly when using aggregate data, that provided valuable information for the preparation of recommendations in the final report. To meet Objective 2, a market segmentation approach was developed to overcome bias problems, when aggregating from households to a subregion and when using aggregate time and cost variables. The Phase II report is available on microfiche (see final page of this section for ordering information).

The project was concluded in a third phase in which disaggregate models were developed for the work trip using the Baltimore Disaggregate Data Set. Guidance on the transferability of these models together with those developed previously using Pittsburgh and Twin Cities (MN) data sets is provided in a final report intended as

an "entry point" for transportation planners interested in applying disaggregate models. In addition to transferability, guidance is given on other impediments to the implementation of disaggregate models such as how to aggregate the results for a corridor or urban area and how to overcome problems in using the multinomial logit form of models.

The report is in two parts. Part I is oriented to the technologist with a familiarity of travel demand forecasting techniques who desires to apply disaggregate models. Part II, Appendixes to Part I, is directed to the expert who already has some knowledge of some major issues in the field.

The project report has been published as: NCHRP Report 253, "Application of Disaggregate Travel Demand Models."

Project 8-14 FY '75

New Approaches to Understanding Travel Behavior

Research Agency:	Boston College
Principal Invest.:	Marc A. Fried
	John Havens
Effective Date:	January 1, 1975
Completion Date:	April 30, 1977
Funds:	$144,135

The over-all objective of this research was to develop, test, and operationalize a behavioral theory of travel based on needs and constraints, system availability, and activity site accessibility of potential travelers. This theory will be responsive to today's policy questions and hold potential for being responsive to future policy questions.

A careful review and evaluation was made of the transportation planning, economics, sociology, geography, and psychology literature to identify theoretical elements related to individual travel. This work was synthesized into a travel behavior theory comprised of two components—a microtheory and a macrotheory. The microtheory concept proposes that individuals in similar social status positions, in similar life stages, living in similar environments, will adapt in similar and partially predictable ways. Important to this theory are role patterns and attitude structures. The macrotheory is concerned with how the existence of activity opportunities and constraints modifies or reinforces behaviors specified in the microtheory. The microtheory deals with the individual's demand for activity opportunities; the macrotheory, with the generation of the activity opportunity sets (i.e., transportation supply).

Microfiche of the project report, "Travel Behavior: A Synthesized Theory," is available (see final page of this section for ordering information). The Summary from the project report has been published in Appendix G of NCHRP Report 250, "New Approaches to Understanding Travel Behavior."

The following unpublished, working papers were written and are available on a loan basis upon written request to the NCHRP:

1. Classification and Evaluation of Social Science and Transportation Issues; Marc Fried and John Havens.
2. Preliminary Dimensions for Classification and Evaluation; Marc Fried and John Havens.
3. Toward a Mathematical Framework for Modelling Urban Travel Behavior; John Havens.
4. Issues in the Analysis of Attitudes (Attitude Theory); Marc Fried.
5. Attitudes toward Transportation; Marc Fried.
6. The Theory of Decision Dilemmas and Directions; John Havens.
7. Residential Mobility, Residential Location and Travel Behavior; Matthew Thall.
8. Spatial Cognition and Transportation; Deana D. Rhodeside.
9. A Review of Temporal Cognition; Daniel Rogan.

Research was continued as Project 8-14A. It is incorporating key elements of the synthesized theory into present travel demand forecast methods.

Project 8-14A FY '77

New Approaches to Understanding Travel Behavior: Phase II

Research Agency:	Charles River Associates
Principal Invest.:	Peter Allaman
Effective Date:	January 1, 1978
Completion Date:	June 30, 1982
Funds:	$221,250

NCHRP Project 8-14 initiated development of a new approach to understanding travel behavior, concentrating on social and psychological relationships between individuals and their households as they exist in spatial layouts. The research carefully reviewed sociology and psychology literature as well as related fields that pertain to travel behavior. From this, a number of elements were identified that would assist in development of a theory, or theories, of travel behavior. Because of the complexity and extensiveness of the elements proposed, it was further determined that research (Phase II) would concentrate on testing three key elements relating to individual and household behavior and incorporating those elements into operational travel forecasting procedures, such as the Urban Transportation Planning System.

The key elements (or concepts) tested included the following:

1. Activity and travel patterns can be related to demographic descriptors such as social class, ethnicity, life cycle, and lifestyle.

2. Intervening factors between activity and travel patterns include social roles and resource constraints.
3. Household activity choice, duration, scheduling, and location determine travel.

Explicitly excluded from consideration were potential models developed from theories of adaptive processes. Although this is a valid subject for future research, the timeliness of useful travel forecasting techniques coming from these theories was questionable.

The interim report, entitled "Behavioral Science Concepts for Transportation Planners," is available on microfiche (see final page of this section for ordering information).

The project report has been published as: NCHRP Report 250, "New Approaches to Understanding Travel Behavior."

Project 8-15 FY '75

State and Regional Transportation Impact Identification and Measurement

Research Agency: Bigelow-Crain Associates
Principal Invest.: Charles D. Bigelow
Effective Date: September 1, 1974
Completion Date: May 31, 1976
Funds: $80,000

The general objective of this research was to develop an improved understanding of specific, and operational, impact identification and measurement techniques, for use by transportation agencies in contributing to a variety of State and regional transportation decisions. To achieve the stated objective, the research was conducted in two phases.

Phase I documented specific identification and measurement techniques in contrast to issues of impact evaluation. The investigation considered the direct and indirect impacts of economic development; land use and housing; air, noise, and water quality; energy utilization; natural resources and ecosystems; and social and community structure.

The Phase I report, "State and Regional Transportation Impact Identification and Measurement," was not published. Loan copies are available upon written request to the NCHRP or microfiche may be purchased (see final page of this section for ordering information).

Project 8-15A FY '75

Economic Impacts of State Transportation Policies and Programs

Research Agency: Regional Science Research Institute
Principal Invest.: Dr. Benjamin H. Stevens
Effective Date: October 1, 1977
Completion Date: March 31, 1980
Funds: $117,852

The identification of social, economic, environmental, and energy impact measurement techniques for use by state and regional transportation agencies was undertaken in NCHRP Project 8-15, "State and Regional Transportation Impact Identification and Measurement." This first phase of a two-phase project resulted in an extensive summary of existing impact measurement techniques and identified a wide range of related research needs.

The objective of the second phase, NCHRP Project 8-15A, was to demonstrate the usefulness of available techniques that estimate the impact of alternative transport policies and/or programs on economic activities, and to document the techniques in the form of operating guidelines and demonstration results. The scale of analysis was at the statewide and/or economic region levels rather than urban, and the techniques selected for demonstration included regional input-output analysis and econometric simulation models.

The final report contains a set of guidelines to permit state and/or regional agencies to apply the techniques to policy and/or program alternatives. Two handbooks were prepared: (1) basic input-output analysis, and (2) forecasting and policy simulation.

The final report and handbooks were not published; however, loan copies are available upon written request to the NCHRP or microfiche may be purchased (see final page of this section for ordering information).

Two computer programs are also available from the NCHRP. The input-output model, including two computer tapes, may be purchased for $60 if NCHRP provides the tapes or $20 if the requester provides blank tapes. The forecasting and policy simulation model may be purchased for $30 on NCHRP's tape or $10 on the requester's tape.

Project 8-16 FY '76

Guidelines for Public Transportation Levels of Service and Evaluation

Research Agency: University of Tennessee
Principal Invest.: Ray A. Mundy
Kenneth W. Heathington
Effective Date: January 1, 1976
Completion Date: December 31, 1980
Funds: $489,952

Project 8-16 was initiated in order to develop a method that would be used by planners to provide public officials with the desired information and direction for local public-transportation actions. The initial 12-month period of the project was spent conducting an in-depth analysis of present procedures and practices of the urban mass transit industry. Included in this effort were research team visits to 18 urban areas within the United States. From this research process, a descriptive, comprehensive, planning model was developed depicting the necessary information and procedural steps required for the application of mar-

ket opportunity analysis (from the private business world) to the planning of short-range public transportation. As depicted in the model, the application of market opportunity analysis requires both direction from policy decision areas and data from an engineering data base. When applied, the market segments are identified, the transportation needs are determined, a transportation system is developed to meet the needs, and the system is tested. The model was tested in a neighborhood of Jacksonville, Florida, and is considered applicable to cities in the 50,000 to 500,000 population range.

Research was completed, and the project report published in five volumes, as follows: NCHRP Report 208, "Market Opportunity Analysis for Short-Range Public Transportation Planning—Procedures for Evaluating Alternative Service Concepts," presents a suggested general procedure to match desirable service attributes resulting from a market segmentation study with alternative service concepts to determine which alternative services are appropriate for a local area. Alternative service concepts were classified as to vehicle type, degree of right-of-way control, and operational strategy (routing, scheduling, and stop location). Also presented are generalized break-even curves for conventional bus, express bus, demand responsive, and ridesharing services. Because various institutional factors (e.g., work rules, public vs. private provider) can greatly affect costs, it is recommended that the planner first complete a rough feasibility analysis to limit the range of alternatives and then perform a "customized" cost analysis. It is proposed that many institutional barriers can be overcome if a viable cost-effective concept can be identified.

NCHRP Report 209, "Market Opportunity Analysis for Short-Range Public Transportation Planning—Transportation Services for the Transportation Disadvantaged," addresses issues arising from the provisions of recent legislation and regulations. Social and economic impacts are substantial. Recommendations are developed on the premise that existing legislation and regulations are susceptible to change. Through an elucidation of the issues and alternative courses of action, this report should help in future selection of more efficient, economical, and socially acceptable approaches.

NCHRP Report 210, "Market Opportunity Analysis for Short Range Public Transportation Planning—Economic, Energy, and Environmental Impacts," contains the recommendation that impact analyses be based on expected market utilization instead of theoretical system capacities. Information is provided both for the Engineering Data Base and the Service Design sections of the model. The findings described in the report will assist the analyst in structuring information to permit an analysis of various public transportation service alternatives in meeting specified objectives even though the objectives may be in conflict.

NCHRP Report 211, "Market Opportunity Analysis for Short-Range Public Transportation Planning—"Goals and Policy Development, Institutional Constraints, and Alternative Organizational Arrangements," presents discussions of the rationale and procedural steps necessary to develop workable goals for urban public transportation. Without such direction, little guidance is given to the decision-maker as to what markets to concentrate on and how to measure systemwide performance. The report addresses the task of determining goals and policies, as well as the issues involved in preparing a goal/policy statement, for public transportation in an urban community. The information developed should serve as a guide for planners responsible for coordinating goal/policy development activities in an urban community.

Also addressed are the critical institutional issues that transportation planner and decision-makers must face when attempting to provide new or improved public transportation services. Various federal, state, and local regulatory and institutional patterns have developed for the provision of urban public transportation services. A thorough understanding of these issues is necessary in order to involve both public and private operators in the provision of public transportation services. The prospective opportunities for new private and minority firms to begin public transportation services have been developed as an integral part of this report.

The report also provides information from which policy decisions can be made regarding appropriate organizational arrangements for providing public transportation services. This material should be of use to two major groups: (a) agencies having the responsibility for developing and implementing the organizational structure for planning and providing public transportation and services at the local level, and (b) agencies having the responsibility for planning, designing, implementing, and operating public transportation services at the local level. It is stressed in this report that with a market-oriented public transportation system management approach the organizational structure must be tailored to the needs of the local area's needs and political environment.

NCHRP Report 212, "Market Opportunity Analysis for Short-Range Public Transportation Planning—Method and Demonstration," adds substantially to the body of knowledge concerning short-range public transportation planning for cities in the 50,000 to 500,000 population range. A descriptive comprehensive planning model was developed depicting the necessary information and procedural steps required for the application of market opportunity analysis (from the private business world) to public transportation planning. As depicted in the model the application of market opportunity analysis requires both direction from policy decision areas and data from an engineering data base. When applied, the market needs are determined, a transportation system is developed to meet the needs, and the system is tested. The

model was tested in a neighborhood of Jacksonville, Florida, at a cost of approximately $100,000. The report concludes that further demonstration of the planning model will be required to determine whether the benefits from application outweigh the costs of data collection. If the entire process were duplicated in another test city, the costs would be expected to be 50 to 60 percent of the initial effort.

Each report is aimed at one specific segment of the overall concept model; together they provide comprehensive guidelines for public transportation officials covering the three primary activities described in the model—policy, marketing, and engineering.

Project 8-17 FY '76

Freight Data Requirements for Statewide Transportation Systems Planning

Research Agency: Roger Creighton Associates, Inc.
Principal Invest.: Frederick W. Memmott
Richard B. Blackwell
Effective Date: July 15, 1975
Completion Date: February 15, 1977
Funds: $231,147

The general objective of this research was, first, to determine the type, amount, and relative importance of freight data required to develop statewide transportation system plans; and, second, to design and develop techniques, methods, and procedures for assembling these data.

This research was conducted in two phases. Specific tasks completed in Phase I were to:

1. Identify the types of freight data necessary for statewide transportation systems planning purposes. Recommend what type of data and the scale of detail that will be required in view of the current and proposed planning methodologies.
2. Rank these data requirements in terms of their relative importance to statewide transportation systems planning.
3. Given the data requirements, catalogue and determine the existence of available data in reference to the planning data requirements determined in Task 1. Investigate the institutional problems and constraints in the use of freight data (e.g., disclosure restrictions, proprietary nature of shipper and carrier data, and joint use and reciprocity agreements among private and public parties).
4. Identify deficiencies in existing freight data and evaluate the criticality of such deficiencies to statewide transportation systems planning.
5. Develop and evaluate alternative strategies for resolving such deficiencies.

Specific tasks completed in Phase II were to:

1. Prepare a manual describing in detail appropriate techniques for the assembly and understanding of existing freight data and the collection and understanding of such additional data as may be required by statewide transportation systems planning.
2. Provide illustrative, realistic examples of how to apply these techniques to typical problems encountered in statewide transportation systems planning.

Research has been completed, and the two-volume project report has been published as: NCHRP Report 177, "Freight Data Requirements for Statewide Transportation Systems Planning—Research Report;" and NCHRP Report 178, "Freight Data Requirements for Statewide Transportation Systems Planning—User's Manual."

Project 8-18 FY '76

Techniques for Evaluating Options in Statewide Transportation Planning/Programming

Research Agency: Planning Environment International, A Division of Alan M. Voorhees & Associates
Principal Invest.: Dr. Salvatore J. Bellomo
Dr. Joseph R. Stowers
Effective Date: September 1, 1975
Completion Date: June 30, 1978
Funds: $300,393

The general objective of this research was to provide transportation planning methodologies that are policy-sensitive, allowing the testing and evaluation of options to produce timely results for decision-making. This research addressed reasonable-cost, sketch-planning-type techniques having an application to issues of statewide transportation planning as part of the programming process. This research was conducted in two phases.

Phase I has been completed, and the final report has been published as: NCHRP Report 179, "Evaluating Options in Statewide Transportation Planning/Programming—Issues, Techniques, and Their Relationships." A comprehensive classification of transportation issues, data requirements, and existing techniques is included.

Phase II, consisting of test applications in Maryland (priority programming system—PPS), Georgia (energy conservation forecasting techniques), and Kentucky (highway user revenue model—HURM, and short-range capital resource availability model—SCRAM), has also been completed, and the final report has been published as: NCHRP Report 199, "Evaluating Options in Statewide Transportation Planning/Programming—Techniques and Applications." The computer programs for PPS, HURM, and SCRAM may be purchased upon written request to the NCHRP.

Project 8-19 FY '77

The Relationship of Changes in Urban Highway Supply to Vehicle-Miles of Travel

Research Agency: Cambridge Systematics, Inc.
Principal Invest.: Earl R. Ruiter
Effective Date: December 1, 1976
Completion Date: November 30, 1978
Funds: $199,954

The objective of this project was to determine whether a relationship exists between measures describing urban highway supply and vehicle-miles of travel (VMT) and, if so, to quantify the relationship for practising planners through preparation of appropriate graphs and nomographs.

The research approach hypothesized that VMT can only be expressed and predicted in terms of its components—vehicle trips and vehicle trip lengths—if it is to be validly predicted. These components, in turn, were predicted using a structural model system—one which employs both travel demand and supply models in a framework which approximates network equilibrium. The recognition of trips, and not VMT, as the appropriate unit for measuring demand was the key to the research approach.

The research results indicate that VMT changes do occur as highway supply changes, but the changes are small (e.g., ½ percent in the peak hour for a new urban freeway) and the relationship is a complex one. To quantify the relationship, the following variables must be considered: trip frequency, trip distance, auto occupancy, and mode split. Different results may be anticipated depending upon (1) the type of highway supply change, (2) the scale of the highway supply change, (3) the context within which the supply change takes place, and (4) the time scale. The complexity of the relationship has two important consequences: first the direction of VMT change for a given highway supply—change can vary; second, there are many variables that affect both the direction and the magnitude of VMT changes.

Because the model system was applied to only two highway supply cases, it was not possible to develop the graphs and nomographs needed to quantify the relationship. Nevertheless, short-range results for two urban radial freeway cases (1) new construction and (2) expansion were obtained. For the new freeway case, VMT increased as highway supply increased, both in peak and off-peak periods. In the freeway expansion case, peak-period VMT increases were offset by off-peak decreases to produce a slight, overall decrease in VMT. The most important components of VMT changes for both facilities were total person trips, which increased; and average trip distance, which decreased. Less important (by an order of magnitude) were the auto mode split and auto occupancy components.

None of the existing, aggregate, areawide VMT models was successful in matching the model system results obtained in this project for both test facilities. Although this fact in itself did not invalidate either modeling approach, it did suggest that areawide models are severely limited in their potential usefulness because they fail to consider differences in types of highway supply changes.

Although VMT increased for one test facility, and slightly decreased for the other, VMT-related impacts for both cases generally improved when studied at the urban area level. Measures of urban mobility, quality of travel service, air quality (with the exception of the relatively less critical level of NO_x pollutants), fuel consumption, and travel safety all were improved.

Two measures, directly relating VMT and highway supply, were recommended. These were the fraction of new capacity "used" (Δ VMT/Δ VMC) and the elasticity of VMT with respect to vehicle-miles of capacity (E [VMT/VMC]).

Microfiche of the agency final draft report is available and the results are summarized in Research Results Digest 127 (see final page of this section for ordering information).

Project 8-20 FY '78

Improved Methods for Vehicle Counting and Determining Vehicle-Miles of Travel

Research Agency: John Hamburg & Associates
Principal Invest.: Charles C. Francis, Jr.
Effective Date: January 2, 1978
Completion Date: July 31, 1980
Funds: $200,000

The objective of this research was to develop improved cost-effective procedures for conducting highway vehicle counting programs and determining vehicle-miles of travel (VMT). Research addressed the collection of traffic counts, processing of such counts, and production and use of traffic information. Although the primary thrust of the research was directed toward state-level programs, the findings include appropriate applications at sub-state, rural, and urban jurisdictional levels.

A three-volume final report was prepared: (1) State of the Art, (2) Traffic Counting Program Design, and (3) Idealized Traffic Volume Information System. Loan copies are available or microfiche of the report may be purchased (see final page of this section for ordering information).

Project 8-21 FY '79

Guidelines for Use of Vanpools and Carpools as a Transportation System Management Technique

Research Agency: George Washington University
Principal Invest.: Marian Misch
Joseph Margolin
Effective Date: March 1, 1979
Completion Date: June 30, 1981
Funds: $265,486

The general objective of this research was to identify effective policies and their impacts to encourage vanpooling and carpooling use based on an understanding of individual and household preferences and behavior. Specifically, the research analyzed individual and household attitudes, preferences, and behaviors related to ridesharing. The goal was to use the analysis results to develop a manual for transportation practitioners and policy-makers for selecting techniques that are compatible with other TSM strategies and were likely to result in significant increases in ridesharing over the short term (2 to 5 years).

The manual is designed to assist both existing and new ridesharing agencies in their continuing development as successful, community-oriented service organizations. It integrates the results of literature search, contacts with local ridesharing agencies, and findings from decision analysis panels and surveys conducted in four metropolitan areas of the United States. The manual provides guidelines for the several stages that any local ridesharing agency will experience in setting up a community ridesharing program; it also details these stages, which are briefly described as follows:

- Understanding the goals and nature of ridesharing and of ridesharers.
- Understanding the community conditions and characteristics that affect ridesharing programs.
- Adopting program design guidelines or policies suited to the community and its commuters.
- Planning the ridesharing program.
- Implementing the program.
- Operating the program while encouraging and/or responding to indirect incentives, such as high occupancy vehicle lanes.
- Evaluating and improving the program.

Research has been completed and the manual has been published as: NCHRP Report 241, "Guidelines for Using Vanpools and Carpools as a TSM Technique." Appendix D of the project report summarizes the research findings on which the manual is based. Detailed findings and survey data are documented in the agency's final report, "Using Vanpools and Carpools as a Transportation System Management Technique: Research Report." The agency research report may be purchased for $11.50. Microfiche is also available. See final page of this section for ordering information.

Project 8-22 FY '79

Transportation Financing Within the Context of Energy Constraints

Research Agency: System Design Concepts, Inc.
Principal Invest.: Dr. Joseph R. Stowers
Effective Date: March 26, 1979
Completion Date: February 27, 1981
Funds: $100,000

The general objective of this research was to determine the impacts of energy conservation policies and proposals on state transportation financing. A methodology was developed to enable States to assess the impact of existing and proposed energy conservation policies on travel and fuel consumption and to determine user and non-user impacts on the various revenue sources currently used to finance highway construction, operation, and maintenance.

The research identified possible modifications of existing State-level revenue sources and/or proposed new sources which would lend themselves to creating some stability and reasonable growth in future over-all highway transportation funding.

The researchers reviewed procedures used at the national and state levels to estimate vehicle-miles of travel and fuel consumption. The procedures included trend-based methods, econometric models, and less complex techniques. Also, revenue sources for each state were summarized. A catalog and description of applicable methodologies and supporting state and national baseline data that are available to the states to predict highway travel and fuel consumption in their jurisdictions under existing and proposed energy conservation policies were developed.

Research has been completed, and the findings have been published as: NCHRP Report 231, "State Transportation Finance Within the Context of Energy Constraints."

Project 8-23 FY '79

Fuel Supply Limitations and Passenger Travel

Research Agency: Charles River Assoc., Inc.
Principal Invest.: Timothy Tardiff
Effective Date: April 2, 1979
Completion Date: September 1, 1980
Funds: $110,000

The research project synthesized planning methods, appropriate for use by professional planners, to evaluate policy alternatives for likely future energy shortfall scenarios. These methods were applied to four energy-deficient scenarios and the resulting changes in travel estimated. The four scenarios were based on a literature review and evaluation of current events during the course of the research. These scenarios considered magnitude, frequency, and duration of shortfall, gasoline price, and government actions to conserve gasoline (odd/even purchasing, gasoline rationing, etc.). Methods chosen were incremental logit models for work trips and linear equation models for nonwork trips. For the four scenarios, policy alternatives were evaluated in terms of modal shares, VMT, bus miles of travel, private vehicle fuel consumption and transit fuel consumption. A comparison of scenario testing results with the selected models provided an indication of the relative effects of price, con-

tingency actions, and sticker plan on fuel consumption. Contingency actions included free tolls for carpools, bus priority treatment at intersections and traffic signals, exclusive contraflow bus lanes on highways, increases in parking fees, and reductions in on-street parking. Driving restriction imposed by the sticker plan led to the highest reduction in private vehicle fuel consumption. The second highest reduction resulted from higher gasoline prices in the range of $2.00 to $3.00 per gallon.

Research has been completed, and the project report has been published as: NCHRP Report 229, "Fuel Supply Limitations and Passenger Travel."

Project 8-24 FY '80

Forecasting the Basic Inputs to Transportation Planning

Research Agency: John Hamburg & Associates, Inc.
Principal Invest.: Dr. George T. Lathrop
Effective Date: January 21, 1980
Completion Date: April 30, 1982
Funds: $81,000

The research has produced a concise reference for transportation planners concerned with using projected socioeconomic and demographic characteristics in transportation planning. Guidance is provided on the accuracy and usefulness of various projection techniques for various levels of aggregation and periods of time.

Two general areas of research were pursued:

1. The sensitivity of the transportation planning process, particularly trip generation, to variation in input socioeconomic and demographic variables.
2. Review and evaluation of methodology for producing study area level projections either on the basis of other projections or independently.

Research has been completed and results have been published in NCHRP Report 266, "Forecasting Inputs to Transportation Planning."

Project 8-24A FY '83

Forecasting the Basic Inputs to Transportation Planning at the Zonal Level

Research Agency: COMSIS Corporation
Principal Invest.: Arthur B. Sosslau
Effective Date: April 1, 1987
Completion Date: June 1, 1989
Funds: $200,000

Transportation planners forecast travel demand on the basis of anticipated changes in socioeconomic variables such as population, employment, vehicle availability, income, and household size. Errors in the forecasts of these variables can lead to substantial errors in information provided to decision-makers in the evaluation of transportation alternatives. NCHRP Project 8-24 investigated and reported on a portion of this problem area, specifically the preparation of aggregate forecasts for sub-state areas. It examined the sensitivity of the process (and particularly its first step, trip generation) to differences (or errors) in input. However, no analysis of the sensitivity of the process to disaggregation—or variation in aggregation—was performed. This continuation project investigates the availability and utility of methods to produce forecasts for units of sub-county levels of geography, typically traffic zones, either by downward allocation of sub-state forecasts or by direct means.

A problem that frequently arises is that the various techniques used to forecast socioeconomic variables produce significantly different results. Some forecasting techniques produce data that are incomplete or lack sufficient detail for travel estimates and impact assessments.

Recent demographic trends have demonstrated that extraordinary changes in the relationships between population, households, and labor force are not effectively treated in many existing forecasting procedures. Many jurisdictions are encountering more volatile growth patterns that demand a great sensitivity in forecasting methods. Moreover, changing demands on the planning process, including more project-oriented activities, and a frequent need for quick response have changed forecasting requirements.

Planning agencies face three types of circumstances in forecasting for sub-county areas: (1) top-down allocation mandated by the state in cooperation with the localities; (2) competing forecasts for localities, which must be reconciled; and (3) a lack of available forecasts from outside authorities. State and local planners need assistance in choosing techniques to respond to these problems.

Research is needed to document techniques that: (1) have been usefully applied by planning agencies, (2) are applicable at any sub-county level of aggregation, (3) are accurate for intended purposes, (4) are responsive to current planning needs, (5) have well-defined areas of application, and (6) can be implemented and updated by users who do not possess a sophisticated demographic, economic, or statistical background.

The objective of this research is to extend the work documented in *NCHRP Report 266* to describe and evaluate techniques for determining and forecasting the input variables critical for estimating transportation demand at the sub-county geographic level. To accomplish this objective, the following tasks will be performed:

Task 1—Representative methods for allocating or otherwise forecasting socioeconomic variables at the zonal level for large and small urban areas will be selected. At least, the following variables will be considered: population, households, employment by place of residence, workers by place of work, automobiles, and income. Agency sources, such as state DOTs and MPOs, will be used as well as traditional literature sources. The effectiveness of the selected methods will be briefly described

relative to extent of use, cost, simplicity, documentation, and software availability.

Task 2—The evaluation criteria to be used in Task 4 for each of the techniques to be considered will be identified.

Task 3—An interim report presenting the findings of the first two tasks will be prepared. This report will provide the basis for panel determination as to whether or not to proceed with the remainder of the research.

Task 4—This evaluation task will expand on the findings of Tasks 1 and 2:

Subtask 4.1—Applicable procedures and techniques for allocation or other forecasting procedures concerning population, jobs, households, vehicle ownership and availability, employment characteristics, income, and such other variables as are necessary for applications in transportation planning at the sub-county geographic level will be described and characterized. The descriptions and characterizations will clarify differences among and appropriateness of each procedure identified. Constraints or conditions under which each procedure is applied will be listed and described.

Subtask 4.2—For each of the procedures described in Subtask 4.1, discuss conditions of applicability, i.e., where and under what circumstances can such procedures be applied, and how universal or limited is the application.

Subtask 4.3—For each of the procedures described, discuss the types and level of skill necessary to apply the forecasting techniques in transportation planning situations. In addition, effectiveness of performance of these techniques (for example, the adequacy of forecasts for the desired levels of application) will be addressed.

Subtask 4.4—Concise numerical examples illustrating how each method is applied will be provided. The examples will clearly show data inputs and sources, step-by-step procedures of application, and output and its format. The data sources will be completely described and serve as guides to application by local planners (e.g., census data, local surveys, other sources). Where computer application is involved, software references will be provided.

Subtask 4.5—The advantages and disadvantages of each technique will be discussed. The discussion will include but not be limited to data needs, required skills, ease of application, output products, and costs.

Task 5—Research on zonal disaggregation problems will be addressed. The researcher will examine the sensitivity of final estimates of travel demand, i.e., link and line volumes, to changes in values, definitions, and dimensions of socio-input variables at the zonal level.

Task 6—A final report will be prepared documenting the research findings. To the extent practical the report will be prepared in a format suitable for use as a manual of practice for state and local transportation planners, specifically showing the individual steps to be taken in applying each method.

Tasks 1 through 4 have been completed and work is underway on Task 5 sensitivity testing. The project completion date was extended 6 months because of problems encountered in the selection, arranging, and scheduling of the sensitivity tests.

Project 8-25 FY '80

Intercity Bus Transportation Planning

Research Agency:	Peat, Marwick, Mitchell & Co.
Principal Invest.:	John F. DiRenzo
Effective Date:	April 1, 1980
Completion Date:	January 31, 1982
Funds:	$200,000

The objective of this research was to investigate intercity travel requirements, including those of small urban and rural areas, and to evaluate the role and potential of intercity bus services in meeting those requirements. Procedures were developed to determine appropriate level-of-service requirements for intercity bus services. The procedures are designed for use by state and local transportation planners as a means of identifying the relative needs of communities or sets of communities for intercity bus transportation, and as a tool for prioritizing the potential recipients of public assistance for the provision of such services.

Alternative bus service designs were developed that utilize the potential resources of intercity bus carriers to satisfy the public transportation requirements. The alternative service options include using smaller size vehicles, employing student or part-time drivers, truncating or extending a route, changing service frequencies, using local or regional operators, adding new stops, altering schedules, and coordinating service with local rural transit operations. The feasibility of these options was tested through case study applications in selected intercity corridors in California, Michigan, Minnesota, Pennsylvania, and South Carolina.

Actions state and local agencies can take to help the intercity bus operators meet the intercity service requirements were also identified. These actions include financial assistance such as fuel tax relief, registration fee reductions, and direct terminal equipment and operating grants; technical assistance such as distribution of intercity bus information, marketing, providing input to terminal location decisions, and coordination with other modes; and removal of regulatory and other barriers to intercity bus travel, as well as initiation of positive incentives to encourage greater utilization of services.

Research has been completed. The agency report has been distributed to the Program sponsors and other interested persons. It will not be published in the regular NCHRP report series but is available on a loan basis or microfiche of the report may be purchased (see final page of this section for ordering information).

Project 8-26 FY '81

Development of Highway Traffic Data for Project Planning and Design in Urbanized Areas

Research Agency: JHK & Associates
Principal Invest.: Neil J. Pedersen
Effective Date: May 15, 1981
Completion Date: December 31, 1982
Funds: $100,000

The objectives of this research were to (1) identify, review, and evaluate typical procedures currently being used to develop highway traffic data for project planning and design in urbanized areas; and (2) using existing techniques to the maximum extent possible, develop a user-oriented manual containing procedures for the full range of planning and design needs together with illustrative case studies.

Procedures and analysis techniques that have been proven reasonably successful were grouped and critiqued in terms of criteria including required degree of precision, resource requirements, ability to replicate the effort, and rationale. In addition, input data requirements such as system-level assignments, historical traffic count data, land-use information, and other factors were addressed.

A user-oriented manual was developed describing recommended procedures. Each procedure includes a commentary describing the benefits, shortcomings, and the circumstances that may require alternative steps. Design project "cases" with appropriate traffic estimating steps are described. Cases were selected to ensure coverage of the full range of applications and include: (1) use of refinement procedures for upgrading of a limited access highway, (2) use of windowing procedures for evaluating an arterial improvement, and (3) application of procedures to highway design.

Research has been completed, and the final report has been published as: NCHRP Report 255, "Highway Traffic Data for Urbanized Area Project Planning and Design."

Project 8-27 FY '80

Cost-Effectiveness of Transportation Services for Handicapped Persons

Research Agency: Transportation Center
University of Tennessee
Principal Invest.: Kenneth W. Heathington
Frederick J. Wegmann
Effective Date: September 1, 1981
Completion Date: April 30, 1983
Funds: $199,543

The objectives of this research were to determine the cost effectiveness of alternative transportation services for handicapped persons and to develop guidelines for state and local planners, transportation providers, and decision-makers on determining the most cost-effective way of meeting the transportation needs of handicapped people.

The research conducted under NCHRP Project 8-27 has resulted in the publication of two documents: *NCHRP Report 261,* "Cost-Effectiveness of Transportation Services for Handicapped Persons—Research Report," and *NCHRP Report 262,* "Planning Transportation Services for Handicapped Persons—User's Guide." NCHRP Report 261 documents the results of a study of the cost-effectiveness of alternative transportation services for handicapped persons. The companion document (NCHRP Report 262) provides planners and decision-makers with guidelines on how to evaluate alternative transportation services for handicapped persons and to identify the most cost-effective solutions for their communities.

Project 8-28 FY '87

Strategic Planning and Management for Transportation Agencies

Research Agency: Ernst & Whinney
Principal Invest.: Gene Tyndall
Effective Date: June 1, 1987
Completion Date: September 30, 1988
Funds: $180,000

Unlike the period from the end of World War II through the mid-1960's, which was generally characterized by stable economic growth and social and public policy environments, the 1970's and 1980's have been affected by an accelerating pace of change in economic, social, technological, and public policy factors. These factors interact in ways that require new efforts to properly position organizations in future operating environments. Institutions must develop mechanisms to assure adaptation to the ever-changing environment.

The need for new management systems incorporating more effective means of identifying new directions for organizations and shifts in allocation of resources to implement change was first recognized by the private sector. Strategic planning was initiated by large U.S. corporations in the late 1960's and early 1970's. Because of dissatisfaction with the results of strategic planning when it was conceived and applied only as a *planning function,* many corporations are expanding their approach to *strategic management.* In applying strategic management, the *skill* of strategic planning is practiced at all levels of the organization and is integrated into all other management systems to assure the "fit" of strategy to an organization. The expected result is a major improvement in organizational effectiveness.

By the late 1970's strategic approaches had begun to be applied in a few public transportation agencies. Research is now needed to determine the status of strategic planning and management in public sector transportation agencies, to develop an understanding of which approaches are applicable and effective in public agencies, and to identify potential pitfalls. The results of the research should provide transportation agencies with guide-

lines to support the successful application of strategic management.

The objectives of this research are to: (1) assess the applicability of strategic management approaches, and (2) provide principles and guidance (including relationships with other innovative management techniques) for implementation by publicly funded transportation agencies. Accomplishment of these objectives will require at least the following tasks:

Task 1—Seek out and evaluate work being done in strategic planning and management with a view to assessing applicability to transportation agencies in the public sector. Specific attention should be given to assessing reasons for success or failure.

Task 2—Identify and describe important principles in strategic management processes for publicly funded transportation agencies (including relationships with other management processes).

Task 3—Compare the relative merits of various approaches to strategic management, considering the needs, responsibilities, and operational procedures of a range of state and local transportation agencies. Given the applicability and principles of strategic management and ranges of organizational types, prepare guidelines for the implementation of strategic management in state and local transportation agencies.

Task 4—Prepare final report.

The agency preliminary draft final report has been submitted and is now under review.

AREA 9: BITUMINOUS MATERIALS

Project 9-1 FY '64 and FY '65

Asphalt Durability and Its Relation to Pavement Performance

Research Agency:	American Oil Company	
Principal Invest.:	Dr. A. W. Sisko L. C. Brunstrum	
Effective Dates:	Feb. 1, 1964	Nov. 1, 1965
Completion Dates:	July 31, 1965	Apr. 30, 1967
Funds:	$50,000	$50,000

The general properties with which this over-all problem was concerned involved rheological, chemical, and physio-chemical properties of the asphalt alone and as influenced by its interfacial relationship with aggregates. These properties and their values in the original asphalt and the retention of these values over a period of time in service are of importance.

Research has been completed, and the project report has been published as: NCHRP Report 67, "Relation of Asphalt Rheological Properties to Pavement Durability."

Project 9-2 FY '65

Asphalt Durability and Its Relation to Pavement Performance—Adhesion

Research Agency:	Montana College of Mineral Science and Technology
Principal Invest.:	D. W. McGlashan
Effective Date:	January 1, 1965
Completion Date:	October 31, 1967
Funds:	$101,903

This research was concerned with asphaltic concrete pavement performance, particularly with regard to the influence of asphalt-aggregate adhesion. The research approach was based on the principle that interfacial activity occurring at the boundary between an asphalt cement and an aggregate is influenced by the characteristics of the particular asphalt and aggregate and that this activity, measured in electrical quantities, provides a comparative assessment of the adhesion between the asphalt and the aggregate.

A data acquisition system was developed for making electrokinetic measurements of interfacial activity when asphalt cements were forced through porous plugs under controlled temperature and pressure conditions. The porous plugs contained aggregates that were being tested for adhesion. Data were collected and analyzed using 15 asphalt cements and a number of different aggregate types to demonstrate the ability of the procedure for assessing the adhesion of an asphalt-aggregate mixture.

The project report was not published in the NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 9-3 FY '65

Evaluation of Pavement Joint and Crack Sealing Materials and Practices

Research Agency:	Rensselaer Polytechnic Institute
Principal Invest.:	Dr. John P. Cook
Effective Date:	June 1, 1965
Completion Date:	June 30, 1966
Funds:	$24,996

The objectives of this research were to (1) prepare a state-of-knowledge report on joint and crack sealing materials, joint design, specifications, test methods, and construction practice; (2) make a critical analysis of the information and define needs to improve performance; and (3) recommend a feasible research program. Bituminous and nonbituminous materials were included, and due consideration was given to such factors as economics and practicalities of usage.

Research has been completed, and the project report has been published as: NCHRP Report 38, "Evaluation of Pavement Joint and Crack Sealing Materials and Practices."

Project 9-4 FY '72

Minimizing Premature Cracking of Asphaltic Concrete Pavements

Research Agency: Materials Research & Development
Principal Invest.: F. N. Finn
Keshavan Nair
Effective Date: November 1, 1971
Completion Date: June 30, 1973
Funds: $99,560

The objective of this project was the determination of suitable materials specifications, paving mix design criteria, and construction requirements that will result in the ability to design and construct asphaltic concrete pavements to carry design traffic with a minimum of premature cracking.

Research has been completed, and the project report has been published as: NCHRP Report 195, "Minimizing Premature Cracking in Asphaltic Concrete Pavement."

Project 9-4A FY '76

Bayesian Analysis Methodology for Verifying Recommendations to Minimize Asphalt Pavement Distress

Research Agency: Woodward-Clyde Consultants
Principal Invest.: F. N. Finn
W. S. Smith
Effective Date: September 15, 1975
Completion Date: November 1, 1978
Funds: $204,194

NCHRP Project 9-4 findings contain recommendations intended to reduce possibility of premature cracking of asphaltic concrete pavements and a proposed verification program. The generally accepted approach to verification has been to monitor performance using statistical analysis for evaluation of the variables. An alternate approach has been to verify an analytical model using a small experimental program and case histories of in-service pavements. One of the findings of NCHRP Project 9-4 indicates that these two approaches are not realistic for verification of the project recommendations because the cost, time, and scope required for such a program to reach definitive conclusions would be excessive.

In the same report, the Bayesian approach is suggested as an alternate for verification and updating of project recommendations. It uses the past experience of engineers in a meaningful statistical format combined with experimental data and experience gained from observation of field performance of new construction.

The objectives of this project were (1) development of a procedure based on Bayesian statistical concepts for verifying recommendations to minimize pavement distress and (2) pilot implementation of the verification procedure for the specific distress mode of cracking from repetitive traffic loading.

Research has been completed, and the project report has been published as: NCHRP Report 213, "Bayesian Methodology for Verifying Recommendations to Minimize Asphalt Pavement Distress."

Project 9-5 FY '80

Design of Emulsified Asphalt Paving Mixtures

Research Agency: The Asphalt Institute
Principal Invest.: V. P. Puzinauskas
B. F. Kallas
Effective Date: April 1, 1980
Completion Date: June 30, 1984
Funds: $150,172

The objective of this research was to verify and/or modify the Asphalt Institute and University of Illinois asphalt emulsion mix design methods described in Federal Highway Administration Reports No. FHWA-IP-79-1, "A Basic Asphalt Emulsion Manual," and No. FHWA-RD-78-113, "Mix Design Methods for Base and Surface Courses Using Emulsified Asphalt."

Research has been completed with partial accomplishment of objectives. It was found that neither of the two mix design methods is totally satisfactory for determining optimum asphalt emulsion and water contents and that there is a lack of compatibility between the methods. Modifications to the methods are recommended. The field studies indicate that construction practices and field activities influence performance of emulsified asphalt pavements to a greater extent than laboratory mix design.

The project report has been published as: NCHRP Report 259, "Design of Emulsified Asphalt Paving Mixtures."

Project 9-6A FY '85

Development of Asphalt-Aggregate Mixtures Analysis System: Phase I

Research Agency: ARE Inc.
Principal Invest.: F. N. Finn
Effective Date: June 2, 1986
Completion Date: October 2, 1986
Funds: $25,000

Improved asphalt concrete mix design methods should optimize the selection of asphalt binders and aggregate materials to produce pavements uniformly resistant to all forms of distress such as rutting, fatigue cracking and moisture damage. The Asphalt Advisory Committee of the Strategic Highway Research Program (SHRP) has recognized that currently used asphalt concrete mix design methods are not adequate for the laboratory evaluation of improved or new asphalt binders that are to be developed under SHRP and that any improved binders should be evaluated within the context of an improved asphalt-aggregate mixture analysis system.

The overall objective of Project 9-6 research was to develop an asphalt-aggregate mixture analysis system for the laboratory evaluation of asphalt binders and aggregate materials with regard to resistance to all forms of distress, both loads and environment associated, when used in the construction of asphalt concrete pavements. The evaluation included such elements as the preparation of test specimens, conditioning of the specimens, testing the specimens, and criteria for acceptance.

This project was funded from a portion of the $1,000,000 included in the FY '85 program for research on properties of asphalt cements with the provision that the research be coordinated with the strategic Highway Research Program activities on asphalt research.

The objective of Phase I of the research was to develop a concept for the design of an asphalt-aggregate mixture analysis system (AAMAS) and a research plan for the conduct of Phase II. This was one of three Phase I contracts.

Research has been completed, and the report has been reviewed in connection with the selection of an agency for conduct of Phase II. The report will not be published in the NCHRP report series.

Project 9-6B FY '85

Development of Asphalt-Aggregate Mixtures Analysis System: Phase I

Research Agency:	Brent Rauhut Engineering Inc.
Principal Invests.:	C. S. Hughes
	H. L. Von Quintus
Effective Date:	June 2, 1986
Completion Date:	October 2, 1986
Funds:	$25,000

See Project 9-6A for project description and status.

Project 9-6C FY '85

Development of Asphalt-Aggregate Mixtures Analysis System: Phase I

Research Agency:	University of Maryland
Principal Invests.:	Dr. M. W. Witezak
	V. P. Puzinauskas
Effective Date:	June 2, 1986
Completion Date:	October 2, 1986
Funds:	$24,879

See Project 9-6A for project description and status.

Project 9-6(1) FY '85

Development of Asphalt-Aggregate Mixtures Analysis System: Phase II

Research Agency:	Brent Rauhut Engineering, Inc.
Principal Invests.:	L. Von Quintus
Effective Date:	January 5, 1987
Completion Date:	November 4, 1988
Funds:	$425,000

The highway community recognizes the need for improved procedures and analysis systems for the design of asphaltic concrete pavement mixtures that will be resistant to heavy truck loads, the use of higher tire pressures, and the wide extremes of climate. Such systems should optimize the selection, proportioning, and processing of asphalt binders and aggregate materials to produce pavements resistant to all forms of distress.

The Strategic Highway Research Program (SHRP) plans to develop improved asphalt and/or new binders, tests and specifications for these binders, and performance-related specifications for asphaltic concrete paving materials. Improved procedures and analysis systems could be used for evaluation of the improved and/or new binders and for the design of the paving mixtures for test sections of the SHRP to obtain the necessary pavement performance information to develop performance-related specifications.

Research is needed to develop and refine an asphalt-aggregate mixture analysis system (AAMAS) for design of optimum paving mixtures based on performance-related criteria. These criteria would encompass a wide variety of failure modes, e.g., fatigue cracking, thermal cracking, permanent deformation, moisture damage, age hardening, etc. The AAMAS should be capable of accommodating conventional asphalt binders, modified asphalts, mixture modifiers, and the range of aggregate materials used in the United States. It should also be capable of evaluating the mixtures under conditions analogous to those found in service, including a wide range of climate, traffic, and age factors.

The objective of this research is to develop an asphalt-aggregate mixture analysis system (AAMAS) for the laboratory evaluation of asphaltic concrete mixtures. The system shall be based on specimens that as nearly as possible duplicate the characteristics of the mixtures in the field. Its application shall be limited to hot-mixed asphaltic concrete, excluding open-graded friction courses and drainage layers; and shall accommodate mixture variables, such as modified binders, aggregates, and fillers, used in the construction of asphaltic concrete pavements and shall provide for resistance to all forms of distress associated with both load and environment. The evaluation system shall include such elements as the preparation of test specimens, conditioning of the specimens, testing the specimens, and criteria for mixture selection. Research is being coordinated with other SHRP research in the asphalt area.

The objectives of Phase II of the research are to (1) develop the AAMAS in accordance with the concepts and plans prepared during Phase I, (2) conduct a laboratory evaluation of the system, and (3) prepare guidelines for its use. Major emphasis during development of the AAMAS will be on preparation, conditioning, testing, and analysis of asphalt-aggregate laboratory specimens that duplicate as nearly as possible the construction, en-

vironmental, and traffic conditions to which the pavement is likely to be subjected.

Asphalt concrete construction projects were selected in Colorado, Michigan, Texas, Virginia, and Wyoming for participation in Phase II of the project. Field construction procedures were documented, cores of newly compacted asphalt concrete obtained, samples of asphalt-aggregate mixtures actually used in the construction obtained, along with samples of the aggregates and asphalt binders. Laboratory specimens were prepared by several different methods to compare with the field cores. The laboratory specimens were subjected to various conditioning procedures and tests methods to identify techniques for predicting traffic loading and environmental forms of distress.

Research has been completed. The final report has been submitted and is being reviewed.

AREA 10: SPECIFICATIONS, PROCEDURES, AND PRACTICES

Project 10-1 FY '64

Development of Guidelines for Practical and Realistic Construction Specifications

Research Agency: Miller-Warden Associates
Principal Invest.: W. B. Warden
Effective Date: November 15, 1963
Completion Date: November 14, 1964
Funds: $25,000

It is recognized that many existing specifications do not properly consider variations in work and materials which are inevitable and characteristic of the best construction possible today. In a development of guidelines for adequate specifications, this project included such areas as surface smoothness for subgrades, bases, and pavements; thickness measurements for bases and pavements; gradation and other requirements for aggregates and aggregate mixtures; and a summary of selected current specifications pertinent to the areas of study. Consideration was given to the validity of specifications with respect to need in the accomplishment of purpose, economic impact inherent in specifications, natural variations inherent in work and material, and variations inherent in methods of measurement and control test procedures.

The final report for this project has been published as: NCHRP Report 17, "Development of Guidelines for Practical and Realistic Construction Specifications."

Project 10-2 FY '64

Evaluation of Construction Control Procedures

Research Agency: Miller-Warden Associates
Principal Invest.: S. B. Hudson
Effective Date: November 4, 1963
Completion Date: February 1, 1966
Funds: $59,750

This research was initiated to obtain needed basic information for the formulation of standards for evaluation and acceptance of work, materials, and highway construction. Its objectives included a study to determine variations inherent to measurement methods, testing techniques, and sampling methods and procedures. The scope of this study was confined to the examination and investigation of gradation of aggregates. It includes a review of measurement and test procedures to determine those not including precision statements and a study involving statistical techniques for evaluating gradation test procedures, sampling methods, and variations inherent in aggregate gradations.

Initial phase research has been completed, and the project report has been published as: NCHRP Report 34, "Evaluation of Construction Control Procedures—Interim Report."

Project 10-2A FY '65

Evaluation of Construction Control Procedures

Research Agency: Materials Research and Development
Principal Invest.: S. B. Hudson
Effective Date: July 15, 1966
Completion Date: November 14, 1967
Funds: $70,945

The continuation phase of Project 10-2 specifically considered (1) the variations in gradation of aggregates, including fine aggregates, drawn from the bins of operating hot-mix plants, with sampling error, short- and long-term variations, and the effect of cold-feed variations to be included; (2) a statistically designed experiment to determine the effect of variation in gradation of coarse aggregate, within the range found to be inherent under existing controls, on the strength and workability of laboratory-prepared concrete; (3) the effect of increment size with respect to maximum particle size and accuracy of the results of sampling to provide additional information as to the shape and minimum capacity of tools to be used for sampling coarse aggregates; and (4) further study of the basic pattern of variation of gradation.

Research has been completed, and the project report has been published as: NCHRP Report 69, "Evaluation of Construction Control Procedures—Aggregate Gradation Variations and Effects."

Project 10-3 FY '64 and FY '65

Effects of Different Methods of Stockpiling and Handling Aggregates

Research Agency:	Miller-Warden Associates	
Principal Invest.:	S. B. Hudson	
Effective Date:	Oct. 22, 1963	Oct. 15, 1964
Completion Date:	Apr. 30, 1964	Oct. 16, 1965
Funds:	$25,000	$30,000

The difficulties associated with producing aggregates and providing them at the job site within desirable specification limits have been recognized for many years. To provide further knowledge for a possible solution to these difficulties, the over-all objectives of this research were to (1) find the effects of stockpiling and handling on the properties of an aggregate, including segregation and degradation, and (2) establish suggested procedures for better practices in stockpiling and handling.

Initial research was directed principally to the aspects of stockpiling, and the results have been published as: NCHRP Report 5, "Effects of Different Methods of Stockpiling Aggregates."

Continuation of the initial research was authorized to expand the scope to include, in addition to further stockpiling investigations, the effects on aggregate properties of several routine methods for handling, spreading, and compacting bases. This work has been completed, and the project report has been published as: NCHRP Report 46, "Effects of Different Methods of Stockpiling and Handling Aggregates."

Project 10-4 FY '64 and FY '65

Rapid Test Methods for Field Control of Construction

Research Agency:	Clemson University	
Principal Invest.:	Dr. A. E. Schwartz	
Effective Date:	Feb. 1, 1964	May 1, 1965
Completion Date:	Feb. 28, 1965	Feb. 28, 1967
Funds:	$30,000	$69,320

It has been recognized that there is a need for improved methods of sampling and testing to keep pace wth accelerated production rates and increased volumes of materials being used in highway construction. In an effort to fulfill this need, this research project proposed to seek out areas in which rapid test needs are most critical and to explore and summarize existing knowledge in these areas with the ultimate aim of accelerating the development of new methods of meeting these needs.

Work in the initial phase of this project consisted of a survey of the state of the art in the development, need, and use of rapid test methods for field control of construction.

During the continuation phase, emphasis was placed on further development and evaluation of improved test procedures in the areas of asphalt content of bituminous paving mixtures, density of aggregate base courses and bituminous layers, gradation of aggregates, and soil compaction.

Research has been completed, and the project report has been published as: NCHRP Report 103, "Rapid Test Methods for Field Control of Highway Construction."

Project 10-5 FY '64 and FY '65

Density and Moisture Content Measurements by Nuclear Methods

Research Agency:	Research Triangle Institute	
Principal Invest.:	Dr. R. P. Gardner	
Effective Date:	Jan. 15, 1964	Apr. 1, 1965
Completion Date:	Jan. 31, 1965	Oct. 7, 1966
Funds:	$28,801	$59,835

For the past several years, investigators have studied the application of nuclear devices for determining moisture content and density of subgrade, subbases, and base components. Some of the researchers have indicated such devices are applicable for field control, while others are still evaluating the technique. If these nuclear devices are capable of accurate and reliable determinations, there is a possibility that considerable economy may result in construction and control procedures. The objectives of the initial research were (1) to review the literature and other available data to determine what has been done by others in the evaluation and correlation of nuclear equipment, (2) to evaluate and analyze assembled data considering such factors as accuracy and precision, and (3) to make recommendations for the development of needed equipment.

Research on the initial phase has been completed, and the project report for this phase has been published as: NCHRP Report 14, "Density and Moisture Content Measurements by Nuclear Methods—Interim Report."

The objective of the continuation phase was to investigate, in depth, the promising findings from the initial research. Theoretical investigations were supplemented by field experiments to establish a technique for calibrating nuclear gauges to provide improved accuracy in the measurement of soil moisture content and density. In the pursuit of these objectives, calibration standards were developed which are applicable to nuclear gauges currently in use.

Research on the continuation phase has been completed, and the project report for this phase has been published as: NCHRP Report 43, "Density and Moisture Content Measurements by Nuclear Methods."

Project 10-5A FY '68

Optimization of Nuclear Density and Moisture Content Measurement Methods

Research Agency: North Carolina State University
Principal Invest.: Dr. R. P. Gardner
Effective Date: February 1, 1968
Completion Date: January 31, 1970
Funds: $51,214

The essential objective of this study was to optimize nuclear gauge calibration methods and thus improve operational performance of the gauges for control of moisture and density during construction of highway subgrade, subbase, and base components. The objectives of the research have been met. Procedures have been developed for optimization of nuclear backscatter-type density gauge calibration, a quantity factor approach has been developed for evaluating the over-all performance of density gauges, and a tentative model is available for improved calibration of nuclear moisture gauges. The research has also provided a basis for design of even better nuclear backscatter-type density gauges.

Research has been completed, and the project report has been published as: NCHRP Report 125, "Optimization of Density and Moisture Content Measurements by Nuclear Methods."

Project 10-6 FY '64 and FY '65

Measurement of Pavement Thicknesses by Rapid and Nondestructive Methods

Research Agency: IIT Research Institute
Principal Invest.: K. E. Feith
Dr. S. D. Howkins
Effective Date: February 1, 1964
Completion Date: October 31, 1966
Funds: $108,821

Present methods of measuring the thicknesses of highway pavements are time consuming and generally do not provide data early enough for the contractor to alter operations so as to comply. It is recognized that a nondestructive technique would be advantageous, both cost- and time-wise, in comparison to present methods. In initiating this research, four objectives were outlined. They included: (1) a study of all past and present methods of measuring thicknesses of highway pavements to determine if any existing method may be suitable; (2) a feasibility study of proposed methods now under development; (3) proposals for other feasible methods; and (4) recommendations for promising methods for development of instrumentation.

Research has been completed, and the project report has been published as: NCHRP Report 52, "Measurement of Pavement Thickness by Rapid and Nondestructive Methods."

Project 10-7 FY '64

Potential Uses of Sonic and Ultrasonic Devices in Highway Construction

Research Agency: The Ohio State University
Principal Invest.: Dr. F. Moavenzadeh
Dr. R. C. McMaster
Effective Date: February 1, 1964
Completion Date: March 31, 1965
Funds: $24,310

The use of sonic and ultrasonic devices is well known in some fields. Present practical application of sonic and ultrasonic frequencies and the results of recent experiments indicate a wide range of potential uses of such devices in highway construction. It is felt that possible uses may include pile driving, mixing and compaction of materials, sampling of materials, drilling, cutting, and many other applications. In an effort to evaluate potential uses, this research study was initiated with the objectives of studying available information on present uses of high-frequency vibrations and making a feasibility study of possible applications to highway construction.

This research has been completed, and the project report has been published as: NCHRP Report 25, "Potential Uses of Sonic and Ultrasonic Devices in Highway Construction."

Project 10-8 FY '70

Evaluating Procedures for Determining Concrete Pavement Thickness and Reinforcement Position

Research Agency: Pennsylvania Dept. of Transportation
Principal Invest.: W. G. Weber
R. L. Grey
Effective Date: March 2, 1970
Completion Date: July 31, 1973
Funds: $151,982

The objective of this research was limited to the field evaluation of available nondestructive systems of inspection testing for determining pavement thickness and reinforcing steel position at the construction site, either before or soon after the concrete has hardened, to permit the elimination of, or substantial reduction in, the coring of pavements.

Research has been completed, and the project report has been published as: NCHRP Report 168, "Rapid Measurement of Concrete Thickness and Reinforcement Location—Field Evaluation of Nondestructive Systems."

Project 10-9 FY '70

Criteria for Need of Seal Coats for Bituminous Pavements

Research Agency: University of Minnesota
Principal Invest.: E. L. Skok
Effective Date: November 1, 1969
Completion Date: February 28, 1974
Funds: $50,000

The objectives of this project were to develop, and evaluate in the field, guidelines for the programming of seal coats on bituminous pavements.

The essential findings of the study have been published as NCHRP Research Results Digest 48. The agency report has been distributed to the Program sponsors and other interested persons, and microfiche of the report may be purchased (see final page of this section for ordering information).

Project 10-10 FY '74

Acceptance Criteria for Electroslag Weldments in Bridges

Research Agency: United States Steel Corporation
Principal Invest.: W. P. Benter, Jr.
C. G. Schilling
Effective Date: May 1, 1974
Completion Date: September 30, 1978
Funds: $300,000

The over-all objective of this project was to develop and verify acceptance criteria for the use of electroslag butt welds in bridges. Research was conducted in two phases. The specific objective of Phase I was to define necessary acceptance specifications based on the most complete study, using laboratory specimens from full-size welds, that current knowledge and testing equipment could provide within the allotted funds. The specific objective of Phase II was to verify the findings of Phase I by conducting dynamic tests of full-size bridge girders.

Research has been completed, and the project report has been published as: NCHRP Report 201, "Acceptance Criteria for Electroslag Weldments in Bridges."

Project 10-11 FY '77

Development of a Performance Specification For Bridge Deck Joint-Sealing Systems

Research Agency: Howard Needles Tammen & Bergendoff
Principal Invest.: Arthur Linfante
Effective Date: December 1, 1976
Completion Date: April 30, 1978
Funds: $29,996

The objective of this research was to develop an effective performance specification for prefabricated, surface-mounted bridge deck joint-sealing systems designed for a total horizontal movement of 4 inches or less.

Research has been completed, and the final report has been published as: NCHRP Report 204, "Bridge Deck Joint-Sealing Systems—Evaluation and Performance Specification."

Project 10-12 FY '77

Acceptance of Aggregates Used in Bituminous Paving Mixtures

Research Agency: Texas A & M University Research Foundation
Principal Invest.: Dr. R. L. Lytton
Effective Date: September 1, 1977
Completion Date: June 30, 1981
Funds: $174,411

The objective of this study was to evaluate currently used methods for the acceptance or rejection of aggregates used in bituminous paving mixtures.

The research was conducted in two phases. Under Phase 1, four overall schemes for evaluating the quality of aggregates to be used in bituminous paving mixtures were formulated, based primarily on various combinations of current state highway department practices. The four schemes were evaluated for their relative usefulness (utility) using a utility decision analysis computer program developed by the researchers. The schemes showing the most utility were comprised of conventional physical and chemical tests of aggregate samples.

Consequently, Phase 2 was designed to evaluate various tests on aggregate samples for their ability to predict bituminous pavement performance. A decision was also made to include some bituminous mixture tests and subjective petrographic ratings and to consider climate or geographic regions.

The research has been completed and the agency final report distributed to all NCHRP sponsors. A limited number of extra copies of the final report are also available to NCHRP sponsors. Copies of an agency interim report documenting Phase 1 and the agency final report, which concentrates on Phase 2, are also available for loan upon written request to the NCHRP. In addition, microfiche of both reports may be purchased (see final page of this section for ordering information).

Project 10-13 FY '79 and FY '82

Ultrasonic Measurement of Weld Flaw Size

Research Agency:	The Welding Institute (England)	
Principal Invest.:	Timothy J. Jessop	Peter J. Mudge
Effective Date:	July 1, 1979	October 1, 1982
Completion Date:	October 31, 1981	August 31, 1985
Funds:	$126,000	$250,000

The overall objective of this study was to identify or develop, and to validate, ultrasonic testing procedures for

accurate measurement of flaw dimensions that will allow fracture-mechanics analysis.

This study was addressed primarily to evaluation of complete joint penetration groove welds containing planar-type flaws such as cracks or incomplete fusion.

In the first phase of research, laboratory tests on intentionally flawed specimens were used to determine the applicability and limitations of AWS D1.1-80 ultrasonic testing procedures for measuring the dimensions of flaws in welds. Phase I also included an evaluation of procedures that extend available ultrasonic techniques and have a potential for accurate measurement of flaws typically found in structural weldments. The accuracy, precision, reliability, and reproduceability of the time-of-flight and probe movement techniques were investigated.

The final report on Phase I has been published as: NCHRP Report 242, "Ultrasonic Measurement of Weld Flaw Size."

The specific objectives of Phase II, designated NCHRP Project 10-13/1, were (1) to develop recommendations for applications of tandem-probe techniques for the characterization of vertical, planar defects and (2) to refine the time-of-flight system for sizing through-thickness flaw dimensions.

The research in this second phase included a review of all relevant literature and test data in order to develop a more realistic means of assessing vertical planar defects within the framework of the currently used AWS D1.1 code. Time-of-flight equipment was designed and assembled and subsequently evaluated in the laboratory in order to establish the accuracy of the equipment in measuring through-thickness dimensions for a variety of weld defects. Finally, a field evaluation of the equipment was performed in order to establish its accuracy and applicability, as well as to provide recommended procedures for use.

The research has been completed, and the final report was submitted at the end of 1988. A decision on publication of the final report will be made in early 1989.

Project 10-14 FY '79

Locating Voids Beneath Pavement Using Pulsed Electromagnetic Wave Techniques

Research Agency:	Georgia Tech Research Corporation
Principal Invest.:	Dr. J. D. Echard Dr. W. J. Steinway
Effective Date:	April 2, 1979
Completion Date:	May 1, 1981
Funds:	$99,850

The primary objective of this project was to determine the practicality of pulsed electromagnetic wave technology for locating voids beneath reinforced and nonreinforced portland cement concrete pavements up to 18 inches thick. Another objective was the identification or development of a data processing technique suitable for use with the equipment that can be operated by field personnel and that will provide information on the parameters of voids beneath pavements. It was further desired that the voids beneath pavements be defined with an accuracy of at least ± ½ inch in depth and ± 6 inches in horizontal dimension.

Research has been completed with reasonable accomplishment of objectives. Theoretical modeling of signal returns from voids led to suitable techniques for locating and sizing voids beneath pavements. Very short pulse radar was connected to a microcomputer to provide real-time processing of the radar signal return. Measurements made inside a laboratory-controlled environment verified the procedure. Additional measurements were made on specially constructed outdoor pavement sections at 100 F, 70 F, and 32 F. At temperatures of 70 F and below, the measurements provided excellent estimates of void location and size, but at 100 F the measurements were not as successful.

The project report has been published as: NCHRP Report 237, "Locating Voids Beneath Pavement Using Pulsed Electromagnetic Wave Techniques."

Project 10-15 FY '80

Structural Strength Evaluation of Existing Reinforced Concrete Bridges

Research Agency:	Engineering Computer Corporation	
Principal Invest.:	Roy A. Imbsen	
Effective Date:	April 1, 1980	April 1, 1984
Completion Date:	Sept. 30, 1982	April 30, 1986
Funds:	$125,000	$100,000

The objective of this project was to develop improved methodology for evaluating the structural capacity of existing reinforced concrete bridge superstructures and to present it in a specification format suitable for consideration by AASHTO.

The final report on the first Phase I of the research included findings and recommendations related to methods of predicting structural capacity for load-rating concrete highway bridges. The limit-state approach to bridge evaluation recommended in this report appeared to be promising; however, some of the factors included in the report are not well documented, and the recommended approach is not yet ready for widespread application.

The Phase I final report will not be published, but copies of the agency's draft final report were distributed to NCHRP sponsors early in 1983. Copies are available on microfiche (see final page of this document for ordering information).

Phase II of the research had as its objective further development of the limit-state approach to evaluate the structural capacity of reinforced concrete bridge superstructures. The research in the second phase included a

statistical analysis of information from the FHWA's computerized national bridge inventory system in order to identify typical reinforced concrete superstructure types that were applicable to this study. A sensitivity analysis was conducted to determine the effects of modifications to the load and resistance factors in the limit-state approach to evaluation. The factors to be used in the limit-state approach were identified and evaluated, and a calibration of the proposed method was performed using available test data. Finally, the results of the proposed method were compared with results from the currently used methods.

The project report has been published as NCHRP Report 292, "Strength Evaluation of Existing Reinforced Concrete Bridges."

The recommendations and guidelines developed in the second phases of Project 10-15 were incorporated into the comprehensive evaluation guidelines developed in Project 12-28(1). Refer to Project 12-28(1) writeup for further discussion.

Project 10-16 FY '81

Assessment of Deficiencies and Preservation of Bridge Substructures Below the Waterline

Research Agency:	Byrd, Tallamy, MacDonald & Lewis
Principal Invest:	Martin Rissel
Effective Date:	February 16, 1981
Completion Date:	December 1, 1982
Funds:	$150,000

This study was intended to use and extend earlier research reported in NCHRP Synthesis of Highway Practice 88, "Underwater Inspection and Repair of Bridge Substructures."

The objectives of Project 10-16 were; (1) to develop improved methodology for evaluating the effects of below-the-waterline deficiencies on the structural capacity of the substructure, and (2) to develop solutions to specific deterioration problems that are found in bridge substructures below the water surface and in the splash zone. Accomplishment of these objectives involved: (1) addressing the deficiencies cited in the previously mentioned synthesis report, (a) review and summarize the present state of the art of structural strength evaluation techniques for bridge substructures below the water surface, with particular emphasis on quantifying the consequences of the deficiencies on the structural integrity of the bridge, and (b) for these deficiencies, develop guidelines for assessing the seriousness of the problem, a rating system to identify the urgency for corrective action, and practical methods to predict structural capacity. (2) Addressing the second part of the objective, (a) based on available information, identify and evaluate methods used to arrest deterioration below the water surface and in the splash zone, and (b) develop new or improved methods that may prove effective in arresting deterioration below the water surface and in the splash zone; this effort was limited to the following elements and problem areas:

- Bridge elements—concrete piers and footings, prestressed concrete piles, and reinforced concrete piles.
- Problem areas—deterioration due to corrosion, freezing and thawing, chemical attack, and abrasion.

Research has been completed, and the final report has been published as: NCHRP Report 251, "Assessment of Deficiencies and Preservation of Bridge Substructures Below the Waterline."

Project 10-17 FY '81 and FY '83

Use of Antistripping Additives in Asphaltic Concrete Mixtures

Research Agency:	David G. Tunnicliff
Principal Invest:	David G. Tunnicliff
Effective Date:	March 1, 1981
Completion Date:	July 1, 1989
Funds:	$500,000

There is an increasing awareness of asphaltic concrete pavement failures caused by stripping of asphalt cements from the aggregates. Consequently, more highway agencies are requiring the use of antistripping additives. If an additive is used when it is not needed, the added cost is an economic waste. If an additive is used ineffectively, the pavement may require early and costly maintenance and/or rehabilitation. Highway agencies need information on the selection, effectiveness, and use of antistripping additives.

The long-term general objective of this research is to provide information on the selection and use of antistripping additives (materials used to improve the asphalt-aggregate adhesion in asphaltic concretes). The specific objective of the initial phase was to develop guidelines for the incorporation of antistripping additives in asphaltic concrete paving mixtures considering the influence of such factors as (1) storage and handling of the additives, and (2) stability and effectiveness of additives during mixing and storage of asphaltic concrete.

Research has been completed on the initial phase with accomplishment of the objectives. The test method for measuring the potential for moisture damage in asphalt concrete pavements described in NCHRP Report 246 was modified to reduce test time and control the degree of saturation. The modified test method was used to evaluate effects of storage and handling of asphalt aggregate mixtures on antistripping additives. The project report for the initial phase has been published as: NCHRP Report 274, "Use of Antistripping Additives in Asphaltic Concrete Mixtures." The report contains a state of the art in use of antistripping additives in asphaltic concrete paving mixtures and guidelines for use of such additives.

Research on the field evaluation phase is in progress. A precision study has been completed for the test method developed in the initial phase. That test method and precision study have been approved by ASTM Committee D-4 and should appear in the 1989 Book of ASTM Standards as Designation D 4867, "Test Method for Effect of Moisture on Asphalt Concrete Paving Mixtures."

Project 10-18 FY '81

Specifying and Obtaining Entrained Air in Concrete

Research Agency:	Construction Technology Laboratories/PCA
Principal Invest:	David C. Stark Dr. David Whiting
Effective Date:	May 4, 1981
Completion Date:	June 1, 1983
Funds:	$73,585

The objective of this research was to develop practical guidelines for specifying and obtaining the optimum amount of entrained air in concrete. Consideration was given to interations between typical concrete ingredients and various admixtures.

Research has been completed and the project objective accomplished in the form of guidelines for field control of air-entrained concrete. A state-of-the-art report on air-entrained concrete was also prepared and copies printed for distribution to program sponsors. Loan copies are available (see final page of this section for ordering information).

The final report including the guidelines has been published as: NCHRP Report 258, "Control of Air Content in Concrete."

Project 10-19 FY '81

Adding Dust Collector Fines to Asphalt Paving Mixtures

Research Agency:	The Pennsylvania State University
Principal Invest:	Dr. David A. Anderson
Effective Date:	March 1, 1981
Completion Date:	November 30, 1982
Funds:	$49,926

The objectives of this project were: (1) to conduct a state-of-the-art survey of studies dealing with the effect of dust collector fines on asphalt concrete and current practices for specifying and handling these fines, and (2) to characterize by generic type those dust collector fines now in use. Of particular concern was the dust collected in baghouses.

Research has been completed, and the final report has been published as: NCHRP Report 252, "Adding Dust Collector Fines to Asphalt Paving Mixtures."

Project 10-20 FY '81, FY '83, and FY '85

Elastomeric Bearings Design, Construction, and Materials

Research Agency:	University of Washington		
Principal Invest:	Dr. C. W. Roeder Dr. J. F. Stanton		
Effective Date:	2/1/81	6/1/83	6/1/86
Completion Date:	6/30/82	11/30/86	5/31/89
Funds:	$74,715	$150,000	$150,000

The objective of the first phase of research was to develop specifications for unconfined, plain and reinforced elastomeric bridge bearings.

The findings of Phase I of Project 10-20 were published as: NCHRP Report 248, "Elastomeric Bearings Design, Construction, and Materials," and included recommendations for improved specifications for unconfined, plain and reinforced elastomeric bridge bearings. These recommendations were based on currently existing information. In 1985, AASHTO adopted many of the recommendations of the Phase I research, substantially revising the provisions for elastomeric bearings in the Standards Specifications for Highway Bridges.

The objective of the second phase of research was to develop a more sophisticated specification for special applications and to improve the simplified provisions recommended in Phase I. The Phase II research included testing and evaluation of bearing compression, rotation, shear, stability, fatigue, and low temperature behavior. Recommendations for a more rational bearing specification are included in the project report and have been made to the AASHTO Bridge Committee.

The findings of Phase II of Project 10-20 were published as NCHRP Report 298, "Performance of Elastomeric Bearings."

The objectives of the third phase of research are to (1) resolve design procedures for special applications of unconfined elastomeric bearings and (2) provide a critical state-of-the-art review of design and construction procedures for confined elastomeric bearings. The Phase III research includes the following tasks:

Unconfined Elastomeric Bearings

1. Further experimental verification of low temperature behavior including effects on heating and cooling rates and shear stiffness of elastomers at low temperatures.

2. Develop guidelines for recommended manufacturing procedures and tolerances.

3. Develop recommended test procedures to prequalify the elastomeric material and also for acceptance of the finished bearings.

4. Preparation of a final report including revisions to the more sophisticated specification developed in Phase II.

Pot Bearings and Slide Surfaces

1. Gather data relevant to pot bearings from the literature and from interviews with manufacturers and engineers.

2. Gather data relevant to PTFE sliding surfaces.

3. Synthesize the information gathered in Tasks 1 and 2.

4. Prepare a final report that includes a summary of the state-of-the-art in pot bearing design and use, including recommendations for further research.

Through December 31, 1988, research on the third phase has fallen slightly behind schedule. The draft pot bearing state-of-the-art report was submitted in mid-1988 and was reviewed by the NCHRP project panel. Technical revisions were suggested for the report, which will be incorporated in the final report to be submitted by the agency in early 1989. The low temperature elastomer tests have also fallen somewhat behind schedule, but should be completed by April 1989.

Project 10-20A FY '88

High-Load, Multi-Rotational Bridge Bearings: Design, Materials, and Construction

Research Agency:	In developmental stage
Principal Invest.:	
Effective Date:	(30 months)
Completion Date:	
Funds:	$250,000

In recent years, specialty bearings have been introduced for use in highway bridge construction. Prominent among these are the high-load multi-rotational (HLMR) types of bearings.

Current specifications for HLMR bearings have been developed from industry standards and vary widely throughout the United States. There is a need for a broad range, generic specification that reflects the best of current practice and will ensure long life, high quality, reliable bearings.

Although there is a proliferation of HLMR bearing specifications, many basic questions remain unanswered. These include questions related to: (1) the performance characteristics of such bearings subjected to induced eccentric loading while under rotation; (2) the apparent loss of full performance capabilities; (3) the long-term durability of certain materials and bearing configurations; and (4) the disparities between domestic and foreign design procedures and materials applications.

There is also inadequate information available to the bridge engineer providing concise guidance on the selection of an appropriate bearing for a specific design situation. Therefore, a selection guide is needed which will inform bridge engineers of the relative performance features for HLMR and conventional bearings used in new bridge designs in the United States.

The objectives of this research are to develop (1) a bearing selection guide for all bearings currently used in new bridge designs in the United States and (2) specifications for high-load multi-rotational bearings that can be recommended to AASHTO for consideration for adoption. Base-isolation bearings are not intended to be included in this research. PTFE slide units associated with high-load multi-rotational bearings shall be considered.

The research will include the following tasks:

Task 1. Review current domestic and foreign codes of practice, research findings, and performance data on all bridge bearings within the scope of the bearings selection guide that will be developed under Task 2. The emphasis of this survey, however, should be placed on the HLMR bearings that will be covered under the specification to be developed in Task 3.

Task 2. Develop a draft bearing selection guide for all bearings currently used in new bridge designs in the United States, with the exception of base-isolation bearings.

Task 3. Develop draft specifications for the design, materials, and construction of HLMR bearings in a format suitable for consideration by AASHTO.

Task 4. Prepare an interim report which includes the following: (1) a summary of the findings from Task 1; (2) the draft selection guide and draft specifications; (3) a prioritized list of laboratory tests, possibly supplemented by field observations, that may be required to complete the selection guide and specifications; and (4) a recommended test program of the highest priority research needs that can be accomplished within a funding level of $150,000.

Task 5. Perform laboratory tests. As a minimum, these tests shall examine the moment-rotation characteristics and lateral load capacity for all types of HLMR bearings, and sealing requirements and internal lubrication for pot bearings.

Task 6. Revise the draft selection guide to incorporate the findings from Task 5.

Task 7. Revise the draft specifications for HLMR bearings to incorporate the findings from Task 5.

Task 8. Submit a final report documenting all research and presenting the recommended bearing selection guide and specifications.

Project 10-21 FY '81

Performance of Bridge Deck Concrete Subjected to Traffic-Induced Vibrations During Placement

Research Agency:	Transportation Research Board
Principal Invest.:	Dr. Paul E. Irick
	Mr. T. L. Copas
Effective Date:	February 1, 1980
Completion Date:	September 30, 1981
Funds:	$25,000

The objective of this study was to determine the effects of traffic-induced vibrations on concrete for various bridge deck repair and widening procedures and to indentify criteria for materials, design, construction, and traffic control procedures to alleviate any negative effects. The research included consideration of the following factors associated with bridge deck concrete used in overlays, full and partial-depth restoration, and widening: (1) bonding to substrate and adjacent concrete: (2) bonding to reinforcing steel; (3) differential consolidation; (4) interaction between concrete properties and differential consolidation; (5) differential deflections; (6) frequency of vibration (traffic induced); (7) porous planes of weakness; (8) traffic control criteria; (9) design criteria (including bridge type); (10) construction practice (including deck preparation); (11) crack development from all sources; and (12) mix design effects.

The study included the following tasks:

1. Identification of relevant research and field investigations.
2. A survey of current practice and attitudes on maintaining traffic during bridge deck restoration or widening.
3. Follow-up contact with a number of highway agencies to gather more detailed information on the field performance of bridge decks that have been restored, patched or widened in the presence of traffic induced vibrations.
4. A recommendation for additional research to be directed toward determining the causes and possible solutions for any negative effects determined to be associated with such vibrations.

NCHRP Project Panel D10-21 decided that a preliminary study should be carried out under NCHRP Project 20-5. "Synthesis of Information Related to Highway Problems," and $25,000 of the $250,000 that was originally allocated for this study were reallocated for this purpose. Research has been completed, and the final report has been published as: NCHRP Synthesis of Highway Practice 86, "Effects of Traffic-Induced Vibrations on Bridge-Deck Repairs."

The draft final report included an evaluation of research needs with recommendations for specific work to meet these needs. The project panel accepted the synthesis topic consultant's recommendation to not carry out additional research on this subject. This recommendation was based on the fact that no convincing evidence was found in this study to indicate that the performance of concrete bridge decks is degraded by traffic-induced vibrations during placement. The unused portion ($225,000) of the allocated funds has been returned to the AASHTO Research Committee for reallocation to other NCHRP projects.

Project 10-22 FY '82

The Performance of Weathering Steel in Bridges

Research Agency:	Sheladia Associates, Inc.	
Principal Invest.:	Dr. Pedro Albrecht	
Effective Date:	April 1, 1982	July 23, 1984
Completion Date:	February 29, 1984	August 31, 1987
Funds:	$74,851	$120,699

The objectives of the first phase of research were (1) to assemble a systematic body of information on the performance of weathering steel, and (2) to document and evaluate the current state of practice.

The first phase of research has been completed, and the final report published as: NCHRP Report 272, "Performance of Weathering Steel in Bridges."

The second phase of research has as its specific objectives (1) to fatigue test 8-year weathered A588 transverse stiffener specimens under constant loading in air and aqueous environments, and (2) to develop practical guidelines for design, construction, maintenance, and rehabilitation of weathering steel bridges.

Research on the second phase is complete. The agency's revised final report is now under review for possible publication in the NCHRP report series.

Project 10-23 FY '82

Removal of Lead-Based Bridge Paints

Research Agency:	Midwest Research Institute
Principal Invest.:	Michael K. Snyder
Effective Date:	July 1, 1982
Completion Date:	June 30, 1983
Funds:	$81,118

The objectives of this research were to: (1) identify the severity of pollution related to bridge cleaning and (2) recommend improved techniques for removal and recovery of lead-based bridge paints. Environmental pollution and toxicity information associated with lead paint removal and disposal, environmental regulations pertaining to lead paint removal, and environmental test methods for lead paint residues were reviewed and commented on. Removal and recovery methods were summarized and evaluated. Concepts for improving existing technology and comments on new techniques under development were generated.

Research has been completed, and the project report published as: NCHRP Report 265, "Removal of Lead-Based Bridge Paints."

Project 10-24 FY '82

Rapid Replacement of PCC Pavement Segments

Research Agency: ARE Inc.
Principal Invest.: Dr. A. H. Meyer
R. F. Carmichael III
Effective Date: March 15, 1982
Completion Date: March 14, 1988
Funds: $240,000

The objective of this research was to identify, describe, and evaluate methods that had been and were being used for rapid replacement of lane-width segments of both continuously reinforced and jointed PCC pavements relative to costs, placement conditions, traffic characteristics, performance and expected service lives. Field sites in six States: California, Illinois, Minnesota, Michigan, Texas, and Virginia were identified and monitored over several years. The field sites represented a variety of environmental regions and PCC pavement types (i.e., jointed plain, reinforced, and continuously reinforced concrete pavements).

Findings indicated little variety in materials being used, but design and replacement techniques vary. Troublesome issues are determining the limits of segments needing replacement and determining the number and size of replacement segments before a major reconstruction is recommended.

Research is complete; a summary of findings will be published in Research Results Digest 169, "Rapid Replacement of PCC Pavement Segments." Copies of the agency final report were distributed to all state highway departments and are available to others for loan or purchase. (See final page of this document for ordering information.)

Project 10-25 FY '83

Measurement of Cement and Water Content of Fresh Concrete

Research Agency: U.S. Army Corps of Engineers Waterways Experiment Station
Principal Invest.: Richard L. Stowe, Alan D. Buck, Tony B. Husbands, Joe G. Tom
Effective Date: October 13, 1983
Completion Date: September 5, 1986
Funds: $149,995

The objective of this research was to establish the applicability and accuracy of test methods for the determination of cement and water content of freshly mixed concrete. The following test methods were investigated: (1) US Army Construction Engineering Research Laboratory/Kelly-Vail (CERL/K-V), Rapid Analysis Machine (RAM), FHWA nuclear device, a centrifuge test, and an x-ray emission spectrometer for determination of cement content; and (2) CERL/K-V, hot plate and microwave oven for the determination of water content.

Research is complete. The final report has been published as NCHRP Report 284, "Evaluation of Procedures Used to Measure Cement and Water Content in Fresh Concrete."

Project 10-25A FY '85

Instantaneous Determination of Water-Cement Ratio in Fresh Concrete

Research Agency: Wiss, Janney, Elstner Associates, Inc.
Principal Invest.: William G. Hime
Effective Date: June 1, 1985
Completion Date: December 31, 1988
Funds: $300,000

The objective of this research project is to develop a method of measuring the water-cement ratio in concrete that could form the basis of an acceptance test at the job site. The desirable characteristics of such a method are: (1) rapidity—results should be obtainable within 2 minutes or less, (2) accuracy—measurement of water-cement ratio to within 0.02, (3) cost—the equipment should be of such price (under $5,000) that a testing agency might reasonably be expected to acquire several items, (4) convenience—the method should consist of a probe to be inserted directly into a central or truck mixer, (5) versatility—the test should be capable of being performed at any time from first mixing up to the maximum delivery time allowable (approximately 90 minutes at a concrete temperature of 70°F), and (6) simplicity—the probe should be easily calibrated so that the effects of changing concrete material and temperature may be accommodated. It is anticipated that a method based on a direct determination of the water-cement ratio is most likely to satisfy all of the above requirements, but an approach that measures cement and water contents separately can be pursued if justified. Some methods that may be appropriate are measurement of dissolved ions, radioactive detection of soluble or insoluble species, and chromatographic analysis of volatile compounds. The following three tasks shall be addressed to achieve the project objective.

Task 1—Evaluate and demonstrate in the laboratory the feasibility of using an element(s) or compound(s) naturally occurring in cement that can be instrumentally measured to define the water-cement ratio of a concrete mixture. The element(s) or compound(s) identified should not occur in typical concrete admixtures or concrete aggregates in sufficient quantity or form to have a significant effect on instrumental (probe) analysis.

Task 2—Investigate candidate materials to be added to cement during its manufacture that can be readily measured and whose concentration will suitably reflect the water-cement ratio of concrete. The selection of a

material(s) must consider: (a) the cost of the basic prototype material, and of the procedures and equipment which could be used to add the material to the cement; (b) the potential availability of analytical equipment of adequate accuracy of discrimination; and (c) the interference from usual concrete ingredients including admixtures. The first step in this task is to identify candidate materials and measurement schemes. Based on estimates of cost and feasibility of additions, one or more materials should be used in the laboratory to demonstrate performance in a high pH environment and to determine if measurements can be made with the required accuracy.

Task 3—Having selected the most promising element(s) or compound(s) whose concentration is to be measured, demonstrate the feasibility of performing measurements quickly in the field. The demonstration may consist of using a commercially available probe, if such exists, or developing a prototype probe for each element or compound to the point where it is apparent that a small rugged commercial model is possible.

Research had initially concentrated on the feasibility of a single electronic probe for directly measuring the water-cement ratio of fresh concrete. Experiments were conducted to detect the dispersion of various elements in cement paste. As a result, the sensitivity of the technique to measure the water-cement ratio in a concrete matrix, given its variability, has been questioned.

Although the future of a probe is likely, current technology is too limiting. The agency suggested pursuing other methods such as: a colormetric procedure for identifying soluble silica in concrete to determine cement content; and a trained ion-specific electrode, microwave oven technique, and an infrared method to determine water content.

Research is complete; the agency preliminary draft final report is now under review.

Project 10-26 FY '83

Data Bases for Performance-Related Specification for Highway Construction

Research Agency: ARE, Inc.
Principal Invest.: Dr. W. Ronald Hudson, Dr. Alvin H. Meyer
Effective Date: June 15, 1983
Completion Date: September 14, 1984
Funds: $60,000

The objective of this study was to establish the state of test records on construction and materials control for pavement structures and foundations. The primary aim was to establish which, if any, of the available records were useful for development of performance-related specifications.

Assessments of various sources of data and statistical techniques for use in developing performance-related specifications resulted. Guidance for future endeavors was given.

Research is complete; copies of the agency final report, "Data Bases for Performance-Related Specifications for Highway Construction," were distributed to all state highway departments. Copies are available to others for loan or purchase. (See final page of this document for ordering information.)

Project 10-26A FY '84

Performance-Related Specifications for Hot-Mix Asphaltic Concrete

Research Agency: The Pennsylvania State University
Principal Invest.: Dr. David A. Anderson and Dr. David R. Luhr
Effective Date: January 6, 1986
Completion Date: June 6, 1988
Funds: $250,000

Performance-related specifications are those that require tests or other control measures on materials and construction, the results of which correlate to a known degree with performance of the completed highway facility. It can be argued that using control measures that cannot be related to performance wastes staff time and increases costs without benefit. The need to use staff effectively and to reduce sampling and testing costs has required a continuing examination of specifications by the states and the Federal Highway Administration. These examinations have convinced many of the need to identify effective performance predictors and their variability limits, to develop specifications based on these predictors, and to apply cost-effective sampling and testing plans to assure compliance.

One of several ways of establishing performance predictors is to correlate the results of condition surveys on pavements directly with original materials and construction test data. However, previous research has demonstrated the difficulty of establishing these direct relationships, especially when they are attempted nationwide with existing data from in-place facilities. A more promising approach may be to recognize the establishment of design factors as predictors of ultimate performance and then to use materials and construction testing as a means to ensure adequate compliance with or achievement of the design factors. As an example, for asphaltic concrete construction, stiffness (elastic modulus) and tensile strain would be possible design factors, while asphalt content and percent air voids would be possible materials and construction test data.

Although the relationships among materials and construction tests, design factors, and performance are of primary interest, the relative impact of other factors cannot be ignored. Factors such as quality of construction, environment, and reliability of testing techniques are among many that can have significant effects.

Establishing or verifying the causal relationships and the sensitivity of these relationships among performance, design factors, and test data requires first the development of an overall conceptual model or framework. This conceptual model should make use of established relationships already identified in the literature. Once the concept has been formulated, the variables and data needs must be identified. Existing, suitable data should be used to the extent possible; however, it is unlikely such data will be available or meet the needs of all data requirements. Therefore, laboratory and field experiments will have to be defined to generate supplemental data. With the identification or generation of data, previously established or conceptual relationships can be verified and further analyzed for the predictive sensitivity of each variable and its reliability. The ultimate purpose will be to develop materials and construction specifications that relate to the actual performance of the facility. This process will be an iterative one, but careful planning will produce meaningful results promptly and with minimum waste.

To limit the problem to a manageable undertaking, and to mesh with ongoing and upcoming research by the Federal Highway Administration, the scope of NCHRP Project 10-26A is confined to performance-related specifications for hot-mix asphaltic concrete.

The objective of this study is to identify the relationships between materials and construction test data and the performance of hot-mix asphaltic concrete. Causal relationships among performance, design factors, and test data should be verified or established with the ultimate aim of formulating specifications that directly (or through identifiable indirect means) relate, within acceptable tolerances, to the performance of hot-mix asphaltic concrete in a pavement cross-section. In some cases, this will require establishing design factors that relate to performance and then establishing the materials and construction tests that will control those design factors. It is noted that all existing materials or construction tests may not be related to performance, and, conversely, the present study may identify the need for tests not currently in use.

Research has been completed. A conceptual frame work for performance-related specifications for hot-mix asphaltic concrete was developed, and the laboratory study providing data to models which indicated relationships between materials and construction variables and pavement performance has been concluded. The project final report has been submitted and is being reviewed.

Project 10-27 FY '84

Determination of Asphaltic Concrete Pavement Structural Properties by Nondestructive Testing

Research Agency: Texas A & M Research Foundation
Principal Invest.: Dr. Robert Lytton
Effective Date: September 17, 1984
Completion Date: August 31, 1989
Funds: $450,000

An increasing responsibility of highway and transportation agencies is the maintenance, rehabilitation, and management of highways that have been built. Particularly with regard to asphaltic concrete pavements, this requires the use of efficient and economical methods for determining the structural properties of existing pavements. Use of nondestructive testing (NDT) data with associated analysis methods appears to have potential for determining these pavement structural properties. Several types of NDT equipment and analysis procedures are currently available for providing the desired information. Analysis procedures utilizing NDT data vary substantially in complexity, accuracy, and availability—making the selection of appropriate equipment and analysis methods for an individual agency's pavement management needs difficult.

Up-to-date information on the application and limitations of available analysis procedures for determining asphaltic concrete pavement structural properties using NDT data is urgently needed.

The objectives of this research are: (1) to provide methods and guidelines for calculating the structural properties of asphaltic concrete pavements, using nondestructive test data, for use in pavement analysis, design, rehabilitation, and other pavement management activities; and (2) to develop detailed procedures to verify the methods and to adjust the results for local conditions.

Research nears completion. Computer programs have been developed and demonstrated to use NDT/deflection basin) data for analyzing up to 4 layers of the existing asphaltic concrete pavement structure and for designing resurfacing layers. Verification of these programs is being provided with field evaluation of in-service pavement sections selected and instrumented for this purpose. Five sections are in Texas and three are in Minnesota. Asphalt concrete thicknesses and base types are varied. Core samples of the different pavement layers have been obtained to determine actual material characteristics. Deflection data are being collected using various NDT devices.

It is anticipated the computer program and users guide will be distributed in early 1989 and the project final report will be available soon thereafter.

Project 10-28 FY '85

A Method to Determine Deteriorated Areas in Portland Cement Concrete Pavement

Research Agency: Gulf Applied Research
Principal Invest.: Lucien C. Bomar
Walter F. Horne
Effective Date: November 1, 1985
Completion Date: December 31, 1987
Funds: $199,784

The need for maintenance and repair of portland cement concrete pavements has increased over the years as these facilities have deteriorated from the effects of age and accumulated traffic loads. This has produced a need for a method to accurately and rapidly determine the location and extent of deteriorated concrete.

An accurate method would enhance the preparation of project plans for needed repairs by permitting more precise calculations of quantities and boundary conditions. And, a rapid method would be desirable for surveying long lengths of pavements minimizing the interference with traffic on heavily traveled roads. To further increase its utility, the method should be suitable for reinforced and nonreinforced concrete pavements with and without overlays.

Various technologies, such as radar, sonics, infrared, and others, have demonstrated to some degree the feasibility of rapid and accurate detection of deteriorated areas; but, data reduction and interpretation are slow and require expertise not generally available in most state highway agencies. Furthermore, the data may not always be sufficient for determining quantities and exact locations and boundaries of the needed repairs at the project level.

Recognizing that existing technologies showed promise, the NCHRP solicited research proposals to improve accuracy and speed of operation in one or more technologies of the proposer's choosing and to produce results more simply displayed and understandable. As a consequence, improvements to the application of ground penetrating radar and high resolution video to detect deteriorated areas of portland cement concrete pavements were researched. Developments in radar technology and the interpretation of radar signals were studied as a means of detecting subsurface deterioration, while studies on video imaging were intended to provide a method for recording and cataloging surface deterioration or distress. Advances in both technologies have made it possible to apply them as practical tools for sampling purposes. The research also provides a basis for further study to enhance the capabilities of both technologies and make them more suitable for project level decisions.

Research is complete, and the agency final report has been published as NCHRP Report 304, "Determining Deteriorated Areas in Portland Cement Concrete Pavements Using Radar and Video Imaging."

Project 10-29 FY '86 and FY '87

Anchorage Zone Reinforcement for Post-Tensioned Concrete Girders

Research Agency: University of Texas at Austin
Principal Invest.: Dr. John E. Breen
Effective Date: October 1, 1986
Completion Date: September 30, 1991
Funds: $490,000

The AASHTO *Standard Specifications for Highway Bridges* do not provide adequate guidance for designing reinforcement for tendon anchorage zones of post-tensioned concrete girders and slabs. Current designs can result in excessive cracking or congested reinforcing details. The wide variation of design practices currently in use suggests the need for research in this area.

Recent investigations at the University of Texas at Austin have developed design procedures for single tendons anchored in the webs of girders. However, additional information is needed for multiple tendons and other problems such as: influence of additional shear in support regions, bearing stresses for different types of anchorage systems, and the influence of diaphragms. Design criteria are needed for reinforcement details for inclined, sharply curved, and/or highly eccentric tendons, and for intermediate anchorages and coupling joints of tendons.

The objective of this research is to develop design procedures for end and intermediate anchorage zones for post-tensioned concrete girders and slabs. The research will include the following tasks:

Task 1—Review of relevant domestic and foreign research findings, available performance data, current domestic and foreign practice, and tendon-supplier recommendations. This information would be assembled from technical literature, unpublished experiences of engineers and tendon suppliers, insurance company records, and surveys of bridge and containment vessel owners, fabricators and designers. This review would include but not be limited to:

a. Procedures used for selecting and designing the different types of tendon anchorage systems and the factors affecting the reliability of these systems.

b. Procedures used for determining the placement and alignment of tendons, for proportioning the reinforcement surrounding the tendon anchorage, and for considering interaction effects for multiple tendons.

c. Procedures adopted for matching reinforcement requirements for anchorage zones with reinforcement requirements for shear, torsion, and continuity.

d. Procedures adopted for considering bearing effect and tendon curvature at anchorages.

e. Procedures to consider effects from factors such as highly skewed structures, diaphragms, and end blocks.

f. Procedures to determine serviceability and failure behavior.

Task 2—On the basis of the information assembled in Task 1, evaluate the available design concepts for proportioning end and intermediate anchorage zone reinforcement. Identify the limitations to existing knowledge

and design concepts. Determine factors in need of detailed evaluation. Conduct preliminary analytical studies to evaluate the relative importance of these factors and to assist in the development of a detailed research plan, including laboratory and analytical studies, needed to accomplish the project objective.

Task 3—Within 12 months of contract initiation, submit the proposed research plan for NCHRP approval in the form of an interim report.

Task 4A—After NCHRP review, modification, and approval of the detailed research plan developed under Task 2, conduct the laboratory tests and analytical studies.

Task 4B—The analytical approaches will be extended to include some nonlinear finite element modeling which will track the possible cracking of anchorage zones and study the effect of nonlinear compression constitutive relations. The applications to be studied include: multiple anchorages along slab edges; end anchors; end anchorages in wider diaphragm type applications; and intermediate anchorages.

Task 5A—On the basis of the available information, experimental data, and analytical results, develop procedures to determine end and intermediate anchorage zone reinforcement for post-tensioned concrete girders.

Task 5B—The criteria will be extended to develop analysis and proportioning criteria for: anchorages in diaphragms and for the effects of local concentrated loads and reactions; distribution of load transfer reinforcement in front of and behind intermediate anchorages; and for intermediate anchorage zones such as slab, flange, and corner blisters including out-of-plane deviation effects.

Task 6—Prepare specification provisions to reflect accomplishment of the objectives in a format suitable for consideration for adoption by AASHTO. The recommended specifications shall be accompanied by a detailed commentary and design examples intended to facilitate their understanding and use.

Task 7—Identify areas in need of further investigation. Recommend priorities and estimate time and costs for needed research.

Task 8—Prepare a final report containing the research findings and proposed design procedures.

The research has validated the effectiveness of the use of strut-and-tie models. On the basis of that validation, Tasks 4B and 5B were added to the research plan in mid-1988 to extend the applicability of the criteria developed in the project.

Through December 31, 1988, research has been completed on Tasks 1 through 4, and is progressing on schedule on Tasks 4A, 4B, 5A and 5B. A detailed progress report is expected to be submitted in late 1989 providing an update on the results of the test program and analytical studies.

Project 10-30(1) FY '86

Nondestructive Methods for Field Inspection of Embedded or Encased High Strength Steel Rods and Cables

Research Agency:	University of Manchester Institute of Science and Technology
Principal Invest.:	Prof. F. M. Burdekin and Dr. D. G. John
Effective Date:	January 6, 1986
Completion Date:	September 29, 1986
Funds:	$25,000

During review of proposals for Project 10-30, two agencies were selected to conduct a Phase I study. After completion of Phase I remaining funds from Project 10-30 and funds from Project 12-28(9) would be combined to pursue an experimental Phase II study, subsequently described under Project 10-30(3). The Phase I research under Project 10-30(1) is described below.

The objective of this Phase I project was to select the most promising NDI methods for determining corrosion activity and structural integrity of high strength steel rods and cables embedded in concrete or encased in ducts. The agency submitted a report to support the selection and pursuit of ultrasonic and acoustic emissions. To enhance the technique, the agency suggested the development of remote transducers to excite the steel of interest without direct physical contact. Copies of the agency's report on Phase I are available for loan upon written request to the NCHRP. In addition, microfiche may be purchased (see final page of this section for ordering information).

Project 10-30(2) FY '86

Nondestructive Methods for Field Inspection of Embedded or Encased High Strength Steel Rods and Cables

Research Agency:	Southwest Research Institute
Principal Invest.:	Dr. R. E. Beissner
Effective Date:	January 20, 1986
Completion Date:	October 3, 1986
Funds:	$25,000

During review of proposals for Project 10-30, two agencies were selected to conduct a Phase I study. After completion of Phase I remaining funds from Project 10-30 and funds from Project 12-28(9) would be combined to pursue an experimental Phase II study, subsequently described under Project 10-30(3). The Phase I research under Project 10-30(1) is described below.

The objective of this project was to select the most promising NDI methods for determining corrosion activity and structural integrity of high strength steel rods and cables embedded in concrete or encased in ducts. The agency submitted a report to support the use of magnetic field disturbance technology and a.c. magnetometry. The

magnetic field disturbance equipment would be used to detect defects in embedded steel and a.c. magnetometry for determining corrosion rates. Copies of the agency's report on Phase I are available for loan upon written request to the NCHRP. In addition, microfiche may be purchased (see final page of this section for ordering information).

Project 10-30(3) FY '86

Nondestructive Methods for Field Inspection of Embedded or Encased High Strength Steel Rods and Cables

Research Agency: University of Manchester
Principal Invest.: Gareth John and F. M. Burdekin
Effective Date: July 1, 1987
Completion Date: September 30, 1989
Funds: $400,000

There is growing concern about corrosion, deterioration, and structural integrity of steel components used in cable-stayed bridges and segmentally constructed concrete bridges when these components are placed in ducts or embedded in concrete and thereby not accessible for visual inspection and evaluation. To make informed decisions on maintenance and rehabilitation of bridge members, engineers need to know the rate at which deterioration or distress is occurring and the extent of damage that has already taken place. Various nondestructive inspection (NDI) methods that could be used to evaluate the condition of these steel components should be assessed, and one or more practical systems for on-site inspection and evaluation of steel components in bridge members should be developed for field use.

After reviewing the results of Projects 10-30(1) and 10-30(2), the University of Manchester Institute of Science and Technology's proposed plan for a Phase II was chosen by the NCHRP. Accordingly, the objective of Phase II is to experimentally evaluate the chosen methods using realistic bridge components. The Phase II objective will be accomplished as follows:

Task 1—Assemble laboratory NDI equipment consisting basically of readily available components and conduct sufficient laboratory tests to establish a data base for determining optimum design concepts for prototype inspection systems. The NDI methods included in the inspection systems should be capable of determining section loss, defects, and corrosion activity of steel components embedded in concrete or encased in ducts. The test specimens shall include lengths of rods and of cables encased in ducts or embedded in concrete. Specimens taken from bridges shall be included.

Task 2—Prepare a final report documenting the findings of the research, including recommendations for the development of systems for the on-site inspection and evaluation of steel components used in cable stayed bridges and segmentally constructed concrete bridges.

Research is focusing on the development of ultrasonic techniques to interrogate the condition of prestressing steel in concrete. A prototype device is expected with actual field demonstrations performed. Investigations of ultrasonic techniques for evaluating cables in suspension and cable stayed bridges are now intended to be confined to the laboratory.

Project 10-31 FY '86

Acceptance Criteria for Steel Bridge Welds

Research Agency: Materials Research Laboratory, Inc.
Principal Invest.: Dr. P. B. Crosley
Dr. E. J. Ripling
Effective Date: January 1, 1986
Completion Date: December 31, 1989
Funds: $348,350

Use of inaccurate methods of nondestructive evaluation and empirical acceptance criteria for bridge welds has resulted in unnecessary repair of welds and has permitted unsound welds to be incorporated in some bridges. Failure to apply accurate bridge weld quality acceptance criteria can significantly increase construction and maintenance costs or can lead to structural failures. Unnecessary weld repairs can generate harmful residual stresses and distortion and can often create new and more serious discontinuities.

Current empirical radiographic and ultrasonic weld quality acceptance standards had their origin in the boiler and pressure vessel industry. Use of these empirical standards has been justified by the inherent inaccuracy of nondestructive test methods. With improvements in the ability of nondestructive tests to accurately measure and characterize weld flaws, it is timely and appropriate to develop better weld quality acceptance criteria. The development of new criteria based on appropriate analytical methods and verification procedures will produce realistic bases for design and inspection decisions. New weld quality criteria will produce safer bridge welds while reducing unnecessary repairs.

The objective of this research is to develop improved acceptance criteria for bridge welds.

The research will include the following tasks:

Task 1—Review relevant current domestic and foreign codes of practice, performance data, and research findings. This information shall be assembled from both technical literature and unpublished experience of designers, fabricators, and owners of steel bridges.

Task 2—Based on currently available information and the application of appropriate analytical techniques, develop rational, practical acceptance criteria for welds in steel bridges.

Task 3—Present the findings of Tasks 1 and 2 in an interim report to be submitted not later than 12 months

after the initiation of the study. The interim report shall present the criteria developed under Task 2 and the rationale for these criteria along with examples illustrating their application. The report shall also include comparisons between results produced by existing and proposed criteria. Finally, a detailed work plan for Task 4 shall be proposed in the interim report. NCHRP authorization will be required before commencing Task 4.

Task 4—Conduct additional analytical studies and laboratory tests for the purpose of further development and validation of proposed acceptance criteria for bridge welds.

Task 5—Revise the acceptance criteria, as necessary, based on the NCHRP review of the interim report and in consideration of additional insight gained from the findings of Task 4.

Task 6—Present the acceptance criteria in a format suitable for consideration by appropriate code-writing authorities. The recommended criteria shall be accompanied by a detailed commentary and examples of specific applications intended to facilitate understanding and use of the criteria.

Task 7—Identify areas in need of further investigation. Recommend priorities and estimate the time and costs for the additional research.

Task 8—Prepare a final report.

Through December 31, 1988, research on the project is progressing on schedule. Tasks 1 through 3 have been completed, and work is progressing satisfactorily on Tasks 4 through 7. Task 4 was modified by the panel and the research team to include an investigation of the fatigue behavior of sharp cracks as well as the fatigue behavior of naturally occurring discontinuities.

Project 10-32 FY '86

Durability of In-Place Concrete Containing High-Range Water-Reducing Admixtures

Research Agency:	Construction Technology Laboratories
Principal Invest.:	Dr. David Whiting
Effective Date:	January 6, 1986
Completion Date:	July 5, 1987
Funds:	$99,811

High-range water-reducing admixtures for concrete, also known as superplasticizers, were first introduced in Japan and West Germany in the 1960's, and more recently they were introduced in the United States. These admixtures can markedly increase the workability of concrete mixtures. They also have the potential for producing very high strength, durable portland cement concrete by reducing the amount of water used while still allowing conventional placement methods.

Research indicates that these admixtures may affect entrained air void systems. Air void spacing factors below 0.008 in. seem to correlate with expected satisfactory laboratory "freeze-thaw" resistance. However, higher spacing factors often found in the concrete containing high-range water-reducing admixtures may or may not result in poor durability based on laboratory tests. Because the correlation between air void characteristics and durability as measured in the laboratory under freeze-thaw conditions has not been well defined for concretes containing high-range water-reducing admixtures, further study is needed. There is also a perception that regardless of laboratory freeze-thaw testing, good field performance can be expected. Therefore, field performance should be studied to evaluate the relevance of the relationship between in-place durability and air void characteristics.

The objective of this research was to assess the relationship between the durability and the air void characteristics of concrete placed with high-range water-reducing admixtures. Existing structures subjected to freezing and thawing were used for this assessment.

Research is complete; the final report has been published as: NCHRP Report 296, "Durability of In-Place Concrete Containing High-Range Water-Reducing Admixtures."

Project 10-32A FY '87

Durability Testing of High-Strength Concrete Containing High-Range Water-Reducing Admixtures

Research Agency:	Utah State University
Principal Invest.:	J. Derle Thorpe
Effective Date:	October, 1, 1987
Completion Date:	March 31, 1990
Funds:	$249,238

Interest in the use of high-range water-reducing (HRWR) admixtures, also known as superplasticizers, for concrete is increasing. These admixtures can markedly improve the workability of concrete mixtures. They also have the potential for producing very high strength, durable portland cement concrete by reducing the amount of water used while still allowing conventional placement methods.

Research indicates that these admixtures may affect entrained-air void systems. Air void spacing factors below 0.008 in. seem to correlate with expected satisfactory "freeze-thaw" resistance as predicted by laboratory tests. However, higher spacing factors often found in concrete placed using HRWR admixtures may or may not produce laboratory results predicting poor durability. Because of the poor correlation between air void characteristics of concretes containing HRWR admixtures and laboratory durability test results, a question arises concerning the relationship of air void characteristics and durability.

There are also concerns about the influence of other concrete properties on durability and the ability of current freeze-thaw testing procedures to adequately measure durability in the laboratory as a predictor of field performance.

Therefore, research should be conducted to improve laboratory testing procedures for evaluating freeze-thaw durability and to better understand the parameters that influence the durability of concretes containing HRWR admixtures. The major concern is the testing of concretes with low water-cement ratios containing HRWR admixtures so that the benefits of high strength and decreased permeability can be realized.

The objectives of this research are to: (1) investigate the significance of various concrete properties, such as air-void characteristics, on the durability of high strength concretes (compressive strength greater than 4,000 psi) containing high-range water-reducing (HRWR) admixtures, and (2) compare and assess the variability of durability factors calculated from various methods of testing concretes for freezing and thawing durability. To accomplish these objectives, the following tasks shall be performed:

Task 1—Conduct a survey of state highway agency practices for performing and applying the results of laboratory freeze-thaw tests.

Task 2—Design a partial factorial testing program to compare and evaluate laboratory methods of freeze-thaw testing considering the effects of various characteristics of the concretes. The test program shall include procedures defined in ASTM C671, ASTM C666 Procedure A (2 hr/cycle), and ASTM C666 Procedure A (5 hr/cycle), and the most common procedure used by states based on Task 1. Details of the measurements and the analyses to be performed on specimens shall be included. Specimens shall be cured as prescribed by the ASTM procedures except that one set of specimens in each test group shall be tested after 2 additional weeks of air drying. The concrete mixtures shall include 3 generic types of HRWR admixtures, multiple cement factors, and a range of air void characteristics. (The recommended testing program must be submitted to the NCHRP for approval prior to conducting subsequent tasks. Two months are expected to be required for review by the NCHRP.)

Task 3—Conduct test program as approved in Task 2.

Task 4—Analyze the data and develop relationships.

Task 5—Prepare the final report including conclusions and recommendations on factors that affect the durability of concretes containing HRWR admixtures, appropriate laboratory testing procedures that produce realistic results, and acceptable air void characteristics of high-strength concrete.

Tasks 1 and 2 are complete. Testing has begun under Task 3.

Project 10-33 FY '86

Potential Benefits of Geosynthetics in Flexible Pavement Systems

Research Agency:	Georgia Tech Research Corporation
Principal Invest.:	Dr. Richard D. Barksdale
Effective Date:	January 6, 1986
Completion Date:	December 15, 1988
Funds:	$100,000

Test results indicate that the tensile forces that can be developed in geotextiles and other geosynthetics, such as geomembranes and geogrids, hereinafter referred to collectively as geosynthetics, will increase the structural capacity and improve the performance potential of aggregate-surfaced roads placed over very weak subgrades (i.e., CBR less than 2). Techniques have been demonstrated whereby geosynthetics can be tensioned either by prestretching the geosynthetic or by loading and developing ruts in the geosynthetic-aggregate system, before placing additional (leveling) aggregate base.

The applicability of geosynthetics to higher type pavement systems incorporating unbound granular pavement layer(s) with an asphalt surface (flexible pavement systems) needs to be studied to determine whether the structural capacity and performance potential can be improved. Although geosynthetics have been used to some extent in the unbound granular layers of higher type pavements, their behavior and influence on pavement performance are not well understood. Consequently, a number of questions must be answered before the feasibility of widespread use of geosynthetics in flexible pavement systems can be determined, for example: (1) What types of geosynthetics should be used and what properties of these geosynthetics must be specified? (2) Is prestressing geosynthetics necessary and practical? (3) Under what conditions do geosynthetics influence flexible pavement systems? (4) Can the benefits of geosynthetics be documented?

The objective of this study is to determine the feasibility of including geosynthetics on the subgrade or in the unbound layers to improve the performance of flexible pavement systems or to provide alternative designs for equal performance. To accomplish this objective, the following tasks are required:

Task 1—Select and/or develop analytical models or procedures to evaluate the behavior of flexible pavement systems incorporating geosynthetics.

Task 2—Analyze and identify the parameters that influence the behavior of the flexible pavement systems incorporating geosynthetics. The parameters to be examined should include but not be limited to: (a) properties of the geosynthetics, (b) location of the geosynthetics in the flexible pavement system, (c) installation methods for geosynthetics including prestressing and the removal of

wrinkles, (d) properties of the aggregate, (e) characteristics of the subgrade, (f) environmental effects such as moisture and temperature, and (g) load magnitude and frequency. Appropriate ranges for significant parameters should be identified and the relative importance of these parameters established using theoretical models or procedures recommended by the investigators.

Task 3—Using a laboratory testing program, validate the model(s) and the appropriateness of the selected parameters. The laboratory testing program should be such that the geosynthetics and aggregate materials can be placed in a manner similar to normal roadway construction. It is anticipated that the validation testing will be done using an appropriate range of the most significant parameters. Relevant properties of each material incorporated in the laboratory test program should be determined using tests selected by the investigators and performed as part of this project.

Task 4—Establish the engineering feasibility of using geosynthetics in flexible pavement systems based on the findings from Tasks 1, 2, and 3. Properties of geosynthetics necessary for installation as well as long-term performance must be considered when establishing this feasibility. Potential benefits to be realized by incorporating geosynthetics in flexible pavement systems, such as improved performance or possible tradeoffs among components of flexible pavement systems, should be presented.

Task 5—Develop a framework for the design, implementation, and evaluation appropriate for full-scale field tests to validate the feasibility established in Task 4.

Research is complete; the agency final report is under review. Research was successfully performed, but indicates that the use of geosynthetics in the unbound layers of high type flexible pavement systems is not economically justified at the present time. Given these circumstances, the most appropriate distribution of the final report is being evaluated.

Project 10-34 FY '86

Transient Protection, Grounding, and Shielding of Electronic Traffic Control Equipment

Research Agency: Georgia Tech Research Corp.
Principal Invest.: Hugh W. Denny
Effective Date: March 1, 1986
Completion Date: January 31, 1989
Funds: $179,992

Electronic traffic control equipment is highly susceptible to disrupted operation and even permanent damage caused by electrical noise and transients (voltage spikes and surges) associated with connected service and signal lines. Lines providing electrical power and cables interconnecting equipment to sensors, communications systems, or peripheral hardware provide a direct path for the conduction of disruptive and damaging electrical transients from externally generated electrical noise. Lightning, switching transients, and other electromagnetic interference (EMI), including radio frequency interference (RFI), may be conducted on electrical and signal lines connected to traffic control equipment. Some disruptive noise may even originate from companion equipment located within the traffic control cabinet.

The problem of electrical transient damage to electronic control equipment may be minimized and in most cases eliminated by proper application of existing technology, i.e., currently available devices may be able to provide sufficient protection against equipment malfunction and deter damage. However, there are no widely accepted specifications or procedures for application of such devices to the control equipment cabinet, terminal blocks, and associated wiring. There is a need to develop such specifications and procedures and to make them available to operating agencies to obtain maximum benefit from the protection devices.

The objectives of this research are to: (1) review current practice and develop recommended procedures for the transient protection, grounding, shielding, and filtering of power and signal conductors, cabinets, and equipment associated with traffic control to assure the proper operation and extended life of the electronic equipment; (2) develop recommended performance specifications and test methods for protective devices; and (3) develop a user's handbook and a video-training tape. To achieve these objectives, the following tasks will be accomplished:

Task 1—Review all available research and technical literature to characterize the magnitude and waveform of transients on all input and output lines of equipment cabinets and to obtain related information for use in subsequent tasks.

Task 2—Identify and summarize current practice (performance specifications, test methods, and installation and maintenance procedures) of the traffic signal community.

Task 3—Develop preliminary draft procedures for providing transient protection of electronic traffic control equipment.

The procedures will address:

a. Ground rods and grounding networks.
b. Bonding and shielding of cabinets, equipment, wiring, and conduit.
c. Protection of cabinet power and signal circuits, including dress and respective location of all wires and harnesses.
d. Fuses and circuit breakers.
e. EMI/RFI filters.
f. Transient protection devices.
g. Test methods and procedures to verify the above.

Describe how the procedures can be applied to both new and existing installations. Also describe how they can be used to mitigate line transients from direct, near, and distant lightning strikes and from conducted and radiated EMI and RFI.

Task 4—Prepare and submit an interim report presenting the findings from Tasks 1 through 3 and also include a preliminary table of contents for the final report and user's handbook.

Task 5—Prepare final recommended procedures, performance specifications, test methods, and estimated hardware costs for transient protective devices for AC service and signal conductors, detector inputs, and communication lines (AC and DC).

Task 6—Prepare a final report and a user's handbook documenting the recommendations and specifications developed in Task 5. Include in the final report discussion of the rationale and implications of each recommendation along with applicable cautions. Describe in the user's handbook representative components, materials and assemblies, specifications, and procedures.

Task 7—Prepare a reproducible video-training tape in ½-inch VHS format in 30-minute segments keyed to the sections of the user's handbook. Prepare an instructor's guide to supplement the user's handbook and training tapes.

Tasks 1 through 6 have been completed and the project panel has reviewed the draft final report. The research agency is revising the final report and completing work on the Task 7 videotapes. The completion date was extended to October 30, 1988 and may have to be extended into early 1989 in order to complete all remaining work.

Project 10-35 FY '87

Fatigue Behavior of Welded and Mechanical Splices in Reinforcing Steel

Research Agency:	Wiss, Janney, Elstner Assoc., Inc.
Principal Invest.:	Conrad Paulson and John M. Hansen
Effective Date:	November 1, 1987
Completion Date:	April 30, 1990
Funds:	$300,000

Many existing bridges cannot accommodate the increasing traffic volumes and loads that are required for new bridge designs; therefore, highway agencies are spending large sums of money in rehabilitating, widening, and repairing these structures. Designs in some cases rely on the capacity of welded and mechanical reinforcing steel splices to transfer loads from the new steel reinforcement to the existing reinforcement. It is often necessary to place these splices in regions of high stress range. The behavior under cyclic stress conditions of many currently used splice configurations has never been adequately determined.

AASHTO specifications are available for consideration of fatigue strength in the design of welded details in structural steel members. Similar guidelines are not available for welded details in reinforcing steel. The American Welding Society's AWS-D1.4 provides standards for fabricating welded reinforcing splices, but provides no information on their fatigue performance. Additionally, the AASHTO Standard Specification for Highway Bridges limits the stress range for reinforcing steel, but provides no guidance on the allowable stresses in welded or mechanical splices.

Some fatigue testing of reinforcing steel splices has been performed. Many of these tests were performed for the nuclear power industry and concentrated on low cycle/high stress range tests on large diameter bars. The results from these tests may be applicable to the development of guidelines for the design of bridge components subject to seismic loadings. It is uncertain, however, whether data exist for the fatigue behavior of reinforcing steel splices under high cycle/low stress range effects.

Research is needed to assess the fatigue behavior of welded and mechanical reinforcing steel splices. On the basis of this assessment, guidelines will be formulated for use by the designer involved in the rehabilitation and design of highway bridges. Better understanding of the fatigue behavior of welded and mechanical splices in reinforcing steel will provide for more cost-effective design, preventive maintenance, and assurance of public safety.

The objective of this research is to evaluate the fatigue behavior of, and develop practical fatigue design guidelines for, welded and mechanical splices for reinforcing steel in bridges.

The research will include the following tasks:

Task 1—Review relevant current domestic and foreign practice, performance data, and research findings. This information shall be assembled from both technical literature and unpublished experiences of engineers, consultants, and owners of concrete structures.

Task 2—Summarize and evaluate the information generated in Task 1 on the design, application, and fatigue behavior of welded and mechanical splices in reinforcing steel.

Task 3—Present the findings of Tasks 1 and 2 in an interim report to be submitted not later than 8 months after initiation of the study. The interim report shall contain a detailed research plan for Task 4 and a framework for the design guidelines to be developed under Task 6.

Task 4—Conduct laboratory tests in accordance with the detailed research plan presented in the interim report. The testing shall consist of constant amplitude fatigue tests in stress ranges realistic for highway structures.

Task 5—Analyze and evaluate all relevant fatigue

test results from Tasks 2 and 4, and summarize the findings.

Task 6—Develop recommended design guidelines in a format suitable for consideration by the AASHTO Subcommittee on Bridges and Structures. The recommended guidelines shall be accompanied by a detailed commentary and examples of specific bridge applications intended to facilitate understanding and use of the guidelines.

Task 7—Prepare and submit a final report containing the research findings, proposed guidelines, and recommendations for further research.

Through December 31, 1988, research has fallen about 4 months behind schedule. The interim report was submitted in mid-October and reviewed by the project panel late in the year. The Task 4 laboratory tests were just starting at the end of 1988.

Project 10-36 FY '88

Evaluation of Weldments Incorporating Backing Materials

Research Agency: Fleet Technology Limited
Principal Invest.: Michael J. Pates
Effective Date: May 2, 1988
Completion Date: May 1, 1991
Funds: $259,503

In current steel bridge fabrication the material most commonly used as a backing for groove welds consists of a continuous steel bar placed against the backside of the groove. This permits complete joint penetration groove welding from one side only. Codes require the weld metal to be thoroughly fused with the steel backing. This fabrication technique is widely accepted, particularly when access to the far side of the joint being fabricated is restricted. Typical applications where access may be restricted are in welded box girders and columns. In some cases, the backing bar is removed after the groove weld has been completed. However, this is not always possible or necessary.

Fused weld backing becomes an integral part of the structure and must be continuous, otherwise sharp, localized discontinuities will concentrate stresses and cause weld cracking. Additionally, the orientation of the backing relative to the direction of the applied stress is critically important. While careful adherence to existing codes regarding design, assembly, welding procedure, workmanship, and testing should lead to acceptable performance, the essentials of good practice are not widely understood. Guidance is required for bridge designers, fabricators, and inspectors on the proper detailing and fabrication procedures for complete joint penetration groove welds incorporating fused steel backing bars.

The geometry of restricted access, complete joint penetration groove welds precludes the use of through-thickness nondestructive evaluation procedures other than ultrasonic testing. However, the presence of the fused steel backing compromises the accuracy of such tests. Additionally, precise measurements of the effective weld throat are often impossible. These problems may be alleviated by the use of other backing materials and designs. However, little information is available for the designer, fabricator, and inspector on the performance of such alternative backing materials in steel bridge applications. Research is needed to identify suitable alternative backing materials and designs appropriate for bridge applications.

The objective of this research is to develop a better understanding of the performance characteristics of fused steel bars and alternative weld backing materials, and to determine their potential benefits and limitations in bridge design and fabrication.

The research will include the following tasks:

Task 1—Review relevant current domestic and foreign codes of practice, performance data, and research findings related to typical bridge framing connections using fused steel backing bars. This information shall be assembled from both technical literature and unpublished experience of designers, fabricators, inspectors, and owners of steel bridges.

Task 2—From the Task 1 findings, develop a user's guide for designers, fabricators, and inspectors providing specific recommendations for the use of fused steel backing bars. The guide should identify critical details and provide appropriate cautions and limitations.

Task 3—Review relevant current domestic and foreign codes of practice, performance data, and research findings related to the use of nonmetallic, nonfused backing materials. Materials such as carbon, which may adversely interact with molten metal or the welding arc, should not be considered.

Task 4—Select a limited number of nonmetallic, nonfused backing materials that may be appropriate for steel bridge applications. Determine if the details of welded joints shown in Chapter 2 of the AWS D1.1 Structural Welding Code—Steel, are appropriate for use with these selected backing materials. (The selected backing materials will be used in laboratory studies to be conducted in Tasks 6 through 9.)

Task 5—Present the findings of the first four tasks in an interim report to be submitted not later than 9 months after initiation of this study. The interim report shall present a detailed research plan for the remainder of the study. NCHRP approval of the detailed research plan will be required before commencing Task 6.

Task 6—Conduct laboratory tests on weldments made with the selected nonmetallic, nonfused backing materials. Tests should include metal chemistry, metallurgical studies, and mechanical tests to ensure that there are no adverse effects on the weld or base material.

Task 7—Fabricate representative T-, corner-, and butt-

type complete joint penetration groove welds using fused metal backing bars and the selected nonfused backing materials. During the fabrication process, methods shall be used to induce acceptable and rejectable discontinuities defined by Paragraph 9.25 in AWS D1.1. Perform and report on ultrasonic indications as required by Chapters 6 and 9 of AWS D1.1.

Task 8—Verify and characterize the existence of representative ultrasonic test indications in the welds produced in Task 7.

Task 9—Conduct performance tests on weldments fabricated with the selected nonfused backing materials. The purpose of these tests will be to identify the advantages and disadvantages of their use in steel bridge applications.

Task 10—Prepare a final report documenting all research. The final report shall include recommendations for areas in need of further investigation.

Through December 31, 1988, research on Tasks 1 and 3 have progressed on schedule. A number of references have been collected and evaluated for applicability.

AREA 11: LAW

PROJECT 11-1 FY '65

Rules of Compensability and Valuation in Highway Land Acquisition

Research Agency: University of Wisconsin
Principal Invest.: Dr. Richard U. Ratcliff
Effective Date: January 1, 1965
Completion Date: April 30, 1967
Funds: $84,840

This project analyzed current legal rules and appraisal practices and suggests methods to eliminate inconsistencies, ambiguities, and inequities based on constitutional mandates, sound judicial analysis, and appraisal theory and practice.

The research was to express the parameters of indemnity representing the ideal based upon logical and acceptable criteria, identify deviations from the ideal basic principles found in statutes, operating rules, and court decisions, analyze the motivation for these deviations, and suggest a workable compromise between the ideal and the practicalities in the application of the power of eminent domain.

The report contains information relative to the present law of evidence in eminent domain proceedings. Divergencies which appear in the law from State to State are identified and analyzed. The cause and extent of diversity are determined, and the connection between evidentiary law and the legal rules and standards of compensability and valuation is examined. The reasons the courts give as a basis for their decisions to admit or exclude various types of evidence are set forth and described.

The final report has been published as: NCHRP Report 104, "Rules of Compensability and Valuation Evidence for Highway Land Acquisition."

Project 11-1(1) FY '68

Eliminating Enhancement or Diminution Effects on Right-of-Way Valuation

Research Agency: Real Estate Research Corporation
Principal Invest.: Stanley F. Miller
Morris A. Lieberman
Effective Date: September 2, 1968
Completion Date: February 28, 1969
Funds: $5,000

The objectives of the research were to assemble and analyze whatever statutory and case law now exists on this subject. Valuation problems involved were also studied.

The research included a study of the general principles and techniques (both valuation and legal) that cause enhancement or diminution in the value of surrounding properties or those being taken by eminent domain as a result of the date of valuation or announcement thereof. Statutory laws of each of the 50 States were examined.

The final report covers a general discussion of valuation principles, including identification of factors which cause enhancement or diminution of value. The impact of date of valuation is discussed, and case studies of the effect of time are presented. There is also a general discussion of the legal aspects and practices.

The final report has been published as: NCHRP Report 114, "Effects of Proposed Highway Improvements on Property Values."

Project 11-1(2) FY '68

Recognition of Benefits to Remainder Property in Highway Valuation

Research Agency: Joseph M. Montano & Assoc.
Principal Invest.: Joseph M. Montanc
Effective Date: October 1, 1968
Completion Date: March 31, 1969
Funds: $5,000

The subject of benefits is often discussed and casually considered, largely because it is a mandatory finding in many States, but rarely pursued with enthusiasm. Because of the need for more equitable treatement of the public interest, the practitioner, both legal and appraisal, needs to be more fully informed of the potential involved.

Actually there is a rather large and surprisingly liberal body of case law allowing a variety of benefits to offset or mitigate the amount of compensation that must be paid. These were collected, analyzed, and grouped, with emphasis on the most recent cases to ascertain trends. The desired end product was a trial memorandum that can be used by the practicing trial lawyer and appraised

on a day-to-day basis. The research explored different approaches, both legal and appraisal, that would lead to greater recognition of benefits to offset or mitigate the amount of compensation which must be paid.

The final report gives a short and concise, but comprehensive, statement of what appellate courts have said about the trial aspects of benefits. It further contains an inventory of these appellate decisions, as well as a list of annotations, treatises, and legal periodicals. Moreover, the report gives some suggestions and ideas about what should be done and how to prove that benefits have resulted by virtue of the construction of public improvements.

The project report has been published as: NCHRP Report 88, "Recognition of Benefits to Remainder Property in Highway Valuation Cases."

Project 11-1(3) FY '68

Taxation Aspects of Right-of-Way Acquisition

Research Agency: University of Tulsa
Principal Invest.: Dr. E. Dale Searcy
Effective Date: September 16, 1968
Completion Date: April 30, 1969
Funds: $2,250

The objective of this research was to identify, analyze, and explain, with appropriate examples, the many elements of the taxation aspects of right-of-way acquisition. It included the Federal income and capital-gains tax elements, but also treated these elements from a state income and ad valorem tax point of view for purposes of illustration.

The research distinguished, for taxation purposes, between all of the different compensation elements involved (i.e., relocation payments, partial takes, etc.). It included these and other elements involved in the various interests or awards (negotiations vs. condemnation, etc.) and types of properties (residential, business, agricultural, investment properties, etc.).

A final report was not submitted; therefore the contract was terminated.

Project 11-1(4) FY '68

Compensation in the Nature of Additives to Market Value

Research Agency: Univ. of Oklahoma Research Inst.
Principal Invest.: J. Dwain Schmidt
Effective Date: December 1, 1968
Completion Date: May 31, 1969
Funds: $2,500

The objective of this study was to analyze statutes and cases on a Federal and State-by-State basis to ascertain the present state of the law of these issues and to measure the trend, if any.

The research examined some outstanding cases concerning additives to market value in highway condemnation cases and delved into recent legislation materially affecting the law of eminent domain as it relates to just compensation.

The final report was not published in the NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 11-1(5) FY '68

Rules of Discovery and Disclosure in Highway Condemnation Proceedings

Research Agency: Long, Mikkelborg, Wells & Fryer
Principal Invest.: Jeremiah Long
Effective Date: September 15, 1968
Completion Date: April 14, 1969
Funds: $2,500

A significantly large body of statute and case law is developing concerning the applicability of State and Federal rules of discovery to eminent domain actions and the rights of the parties to compel disclosure of the opposition's valuation and other testimony. Depending on the way such disclosure is permitted, advance possession of the other party's valuation evidence, which is largely opinion, and the reasons therefor, may materially affect cross examination. The highway legal practitioner should be aware of the state of the law in this field.

Divergent conclusions and opinions relating to value are not based on the existence of differing facts but on individual interpretation of those facts in the expert's valuation of the property before and after acquisition. No amount of independent pre-trial effort on the part of opposing counsel or his client will reveal the conclusions and opinions of the opposing experts. Add to the uncertainties of preparation for cross-examination and rebuttal the primary importance of expert testimony in condemnation actions and the wide divergence in the contents of such opinion, and it is not surprising that the field of eminent domain has produced the most activity and the greatest diversity of legal opinion in the area of pre-trial discovery of the opinions and conclusions of value experts retained for negotiation and in anticipation of litigation.

The final project report discusses the existing Federal and State cases on the subject, the statutes, and rules adopted in various jurisdictions to resolve the uncertainties attending discovery of expert opinion.

The project report has been published as: NCHRP Report 87, "Rules of Discovery and Disclosure in Highway Condemnation Proceedings."

Project 11-1(6) FY '68

Valuation and Condemnation Problems of Selected Special Purpose Properties

Research Agency: Edward E. Level
Principal Invest.: Edward E. Level
Effective Date: September 2, 1968
Completion Date: November 28, 1969
Funds: $7,500

Properties put to special uses are frequently required, in whole or in part, for highway right-of-way purposes. The rules of compensation and methods of valuation of such properties are inconsistent in their practical application, often with incongruous and varying results from State to State.

Research is needed to clarify the special-purpose-property field illustrated by the taking of cemeteries, parks, schools, and churches, or portions thereof. The research was to assemble and analyze the case law applicable to this class of property and the present state of appraisal practice in the field involving these special-use properties and to provide a clear exposition of the correct theory and practice in terms of a series of alternatives applicable to such properties.

Schools, churches, cemeteries, parks, utilities, and similar properties, due to the lack of sales data, cannot readily be valued by the usual appraisal methods or legally allowable proof. The project report considers what special appraisal techniques and legal rules are applied in valuing such properties.

Cases and appraisal methods are discussed as to just compensation, elements of the special-purpose properties, appraisal evidence and evidence allowed, and the competency of witnesses in trials concerning special-purpose properties. Specific discussions of appraisal techniques and legal rules applicable to cemeteries, churches, parks, schools, and other special properties are discussed.

The project report has been published as: NCHRP Report 92, "Valuation and Condemnation of Special Purpose Properties."

Project 11-1(7) FY '68

Valuation and Compensability of Noise, Pollution, and Other Environmental Factors

Research Agency: Univ. of Oklahoma Research Inst.
Principal Invest.: J. Dwain Schmidt
Effective Date: October 1, 1968
Completion Date: March 31, 1969
Funds: $2,500

Highway departments today are confronted with some complicated takings, particularly in urban areas, wherein allegations are made claiming damages which arise from highway-oriented noise, air, and water pollution and other similar environmental factors.

The decided cases in this limited area were singled out and examined, with careful analysis given to the valuation and legal compensability problems.

The power to take private property for a public purpose by eminent domain is a basic right of government. However, in the United States, private property shall not be so taken without the payment of just compensation. The question researched in this project was whether highway-produced noise, air, and water pollution—and other similar environmental factors—are the type of injuries for which compensation must be paid.

The final report was not published in the NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 11-1(8) FY '68

Remainder Damages Caused by Drainage, Runoff, Blasting, and Slides

Research Agency: Harrison Lewis
Principal Invest.: Harrison Lewis
Effective Date: October 15, 1968
Completion Date: January 15, 1970
Funds: $7,500

During highway construction, or shortly thereafter, there are special types of damages relating to drainage, runoff, blasting, slides, etc., which sometimes result. Generally speaking, all damages which are the natural and probable result of involuntary takings are to be included and assessed in the condemnation proceedings, but the law and the appraisal practice relating to such special situations, litigated and negotiated, is far from clear and is not understood by many appraisers.

The purpose of the research was to identify and clarify these elements. The research included an assembly and analysis of case law from a majority of jurisdictions applicable to each of these special situations; an assembly and analysis of the best and prevailing appraisal principles applicable thereto; and a statement of the logical alternative methods of dealing with the valuation and damage problems involved, including the pros and cons of each such legal alternative.

The project report has been published as: NCHRP Report 134, "Damages Due to Drainage, Runoff, Blasting, and Slides."

Project 11-1(9) FY '68

Valuation and Condemnation Problems Involving Trade Fixtures

Research Agency: Edward L. Snitzer
Principal Invest.: Edward L. Snitzer
Effective Date: March 15, 1969
Completion Date: December 1, 1969
Funds: $5,000

The objective of the research was to review all appellate cases in the trade fixture area and to cite and compare these with selected typical landlord-tenant and mortgagor-mortgagee cases to illustrate the different rules of law applicable. Appropriate jury instructions, based on the decided cases, were developed as to the acquisition and valuation criteria that have been judicially prescribed. Comments were made on the valuation techniques involved, particularly as to how they may differ, if they do, from conventional methods of fixture valuation. Existing legal and appraisal literature was reviewed and cited, particularly law review articles, *ALR* annotations, and *The Appraisal Journal.*

The project report has been published as: NCHRP Report 94, "Valuation and Condemnation Problems Involving Trade Fixtures."

Project 11-1(10) FY '68

Compensability and Valuation Aspects of Residential Displacement in Highway Programs

Research Agency: Ross, Hardies, O'Keefe, Babcock, McDugald & Parsons
Principal Invest.: Fred P. Bosselman
Effective Date: March 15, 1969
Completion Date: September 15, 1969
Funds: $5,000

Serious practical problems arise when highway construction unavoidably necessitates substantial displacement of residential units both in urban and rural areas. Relocation of displaced residents is, in varying degrees, becoming a responsibility of public agencies. However, up to the present time, alternative means and procedures for performing this responsibility have been limited, and it is evident that new and greater efforts in this activity must be made. Significant legal and valuation problems must be solved if legislators and administrators are to have guidelines for development of new methods of improving relocation assistance and for decisions between alternatives in specific situations.

The research report contains discussions of the constitutional requirements and limitations and how the basic standards for the payment of compensation to persons whose property is taken for public use are derived from such sources. The need for new compensation techniques is discussed and analyzed. Traditionally, "consequential damages" resulting from the taking of a man's property have been considered part of the burden of citizenship. The rapid increase of residential takings has caused great pressure on government to compensate more of these consequential damages. The various monetary and nonmonetary effects are outlined to indicate the wide range of losses that may result when residences are taken.

The project report has been published as: NCHRP Report 107, "New Approaches to Compensation for Residential Takings."

Project 11-1(11) FY '68

Valuation Elements of Joint Development Projects, Including Air Rights

Research Agency: Real Estate Research Corp.
Principal Invest.: John M. Bohling
Effective Date: February 24, 1969
Completion Date: August 25, 1969
Funds: $5,000

This study briefly reviewed the legal factors covering the valuation of air rights and of joint development projects. An exploration was made of known appraisal concepts and valuation principles and their application to the valuation of multiple-use projects. The findings of this study will provide guidance for appraisal practitioners and public officials concerned with the valuation of joint development projects.

The study found that the current appraisal technique, as presented by the Keuhnle and White formulas, appears to present the best potential for the valuation of multiple-use projects, particularly as they apply to rights-of-way. These formulas present the value of the property interest to be disposed of (the air rights or tunnel easement) in order to approximate the difference between the value of the fee property before and after the specific property interest is conveyed. These formulas take into consideration other costs or benefits, such as (a) economic value loss because of reduction in functional utility due to construction, (b) added costs of constructing improvements in a different fashion than if erected on surface fee, (c) additional interest expense which would be incurred, (d) savings in excavation costs, (e) tenant relocation, (f) demolition.

The final report was not published in the NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 11-2 FY '65

Theory and Practice in Inverse Condemnation

Research Agency: Regional and Urban Planning Implementation
Principal Invest.: Mrs. Barbara Hering
Effective Date: February 1, 1965
Completion Date: June 30, 1966
Funds: $15,000

This project was intended to review case law covering inverse condemnation, review techniques to litigate inverse condemnation claims and defenses, analyze administrative techniques used in handling such claims, and compare judicial treatment and alternative statutory proposals applicable to State highway department problems.

An intensive review of legal cases has been conducted for five States having a substantial volume of such cases. Questionnaires supplemented by personal contact studied legal and administrative practice.

The project report has been published as:

NCHRP Report 72, "Theory and Practice in Inverse Condemnation for Five Representative States."

Project 11-3 FY '67

Valuation and Legal Implications of Scenic, Conservation, and Roadside Easements

Research Agency: Donald T. Sutte, Jr., and Assoc.
Principal Invest.: Donald T. Sutte, Jr.
Prof. Roger A. Cunningham
Effective Date: November 1, 1966
Completion Date: December 15, 1967
Funds: $25,000

This project relates to the identification and application of legal and valuation principles for the acquisition of scenic, conservation, and roadside easements; outdoor advertising and junkyard activities; scenic enhancement interests; and the like.

All the available information was assembled pertaining to past experience in the use of scenic roadside easements and similar property interests in programs for scenic enhancement. An annotated bibliography of the relevant legal and appraisal literature has been prepared, and State and Federal highway agencies that have been active in acquisition of scenic easements were interviewed. The material was analyzed with regard to the statutory bases, the character of the easement, and the administrative and acquisition practices developed.

The researchers studied the steps for acquiring scenic easements, the advantages and disadvantages of scenic easements, and similar less-than-fee property interests. Model legislation was developed to deal with the legal problems identified.

The project report has been published as: NCHRP Report 56, "Scenic Easements—Legal, Administrative, and Valuation Problems and Procedures."

Project 11-3(1) FY '68

Public Control of Roadside Advertising Signs for Highway Beautification

Research Agency: Donald T. Sutte, Jr., and Assoc.
Principal Invest.: Donald T. Sutte, Jr.
Prof. Roger A. Cunningham
Effective Date: October 1, 1968
Completion Date: December 31, 1969
Funds: $20,000

The Highway Beautification Act of 1965 made several major changes in Federal policy regarding control of roadside advertising, which changes have affected State and local programs on such matters and require valuation and legal studies.

Based on the assumption that compensation must be paid for the elimination of those signs erected before October 1965 that must be removed, the legal research included a review of all the decided cases discussing all the various elements of compensation and, in particular, the taking from the owner of the sign, display, or device of all right, title, leasehold, and interest in such sign, display, or device and the taking from the owner of the real property on which the sign, display, or device is located, the right to erect and thereafter maintain such signs, displays, and devices thereon.

The valuation research included a general discussion of all applicable valuation principles and concepts considering the special-purpose nature of outdoor advertising signs; gave consideration to the explanation of the alternative methods of estimating compensation for all elements; gave separate treatment to the methods of measuring business losses; and recognized and separately treated the different types of outdoor advertising signs. Actual illustrations and case studies were utilized.

The project report has been published as: NCHRP Report 119, "Control of Highway Advertising Signs—Some Legal Problems."

Project 11-3(2) FY '68

Public Control of Junkyards for Highway Beautification

Research Agency: Real Estate Research Corp.
Principal Invest.: Stanley F. Miller
Morris A. Lieberman
Effective Date: September 2, 1968
Completion Date: February 28, 1970
Funds: $13,300

Based on the assumption that compensation must be paid for the relocation, removal, or disposal of junkyards specified in the Highway Beautification Act of 1965, the legal research included an investigation of decided cases in five representative States. Furthermore, the statutory laws of the 50 States were examined as they pertained to the problem and the research objective.

The research included a general examination of valuation principles and concepts applicable to the valuation of junkyards. Careful and objective consideration was given to alternative methods of estimating compensation for all elements. The studies recognized and separately treated the different types of junkyard establishments.

The project report covers the basic principles of market value and compensation. Valuation practices and procedures are discussed, and factors that cause enhancement or diminution of value are identified. Case studies are included in the report to show examples of the effect of time on value and to show examples of remainder and specific parcels.

The project report has been published as: NCHRP Report 112, "Junkyard Valuation—Salvage Industry Appraisal Principles Applicable to Highway Beautification."

Project 11-4 FY '68

Elimination of Wide Divergence in Right-of-Way Valuation

Research Agency: Amer. Inst. of Real Estate Appraisers
Principal Invest.: Frances Hokanson
Effective Date: July 1, 1969
Completion Date: February 28, 1971
Funds: $24,959

Wide variations in valuation have been reported in many States. These have most frequently occurred in instances (a) where two or more appraisers are so divergent that their testimony has little merit and (b) where appraisal of severance damage is shown by subsequent experience to be wholly unrealistic. Continued occurrence of such instances results in unnecessarily high awards and raises questions regarding validity of current valuation methods.

This research reviews, analyzes, and evaluates actual cases in which divergences existed. The reasons or bases for such divergences are identified. The research includes analyses of how divergencies relate to type of taking, type of use, level of government that acquires, and other factors. It also covers the extent to which appraisal divergencies reflect inadequacies in the appraisal process and techniques such as (a) misunderstanding of the facts of a particular appraisal, (b) lack of training and experience of appraisers, (c) conflicting legal and engineering premises, and (d) problems of severance damages. Alternative solutions are suggested to eliminate or diminish such divergences. The alternative solutions explored include possible changes in the law, presentation and admissibility of valuation evidence, changes of appraisal concept, or methods of administration.

The project report has been published as: NCHRP Report 126, "Divergencies in Right-of-Way Valuation."

Project 11-5 FY '71

Valuation of Air Space

Research Agency: Daniel, Mann, Johnson, & Mendenhall
Principal Invest.: Daniel J. McNichol
Effective Date: October 1, 1970
Completion Date: May 31, 1972
Funds: $49,800

The objective of this study was to provide guidelines, procedures, and documentation for the right-of-way agent and lawyer in valuation, legal, and administrative problems as applied to air-space acquisition and planning. The primary emphasis was on developing applicable valuation theory and criteria.

The research included an inventory and review of before-and-after case-study material where air space had been bought, sold, or leased. An analysis was made in terms of factors common to all cases and of special factors relevant to various uses of air space and various types of highway structures.

The research also evaluated the adequacy of existing legislation and analyzed and reported on legal ramifications that influence the valuation process, taking into consideration legal constraints peculiar to air-space valuation. A basic theory for the evaluation of air rights was developed.

The variables and factors that influence air-space acquisition and the valuation processes were identified and analyzed. Matrices were developed to provide a comprehensive collection of relevant valuation factors, including economic feasibility analysis. The primary aim was to provide a clear and precise presentation of all factors considered in the valuation process and a basis for selecting the most desirable use.

The project report has been published as: NCHRP Report 142, "Valuation of Air Space."

Project 11-6 FY '74

Valuation and Compensability of Noise Pollution

Research Agency: Jack Faucett Associates
Principal Invest.: Dr. E. J. Mosbaek
Effective Date: April 1, 1974
Completion Date: July 31, 1975
Funds: $94,744

The objective of this research was to identify and develop fair and equitable valuation methods and compensability criteria for the effect on adjacent areas of noise anticipated to be produced by traffic on proposed highway improvements. To accomplish these objectives, the research included the following tasks:

1. Review and summarize recent literature, including court decisions, pertaining to elements of damages arising from noise, and theories of compensation therefor, including methods of measurement and valuation of such damage.
2. Define measures and scales for quantifying the extent of potentially compensable damages resulting from exposure to highway traffic noise. Variables to be quantified should include such factors as impact on property values and interference with human activities.
3. Develop a compensation model or models that relate levels of compensation to varying levels of noise exposure and different land uses.
4. Apply and evaluate the use of the compensation models against a set of representative highway environments to assess the economic effects of noise compensation

and revise the compensation models on the basis of the evaluation.

5. Prepare a guide for determining rates of compensation for damages resulting from exposure to highway traffic noise for practical application in planning and design of highways.

Research has been completed, and copies of the agency's final report have been distributed to NCHRP sponsors. Microfiche of the agency's final report may be purchased (see final page of this section for ordering information).

AREA 12: BRIDGES

Project 12-1 FY '65

Deformation of Steel Beams Related to Permitted Highway Bridge Overloads

Research Agency: University of Missouri
Principal Invest.: Dr. Adrian Pauw
Dr. J. W. Baldwin, Jr.
Effective Date: February 1, 1965
Completion Date: June 30, 1967
Funds: $50,000

This research was initiated to study the magnitude and effect of permanent deformations in simple-span composite and noncomposite steel-stringer highway bridges. Included in the work was a study of the causes and magnitudes of stress which, in addition to normal load stresses, lead to yielding of the steel stringer at load stresses with calculated magnitudes lower than the yield point of the material. Such factors as residual stress distribution due to rolling and welding, effects of thermal gradients, and the effects of creep and shrinkage of the slab on the stress in the steel were considered.

The final report has been included in the report for Project 12-6, which was not published in the NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 12-2 FY '66

Distribution of Wheel Loads on Highway Bridges

Research Agency: Iowa State University
Principal Invest.: Dr. W. W. Sanders, Jr.
Effective Date: June 1, 1966
Completion Date: December 31, 1968
Funds: $79,512

The current AASHO specifications for the distribution of wheel loads to highway bridge floor systems are inadequate. This study correlated and evaluated the large amount of research conducted on this problem to date and made suitable recommendations for changes in the specifications covering wheel-load distribution factors for the various types of floor systems used in bridges. The major emphasis was on short- and medium-span bridges without skew. Included were floor slabs supported by steel, reinforced concrete, and prestressed concrete, as well as floor systems produced by adjacent box beams.

The final report has been published as: NCHRP Report 83, "Distribution of Wheel Loads on Highway Bridges."

Project 12-3 FY '66

Development of Waterproof Roadway Joints for Bridges

Research Agency: Southwest Research Institute
Principal Invest.: Dr. E. W. Kiesling
J. E. Minor
Effective Date: December 15, 1965
Completion Date: March 14, 1969
Funds: $149,895

The research was directed toward the development of designs for economically feasible waterproof bridge expansion joints that adequately provide for thermal expansion and contraction and remain serviceable when installed normal or skewed to the line of traffic. Recommendations were made for the design, installation, and maintenance of the joints.

The research has been completed. The essential findings from the study have been reported in NCHRP Research Results Digest 14 (Oct. 1969). Because it contains proprietary information, the final report will not be published in the NCHRP report series and is available only to the sponsors of the Program.

Project 12-4 FY '66

Thermal Characteristics of Highway Bridges

Research Agency: Southwest Research Institute
Principal Invest.: Dr. Thein Wah
Effective Date: December 15, 1965
Completion Date: March 31, 1968
Funds: $102,400

This study sought to determine the magnitude and significance of thermal gradients in girder-supported highway bridges and to develop an analytical method for predicting the resulting thermal stresses. Field tests were conducted to attempt to validate the analytical method.

The final report was not published in the NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 12-5 FY '67

Protection of Steel in Prestressed Concrete Bridges

Research Agency: University of Denver
Principal Invest.: Dr. W. C. Hagel

Effective Date: September 15, 1966
Completion Date: November 15, 1968
Funds: $173,255

This project sought to determine environmental conditions under which special protection is required and to develop effective protective systems under both pre- and post-tensioning configurations. Specifically, the objectives were (1) to conduct a thorough survey of available domestic and foreign data on corrosion and prevention of corrosion of prestressing steel in bridges, buildings, pavements, and other structures; (2) to review present practice to evaluate the effectiveness of prevention of corrosion and mechanical damage during manufacturing, shipping, and placing; (3) to identify the mechanisms of corrosion which attack prestressing tendons under various conditions, possibly including, but not limited to, the influence of concrete and grout composition, the presence of free water, electrolysis, and the presence or absence of cracking; (4) to devise an appropriate accelerated corrosion test or tests simulating the various service conditions surrounding prestressing tendons; (5) to evaluate various possible protective systems for prestressing tendons, including, but not limited to, metallic, plastic, or inhibitive coatings, grout substitutes or admixtures, cathodic protection, etc.; (6) to perform field and laboratory experiments to determine the effectiveness of present grouting methods for post-tensioned work and to suggest improvements in methods and/or materials; and (7) to evaluate the effectiveness of concrete cover over tendons.

The final report has been published as: NCHRP Report 90, "Protection of Steel in Prestressed Concrete Bridges."

Project 12-6 FY '67

Prediction of Permanent Camber of Bridges

Research Agency: University of Missouri
Principal Invest.: Dr. James W. Baldwin, Jr.
Dr. Adrian Pauw
Effective Date: February 1, 1967
Completion Date: April 30, 1972
Funds: $82,253

The primary objective of this research was to recommend a means of predicting the permanent camber in rolled beams resulting from specific fabrication methods and to include (1) a thorough survey of available data on residual stresses in rolled beams; (2) a survey of existing methods of cambering beams and a classification of methods into different categories, if possible, with cambering by both mechanical and thermal means being studied; (3) the determination of the magnitude and distribution of residual stresses in beams as rolled and delivered to the fabricator without camber, with the beams studied being of sizes representative of typical highway bridges; (4) the determination of the effect of the cambering methods investigated on residual stresses; (5) the determination of permanent deformations in rolled beams without added camber when subjected to repeated loads at various levels with loads lower than those causing computed yield-point stresses (this does not presume to be fatigue loading, but the number of cycles applied would be equal to six-months service life of a bridge); (6) the determination of permanent deformations in rolled beams cambered by the methods investigated when subjected to repeated loads at various levels of loading lower than those causing computed yield-point stresses, the number of cycles applied being equal to six-months service life of a bridge; and (7) the formulation of a mathematical model (after the determination of objectives 5 and 6) for predicting the permanent camber.

The final report, which includes the findings of Project 12-1, was not published in the NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 12-7 FY '67

Effects of Weldments on Fatigue Strength of Steel Beams

Research Agency:	Lehigh University	
Principal Invest.:	Dr. John W. Fisher	
Effective Date:	Oct. 1, 1966	July 1, 1970
Completion Date:	Jan. 31, 1970	Dec. 31, 1972
Funds:	$199,023	$200,000

The principal objective of Phase I of this research was to develop design relationships that define the basic behavior of welded coverplated beams under constant-amplitude fatigue loading. The results of the Phase I work have been reported in: NCHRP Report 102, "Effect of Weldments on the Fatigue Strength of Steel Beams."

The Phase II work had the objective of extending the basic knowledge obtained under Phase I into important design considerations, including stiffeners and/or lateral and transverse connections. Phase II included a continuing review of existing data and mathematical relationships defining the fatigue behavior of various details under constant-amplitude loading. It also included a statistically designed and controlled experiment that was intended to provide new information for the development of suitable mathematical relationships that can predict the fatigue behavior of welded beams with stiffeners and/or lateral and transverse connections. Variables studied included applied stresses, design details, and type of steel.

Phase II research has been completed, and the final report has been published as: NCHRP Report 147, "Fatigue Strength of Steel Beams with Welded Stiffeners and Attachments."

Project 12-8 FY '66

Bridge Rail Service Requirements as a Basis for Design Criteria

Research Agency:	Texas A & M University Research Foundation	
Principal Invest.:	Dr. Robert M. Olson	
Effective Date:	Mar. 1, 1968	Jan. 2, 1970
Completion Date:	Feb. 28, 1969	June 30, 1971
Funds:	$28,793	$69,753

The Phase I research effort had as its objective the development of tentative service requirements, and the results have been published as: NCHRP Report 86, "Tentative Service Requirements for Bridge Rail Systems."

The Phase II effort had as its objective the quantification of the service requirements to produce design criteria for bridge rail systems. This objective was to be pursued by further establishing the validity of a simple mathematical model developed under Phase I; by conducting parameter studies using the mathematical model to evaluate simulated vehicle-barrier collisions; by developing tables, curves, or nomographs for use by design engineers; and by refining the limits of tolerable deceleration on the basis of more recent information.

Phase II research has been completed, and the final report has been published as: NCHRP Report 149, "Bridge Rail Design—Factors, Trends and Guidelines."

Project 12-9 FY '67

Elastomeric Bearing Research

Research Agency:	Battelle Memorial Institute
Principal Invest.:	J. C. Minor
Effective Date:	September 1, 1967
Completion Date:	January 31, 1970
Funds:	$84,800

This project contemplated research on elastomeric bearings and bearing systems using materials as defined in the AASHTO specifications for elastomeric bearing pads. The major objectives of the project were to evaluate (1) effect of geometry on compressive strain, compressive set, shear modulus, and rotational modulus for hardness between 50 and 70 durometer and sizes from 50 to 200 sq in., and the effect of lamination on these values; (2) relative performance of glued laminated pads compared to fully vulcanized units, including an effective test of the adhesion between layers; (3) relative performance of molded pads versus pads sawed from larger sheets with an evaluation of the sawing process and determination of an acceptable cut surface; and (4) evaluation of the aging and low-temperature (to −40 F) characteristics of the various pads.

The research has been completed, and the final report has been published as: NCHRP Report 109, "Elastomeric Bearing Research."

Project 12-10 FY '70

Analysis and Design of Bridge Bents

Research Agency:	Portland Cement Association
Principal Invest.:	Dr. James E. Carpenter
Effective Date:	January 1, 1970
Completion Date:	December 31, 1973
Funds:	$297,900

The present strong emphasis on safe and aesthetic design of reinforced concrete highway bridges has resulted in substructure configurations that depart widely from the traditional footing-column-cap frame design. Aesthetic considerations often dictate the concealment of massive concrete caps and elimination of numerous vertical columns; however, design procedures in current use are not applicable to these new configurations. There is a general feeling that current procedures result in overdesigned structures containing much more steel than is necessary. Therefore, an urgent need exists for the development of appropriate design procedures.

Although the ultimate need is to establish valid design procedures that are applicable to many configurations of bridge bents, this project was limited to investigation of bent caps concealed in straight, continuous, reinforced concrete bridges.

Design procedures were developed by (1) constructing and testing adequately scaled reinforced concrete models of representative bents and (2) developing a mathematical model to correlate with the experimental results. The design procedures may be corroborated by data taken from full-size bridges instrumented during construction but not as a part of this project.

Research was based on prototypes representative of popular box-girder designs. The accomplishment of the research included: (1) reviewing the technical literature; (2) determining a design procedure for single- and multiple-column bents; (3) determining the cap design width by defining the extent of superstructure participating in supporting the cap loads; and (4) specifying changes required in the AASHTO specifications to permit use of the recommended design procedures.

To achieve the objectives of this research, a plan was developed that includes testing of $\frac{1}{5}$-scale models of two reinforced concrete box girder bridges. These tests provided information on distribution of loads in the vicinity of the integrated bent cap. Five additional tests on model bent specimens provided further information on the location of critical sections and the effective width of the bent cap. These $\frac{2}{5}$-scale specimens were intended to represent a transverse strip of bridge superstructure that is parallel to and includes the bent cap and columns. The reinforcement of the bent cap was varied in these models, as well as column flare and the thickening of the deck slab. Analytical studies of load distribution in the entire bridge and of stress distribution in the bent cap accompanied the experimental work.

Research has been completed, and the project report has been published as: NCHRP Report 163, "Design of Bent Caps for Concrete Box Girder Bridges."

Project 12-11 FY '71

Waterproof Membranes for Protection of Concrete Bridge Decks

Research Agency:	Materials Research and Development	
Principal Invest.:	C. J. Van Til B. J. Carr	C. J. Van Til
Effective Date:	Aug. 1, 1970	July 15, 1973
Completion Date:	Mar. 31, 1973	Sept. 30, 1978
Funds:	$206,025	$96,979

The objective of this research was to develop, or discover, one or more effective waterproofing membrane systems for use on concrete bridge decks.

The objective was approached in a two-phase study. Phase I, now complete, was devoted to preliminary evaluation of all available membranes, selection of the most promising for field evaluation and development of a field evaluation plan. Phase II was the field evaluation.

The results of Phase I have been reported in: NCHRP Report 165, "Waterproof Membranes for Protection of Concrete Bridge Decks—Laboratory Phase."

Under Phase II, the five systems selected as most promising were experimentally installed on new decks at each of four bridge sites in 1974 and 1975. Semiannual observations of performance of the installed systems were made. Research is completed, and the agency's final report has been distributed to the Program sponsors. Loan copies are available or microfiche of the report may be purchased (see final page of this section for ordering information).

Project 12-12 FY '71

Welded Steel Bridge Members Under Variable-Cycle Fatigue Loadings

Research Agency:	United States Steel Corporation
Principal Invest.:	C. G. Schilling K. H. Klippstein
Effective Date:	October 1, 1970
Completion Date:	October 31, 1975
Funds:	$310,000

The primary objective of this project was to develop information on the properties of welded steel bridge members under variable-cycle fatigue loadings and to develop a hypothesis for the prediction of life expectancy from any spectrum of loading.

The agency pursued the project objectives by: a study of pertinent past work with particular emphasis on field measurements of stresses in bridges under traffic; a theoretical study to predict from existing hypotheses the fatigue behavior of small specimens and beams that were tested later in the study; variable-amplitude fatigue tests of small specimens simulating certain beam details for the purpose of verifying the variable-amplitude load spectra selected and crack propagation threshold assumptions; variable-amplitude fatigue tests of relatively large beams of various steels with typical bridge details similar to those tested in NCHRP Project 12-7; and complete evaluation of the experimental results and development of methods of utilizing the results for design and specification purposes.

Research has been completed, and the final report has been published as: NCHRP Report 188, "Fatigue of Welded Steel Bridge Members Under Variable-Amplitude Loadings."

Project 12-13 FY '73

Cathodic Protection for Reinforced Concrete Bridge Decks

Research Agency:	USS Engineers and Consultants
Principal Invest.:	J. B. Vrable
Effective Date:	October 1, 1972
Completion Date:	July 31, 1974
Funds:	$174,601

The objective of this research was to develop a technically and economically feasible cathodic protection system(s) for reinforced concrete bridge decks.

In this study, the two primary approaches to cathodic protection—the impressed current system and the sacrificial anode system—were investigated. Analog studies in the laboratory and prototype model studies were main features of the investigation. The feasibility of applying either approach to protecting bridge deck steel reinforcement against corrosion was demonstrated. A detailed work plan for a field evaluation of cathodic protection, applying the results of the study, was developed.

Research has been completed, and the project report has been published as: NCHRP Report 180, "Cathodic Protection for Reinforced Concrete Bridge Decks—Laboratory Phase."

Project 12-13A FY '73

Field Evaluation of Galvanic Cathodic Protection for Reinforced Concrete Bridge Decks

Research Agency:	Portland Cement Association
Principal Invest.:	Dr. David A. Whiting
Effective Date:	August 1, 1975
Completion Date:	May 15, 1981
Funds:	$74,405

Research under a previous NCHRP study, Project 12-13, had a primary objective of developing technically and economically feasible cathodic protection systems for the uppermost reinforcing steel in concrete bridge decks. The findings, published in NCHRP Report 180, "Cathodic Protection for Reinforced Concrete Bridge Decks—Lab-

oratory Phase," demonstrated the potential of cathodic protection and recommended field demonstration programs. These recommendations included both forms of cathodic protection: impressed current cathodic protection and galvanic cathodic protection, i.e. the use of sacrificial anodes.

On completing Project 12-13, the NCHRP elected to pursue field evaluations of galvanic cathodic protection only. Impressed current cathodic protection was already receiving attention from several states.

The evaluations and related research are now complete. Absolute judgments on galvanic cathodic protection of reinforced concrete bridge decks were not possible. However, the performance of two variations of protective systems, perforated zinc sheet anodes and closely spaced zinc ribbon anodes, provides encouragement for further research and field demonstrations of this relatively simple method of cathodic protection systems as a possible preservation technique for reinforced concrete bridge decks.

Research has been completed, and the project report has been published as: NCHRP Report 234, "Galvanic Cathodic Protection for Reinforced Concrete Bridge Decks—Field Evaluation."

Project 12-14 FY '73

Subcritical Crack Growth in Steel Bridge Members

Research Agency: United States Steel Corporation
Principal Invest.: Dr. John M. Barsom
Effective Date: October 1, 1972
Completion Date: June 30, 1974
Funds: $99,923

The long-range objective of this research was to develop information that would lead to prevention of unstable crack growth in welded steel bridge members. This objective included the definition of material requirements and design specifications to avoid brittle fracture.

The main objectives of this project were:

1. To develop corrosion-fatigue data on bridge steels in distilled water and 3 percent sodium chloride solution under stress fluctuations such as occur in actual bridges.
2. To develop an analytical method for predicting the cyclic life of bridge components in distilled water and 3 percent sodium chloride solution under stress fluctuations such as occur in actual bridges.
3. To develop methods of utilizing the results for design and specifications purposes.

The steels studied were A36, A588 grades A and B, and A514 grades E and F. The test specimens were made from base metal of 1-in. plate material and were 1 in. thick.

The longitudinal and transverse tensile properties at room temperature were established for each grade of steel. Moreover, energy absorption, lateral expansion, and percent shear were determined in the temperature range between −100°F and room temperature by using standard impact Charpy V-notch specimens.

Research has been completed, and the project report has been published as: NCHRP Report 181, "Subcritical Crack Growth in Steel Bridge Members."

Project 12-15 FY '73

Detection and Repair of Fatigue Cracking in Highway Bridges

Research Agency: Lehigh University
Principal Invest.: Dr. John W. Fisher
Effective Date: October 1, 1972
Completion Date: April 30, 1975
Funds: $100,000

The objectives of the study were to: (1) compile a state-of-the-art review of existing methods of nondestructive inspection and evaluate their reliability and adaptability in the detection of fatigue cracks in welded highway bridges; (2) compile a state-of-the-art review of typical existing and currently designed welded bridge details and evaluate those most susceptible to fatigue crack growth; (3) review and evaluate methods for improving the fatigue life and arresting the progress of fatigue damage that occurs at the weld toes of severe notch-producing details where the probability of failure is greatest. The methods were evaluated by tests of "as welded" and of fatigue-damaged coverplate beam specimens of A36 steel. These tests were comparable to and correlated with those conducted in NCHRP Project 12-7 and reported in NCHRP Reports 102 and 147. The experimental variables include crack size at the time of treatment, methods of improvement, stress range, and minimum stress; and (4) recommend methods for improving the fatigue life of, and arresting the progress of fatigue damage to, welded highway bridges.

Research has been completed, and loan copies of the agency's final report are available from the NCHRP upon written request. The findings have been combined with those from Project 12-15(2) and published as: NCHRP Report 206, "Detection and Repair of Fatigue Damage in Welded Highway Bridges."

Project 12-15(2) FY '75

Retrofitting Procedures for Fatigue-Damaged Full-Scale Welded Bridge Beams

Research Agency: Lehigh University
Principal Invest.: Dr. John W. Fisher
Effective Date: June 1, 1976
Completion Date: November 30, 1978
Funds: $150,000

This study built on research completed earlier under NCHRP Project 12-15, "Detection and Repair of Fatigue

Cracking in Highway Bridges." Project 12-15 demonstrated that peening the weld toe and applying a gas tungsten arc remelt process were successful in improving fatigue strength in the laboratory. The current study included further work on these methods and was concerned with three major areas related to the retrofit or repair of fatigue-damaged members.

Task 1 was intended as a pilot study to demonstrate the applicability of peening and gas tungsten arc remelting in the field.

Task 2 was intended to provide supplemental information on the low stress range behavior of full-size bridge beams. These beams were retrofitted and retested after various levels of fatigue crack growth.

Task 3 was intended to examine the fatigue strength of beams, with cracks at the ends of transverse stiffeners, that have subsequently been repaired by drilling holes at the crack tip. Five existing welded built-up beams were available for this study from an earlier test program.

Research is completed, and the final report, including findings from Project 12-15, has been published as: NCHRP Report 206, "Detection and Repair of Fatigue Damage in Welded Highway Bridges."

Project 12-15(3) FY '78

Fatigue Behavior of Full-Scale Welded Bridge Attachments

Research Agency: Lehigh University
Principal Invest.: Dr. John W. Fisher
Effective Date: February 1, 1978
Completion Date: July 31, 1980
Funds: $125,000

The objective of this study was to examine the fatigue strength of beams with web and flange lateral attachment plates. In addition to providing a more comprehensive data base for this type of detail, the program was intended to examine the influence of lateral bracing members on the out-of-plane distortion of the lateral plate. Further work was also undertaken during the experimental studies on the effectiveness of peening and gas tungsten arc remelting the fatigue-damaged connections and on the ability of drilled holes to arrest crack growth.

A total of 18 beams, each with three welded gusset plate details, were tested in fatigue with stress ranges of 6 to 15 ksi. The results of these tests were used to assess the adequacy of applicable provisions of the AASHTO Specification. In addition, the influence of lateral bracing on the fatigue performance of the attachments was evaluated.

Research has been completed, and the final report has been published as: NCHRP Report 227, "Fatigue Behavior of Full-Scale Welded Bridge Attachments."

Project 12-15(4) FY '79

Steel Bridge Members Under Variable-Amplitude, Long-Life Fatigue Loading

Research Agency: Lehigh University
Principal Invest.: Dr. John W. Fisher
Effective Date: April 1, 1980
Completion Date: September 30, 1983
Funds: $150,000

The objective of this study was to provide additional information on fatigue crack growth behavior of steel bridge members under randomly applied, variable amplitude loadings in the fatigue limit, extreme life region. Testing was carried out on center-crack specimens, cruciform specimens, and full-scale welded beams.

The currently available test data in this region of behavior are very sparse and do not provide an adequate basis on which to assess this problem. The consequences of triggering fatigue crack growth in existing bridges as a result of increased loads could have a major impact on the life expectancy and safety of bridge on high volume arteries where large numbers of random variable stress cycles are expected.

Research has been completed, and the final report has been published as: NCHRP Report 267, "Steel Bridge Members Under Variable-Amplitude Long-Life Fatigue Loading."

Project 12-15(5) FY '82

Fatigue Behavior of Variable Loaded Bridge Details Near the Fatigue Limit

Research Agency: Lehigh University
Principal Invest.: Dr. John W. Fisher
Effective Date: September 1, 1983
Completion Date: December 31, 1989
Funds: $399,999

Fatigue cracks have developed at the ends of cover-plates in beams that are only infrequently subjected to stress ranges exceeding the fatigue limit of AASHTO's Category E'. For example, in one particular structure, small cracks have been detected in several beams where only 0.1 percent of the measured stress cycles exceeded the estimated fatigue limit. This observed field behavior suggests that more severe fatigue problems could result if bridges are subjected to heavier loads in the future, and the consequences of occasional overloads from permits and other sources may be more critical than previously assumed.

The objective of this study is to extend the findings of Project 12-15(4) by providing additional information on fatigue crack growth behavior of steel bridge members under randomly applied, variable-amplitude loadings in the fatigue limit, extreme life region. Testing will be carried out on eight full-scale welded girders.

The currently available test data in this region of behavior are very sparse and do not provide an adequate basis on which to assess this problem. The consequences of triggering fatigue crack growth in existing bridges as a result of increased loads could have a major impact on the life expectancy and safety of bridges on high volume arteries where large numbers of random variable-stress cycles are expected.

In addition to the test program directed at the primary objective, a small portion of the total effort was expended on a reassessment of the fatigue specifications in the AASHTO *Standard Specifications for Highway Bridges.* Minor revisions to the fatigue design provisions were recommended to, and adopted by, the AASHTO Subcommittee on Bridges and Structures. The evaluation and recommended specifications were published in: NCHRP Report 286, "Evaluation of Fatigue Test Data and Design Criteria on Welded Details."

The fatigue testing has continued through December 31, 1988. One pair of girders was tested for 107 million cycles with fatigue failures noted in two connection plate details and three web attachments. A second pair of girders has received over 50 million fatigue cycles to date, with no sign of cracking at any detail. Testing on the remaining two pairs of girders was initiated in late December 1988.

Project 12-16 FY '75

Influence of Bridge Deck Repairs on Corrosion of Reinforcing Steel

Research Agency: Battelle Columbus Laboratories
Principal Invest.: Walter K. Boyd
Effective Date: September 1, 1974
Completion Date: November 30, 1977
Funds: $214,912

This study was concerned with the problem of corrosion of reinforcing steel caused by chloride ions in bridge deck concrete. The over-all objective of this research was to determine the relative effectiveness of the various repair methods in arresting corrosion of the reinforcing steel, both within and outside the repaired areas, and whether some of these methods actually aggravate the corrosion problem.

Research has been completed. Copies of the agency report may be obtained on a loan basis upon written request to the NCHRP. A limited number of copies is available to NCHRP sponsors for permanent retention, and others may purchase microfiche of the report (see final page of this section for ordering information).

Project 12-17 FY '77

Evaluation of Repair Techniques for Damaged Steel Bridge Members

Research Agency: Battelle Columbus Laboratories
Principal Invest.: H. W. Mishler
Effective Date: November 15, 1976
Completion Date: April 30, 1978
Funds: $49,974

The over-all objective of this project was to provide guidance for the assessment of accidental damage to steel bridge members and to identify, develop, and evaluate the effectiveness of repair techniques. The specific objective of Phase I was to synthesize available information on the subject and to identify areas in need of investigation. The specific objective of Phase II is to evaluate the effect of the damage and the repair techniques identified in Phase I on the behavior of the structure, determine potential detrimental effects, and define the limits within which these repair techniques can be used.

Research under Phase I has been completed. The project final report has been distributed to state highway agencies, and copies may be obtained on a loan basis upon written request to the NCHRP. A limited number of copies is available to NCHRP sponsors for permanent retention, and others may purchase microfiche of the report (see final page of this section for ordering information).

Project 12-17A FY '79

Guidelines for Evaluation and Repair of Damaged Steel Bridge Members

Research Agency: George O. Shanafelt and Willis B. Horn
Principal Invest.: W. B. Horn, G. O. Shanafelt
Effective Date: October 1, 1981
Completion Date: May 31, 1984
Funds: $99,950

The overall objective of this two-phase project was to provide guidance for the assessment of accidental damage of steel bridge members and to identify, develop, and evaluate the effectiveness of repair techniques. The specific objective of Phase I (Project 12-17) was to synthesize available information on the subject and to identify areas in need of investigation. The specific objective of the second phase of research (Project 12-17A) was to extend the effort carried out under Project 12-17 and to develop a manual of recommended practice.

Research under Phase II produced a detailed procedure of assessment and evaluation of damage. Recommendations of repair techniques and the effects of those repairs were detailed to the extent possible using currently available information. These results were presented in a user's manual recommending procedures and specifications for steel bridge repair.

Research has been completed, and the final report has been published as: NCHRP Report 271, "Guidelines for Evaluation and Repair of Damaged Steel Bridge Members."

Project 12-18 FY '77

Development of an Integrated Bridge Design System

Research Agency: Multisystems Inc.
Principal Invest.: Dr. Som P. S. Virk
Effective Date: September 6, 1977
Completion Date: December 31, 1982
Funds: $224,985

The objective of this research was to initiate the development of an integrated, modular bridge design system encompassing current bridge design specifications and allowing the engineer a wide range of interaction with the computer in performing his design functions. Such a system should be able to accommodate a variety of typical bridges.

The project consisted of two phases. Phase I included a preliminary investigation with the most important products being an inventory of currently used bridge design software and the definition of a framework for an integrated bridge design system. The actual development of the system and its functional modules occurred in the second phase of research.

Research has been completed. The objective of this research was not fully accomplished. A limited, follow-up study was carried out under NCHRP Project 12-18A to evaluate the current status and provide information for future activity in this area.

Project 12-18A FY '81

Assessment of an Integrated Bridge Design System

Research Agency: Engineering Computer Corporation
Principal Invest.: Roy A. Imbsen
Effective Date: February 1, 1984
Completion Date: January 3, 1986
Funds: $15,000

The objective of Project 12-18 was to initiate the development of an integrated, modular bridge design system encompassing current bridge design specifications and allowing the engineer a wide range of interaction with the computer in performing his design functions. Such a system should be able to accommodate a variety of typical bridges.

Project 12-18 did not reach its objective. A module for computation of bridge geometry was demonstrated to operate within the integrated system, but, for undetermined reasons, the superstructure design module did not function properly as part of the system.

Because of the limited success of Project 12-18, an independent assessment of the status of the integrated bridge design system was made. This study included an evaluation of the computer code developed in Project 12-18 in order to determine if it could be used in future programs, and a determination of the options available for additional research.

The project has been completed. The final report provided the following conclusions:

1. In the development work of NCHRP Project 12-18 for the integrated software system, too much emphasis was placed on the computer system aspect and not enough on the end-user needs.
2. The geometry module works well and is quite useful.
3. The superstructure module does not work properly.
4. AASHTO had initiated development of its own bridge design program (BDS) rendering Project 12-18 obsolete.

The agency final report will not be published in the regular NCHRP report series. It has been distributed to Program Sponsors only.

Project 12-19 FY '78

Cathodic Protection of Concrete Bridge Structures

Research Agency: Corrosion Engineering & Research Co.
Principal Invest.: William J. Ellis
Effective Date: January 1, 1978
Completion Date: December 31, 1980
Funds: $250,000

The primary objective of this study was to develop and evaluate one or more cathodic protection systems to control corrosion of steel in chloride-contaminated structural members (excluding top reinforcement in decks and steel in members below water or soil).

The cathodic protection system developed reflects consideration of: economic feasibility, including design, installation, operating, and maintenance costs; compatibility with the structure, including repaired areas; potential safety hazards; life expectancy; and resistance to various environments, such as freeze-thaw and marine conditions.

A secondary objective was to prepare a state-of-the-art report based on a thorough survey of methods, materials, and criteria that have been used to control corrosion in concrete bridge members other than the top portion of decks. The report describes both successful and unsuccessful experiences.

Research has been completed. The state-of-the-art report and the final report have been distributed to state highway agencies. Copies are available for loan upon written request to the NCHRP or microfiche of the report

may be purchased (see final page of this section for ordering information).

Project 12-19A FY '79

Concrete Sealers for Protection of Bridge Structures

Research Agency:	Wiss, Janney, Elstner Assoc., Inc.
Principal Invest.:	Donald W. Pfeifer
Effective Date:	August 1, 1979
Completion Date:	December 1, 1981
Funds:	$99,190

The objective of this study was to establish the efficacy of sealers used to protect reinforced concrete bridges exposed to chloride contamination and to provide guidance for their use on bridge members concentrating on structural elements other than the top surface of the deck. Accordingly, a variety of testing procedures were developed and several candidate sealers were evaluated. The proprietary labelling of the sealers tested has only been made available to NCHRP sponsors. Of widespread interest, however, should be the testing procedures used.

The research has been completed, and the project report has been published as: NCHRP Report 244, "Concrete Sealers for Protection of Bridge Structures."

Project 12-19B FY '81

Cathodic Protection of Concrete Bridge Structures

Research Agency:	Wiss, Janney, Elstner Assoc., Inc.
Principal Invest.:	William F. Perenchio J. Robert Landgren
Effective Date:	November 1, 1982
Completion Date:	April 30, 1985
Funds:	$138,900

Although the NCHRP project panel was generally pleased with the contents and presentation of the final report for Project 12-19, they agreed that the findings were not ready for widespread application. Consequently, a decision was made to pursue further the Project 12-19 objective of developing and evaluating one or more cathodic protection systems to control corrosion of steel in chloride contaminated structural elements (excluding top reinforcement in decks and steel in members below water or soil). Specifically Project 12-19B included: (1) laboratory investigations aimed at further development and evaluation of cathodic protection systems using conductive coatings as secondary anodes, and (2) field evaluations based on actual applications and monitoring.

Laboratory tests were performed on three conductive coatings. After optimizing the test results for the primary requirements of conductivity and durability, one coating was selected for further work. A cathodic protection system using the selected coating was applied to a laboratory-size concrete slab located at the Federal Highway Administration's Turner-Fairbank Highway Research Center and to an actual bridge pier in cooperation with the Illinois DOT.

Research has been completed, and the project report published as: NCHRP Report 278, "Cathodic Protection of Concrete Bridge Substructures."

Project 12-20 FY '78 and FY '80

Bridges on Secondary Highways and Local Roads: Rehabilitation and Replacement

Research Agency:	University of Virginia	
Principal Invest.:	Henry L. Kinnier	
Effective Date:	March 1, 1978	June 1, 1980
Completion Date:	Feb. 29, 1980	Nov. 30, 1981
Funds:	$119,923	$49,955

The objective of the first phase of this project was to develop (1) procedures for accomplishing repair and strengthening operations for bridges on secondary highways and local roads, (2) standard replacement structures and components that could be mass produced, and (3) an economic process for determining the most cost-effective alternative available in a given situation.

Phase I has been completed, and the final report was published as: NCHRP Report 222, "Bridges on Secondary Highways and Local Roads—Rehabilitation and Replacement." The primary content of this report consists of a manual of recommended practice comprising 34 repair procedures for common bridge deficiencies and 27 bridge replacement systems available for use in the United States.

The objective of the second phase of research was to expand the effort carried out under Phase I. Additional procedures for repair of the following types of bridge damage were studied: fatigue of steel members, scour, deck deterioration, fire, seismic, and accidental impact. Replacement systems based on the following concepts were considered: short-span segmental construction, sectional prestressing, modular construction and precast concrete box culverts. These repair procedures and replacement systems were prepared in the format used in the manual developed in Phase I. Innovative concepts for bridge rehabilitation and replacement were also studied.

Phase II has been completed, and the final report has been published as: NCHRP Report 243, "Rehabilitation and Replacement of Bridges on Secondary Highways and Local Roads."

Project 12-21 FY '79 and FY '82

Evaluation of Damage and Methods of Repair for Prestressed Concrete Bridge Members

Research Agency:	George O. Shanafelt and Willis B. Horn
Principal Invest.:	W. B. Horn, G. O. Shanafelt

Effective Date:	April 15, 1979	May 15, 1982
Completion Date:	Sept. 14, 1980	Jul. 8, 1985
Funds:	$58,520	$129,934

The over-all objective of this study was to provide guidance for the assessment of accidental damage to prestressed concrete bridge members and to identify, develop, and evaluate the effectiveness of repair and replacement techniques. The research was carried out in two phases.

The specific objective of Phase I was to synthesize available information on the subject and to identify areas in need of investigation. The specific objective of Phase II was to develop and evaluate improved repair procedures for damaged prestressed concrete bridge members and to prepare a manual of recommended practice.

Phase II included an evaluation of the effect of damage and the positive and negative aspects of selected repair techniques on the behavior of the structure and of the limits within which these repair techniques can be used. This was being accomplished through application of selected techniques to damaged members and subsequent laboratory testing. A detailed procedure for assessment and evaluation of damage was produced. Recommendations of repair techniques and effects of those repairs were detailed. These results are presented in a user's manual recommending procedures and specifications for prestressed concrete bridge repair. Repair methods include: the metal sleeve (see NCHRP Report 226, Nos. 3 and 5), the internal splice (Nos. 7 and 8), and the external post-tensioning system (No. 2).

Research is complete and project reports for Phase I and Phase II have been published as: NCHRP Report 226, "Damage Evaluation and Repair Methods for Prestressed Concrete Bridge Members," and NCHRP Report 280, "Guidelines for Evaluation and Repair of Damaged Prestressed Concrete Bridge Members."

Project 12-22 FY '81

Thermal Effects in Concrete Bridge Superstructure

Research Agency:	Engineering Computer Corporation
Principal Invest.:	Roy A. Isabsen
Effective Date:	October 1, 1981
Completion Date:	January 31, 1984
Funds:	$100,000

The objective of this research was to develop recommended specifications and design procedures for consideration of thermally induced stresses and movements in concrete bridge superstructures.

The research has been completed. The report and recommended specifications have been published as NCHRP Report 276, "Thermal Effects in Concrete Bridge Superstructures."

Project 12-23 FY '89

Recommended Revisions to the AASHTO *Manual for Maintenance Inspection of Bridges*

Research Agency:	A. G. Lichtenstein & Associates, Inc.
Principal Invest:	Abba G. Lichtenstein
Effective Date:	January 3, 1989
Completion Date:	January 2, 1991
Funds:	$200,000

The AASHTO *Manual for Maintenance Inspection of Bridges* is intended as a guide to provide uniformity in the inspection procedures and evaluation techniques for all bridges on public roads. The Manual was initially adopted by AASHTO in 1970, and since that time only minor changes and additions have been made. Many subsequent advances in analytical and practical techniques are being used in bridge design, construction, and evaluation, but have not been reflected in the Manual.

Research is needed to update the existing Manual. A thorough review and revision of the inspection and evaluation criteria, on the basis of current technology and recently completed and on-going research, will result in better assessment of the condition and load capacity of existing bridges.

The objective of this report is to develop a revised *Manual for Maintenance Inspection of Bridges* that can be recommended to AASHTO for consideration for adoption.

In developing the revised Manual, consideration shall be given to current practice, recently completed and ongoing research, and appropriate AASHTO committee and FHWA activities to provide: (1) guidance for inspection, evaluation, and load capacity rating of existing bridges; (2) a recommended method for load capacity rating along with acceptable alternate methods; (3) appropriate consideration of inspection requirements and preparation of inspection reports; (4) a methodology for assessing the safe load capacity from load tests; and (5) consideration of fatigue and other serviceability requirements. The revised manual shall also include consideration of factors such as scour, redundancy, and detail criticality and evaluation procedures that are applicable to bridge management systems.

The revised Manual shall be prepared in a flexible format that allows for future revisions, and a commentary shall also be provided.

The project will include the following tasks:

Task 1. Review relevant literature and current domestic and foreign procedures and specifications for inspection, evaluation, and load capacity rating of existing bridges and other structures.

Task 2. After evaluating the information developed in Task 1, prepare a comprehensive list of, and rationale for, recommended revisions to the existing Manual.

Task 3. Prepare a detailed outline for a revised Manual. As a minimum, the outline shall include chapter and topical headings along with a description of the intent of each topic.

Task 4. Present the findings of Tasks 1, 2, and 3 in an interim report to be submitted not later than 8 months after initiation of the study. NCHRP approval of the interim report will be required before commencing Task 5.

Task 5. Prepare a revised Manual and commentary in a format suitable for consideration by the AASHTO Highway Subcommittee on Bridges and Structures. Both shall be prepared in a format that can be easily updated in the future.

Task 6. Prepare a final report.

Project 12-24 FY '83

Design of Multi-Beam Precast Bridge Superstructures

Research Agency:	University of Michigan
Principal Invest.:	Dr. A. H. Mattock Dr. J. F. Stanton
Effective Date:	August 1, 1983
Completion Date:	May 31, 1986
Funds:	$149,879

The objectives of this research were to develop criteria for design of connections between adjacent precast elements in multi-beam bridge superstructures, and to develop specification provisions for the lateral distribution of wheel loads in precast multi-beam bridge superstructures of single-, double-, and multiple-stem tee girders.

The research has been completed. The report and recommended specifications have been published as NCHRP Report 287, "Load Distribution and Connection Design for Precast Stemmed Multibeam Bridge Superstructures."

Project 12-25 FY '83

Fatigue and Fracture Evaluation for Rating Riveted Steel Bridges

Research Agency:	Lehigh University
Principal Invest.:	Dr. John W. Fisher
Effective Date:	September 1, 1984
Completion Date:	September 30, 1987
Funds:	$199,957

The objective of this study was to develop a rational rating plan for riveted bridges based on available information on the fatigue and fracture resistance of such bridges and components. The research included analytical studies of existing riveted steel fatigue and fracture data and laboratory tests on riveted girders and components.

Research has been completed and the final report has been published as: NCHRP Report 302, "Fatigue and Fracture Evaluation for Rating Riveted Bridges." The report includes recommendations for revisions to the fatigue and fracture provisions in the AASHTO *Manual for Maintenance Inspection of Bridges.* It is expected that the AASHTO Highway Subcommittee on Bridges and Structures will consider the recommendations in this report for possible adoption in the near future.

Project 12-26 FY '85 and FY '89

Distribution of Wheel Loads on Highway Bridges

Research Agency:	Imbsen & Associates, Inc.	
Principal Invest.:	Roy A. Imbsen	
Effective Date:	April 15, 1985	August 22, 1988
Completion Date:	December 15, 1987	May 21, 1990
Funds:	$300,000	$200,000

The objective of this research is to develop comprehensive specification provisions for distribution of wheel loads in highway bridges.

Research under NCHRP Project 12-26 should consider all variables affecting the distribution of wheel loads. The recommended provisions shall apply to both the Service Load and the Strength Design Methods as well as to structural evaluation of existing bridges.

Load distribution criteria developed in this study are expected to include: (1) simplified methods of analysis including code formulas and (2) analytical models that are more comprehensive and exact and are intended for computer-based application.

The first phase of the project focused on steel and concrete beam-and-slab bridges and multi-cell concrete box girder bridges. The formulas that were developed in Phase 1 produced accurate and reliable results for moment and shear wheel load distributions. Correction factors for skew and continuity were also developed and presented in the format of an AASHTO specification.

The Phase I final report will not be published, but copies of the agency draft report were distributed to NCHRP sponsors in mid-1988. Copies are available on loan or microfiche (see final page of this document for ordering information).

The second phase of the project will concentrate on concrete slab bridges, precast concrete multigirder bridges, and spread box beam bridges. The results of both the first and second phases of the project will be combined into one comprehensive report and recommended specification at the end of the second phase.

Through December 31, 1988, research on Phase II of the project is proceeding on schedule. Simple formulas are being developed for longitudinal moment distribution in concrete slab, precast concrete multigirder, and spread box beam bridges. Work has also progressed well on the development of correction factors for support skew in such bridges.

Project 12-27 FY '84

Welded Repair of Cracks in Steel Bridge Members

Research Agency: The Welding Institute
Principal Invest.: Mr. E. N. Gregory
Effective Date: October 15, 1984
Completion Date: February 28, 1989
Funds: $374,575

The objective of this research was to identify and evaluate welding methods for repair of cracked steel bridge members to restore their load carrying capacity and fatigue life. The research included a synthesis of existing information on welding repair procedures including an identification of the problems and solutions for repair welding of members while under traffic loading. Laboratory and field tests were performed to evaluate the proposed guidelines for welded repair of cracked steel members, and a manual of recommended practice was developed.

Research has been completed. The final report was reviewed and approved by the NCHRP project panel. It is expected that the report will be published in the regular NCHRP report series in early 1989.

Project 12-28(1) FY '85

Load Capacity Evaluation of Existing Bridges

Research Agency: Case Western Reserve University
Principal Invest.: Dr. Fred Moses
Effective Date: September 1, 1985
Completion Date: August 31, 1989
Funds: $302,000

The elements fundamental to the process of estimating the load capacity of existing structures are distinct from design elements that have been generalized for applicability to a wide range of structure types and service conditions. This generalization, when extended to the evaluation of existing bridges, often results in overly conservative estimates of load capacity and may result in unjustified actions such as the replacement of adequate structures. Refinements in assumptions concerning loading and resistance can be justified because the cost of evaluation is only a fraction of the bridge replacement cost. A more detailed and flexible methodology for the evaluation of the load capacity of existing bridges is required.

The load capacity of existing bridges can be determined most reliably and economically through a multilevel procedure. A large number of existing bridges is clearly capable of accommodating modern highway loads, and changes in the present rating procedures are not required in these cases. However, bridges found to be deficient under the present rating procedures should be reevaluated using higher level methods. This higher level rating system should permit selection of safety levels in a rational manner based on the effort expended on inspection, maintenance, and evaluation. This system should take into account the states of deterioration and distress of the bridge and permit the owner to make informed decisions about the pay-off in terms of higher load ratings resulting from such measures as additional load control, inspection, and calculation effort.

The higher level approach should combine probability theory and engineering judgment to account for uncertainties in load effects and resistances. The load and resistance factors incorporated in this approach should be determined by a procedure that would permit future improvements in knowledge to be incorporated conveniently. The concepts of operating and inventory ratings are unsuitable as the only method of bridge evaluation, but could be retained as a screening process for the application of the higher level rating system.

NCHRP Report 292, "Strength Evaluation of Existing Reinforced Concrete Bridges," documents the findings of NCHRP Project 10-15. Project 10-15 developed a limit-state approach for the evaluation of the structural capacity of reinforced concrete bridge superstructures.

The objective of Project 12-28(1) was to extend the application of the limit-state approach to load capacity evaluation of other common bridge types, including steel and prestressed concrete bridge superstructures.

The first phase of this research was completed in late 1987. The research provided recommendations for revisions to the AASHTO *Manual for Maintenance Inspection of Bridges.* Evaluation procedures were developed for steel bridges of different types and for prestressed concrete spans. The proposed guidelines allow flexibility by providing a range of ratings depending on site conditions and the degree to which the evaluation uses available information on traffic, bridge performance, and bridge maintenance.

A second phase of the project was initiated in August, 1987. The objectives of this phase are to: (1) integrate the recommended specifications from Project 10-15 and 12-28(1) into one comprehensive code document and prepare a commentary; (2) work with several states so that the recommended procedures can be verified and refined, as necessary; and (3) develop a workshop and training manuals for implementation of the procedures on a state-wide basis.

The report from the first phase of work was published as NCHRP Report 301, "Load Capacity Evaluation of Existing Bridges."

Under the second phase, the evaluation recommendations presented in the report were combined with the evaluation recommendations presented in Report 292 to create a recommended comprehensive evaluation specification covering the majority of bridges in service. The AASHTO Highway Subcommittee on Bridges and Structures adopted the recommended specifications as a Guide Specification in 1988.

Work has progressed on schedule on the remaining tasks of the second phase.

Project 12-28(2) FY '85 and '87

Bridge Management Systems

Research Agency:	ARE Inc.	
Principal Invest.:	Dr. W. Ronald Hudson	
Effective Date:	June 24, 1985	November 2, 1987
Completion Date:	June 23, 1987	November 1, 1989
Funds:	$225,000	$250,000

The objective of this research is to develop a model form of effective bridge management at the network level. At a minimum it will include:

1. Methods to assess present and future needs of existing bridges (inventory, inspection, capacity, maintenance, rehabilitation, replacement, and funding).
2. Guidelines for determining cost-effective alternatives both with and without financial constraints.
3. Priority treatment of needs through the use of generalized work activities (ranging from posting through preventive maintenance through replacement).
4. Flexibility to accommodate a variety of policy approaches.
5. Flexibility to accommodate future expansion to the project level.
6. Methods to ascertain standards of data reliability.

The first phase of research resulted in the conceptual development of the modular elements required for a model bridge management system (BMS). The elements identified for inclusion in the model BMS are: the BMS data base module; the network level maintenance, rehabilitation, and replacement selection module; a maintenance module that will assign maintenance programs in a rational and continuing way within the system; the historical data analysis module; a project level interface module; and the reporting module. The final report from the first phase research has been published as NCHRP Report 300. "Bridge Management Systems."

A second phase of research was initiated in November 1987. The second phase has as its objective the further development and refinement of the model BMS. This phase will result in completion of the engineering concept development for a network level BMS, programming the system on a microcomputer, and validation of the system and engineering concepts with actual bridge inventory data obtained from several transportation agencies.

The second phase scope of work will consist of the following:

- Design and construction of each module (i.e., the required input and output and the operations within each module).
- Definition of the required communications between modules.
- Complete documentation of each module including flowcharts, algorithms, and rationale.
- Submission of an interim report.
- Development of a complete microcomputer-based operational system.
- Validation with live bridge data.
- Submission of a final report documenting all Phase II work.

Through December 31, 1988, research on Phase II of the project is progressing on schedule. The interim report was submitted by the research agency and reviewed by the NCHRP project panel. Work has started on programming the microcomputer-based system.

Project 12-28(3) FY '85

Fatigue Evaluation Procedures for Steel Bridges

Research Agency:	Case Western Reserve University
Principal Invest.:	Dr. Fred Moses Mr. Charles G. Schilling
Effective Date:	July 1, 1985
Completion Date:	September 30, 1987
Funds:	$200,000

The objective of this study was to develop practical procedures that more accurately reflect the actual fatigue conditions in steel bridges, and that can be applied for evaluation of existing bridges or design of new bridges. The procedures were intended to permit determination of fatigue-load ratings and estimation of remaining fatigue life for existing bridges.

Research has been completed and the final report published as: NCHRP Report 299, "Fatigue Evaluation Procedures for Steel Bridges." The report provides recommended revisions to the fatigue evaluation requirements in the AASHTO *Manual for Maintenance Inspection of Bridges,* and to the design requirements in the AASHTO *Standard Specifications for Highway Bridges.*

The recommended design provisions were adopted by the AASHTO Highway Subcommittee on Bridges and Structures as a Guide Specification in 1988. In addition, the fatigue evaluation and remaining life guidelines were added as a reference in the AASHTO *Manual for Maintenance Inspection of Bridges* by the Subcommittee in 1988.

Project 12-28(4) FY '85

Methods of Strengthening Existing Highway Bridges

Research Agency:	Iowa State University
Principal Invest.:	Dr. F. Wayne Klaiber
Effective Date:	July 1, 1985

Completion Date: July 31, 1987
Funds: $164,985

About one-half of the approximately 600,000 highway bridges in the United States were built before 1940, and many have not been adequately maintained. Most of these bridges were designed for lower traffic volumes, smaller vehicles, slower speeds, and lighter loads than are common today. In addition, deterioration caused by environmental factors is a growing problem. As a result, a high percentage of the nation's bridges are classified as deficient and in need of rehabilitation or replacement. Many of these bridges are deficient because their load carrying capacity is inadequate to carry today's traffic. Strengthening can often be used as a cost-effective alternative to replacement or posting. Therefore, the research objectives were to evaluate the feasibility and cost-effectiveness of present strengthening methods as applied to various types of bridges and to identify cost-effective innovative methods.

Research is complete; the final report has been published as NCHRP Report 293," Methods of Strengthening Existing Highway Bridges." The report details various methods of strengthening highway bridges. An extensive overview of all applicable methods is presented. The types of structures most suitable for strengthening are identified, and the effectiveness of the various methods is discussed for these structures. A major part of the study was the development of a strengthening manual (Chapter 3) for use by practicing engineers. This manual describes the most effective techniques and indicates how they may be used in various types of structures to increase or restore their load carrying capacity.

Project 12-28(5) FY '85

Standard Methodology for Conducting Condition Surveys of Concrete Bridge Components

Research Agency: New Mexico State University
Principal Invest.: Dr. John Minor
Effective Date: August 1, 1985
Completion Date: August 31, 1987
Funds: $98,338

Although concrete structures have generally demonstrated good resistance to loss of load capacity and have only rarely been removed from service for this reason, determinations of bridge load capacities are often necessary to fully evaluate the effects of deterioration. Currently, work is progressing to develop methods to permit more accurate load capacity analysis; however, inspection and reporting methods need to be enhanced or refined and then standardized to help support this work.

In addition, more than one level of inspection should be available for structures with more severe damage. The current, federally mandated biennial inspections are expected to be adequate for the majority of structures; however, refinements and additional guidance would improve the uniformity of inspection and reporting. Structures where the initial inspection and available data indicate a reduced load capacity also should be reinspected using procedures that provide a higher level and quality of data of the structure's properties.

Consequently a research project was needed that would provide a framework for surveying and reporting the condition of reinforced and prestressed concrete structures. The framework would have to include more than one inspection level to improve the reliability of data when conditions warrant.

The objective of this research was to prepare a manual for conducting inspections of reinforced and prestressed concrete bridges to assess their condition and obtain material and cross-sectional properties needed to determine load ratings. The manual should provide guidance to enable field inspectors to recognize various types of distress and to assess their significance on capacity. Techniques would also be included to evaluate the strength and other physical properties of component materials. The manual would describe the techniques used in routine biennial inspections, and the nondestructive and destructive testing techniques required to obtain more detailed information.

Research is complete. The final report will be published as NCHRP Report 312, "Condition surveys of Concrete Bridge Components—User's Manual."

Project 12-28(6) FY '85

Distortion-Induced Fatigue Cracking in Steel Bridges

Research Agency: Lehigh University
Principal Invest.: Dr. John W. Fisher
Effective Date: October 1, 1985
Completion Date: June 30, 1989
Funds: $250,000

Forces in various steel bridge members, such as cross bracing, can cause lateral (out-of-plane) distortions in webs and gusset plates that can eventually result in fatigue cracking. Such cracking is most likely to occur if the distortions must be accommodated in a short length of the web or gusset plate, for example, in the gap between the end of a stiffener and the flange. In fact, most of the fatigue cracks that have been observed in existing bridges have resulted from this cause. The distortions that contribute to this type of fatigue cracking are not calculated in normal design and rating procedures. Therefore, the

usual AASHTO fatigue provisions can not be applied to this type of cracking. Instead, existing or proposed bridge designs must be systematically reviewed to identify and evaluate potential fatigue problems that might result from out-of-plane distortions. Although some preliminary guidelines have been developed (AISC Bridge Fatigue Guide—Design and Details) to assist in this type of review, more comprehensive guidelines and more detailed criteria are needed.

The objectives of this research are: (1) to categorize the kinds of fatigue cracks that have occurred because of out-of-plane distortions; (2) to develop comprehensive guidelines, including quantitative criteria, if possible, that define the conditions that are likely to cause fatigue cracking related to out-of-plane distortions; and (3) to evaluate possible retrofitting techniques, such as drilling holes at the ends of the cracks, modifying attachment details to minimize lateral distortions, and increasing the gap between restraints. Laboratory fatigue tests of selected details that appear to be particularly susceptible to this type of fatigue cracking will be needed to accomplish these objectives. This testing should be correlated with an FHWA Regional Pooled Funds Study to be conducted at the University of Missouri and also with relevant present and planned field studies on actual bridges.

NCHRP Project 12-28(6) is intended to dove-tail with the Penn DOT-sponsored HP&R study entitled, "The Causes of Deformation Induced Cracking in Steel Bridges and Methods to Retrofit the Damage." The two studies are expected to be carried out concurrently and the research plans must be complementary. It is intended that the final report on NCHRP Project 12-28(6) should be self-sufficient.

By way of expanding on the scope of the Penn DOT-sponsored study, the following items will be considered under NCHRP Project 12-28(6).

- Fatigue cracking caused by live load-induced secondary stresses, both in-plane and out-of-plane.
- Common structural details not frequently encountered in Pennsylvania and, therefore, not included in the Penn DOT research.
- Structural details in multi-stringer bridges.
- Interaction between roadway-support stringers and underlying main structural members.
- Design guidelines for structural details that are less susceptible to distortion-induced fatigue cracking (e.g., NY DOT details for connection plates at cross frames).
- Guidance on retrofit and repair for use on a nationwide basis.

Through December 31, 1988, research on the project has progressed on schedule. The laboratory test program is nearing completion, and work has started on the preparation of specification provisions that can be recommended to AASHTO for consideration for adoption.

Project 12-28(7) FY '86

Guidelines for Evaluating Corrosion Effects in Existing Steel Bridges

Research Agency: Modjeski and Masters
Principal Invest.: Dr. J. M. Kulicki
Effective Date: May 5, 1986
Completion Date: July 31, 1989
Funds: $298,644

Engineers normally assess the detrimental effects of corrosion on steel bridge components in terms of the increased static and fatigue stresses caused by the reduction in cross-sectional area of the components. Limited studies have shown that stress concentrations caused by corrosion in steel bridge members can result in fatigue behavior equivalent to AASHTO Category E details or worse. However, corrosion can produce other severe effects such as (1) the "freezing" of pinned joints causing unintended bending moments; (2) the freezing of bearings causing unanticipated forces in piers, abutments, and bridge members; and (3) the build up of corrosion products causing local forces and distortions usually perpendicular to the plane of a plate element. Some of these detrimental effects are produced by nonuniform patterns of corrosion. Guidelines do not exist for bridge engineers to adequately identify and evaluate these effects of corrosion on critical details of steel bridges.

The objective of this research is to develop practical guidelines that can be used to assess the effects of corrosion on structural details in steel highway bridges. The guidelines shall apply to all of the steps involved in evaluating the effects of corrosion on the performance of existing bridges, and shall be suitable for incorporation into AASHTO's Manual for Maintenance Inspection of Bridges.

The research will include the following tasks:

Task 1—Review relevant current domestic and foreign practice, performance data, and research findings. This information shall be assembled from both technical literature and unpublished experiences of bridge engineers, consultants, and owners of steel bridges.

Task 2—Analyze and use the information generated in Task 1 to establish a framework for the development of procedures to evaluate corrosion effects in steel bridges.

Task 3—Present the findings of Tasks 1 and 2 in an interim report to be submitted not later than 8 months after the initiation of the study. The interim report shall contain a detailed research plan for Task 4 and a framework for the guidelines to be developed under Task 5. It shall also include examples illustrating application of the anticipated guidelines.

Task 4—Conduct laboratory tests, field investigations, and analytical studies in accordance with the detailed plan presented in the interim report. The purpose of this task is to provide insight for use in developing

guidelines for evaluating the effects of corrosion on the structural behavior of steel bridges.

Task 5—Develop the detailed guidelines in a format suitable for consideration by the AASHTO Subcommittee on Bridges and Structures. The recommended guidelines shall be accompanied by a detailed commentary and examples of specific applications intended to facilitate understanding and use of the guidelines.

Task 6—Prepare and submit a final report containing the research findings and proposed guidelines. Further research necessary for understanding the causes of the corrosion process on steel bridges and improving the ability to evaluate their effects should be identified and prioritized along with estimated costs.

Research is in progress. An interim report was submitted and reviewed, and approved after revision. A meeting of the project panel was held in mid-1988 to review progress and provide direction to the research agency. A draft corrosion inspection procedure has been reviewed by the panel, and work is now proceeding on the completion of the inspection and evaluation guidelines and manual.

Project 12-28(8) FY '86

Improving Bridge Load Capacity Estimates by Correlation with Test Data

Research Agency:	University of Tennessee, Transportation Center
Principal Invest.:	Dr. E. G. Burdette, Dr. D. W. Goodpasture
Effective Date:	February 1, 1986
Completion Date:	February 19, 1988
Funds:	$199,994

The objective of this study was to assemble domestic and foreign bridge test data in order to identify, quantify, and report on significant aspects of observed behavior that are now not considered during bridge evaluation and rating. More than 50 years of bridge test data were collected and evaluated in an attempt to isolate specific mechanisms through which bridges resist loads in ways other than those assumed during typical bridge design or evaluation.

Research has been completed and the final report published as: NCHRP Report 308, "Correlation of Bridge Load Capacity Estimates with Test Data." Several potential sources of unaccounted for load capacity are identified and discussed in detail in the report. In order to quantify the effects of these sources, recommendations are provided on the need to perform additional analytical work or bridge load testing.

Project 12-28(9) FY '86

Methods of Flaw Detection in Concrete Bridge Components

This project overlapped with another FY '86 NCHRP project, Project 10-30, "Nondestructive Methods for Field Inspection of Embedded or Encased High Strength Steel Rods and Cables." The financial resources originally assigned this project have been combined with those of Project 10-30.

Project 12-28(10) FY '86

Guidelines for Determining Redundancy in Steel Bridges

Research Agency:	Lehigh University
Principal Invest.:	Dr. J. Hartley Daniels
Effective Date:	March 1, 1986
Completion Date:	January 31, 1989
Funds:	$299,995

Redundancy in a bridge has been generally defined as the absence of critical components whose failure would cause collapse of the structure. To minimize the risk of collapse, fracture-critical members (FCMs) in existing bridges generally require more frequent and thorough inspections than other members, and, in new bridges, special design, fabrication, and material requirements apply to FCMs. However, there are considerable differences of opinion about which types of steel bridges can be safely classified as redundant.

Current AASHTO specifications define an FCM as a nonredundant tension member or other component whose failure would be expected to cause collapse of the bridge because a suitable alternative load path is not present. Nevertheless, specific criteria are not available to adequately define redundancy. Experience suggests that many bridge types have viable alternative load paths that are not easily identified. For example, longitudinal continuity, bracing, floor systems, and certain other structural conditions might have significant effects. Other considerations include the effects of failure of various individual components of built-up riveted girders and possible Vierendeel action due to partial joint fixity when diagonal members fracture in truss bridges.

Therefore, engineers need a better understanding of alternative load paths and specific criteria for redundancy. Furthermore, a classification of various types of steel bridges by degree of redundancy would be very useful in establishing bridge inspection and replacement priorities as well as in design of safe and economical bridges for new construction.

The objectives of this research are: (1) to develop a better understanding and definition of redundancy in various types of steel bridges; (2) to establish specific criteria

for redundancy in such bridges, and (3) to develop guidelines for establishing redundancy classifications for various types of steel bridges.

The research will include the following tasks:

Task 1—Review relevant current domestic and foreign practice, performance data, and research findings. This information shall be assembled from both technical literature and unpublished experiences of bridge engineers and owners of steel bridges. Emphasis shall be placed on the performance of steel bridges in which failures of FCMs were observed.

Task 2—Analyze and evaluate the information generated in Task 1 and establish a general definition of redundancy in steel bridges. Consideration shall be given to load levels. New and innovative ideas as well as established practice shall be considered.

Task 3—Using the definition adopted in Task 2, develop a methodology for applying specific criteria for redundancy to various types of steel bridges.

Task 4—Present the findings of Tasks 1, 2, and 3 in an interim report to be submitted not later than 12 months after the initiation of the study. The interim report shall contain a detailed, updated working plan for Task 5 and shall describe the framework for the guidelines to be developed under Task 6. The report shall include examples illustrating the application of the methodology developed in Task 3 and comparisons between results produced by existing and proposed methods. NCHRP approval of the interim report will be required before commencing the remaining tasks.

Task 5—Verify the methodology developed in Task 3 for selected types of steel bridges such as two-girder, simple- and continuous-span bridges, and other types of bridges that would be classified as nonredundant by the present AASHTO criteria. Implementation of this task may include analytical and experimental methods.

Task 6—Develop guidelines for establishing redundancy classifications for various types of steel bridges. These guidelines should be particularly useful in establishing bridge inspection and replacement priorities as well as in the design of safe and economical bridges for new construction. The recommended guidelines shall be in a format suitable for consideration by the AASHTO Subcommittee on Bridges and Structures. These guidelines shall be accompanied by a detailed commentary and examples of specific applications intended to facilitate the understanding and use of the methodology.

Task 7—Prepare a final report.

The agency's preliminary draft final report has been submitted and is now being reviewed by the NCHRP. The research results are based on detailed evaluations of 2-girder type bridges. However, methods used to evaluate redundant load paths and shared loading can be translated to the extent possible to other bridge types.

Project 12-28(11) FY '87

Development of Site-Specific Load Models for Bridge Rating

Research Agency:	Imbsen & Associates, Inc.
Principal Invest.:	W. David Liu and C. Allin Cornell
Effective Date:	February 9, 1987
Completion Date:	February 8, 1989
Funds:	$200,000

Throughout the United States bridges are evaluated for their capacity using standard design loads and truck configurations. In some cases bridges are judged to be structurally deficient for the current design loadings and therefore require load posting. The public pays a high price when bridges are posted, either in increased travel time or in costs associated with bridge rehabilitation and replacement. Bridge design loads and design load frequencies are typically used as inputs to the rating process. However, the bridge location determines the actual loads, load frequencies, and truck configurations that an existing bridge will experience. These factors may differ substantially from the current design loadings for which the bridge is presently rated. Data on truck traffic show considerable variation with respect to the functional highway classifications and locations on which they had been collected. More realistic evaluations of bridges may be possible by developing site-specific loading models.

The bridge rating process must give due consideration to both safety and serviceability, and it should be highly dependent on the site-specific loadings. An estimate of the maximum bridge loading is needed to evaluate the safe upper limit strength. Loading histograms are required to determine a bridge's susceptibility to fatigue and for estimates of remaining life. Realistic loading data would allow the rating engineer to make a better assessment of a bridge. Such data would result in improved strategies for bridge posting, rehabilitation, replacement, and management.

Research is needed to enable engineers to take advantage of the variations in bridge loadings that can be related to bridge site characteristics. Substantial improvements in bridge rating and associated economic benefits could be realized by using site-specific load data.

The objective of this research is to develop rational site-specific live-load models for bridge rating that accurately reflect bridge site characteristics.

In developing these models the following factors, as a minimum, should be considered: location of bridge, functional classification of highway system, expected vehicle types and configurations, multiple presence of vehicles, peak load spectra, and degree of enforcement of legal load limits.

The research will include the following tasks:

Task 1—Review relevant domestic and foreign practice and research findings. This information shall be as-

sembled from both technical literature and unpublished experience of bridge owners and consultants. This information shall include both loading histograms and load models that have been and are presently being developed.

Task 2—Analyze and evaluate the Task 1 data and determine its applicability. Identify and evaluate the shortcomings of using current design loadings for bridge rating. Assess the opportunities for, and the benefits from, the use of a site-specific load model in bridge rating.

Task 3—Define the specific factors that must be considered and their anticipated effects on the development of the loading models.

Task 4—Prepare an interim report presenting the findings of the first three tasks and proposing a detailed working plan for the remainder of the study. The interim report shall be submitted within 8 months after the research begins. Research on the remaining tasks shall not be initiated until the proposed working plan has been approved by the NCHRP.

Task 5—Develop the loading models that account for bridge site characteristics.

Task 6—Demonstrate the validity of the models developed in Task 5 by applying them to a number of typical bridges and sites. Define the limitations for application of the live-load models.

Task 7—Prepare a final report documenting the research findings.

Research on the project is nearing completion. The draft final report was expected near the end of December. A decision on the publication of the report will be made after the project panel review has been completed in early 1989.

Project 12-28(12) FY '87

Inelastic Rating Procedures for Steel Beam and Girder Bridges

Research Agency: University of Minnesota
Principal Invest.: Dr. Theodore V. Galambos
Effective Date: September 1, 1987
Completion Date: November 30, 1989
Funds: $199,898

In the United States there are a large number of older steel beam and girder bridges. Many of them have been evaluated by elastic analytical methods and judged to be structurally deficient for current traffic. In some cases these bridges were not designed for current legal loadings. In other cases deterioration has reduced their load-carrying capacity. The public pays a high price for deficient bridges both in increased travel time required when bridges are posted and in the cost of bridge rehabilitation and replacement. Full-scale tests show that bridges sometimes possess considerably greater load-carrying capacity than predicted by current evaluation methods. Improved methods of structural evaluation can produce more realistic estimates of load-carrying capacity and might reduce the number of bridges classified as structurally deficient. More realistic evaluation of steel bridges might be possible by taking inelastic flexural behavior into account.

Procedures incorporating inelastic flexural behavior are used to design buildings and bridges. However, these design procedures can not always be applied directly to the evaluation of existing bridges. This may be because of constraints such as high slenderness ratios or inadequate lateral support. Additionally, present procedures do not account for changes in lateral load distribution when stresses are in the inelastic range.

For continuous bridges, the application of such procedures may permit a higher rating without structural modification. On the other hand, by providing minor modifications and applying inelastic rating procedures, some steel bridge ratings may be further improved. The load-carrying capacity of a continuous bridge may be further increased if the unsupported length of the compression flange at intermediate supports is reduced by the addition of intermediate diaphragms. The load-carrying capacity of multi-span bridges with simply supported spans or with suspended spans may be increased by modifications which provide partial or full continuity. A realistic assessment of the benefits of such modifications can be made by use of practical inelastic rating techniques.

Research is needed to enable engineers to take advantage of inelastic behavior in rating the structural capacity of typical fully or partially continuous steel beam and girder bridges.

The overall objective of this research is to develop practical methodologies for rating existing steel bridges based on inelastic analysis. The specific objective of the first phase of research is to determine whether those methods that account for inelastic action can be applied to improve the rating of steel bridges.

In the development of inelastic rating procedures the following factors, as a minimum, should be considered: plastic-moment and shear capacity criteria; permissible permanent deflections; and serviceability of the bridge. Conditions for use of the procedures shall be defined in terms of the frequency and form of inspections, material characteristics, state of deterioration, and other relevant factors.

The research will include the following tasks:

Task 1—Review relevant domestic and foreign practice and research findings. This information shall be assembled from both technical literature and unpublished experience of bridge owners and consultants. Recent unpublished data on the inelastic behavior of beams and girders are available from the American Iron and Steel Institute.

Task 2—Analyze and evaluate the Task 1 results to identify opportunities for beneficial application of inelastic methods to steel bridge rating.

Task 3—Identify bridge types, conditions, and analytical concepts that show promise for inelastic rating procedures.

Task 4—Prepare an interim report presenting the findings of the first three tasks and proposing a detailed working plan for the remainder of the study. (The interim report shall be submitted within 9 months after the research begins. Research on the second phase shall not be initiated until the proposed Phase II working plan has been approved by the NCHRP.)

Task 5—Using available test results, develop analytical procedures to account for inelastic action in evaluating the structural capacity of steel bridges.

Task 6—Develop methods for modifying existing structures to take advantage of the analytical procedures developed in Task 5.

Task 7—Apply the developed procedures to selected examples of various steel bridge types and compare the results with those from current rating methods.

Task 8—Present the proposed methodology, its rationale, and the justification for its adoption at the regional meetings of the AASHTO Subcommittee on Bridges and Structures.

Task 9—Identify needed research to extend the application of the proposed methodology.

Task 10—Prepare a final report documenting the research findings and presenting the recommendations in a format suitable for adoption by AASHTO.

Through December 31, 1988, research on the project is progressing on schedule. The interim report was submitted in mid-1988 and reviewed at a meeting of the project panel in September 1988. Since then, work has progressed on the development of analytical models and procedures under Task 5.

Project 12-28(13) FY '87

Nondestructive Load Testing for Bridge Evaluation and Rating

Research Agency: Raths, Raths & Johnson, Inc.,
Principal Invest.: Dr. Suresh G. Pinjarkar
Effective Date: October 4, 1987
Completion Date: April 3, 1989
Funds: $150,000

In recent years, bridge engineers have been faced with an increasing need to reevaluate a growing number of older, sometimes deteriorated, bridges. These bridges are expected to carry higher volumes and heavier traffic than anticipated when they were originally designed. In the evaluation of these bridges, attempts are made to compensate for uncertainties by using conservative analysis techniques and idealized mathematical models to assess load-carrying capacity. This approach results in posting or removal of adequate structures. Substantial benefits would be realized if bridges could be evaluated through nondestructive load testing. Nondestructive load testing of bridges might be used as an alternative bridge evaluation procedure, and it may reduce the degree of uncertainty by validating assumptions inherent in analytical rating processes.

Bridge testing is used as a research tool and, to a limited extent, for determining load-carrying capacity. These tests require costly equipment and expertise normally not available to bridge owners. There is evidence that many structures possess greater load-carrying capacity than can be predicted by conventional analytical load rating procedures. Load testing methods that can be used reliably by agencies not specialized in physical bridge testing will improve the rating process. The primary use of such methods would be for structures that are found to require posting based on analysis. It is conceivable that load testing methods can be developed which permit estimates of load capacity at lower cost than analytical procedures.

There are no clearcut guidelines that help bridge owners to determine when load testing is an appropriate method for use in the bridge rating process. An analysis must be made of the possible benefits, risks, and costs that would be involved in deciding to load test a bridge. The application of a load produces responses in bridges including strains, deflections, dynamic effects, fatigue crack growth, and load distribution. The extent and nature of the testing needed are dependent on the responses which control the load capacity of the bridge.

Research is needed so that bridge owners can take advantage of the benefits that may be obtained by performing nondestructive load testing on highway bridges.

The objective of this project is to develop guidelines for nondestructive load testing of highway bridges that may augment or enhance the analytical rating process.

The research will include the following tasks:

Task 1—Review domestic and foreign practice and research findings on physical testing for the purpose of establishing load-carrying capacity. This information shall be assembled from both technical literature and unpublished experience of bridge and building owners and consultants.

Task 2—Identify typical nondestructive tests that can be performed on the structure as a whole and on individual bridge components. Identify the limits of applicability of these tests. In particular, distinguish between tests that are diagnostic (e.g., producing input to the usual analytical rating techniques) and tests that are comprehensive (e.g., used in lieu of usual analytical rating techniques).

Task 3—Identify bridge types and structural conditions that are unsuitable for physical testing of load capacity.

Task 4—Develop a strategy for load rating through

physical testing. In the development of this strategy, consideration shall be given to cost and risk assessment. Risk assessment shall include, as a minimum, considerations of damaging a structure, safety of personnel, loss of equipment, and acceptance of an unsafe structure.

Task 5—Present the findings of Tasks 1 through 4 in an interim report to be submitted not later than 8 months after initiation of the study. NCHRP approval of the interim report will be required before commencing the remaining tasks.

Task 6—Develop detailed and specific testing procedures. Each procedure shall include, but not be limited to, criteria for establishing test load levels, type and location of monitoring, loading methods, types of equipment required for monitoring and loading, and criteria for evaluation of test results.

Task 7—Identify the technical and nontechnical factors that must be considered when screening candidate bridges. Provide examples to show how field testing would be beneficial to the rating process.

Task 8—Develop guidelines for nondestructive load testing of bridges.

Task 9—Prepare a final report documenting the research findings and presenting the recommended guidelines.

Through December 31, 1988, research on the project is progressing on schedule. The interim report was reviewed and approved during a meeting of the project panel at the end of October 1988. It appears that there can be substantial benefits that can be gained from the successful completion of this project.

Project 12-29 FY '85

Design of Simple-Span Precast Prestressed Bridge Girders Made Continuous

Research Agency:	Construction Technology Corporation
Principal Invest.:	R. G. Oesterle
Effective Date:	August 26, 1985
Completion Date:	May 31, 1988
Funds:	$241,993

The design and construction of bridges composed of simple-span, pre-tensioned girders made continuous for composite dead loads and for live loads has become widespread. In general, the design of these structures has been based on the procedure outlined in "Design of Continuous Highway Bridges with Precast, Prestressed Concrete Girders," published by the Portland Cement Association in 1969. Although existing bridges designed by this procedure are generally performing well, it is believed that this method may not accurately predict the true behavior of these structures in light of new knowledge regarding material properties and behavior, new methods of analysis, and expansion of this concept to longer spans and wider girder spacings.

One of the major uncertainties in the design of these structures is the prediction of the positive and negative moments at the cast-in-place connections at the piers. This uncertainty is due to the different loading and construction stages, time-dependent effects, and the details used to make the connections. Because of these uncertainties and the lack of guidance in the AASHTO specification, widespread differences exist in applying the results of the PCA procedure for selecting the actual continuity moments used for the connections at the piers. Research is needed to resolve these uncertainties and to develop guidelines for more rational design and to take advantage of opportunities for more economical construction.

The objectives of this research are: (1) to investigate the behavior of precast prestressed bridge girders made continuous by connections using cast-in-place slabs and diaphragms at the piers, and (2) to develop design procedures and guide specifications that can be used to compute elastic, inelastic, time-dependent, and ultimate moments commensurate with the degree of continuity developed by the connections at the piers.

The research will include the following tasks:

Task 1—Review relevant current practice, performance data, and research findings. This information shall be assembled from both technical literature and unpublished experiences of designers and owners of structures of this type.

Task 2—Based on available information and the application of analytical techniques, develop improved procedures to determine the degree of continuity and the moments resulting from dead loads, live loads, and time-dependent effects.

Task 3—Based on available information and the application of analytical techniques, develop improved procedures to predict the inelastic redistribution of moments and the ultimate strength of the structure at all critical stages.

Task 4—Based on available information and the application of analytical techniques, develop improved procedures to determine the strength and serviceability requirements for the positive and negative moment connections at the piers, allowing for the use of either mild steel or prestressing steel for positive moment and mild steel for negative moment. The consequences of providing no positive moment connection shall also be investigated.

Task 5—The analytical portion of this study shall be verified by correlation with available experimental data that are relevant.

Task 6—Present the findings of Tasks 1 through 5 in an interim report to be submitted not later than 18 months after the initiation of the study. The interim report shall outline the framework of the specifications to be

developed under Task 7 and shall include examples illustrating the application of the recommended procedures. The report shall also include comparisons between results produced by existing and proposed methods. NCHRP approval of the interim report will be required before commencing Task 7.

Task 7—Prepare detailed specifications in a format suitable for consideration by the AASHTO Subcommittee on Bridges and Structures. The recommended specifications shall be accompanied by a detailed commentary and selected design examples intended to facilitate their understanding and use.

Task 8—Identify areas in need of further investigation. Recommend priorities and estimate the time and costs for the additional research.

Task 9—Prepare a final report.

Research has been completed. The draft final report was submitted and approved by the project panel near the end of 1988. The report included recommendations for changes to the design requirements in the AASHTO *Standard Specifications for Highway Bridges,* which will likely be considered by the AASHTO Highway Subcommittee on Bridges and Structures in 1989. It is expected that the report will be published in the regular NCHRP report series in early 1989.

Project 12-30 FY '86

Fatigue of Cables in Cable-Stayed Bridges

Research Agency: ACER/Freeman Fox
Principal Invest.: Jolyon A. Gill
Effective Date: January 13, 1986
Completion Date: February 12, 1989
Funds: $124,975

Cable-stayed bridges have become an advantageous and economical type of structure for medium- and long-span crossings in the United States. As of 1985, five cable-stayed bridges are in service, seven are under construction, and seven are in the design stage. The cable stays are vital components, and, because they are subjected to repeated loads, fatigue is an important design consideration. AASHTO Bridge Specifications do not include design or material requirements for cable stays; criteria and guidelines are needed. Information on fatigue design criteria for cable-stayed bridges is available in certain foreign codes, such as the German Specifications DIN-1073 and subsequent revisions. Those foreign codes presently in use, together with data available in the United States, should serve as a basis to develop design criteria and material requirements suited to American practice.

The objectives of this project are (1) to develop criteria and guidelines for fatigue design of cable stays and (2) to develop practical guidelines for material requirements and for testing wires, strands, and cable-stays.

The project will include the following tasks:

Task 1. Review performance history and data, current domestic and foreign codes of practice, and research findings. This information shall be assembled from both technical literature and unpublished experiences of designers and owners of cable-stayed bridges. Although this review shall emphasize fatigue behavior in cables of cable-stayed bridges, care should be taken to include all relevant aspects of fatigue in other structural systems.

Task 2. Analyze and evaluate the information generated in Task 1 to establish rationales for alternative approaches to the development of design criteria and testing requirements for fatigue effects in cables. This evaluation will include consideration of the following: (1) intensity and frequency of fatigue loading; (2) number and position of lane loadings including their relationship to the number and location of stay planes; (3) multiple lane reduction factors; (4) spacing of cable stays; (5) local stresses in stay cables at saddles and anchorages; (6) assessment of fatigue strength of cables from tests on short lengths of individual wires or strands; (7) length similitude factors to relate tests of short cable specimens to full-length cables; and (8) quality control and quality assurance of wire and strand to maximize fatigue resistance.

Task 3. Present the findings of Tasks 1 and 2 in an interim report to be submitted not later than 12 months after initiation of the study. The interim report shall include design examples illustrating the alternative approaches. NCHRP approval of the interim report will be required before commencing Task 4.

Task 4. Prepare cable fatigue design provisions in a format suitable for consideration by the AASHTO Subcommittee on Bridges and Structures. The recommended provisions shall be accompanied by a commentary and design examples intended to facilitate their understanding and use.

Task 5. Prepare materials and testing requirements to supplement existing provisions in a format suitable for consideration by appropriate authorities.

Task 6. Identify additional research that is needed for further development and refinement of the recommended design criteria and materials requirements. Recommend priorities and estimate time and costs for the needed research.

Task 7. Prepare a final report.

Research has been completed. The draft final report was submitted at the end of 1988, and is being reviewed by the project panel for acceptability. If the report is approved, it will be published in the regular NCHRP report series probably in mid-1989.

Project 12-31 FY '86

Notch Toughness Variability in Bridge Steel Plates

Research Agency: University of Texas at Austin
Principal Invest.: Dr. Karl H. Frank

Effective Date: September 1, 1987
Completion Date: February 28, 1990
Funds: $355,000

In 1979, the American Iron and Steel Institute (AISI) published a report of a test program that demonstrated the variability in the impact properties within steel plates based on tests of plates up to 1½ inches in thickness. These data, plus a concern about variability in thick plates of A588 steel, prompted AASHTO to publish an interim specification that resulted in more conservative notch toughness requirements for steel plates that were to be used in Fracture Critical Members (FCM's). Because the toughness requirements in these interim specifications were not based on any test results, AISI began a second study to develop data on plates of larger thicknesses and of grades commonly used as bridge steels.

The second study was recently completed and the results were presented to the AASHTO Subcommittee on Bridges and Structures. The recommendation from the study was to replace the AASHTO interim specification requirements with the previous specification requirements for temperature Zones 1 and 2 (P-frequency testing with removal of the 20°F temperature shift), but to leave the interim Zone 3 requirement as is, because not enough Zone 3 test data were generated to enable a sound conclusion to be drawn. Accordingly, removal of the interim AASHTO notch toughness requirements for Zones 1 and 2 was approved in 1986.

The objective of this project is to establish the variability of CVN impact notch toughness within plates of A572 Grade 50 and A588 steels for plate thicknesses up to 4 inches meeting AASHTO Zone 3 fracture notch toughness requirements. The research will include the following tasks:

Task 1—Review relevant research findings and performance data in the literature on notch toughness variability within steel plates. In particular, meet with representatives of AISI to review the information developed by AISI on such variability of steel plates meeting Zones 1 and 2 notch toughness requirements.

Task 2—Review the various methods available for analyzing variability in notch toughness data within steel plates.

Task 3—Based on the results of Tasks 1 and 2, select a method of analysis of test results and develop a system for reporting test results that will be useful to bridge engineers. Present the findings of Tasks 1, 2, and 3 in an interim report to be submitted not later than 9 months after initiation of the study.

Task 4—Concurrently with Task 1, obtain plates of A572 Grade 50 and A588 to meet AASHTO Zone 3 toughness requirements, as specified in the 1978 AASHTO *Guide Specifications for Fracture Critical Non-Redundant Steel Bridge Members.*

Task 5—Develop a specific test matrix to study the variability of CVN impact notch toughness within each plate. As a minimum, nine locations per plate shall be studied.

Task 6—Perform chemical analyses and tensile tests for each plate. Three longitudinal CVN specimens shall be machined from the plate blank at each location and impact tested at +10°F, i.e., the AASHTO Zone 3 test temperature. In addition, full transition curves shall be obtained for longitudinal CVN specimens at 3 locations. Specific requirements regarding the Charpy V-Notch impact testing shall be as follows:

a. The position of the test specimens within the sampling locations shall be at the ¼ thickness as described in ASTM A673 (AASHTO T243).
b. The material blanks at each location shall be large enough to provide material for retests or tensile tests, if necessary. All test specimens shall be at least 1 thickness away from any flame cut edge.
c. Only full-size test specimens shall be used (10 mm × 10 mm).
d. Tests are to be conducted according to ASTM A370 (AASHTO T244).
e. Absorbed energy in foot-pounds, lateral expansion in mils, and percent shear shall be reported for each individual test specimen.

Task 7—Analyze the test results using the methodology developed in Task 3. Only values which are the average of three specimens shall be analyzed. Variability within each plate shall be determined and compared with the average results from the mill report and compared with the 1978 AASHTO Guide Specification requirements.

Task 8—Should there be any unusually low notch toughness values at any location, an investigation shall be made to establish the reason.

Task 9—Prepare a final report documenting the findings of the research including recommendations for needed specification revisions.

Through December 31, 1988, research is progressing on schedule on the project. The interim report was submitted in October 1988. A meeting of the project panel will be held in early 1989 to review the report and approve the recommended laboratory test program.

Project 12-32 FY '86

Evaluation of Bridge Deck Protective Strategies

Research Agency: University of Washington
Principal Invest.: Dr. N. M. Hawkins
Mr. K. Babaei
Effective Date: April 1, 1986
Completion Date: May 15, 1987
Funds: $92,515

During the 1960's and early 1970's, corrosion of steel reinforcement embedded in concrete contaminated by chloride deicing chemicals was determined to be a major

cause of concrete bridge deck deterioration. As a result, various bridge deck protective strategies were developed such as epoxy-coated steel reinforcement, latex-modified concrete overlays, high density concrete overlays, interlayer membranes, and thicker concrete cover over steel reinforcement. Laboratory studies and early experience indicate that these strategies are effective in improving the performance of bridge decks. However, because of the large national investment in bridges and their importance in the efficient operation of highways, it is appropriate to examine the performance of these bridge deck protection strategies to see if original expectations are being attained and to determine whether unforeseen problems may occur.

The specific objectives of this project were to compile information on currently used bridge deck protective strategies and evaluate the performance of bridge decks with more commonly used protective strategies.

The research is complete. The final report has been published as NCHRP Report 297, "Evaluation of Bridge Deck Protective Strategies."

Project 12-33 FY '88 and FY '89

Development of a Comprehensive Bridge Specification and Commentary

Research Agency: Modjeski and Masters
Principal Invest.: Dr. John M. Kulicki
Effective Date: July 1, 1988
Completion Date: December 31, 1991
Funds: $295,000

Since initial adoption more than 50 years ago, the AASHTO *Standard Specifications for Highway Bridges* have been modified annually by the AASHTO Subcommittee on Bridges and Structures. These specifications are relied on by engineers in state highway agencies, consulting firms, and other organizations responsible for design, construction, and maintenance of bridges. Because of the piecemeal development of the current specifications, extra care is required to avoid inconsistencies, fragmentation, and internal conflicts as individual sections of the specifications are revised each year. This problem is compounded by the fact that a comprehensive commentary is not available to clarify the intent and record the origin of key provision. Some of the specification's shortcommings were corrected by complete editorial revision of the specification in 1984.

The AASHTO Subcommittee on Bridges and Structures recognizes the need for clear, practical specifications based on the best current technology, and state bridge engineers and others devote a substantial amount of time and attention to this end. In recent years, some bridge engineers have called attention to the potential advantages of developing a completely new comprehensive specification and an accompanying commentary.

In response to a high level of interest among state bridge engineers, the AASHTO Subcommittee on Bridges and Structures requested the NCHRP to conduct a study to recommend an outline for an updated AASHTO bridge specification. The scope of the study required an identification of the gaps and inconsistencies in the present specifications and an assessment of the feasibility of basing the revised specifications on a probabilistic load and resistance factor design (LRFD) philosophy.

The study has been completed. It identified many areas where current bridge design technology and design practice are not reflected in the existing AASHTO specifications. Additionally, it recommended that new specifications be developed based on LRFD concepts. The study also recommended that a comprehensive companion commentary be developed.

NCHRP Project 12-33 was initiated in mid-1988 with the objective of developing recommended LRFD-based bridge design specifications and commentary for consideration by the AASHTO Subcommittee on Bridges and Structures. The new specifications are expected to draw heavily from recent developments in bridge design practice throughout the world as well as from recently completed and current bridge research.

It is estimated that a completely new LRFD-based bridge specification will be developed in 42 months at a cost of approximately $1.6 million.

Thirteen task groups will be responsible for developing the recommended specifications. The task groups are: general features; loads; analysis and evaluation; deck systems; concrete structures; metal structures; timber structures; joints, bearings, and accessories; foundations; soil-structure interaction systems; moveable bridges; bridge rail; and specification calibration.

Through December 31, 1988, work on the project is proceeding on schedule. A number of contractors and consultants have been hired to work with the Principal Investigator and overall project manager, Dr. John Kulicki of Modjeski and Masters, on the development of the specification philosophy and draft "strawman" specification. It is expected that a first draft of the complete specification will be available for review by AASHTO in mid-1990.

To date, $396,000 has been obligated on the project. Included in this amount is $280,000 for Projects 12-33, 12-33A, and 12-33B. The remainder of the obligated amount covers consultant fees and expenses.

Project 12-33A FY '88 and '89

Development of a Comprehensive Bridge Specification and Commentary—Timber Structures and Code Calibration

Research Agency: Sensei Engineers
Principal Invest.: Dr. Andrzej Nowak
Effective Date: September 16, 1988

Completion Date: December 31, 1991
Funds: $20,000

NCHRP Project 12-33 was initiated in mid-1988 with the objective of developing specifications for bridge design based on the load and resistance factor design philosophy that can be recommended to AASHTO for consideration for adoption. (See Project 12-33 writeup for more detail.) A number of agencies and individuals will be employed during the course of the project for various tasks and responsibilities.

The agency employed on Project 12-33A will act under the direction of the Principal Investigator on Project 12-33, Dr. John Kulicki. Sensei Engineers will be responsible for coordinating the activities of the task groups on timber design and specification calibration.

Project 12-33B FY '88 and '89

Development of a Comprehensive Bridge Specification and Commentary—Concrete Structures

Research Agency: Imbsen & Associates, Inc.
Principal Invest.: Mr. Robert C. Cassano
Effective Date: September 16, 1988
Completion Date: December 31, 1991
Funds: $20,000

NCHRP Project 12-33 was initiated in mid-1988 with the objective of developing specifications for bridge design based on the load and resistance factor design philosophy that can be recommended to AASHTO for consideration for adoption. (See Project 12-33 writeup for more detail.) A number of agencies and individuals will be employed during the course of the project for various tasks and responsibilities.

The agency employed on Project 12-33B will act under the direction of the Principal Investigator on Project 12-33, Dr. John Kulicki. Imbsen & Associates, Inc., will be responsible for coordinating the activities of the task group on concrete structures design.

Project 12-34 FY '88 and FY '89

Update of AASHTO Standard Specifications for Highway Bridges: Division II—Construction

Research Agency: Imbsen & Associates, Inc.
Principal Invest.: Robert C. Cassano
Effective Date: October 19, 1987
Completion Date: October 18, 1989
Funds: $200,000

The *AASHTO Standard Specifications for Highway Bridges* consists of two sections: Division I—Design, and Division II—Construction. Both sections should play an important role in bridge design and construction. These sections, along with additional guide and material specifications, aid public agencies in the preparation and use of their standard specifications and contract documents.

It is imperative that both sections reflect the latest state of the art in proven bridge design and construction practices. As technology changes, it is important to have these changes reflected in the specifications. Although Division I has been periodically updated, changes that have occurred in Division II have been made on a piecemeal basis and do not reflect current practice in bridge construction. Therefore, the content of Division II is incomplete and the format is inconsistent. As a result, less than one-half of the states presently use the current Division II specification.

The current Division II—Construction specification is in need of revision and updating. Research should be undertaken to provide the basis for such a revision followed by the preparation of a revised Division II—Construction specification.

The objective of this project is to revise the Division II—Construction specification to reflect current practice in highway bridge construction. This will then provide a more useful document to public agencies.

The project will include the following tasks:

Task 1. Review current domestic and foreign construction practices and specifications for highway bridges and similar structures. At a minimum, this should include representative AASHTO and state construction documents.

Task 2. Develop a strategy for evaluating the information developed in Task 1 in order to identify the following: articles no longer needed in the current Division II specification; articles requiring revision; and new articles which should be added.

Task 3. Using the strategy developed in Task 2, prepare a comprehensive list of, and the reasons for, recommended deletions, modifications, and additions to the current Division II—Construction specification.

Task 4. Present the findings of Tasks 1, 2, and 3 in an interim report to be submitted not later than 6 months after initiation of the study. The interim report shall also include a suggested format for the recommended revisions and new additions. NCHRP approval of the interim report will be required before commencing Task 5.

Task 5. Prepare a revised Division II—Construction specification and comprehensive companion commentary in a format suitable for consideration by the AASHTO Subcommittee on Bridges and Structures.

Task 6. Prepare a final report.

Through December 31, 1988, research on the project is progressing on schedule. The interim report was reviewed and approved by the project panel in September 1988. Work is underway on the completion of the recommended specification and commentary.

Project 12-35 FY '88

Recommended Specifications for the Design of Foundations, Retaining Walls, and Substructures

Research Agency: D'Appolonia
Principal Invest.: Dr. James L. Withiam
Effective Date: January 4, 1988
Completion Date: July 3, 1989
Funds: $100,000

The *AASHTO Standard Specifications for Highway Bridges* are used for the design of highway bridges by many public and private agencies in the United States and abroad. Sections 4, 5, and 7 of Division I—Design, provide guidance for the design of highway bridge foundations, retaining walls, and substuctures.

It is imperative that these sections be based on the state of the art of proven bridge foundation and retaining structure design practice. Advances in technology should be reflected by revisions to the specifications. Although much of Division I has been periodically updated, the revisions to Sections 4, 5, and 7 of the specifications have been minimal. Therefore, the specifications do not reflect current practice and the content of these sections is incomplete.

Research is needed to develop recommendations for reorganization and revision to Sections 4, 5, and 7 of the *AASHTO Standard Specifications for Highway Bridges.*

The objective of this project is to develop recommended revisions to Sections 4, 5, and 7 of the *AASHTO Standard Specifications for Highway Bridges* to reflect the current practice and state of the art in geotechnical engineering and substructure design.

The research proposed should address the design of foundations for highway bridges including, but not limited to, spread footings, piles, and drilled shafts, as well as the design of conventional and alternate retaining structures. Revised specifications should also include subsurface investigation, performance predictions, performance criteria including tolerable movements and allowable stresses, and soil-structure interaction effects.

The research will include the following tasks:

Task 1. Review relevant current domestic and foreign practice and research findings. This information shall be assembled from the technical literature and the unpublished experiences of bridge and geotechnical engineers, consultants, and owners of highway structures.

Task 2. Analyze and evaluate the information obtained in Task 1. On the basis of this evaluation, develop a comprehensive outline for the recommended specifications. Discuss the significance of each topic in the proposed outline.

Task 3. Present the findings of Tasks 1 and 2 in an interim report to be submitted not later than 10 months after initiation of the research. NCHRP approval of the interim report will be required before commencing the remaining tasks.

Task 4. Prepare recommended revisions to the specprjaifications for highway bridge foundations, retaining walls, and substructures in a format suitable for consideration by the AASHTO Subcommittee on Bridges and Structures. The recommended specifications shall be accompanied by a detailed commentary.

Task 5. Identify and comment on other sections of the *AASHTO Standard Specifications for Highway Bridges* that may be affected by the proposed revisions.

Task 6. Prepare a final report documenting all research findings and containing the recommended specification revisions and commentary.

Through December 31, 1988, research on the project is proceeding on schedule. The interim report was reviewed and approved in late 1988. Work on Tasks 4 through 6 is now underway.

AREA 13: EQUIPMENT

Project 13-1 FY '65

Equipment Rental Rates

Research Agency: Ernst & Ernst
Principal Invest.: T. S. Dudick
Effective Date: February 1, 1965
Completion Date: January 31, 1966
Funds: $22,800

This research dealt with the development of uniform methods and procedures for establishing construction equipment rental rates. It included the establishment of the purposes for which rental rates are used; the feasibility of determining equipment rental rates by type, use, and region; a formula for equitable rental rates; and recommended procedures for obtaining and evaluating all information required for the various factors in the formula.

This research has been completed and the project report has been published as: NCHRP Report 26, "Development of Uniform Procedures for Establishing Construction Equipment Rental Rates."

AREA 14: MAINTENANCE OF WAY AND STRUCTURES

Project 14-1 FY '65

Upgrading of Unit Maintenance Cost Index and Development of Interstate Maintenance Requirements

Research Agency: Bertram D. Tallamy Associates
Principal Invest.: Dr. Bertram D. Tallamy

Effective Date: March 1, 1965
Completion Date: March 31, 1967
Funds: $205,128

This research involved an intensive study into typical maintenance operations on 28 Interstate test sections in several States for the purpose of satisfying the urgent need for a definitive system of determining maintenance requirements on a quantitative basis with due consideration being given to the requirements in terms of type, magnitude, and frequency. This system is applicable to Interstate highways within individual States and to comparable activities on the State highways. Attempts have been made to develop means for relating utilization of men, equipment, and material to production and maintenance operations and, further, to optimize efficiency in maintenance operations. The standards which were developed have been tested on a sample of maintenance operations on Interstate highways, and a unit maintenance cost index suitable for periodic updating was developed.

Research has been completed, and the project report has been published as: NCHRP Report 42, "Interstate Highway Maintenance Requirements and Unit Maintenance Expenditure Index."

Project 14-2 FY '71

Techniques for Reducing Roadway Occupancy During Routine Maintenance Activities

Research Agency: Byrd, Tallamy, MacDonald, and Lewis
Principal Invest.: L. G. Byrd
Effective Date: October 1, 1970
Completion Date: March 31, 1973
Funds: $200,000

The objectives of this project were to identify and evaluate techniques that will significantly reduce the time of occupancy of the highway travel way and shoulders by maintenance forces for at least the following specific routine maintenance activities:

(a) Bridge deck repairing.
(b) Travel way patching.
(c) Crack and joint sealing.
(d) Mudjacking and subsealing.

Techniques for accomplishment of maintenance activities were intended to encompass the entire operation, including the necessary manpower, equipment, and materials. However, development of new materials or equipment was not considered to be within the scope of this study.

Research has been completed, and the project report has been published as: NCHRP Report 161, "Techniques for Reducing Roadway Occupancy During Routine Maintenance Activities."

Project 14-3 FY '73

Improved Pavement-Shoulder Joint Design

Research Agency: Georgia Institute of Technology
Principal Invest.: Dr. R. D. Barksdale
Effective Date: September 15, 1972
Completion Date: March 15, 1976
Funds: $100,838

Although the construction and maintenance of completely watertight pavement/shoulder joints for the life of the pavement is generally conceded to be impossible, it is believed that an effort should be made to minimize the passage of surface water through the joint. Therefore, some water is likely to enter through the joint at some time during the pavement life, and provisions should be made for subsurface drainage and/or treating the pavement layers to minimize the effects of the water. Consequently, there is need to develop reasonably adequate sealing systems for the joint and to identify suitable design and construction techniques, including subsurface drainage, that will minimize the effects of the presence of some water.

Project objectives were accomplished with the development of a series of recommendations for pavement shoulder joint design and construction, sealant specifications, shoulder design, and underdrainage facilities intended to improve the performance of shoulders immediately adjacent to pavements. Guidelines are offered for a test program to evaluate several promising joint design and sealant systems developed by the project.

Research has been completed, and the project report has been published as: NCHRP Report 202, "Improved Pavement-Shoulder Joint Design."

Project 14-4 FY '74

Reconditioning Heavy-Duty Freeways in Urban Areas

Research Agency: Texas A & M University Research Foundation
Principal Invest.: Dr. William B. Ledbetter
Dr. Alvin H. Meyer
Effective Date: April 15, 1974
Completion Date: March 24, 1976
Funds: $99,665

The over-all objective of this project was development of a new technology for reconstituting and/or replacing all or part of the pavement structure on a heavily traveled urban freeway so that the finished product has a design service life equal to or greater than that of the original pavement, including restoration of riding and nonskid characteristics. The capabilities of producing substantial lengths of new or reconstituted pavement during off-peak hours, minimal interference with traffic during construction, and full reopening during the hours of maximum traffic flow were required characteristics. The methods

and procedures were evaluated in terms of economic feasibility for the rehabilitation of substantial segments of urban expressways. Lowest first cost per unit of repair or replacement is not a necessary limitation.

Research has been completed, and the project report has been published as: NCHRP Report 196, "Reconditioning Heavy-Duty Freeways in Urban Areas."

Project 14-5 FY '78

Maintenance Level-of-Service Guidelines

Research Agency: Woodward-Clyde Consultants, Inc.
Principal Invest.: Ram B. Kulkarni
Effective Date: January 1, 1978
Completion Date: April 30, 1980
Funds: $204,200

To optimize the expenditure of maintenance resources, there has been a need to develop a systematic and objective method to establish maintenance levels of service guidelines for all maintenance elements of the highway (such as pavement surface, shoulder, vegetation, signs, structure, drainage ditches). Such a method, based on decision analysis theory, was successfully developed and demonstrated in two states for pavement edge drop-off and vegetation control. Users of the method find it useful in the following ways:

1. The method assists in determining a set of levels of service that maximizes highway user benefits subject to the constraints of available resources (dollars, personnel, etc.). This will assure the most efficient allocation of limited resources.
2. The method allows levels of service to be systematically adjusted for changes in available resources. The method also allows differing levels of service to be established for various road classifications.
3. The policy decisions to implement various levels of service will be defensible because the rationale can be well documented.
4. The method provides a mechanism for combining effects of alternative levels of service on multiple considerations (e.g., safety, user comfort, protection of investment, and aesthetics) in a logical and theoretically sound manner. The procedures will allow the agency to establish acceptable tradeoffs between different considerations based on collective inputs from a group of people that may include maintenance engineers, field supervisors, legislators, and highway users.
5. The method allows the decision-maker to establish explicit levels of service that clearly communicate to field personnel when maintenance of different highway elements should be scheduled. The explicit levels of service will also permit an objective evaluation of whether the intended levels of service are, in fact, being achieved in the field.

A computer program package, including a user's manual for the computer program is available on a loan basis, or may be purchased for $6.00, plus $1.00 for postage and handling, by writing to the NCHRP, and supplying an EBCDIC 9-track tape, or equivalent, with a density of 1600 BPI.

The final report has been published as: NCHRP Report 223, "Maintenance Levels-of-Service Guidelines".

Research has been continued as Project 14-5(2).

Project 14-5(2) FY '81

Maintenance Levels-of-Service Guidelines

Research Agency: Woodward-Clyde Consultants
Principal Invest.: Ram B. Kulkarni
Effective Date: September 15, 1981
Completion Date: August 31, 1984
Funds: $107,950

The primary objective of this study was to develop a user's manual that can be used by transportation agencies in establishing maintenance levels-of-service. The manual is comprehensive, i.e., it describes all the steps involved in implementing the methodology; it is self-sufficient, i.e., transportation agencies are able to use the methodology without consultant assistance; and the manual is tested, i.e, 3 state Departments of Transportation have implemented the methodology for 11 to 57 maintenance conditions. Experience with the software indicated that maintenance conditions should be limited to 25 or less. Consequently those maintenance conditions on which a very small percentage of the budget is expended should be excluded from the system.

The manual is published as NCHRP Report 273, "Manual for the Selection of Optimal Maintenance Levels of Service."

Project 14-6 FY '82

Evaluating Deferred Maintenance Strategies

Research Agency: ARE Inc.
Principal Invest.: Bertell C. Butler
Fred N. Finn
Effective Date: June 1, 1982
Completion Date: December 31, 1985
Funds: $325,000

The general objective of this study was to develop procedures, guidelines, and criteria for state highway agencies to use in determining alternative maintenance strategies (involving timing and practice) for highway facilities. The results should have application by highway agencies to (1) budget preparation and financial planning, (2) legislative discussions and discussions with local governments, (3) maintenance work program preparation and use in maintenance management systems, and (4) work prioritization and assignment.

Research was completed. To the extent that the effec-

tiveness of various maintenance treatments are known, maintenance managers have a powerful tool to assess the economic consequences of deferring pavement maintenance. Research on the consequences of deferring bridge maintenance was only partially successful. Use of the results awaits further research and consensus on what are the bridge-maintainable elements and the effectiveness of various maintenance treatments.

The project report has been published as: NCHRP Report 285, "Evaluating Alternative Maintenance Strategies."

Project 14-7 FY '87

Interactive Microcomputer Network for Innovative Maintenance Operations

Research Agency: Woodward-Clyde Consultants, Inc.
Principal Invest.: Fred Reid
Effective Date: September 1, 1987
Completion Date: February 1, 1989
Funds: $75,000

Innovations in areas of materials, equipment, and methods are continuously being developed by maintenance operations personnel. These innovations are rarely communicated beyond organizational boundaries. Today operational-level personnel often are not aware that their innovations could solve problems in other organizations and they do not have a comfortable way for transferring this information. Consequently, other operations personnel do not have access to knowledge that could increase productivity. A data base identifying these innovations, and shared within and between states, is needed that would be available to the "man in the field."

The objective of this project is to develop a system design for a cost-effective microcomputer-oriented network to create and to access a dynamic data base of innovations in highway maintenance operations. The users are intended to be the operational-level maintenance personnel in highway agencies for first and second level supervisors.

Key characteristics of the system are that it be menu-driven for data-base entry and retrieval and other associated functions. It is to be networked using a modum or other cost-effective communication link. As a starting point it is planned that the menu be structured with maintenance elements as described in NCHRP Report 273, "Maintenance Levels of Service Guidelines," and that it include equipment as a major category.

Key deliverables of the project will be a report describing the system design and a plan for a prototype installation to evaluate the feasibility and practicality of the system.

Research has been completed and the final draft report is being reviewed.

Project 14-8 FY '87

Chip Seal Coats for High-Traffic-Volume Asphalt Concrete Pavements

Research Agency: Intermountain Research Foundation, Inc. (University of New Mexico)
Principal Invest.: Dr. T. S. Shuler
Effective Date: July 6, 1987
Completion Date: October 5, 1990
Funds: $240,000

Chip seal coats, usually applied to low-volume roads, are used to extend pavement service life by reducing water infiltration and improving skid resistance. The use of chip seal coats on high-traffic-volume roads has had limited application because of unknown cost effectiveness, potential windshield damage, unsatisfactory results because of lack of adherence to sound engineering principles, and traffic disruption during construction. However, chip seal coats may be suitable on roads with relatively high volumes, in the vicinity of 20,000 vehicles per day on four-lane roads, thereby postponing the need for overlays. Research is needed to investigate the causes and provide solutions to the problems that discourage the use of chip seal coats on high-volume roads.

The objective of this research is to develop a workable system for applying chip seal coats to high-traffic-volume asphalt concrete pavements as a cost-effective alternative to asphalt concrete overlays. For purposes of this project high traffic volumes are those in excess of 7,500 vehicles per day in one direction on a four-lane highway.

Research is in progress. Literature review has been completed, and an annotated bibliography has been prepared. Initial contacts with state highway personnel indicate there is a considerable reluctance to permit use of chip seal coats on major highways because of possible legal consequences from windshield damage. On the other hand, such treatments are used extensively in countries other than the United States. It may be difficult to obtain approval for the desired field test projects. Possibilities for test projects in various localities are being investigated. Equipment and operator personnel have been located to construct all field test projects so that these variables can be controlled. A questionnaire has been developed to poll experienced personnel to (1) determine the extent of use of chip seals on high volume pavements, (2) determine materials, design methods, procedures, performance, etc., where chip seals are used, and (3) understand and quantify the effects of various factors on chip seal performance.

Project 14-9 FY '89

Workshop on Research Needs in the Management of Highway Maintenance

Research Agency: Transportation Research Board
Principal Invest.: —

Effective Date: June 12, 1988
Completion Date: June 15, 1988
Funds: $42,000

In September 1987, the AASHTO Select (now Standing) Committee on Research (SCOR) directed the staff of the National Cooperative Highway Research Program (NCHRP) to convene a workshop for the purpose of identifying high priority research needs in highway maintenance. Accordingly, a workshop on improving the management of highway maintenance was held on June 13-15, 1988, at the Beckman Center, National Academies of Sciences and Engineering, Irvine, California. The workshop participants, most representing government and private organizations, developed 15 high priority highway maintenance research problem statements. The problem statements will be considered by SCOR for separate funding in subsequent NCHRP programs.

Project 14-10 FY '89

Improvements in Date Adjustment Technology for Maintenance Management Systems

Research Agency: In developmental stage
Principal Invest.:
Effective Date: (12 months)
Completion Date:
Funds: $100,000

Accurate and timely data acquisition and reporting are key components to an efficient maintenance management system. These systems can provide quality information that is essential to field managers for allocating limited resources, improving crew performance, and developing cost-effective methods for highway, bridge, and equipment maintenance. Presently, the methods for entering data into maintenance management systems are laborious, requiring, in many cases, the field manager to record work accomplishments using field books or a variety of forms. The information must be checked for obvious errors and entered into a computer by a time keeper or computer technician. "One-time, quick and easy" data acquisition, entry, and verification systems will permit direct input into maintenance management system computer files. This will reduce work loads and improve and encourage the accurate entry of data.

Most maintenance management systems generate a variety of reports that indicate such information as measurements of productivity, cost of performing individual activities, and expenditures for given periods. The field manager must be able to extract this information from the system in a timely fashion to correct particular problem areas or make effective maintenance decisions.

Therefore, more efficient and accurate mechanisms for acquiring and transmitting field data need to be adopted to assist the maintenance field manager in job performance and thereby improve performance of the state highway agency. Some potential improvements include, but are not limited to, the use of portable or hand-held computers, the ability to accept data from locational and navigational systems, and the incorporation of automatic distance measuring and recording devices or other direct data acquisition systems such as voice recognition or bar coding techniques.

The objective of this research is to identify and evaluate the latest technological means to effectively and efficiently acquire, record, field-verify, transmit, and receive field-related data for maintenance management systems. Emphasis shall be placed on addressing the informational needs of first-level maintenance field managers. Examples of field-related data include location information, work needed and accomplished, resources needed and used, equipment management information, and features inventory updates. Accomplishment of the objective will require, as a minimum, the following tasks:

Task 1. Identify data gathering and transmission requirements of current maintenance management systems. Based on these requirements, develop criteria for evaluating the feasibility of applicable technologies.

Task 2. Identify and evaluate available technologies and devices that will meet the criteria developed in Task 1. Recommend ways in which existing maintenance management systems can be enhanced by these technologies and devices. Consideration shall be given to modular, but integrated, components to provide for incremental improvements and flexibility that may be necessary in meeting the needs of existing management systems.

Task 3. Submit a final report that documents the findings of this research and catalogues the technologies and devices. The report shall recommend the more universally adaptable technological applications to the variety of maintenance management systems now in place. Guidance must be provided to assist state highway agencies in the implementation of these applications and first-level maintenance field managers in their use.

Project 14-11 FY '89

Effective Motivation of Highway Maintenance Personnel

Research Agency: In developmental stage
Principal Invest.:
Effective Date: (27 months)
Completion Date:
Funds: $200,000

The objective of this research is to develop a training program, with associated materials, for highway maintenance managers and supervisors at all levels which will enable them to effectively motivate themselves and their subordinates. The goal of this program is to provide managers and supervisors with the skills necessary to assess

personal and organizational needs, and to identify suitable motivational tools that can enhance employee satisfaction, work quality, efficiency, and other aspects of performance.

Accomplishment of this objective will require at least the following tasks:

Task 1. Use an extensive literature search, interviews with knowledgeable individuals, and other appropriate survey techniques to identify, from a broad spectrum of private and public organizations, those personal and organizational attributes and needs that are associated with employee motivation. Emphasis should be placed on information relevant to a state highway agency environment.

Task 2. Based on the results from Task 1, develop a practical method that can be used at all levels from the first-level supervisor to the top maintenance manager to recognize and assess those personal and organizational attributes and needs that can affect employee behavior and performance. This method should be applicable to highway maintenance organizations at the state, city, or county level.

Task 3. Identify and develop motivational tools that can be used in a highway agency environment to address personal and organizational needs and, thereby, produce desirable changes. Document the conditions under which the motivational tools should and should not be used, and the expected end results. In addition, identify and evaluate available training materials, visual aids and resource materials that illustrate the application of these motivational tools.

Task 4. Develop a comprehensive training program to instruct maintenance managers and supervisors in the use of the method developed in Task 2, and the motivational tools identified or developed in Task 3. In addition, develop criteria for evaluating the effectiveness of the training program on a short-term and long-term basis. At a minimum, this task should produce visual aids, testing materials, program evaluation criteria, an instructor's handbook properly referenced with the visual aids, and a handbook for maintenance managers and supervisors.

Task 5. Prepare an interim report documenting the research completed in Tasks 1 through 4. Submit the interim report for review by the NCHRP project panel. Soon after distribution of the interim report, a meeting between the research team and the NCHRP project panel will be held for the purpose of providing panel members with a "walk through" of the training program and the opportunity to discuss the contents of the interim report. NCHRP approval of the interim report will be required before proceeding with Task 6.

Task 6. Conduct a pilot presentation of the training program in a highway maintenance organization to be selected by NCHRP. Using the short-term evaluation criteria developed in Task 4, evaluate the pilot effort and adjust the training program materials, as necessary, to maximize their effectiveness.

Task 7. Prepare a final report documenting the research, including the instructor's handbook, maintenance manager's and supervisor's handbook, and testing materials. It should also include a discussion on the expected benefits to an agency using the training program. Ten reproducible copies of all visual aids will also be required.

AREA 15: GENERAL DESIGN

Project 15-1 FY '66

Guardrail Design

Research Agency:	Cornell Aeronautical Laboratory
Principal Invest.:	Raymond R. McHenry
Effective Date:	December 15, 1965
Completion Date:	June 14, 1966
Funds:	$19,723

Phase I of the project was directed toward the search and evaluation of existing data on design and warrants, a critical analysis of past and current research, and defining additional needed research.

Research has been completed, and the project report has been published as: NCHRP Report 36, "Highway Guardrails—A Review of Current Practice."

Project 15-1(2) FY '66 and FY '70

Guardrail Performance and Design

Research Agency:	Southwest Research Institute	
Principal Invest.:	J. D. Michie	
Effective Date:	July 1, 1967	May 1, 1970
Completion Date:	Aug. 31, 1970	Dec. 31, 1971
Funds:	$280,000	$100,000

The objectives of the Phase I research were: (1) to critically analyze existing data on guardrail performance and identify additional needed research; (2) to conduct additional full-scale performance tests; and (3) to evaluate performance of various guardrail systems considering vehicle response and damage as a measure of accident severity and rail repair.

The Phase I findings have been published as NCHRP Report 54, "Location, Selection, and Maintenance of Highway Guardrails and Median Barriers," and NCHRP Report 115, "Guardrail Performance and Design." A 10-min sound film of the same title summarizes the Phase I research and is available on a loan basis from the TRB Audio-Visual Library for the cost of mailing and handling.

The Phase II work consisted of four major tasks. The first task was to prepare a revision to NCHRP Report 54 that incorporates pertinent findings from the Phase I research and the findings from research conducted by others. Task 2 of the Phase II work was the preparation

of a document to delineate warrants, service requirements, design criteria, and design procedures for all traffic barrier systems. For this purpose, traffic barrier systems were defined as including guardrail, median barrier, bridge rail, and energy attenuation devices. Task 3 included the formulation of new concepts for improved end treatments for longitudinal traffic barriers with some work devoted to improved transitions. Task 4 included the full-scale crash test evaluation of those promising concepts produced under Task 3.

The results of Phase II Tasks 1 and 2 have been published to NCHRP Report 118, "Location, Selection and Maintenance of Highway Traffic Barriers." The results of Phase II Tasks 3 and 4 have been published as NCHRP Report 129, "Guardrail Crash Test Evaluation—New Concepts and End Designs."

For administrative reasons, additional related research has been placed under Area 22, "Vehicle Barrier Systems." Details will be found under that heading.

Project 15-2 FY '66

Design to Control Erosion in Roadside Drainage Channels

Research Agency: University of Minnesota
Principal Invest.: Dr. Alvin G. Anderson
Effective Date: July 1, 1966
Completion Date: June 30, 1974
Funds: $97,300

The highway drainage engineer is required to provide designs to control erosion in roadside drainage channels over a wide range of conditions. Acceptable procedures have been developed for the design of channels for conditions where easily established grass cover will suffice and for conditions where paved linings are required. The objectives of this study were to establish criteria and extend existing procedures for conditions intermediate between these two. The major emphasis of the research was placed on developing a procedure for the design of armored channels with investigations into the critical tractive force of gravel and crushed stone.

Research has been completed, and the project report covering development of design procedures for armored channels has been published as: NCHRP Report 108, "Tentative Design Proceduure for Riprap-Lined Channels."

During an extension of the project, a limited field-evaluation of the tentative design procedure was undertaken. The performance of four channels, designed and built in accordance with the procedures, was observed. Two of the four channels have been subjected to discharges approaching the design discharge and appear to be stable after the floods.

The agency's final report for this latter phase was not published in the NCHRP report series; however, a copy of the report, "Tentative Design Procedure for Riprap-Lined Channels," may be purchased for $4.00 (see final page of this section for ordering information).

Project 15-3 FY '68

Rational Structural Analysis and Design of Pipe Culverts

Research Agency: Northwestern University
Principal Invest.: Dr. R. J. Krizek
Dr. R. A. Parmelee
Effective Date: October 1, 1967
Completion Date: December 31, 1968
Funds: $49,937

The objective of this study was to evaluate previous research and current practice for the purpose of developing rational design methods for both rigid and flexible pipe culverts.

Research has been completed, and a project report has been received containing an extensive bibliography and synthesis of current knowledge on the design and installation of pipe culverts. It is apparent that information is not available at this time to develop a completely rational structural design procedure, due largely to lack of a generally accepted definition of pipe failure. However, several specific factors, such as installation practices, construction techniques, soil type, and safety factor, can be given greater consideration in design criteria.

The project report has been published as: NCHRP Report 116, "Structural Analysis and Design of Pipe Culverts."

Project 15-4 FY '68

Estimating Runoff Rates from Small Rural Watersheds

Research Agency: The Travelers Research Center
Principal Invest.: Dr. Paul Bock
Isadore Enger
Effective Date: September 1, 1967
Completion Date: March 16, 1970
Funds: $299,902

Many State highway departments and other agencies are participating with the U.S. Geological Survey in programs to collect runoff information from small rural watersheds that is intended to provide a better understanding of the generation of runoff. With this background, it appeared possible to develop improved procedures for estimating the magnitude and frequency of peak flows for small rural watersheds (approximately 20 sq mi or less). The objective of this project was to develop such procedures that (1) require only data readily obtainable by designers, (2) use parameters that are logically justified, (3) take cognizance of differences due to geographic characteristics, and (4) present the results in readily usable form.

The objectives have been partially met in that methods

for estimating the magnitude and frequency of runoff from small rural ungaged watersheds have been developed. The question of whether they provide better estimates of runoff than currently used methods for a given watershed is not easily answered. Indications are that they may provide better estimates in some cases. Of probably greater significance is the compilation of information for 493 rural watersheds with an area of 25 square miles or less and at least 12 years of surface runoff data that can be used by others to develop better methods of prediction for a particular locality.

The research has been completed, and the project report has been published as: NCHRP Report 136, "Estimating Peak Runoff Rates from Ungaged Small Rural Watersheds."

Project 15-5 FY '68

Dynamic Characteristics of Heavy Highway Vehicles

Research Agency: General Motors Corporation
Principal Invest.: D. E. Pollack
Effective Date: August 15, 1967
Completion Date: January 10, 1969
Funds: $135,000

The dynamic loading of bridges and pavements by heavy highway vehicles influences the life expectancy of these highway structures by an unknown amount. Increasing permissible vehicle loads and speeds may increase the dynamic loading and shorten the life of these structures.

Dynamic pavement loading is influenced by the pavement roughness characteristics and by certain characteristics of the vehicle. It is necessary to consider these factors in order to predict the loads that will be produced.

With the foregoing in mind, information was gathered on those vehicles characteristics that make a significant contribution to the dynamic forces. Equipment for measuring these characteristics was constructed, and the characteristics of representative types of heavy vehicles were determined.

The research has been completed, and the final report has been published as: NCHRP Report 105, "Dynamic Pavement Loads of Heavy Highway Vehicles."

15-6 FY '68

Development of Criteria for Safer Luminaire Supports

Research Agency: Texas A & M University Research Foundation
Principal Invest.: Dr. T. C. Edwards
Effective Date: September 1, 1967
Completion Date: August 31, 1968
Funds: $147,254

Conventional luminaire support poles are, of necessity, mounted close to the traveled roadway. In these locations, they constitute a severe roadside hazard and are frequently struck by vehicles that are out of control, with attendant severe vehicle damage and injury or death to occupants.

The purpose of this study was the development of luminaire support design criteria to minimize the hazard described. Consideration was given to the hazard presented to both the striking vehicle and to nearby traffic.

The research has been completed, and the final report has been published as: NCHRP Report 77, "Development of Design Criteria for Safer Luminaire Supports." A 20-minute film, "Lights Out," is available on a loan basis from the TRB Audio-Visual Library (see final page of this section for ordering information).

Project 15-7 FY '80

Flow Modifications by Storage Loss Through Flood Plain Encroachment

Research Agency: Dames & Moore:
Principal Invest.: Dr. Donald L. Chery, Jr.
Effective Date: May 1, 1980
Completion Date: January 31, 1982
Funds: $99,730

The objective of this project was to provide simple and reliable procedures to compute the changes in flow and water surfaces affected by encroachments on flood plains. Hydrologic information outside the affected reach, such as input hydrographs and inflows, was assumed to be available to the user. The products of this investigation were intended for use in general assessment and preliminary planning rather than for detailed design.

Research is complete. The agency has submitted a final report with an appended user's manual. Both reports are available on a loan basis or microfiche of the report may be purchased (see final page of this section for ordering information).

Project 15-8 FY '82

Parameters Affecting Stopping Sight Distance and Vehicle Acceleration/Deceleration Characteristics

Research Agency: University of Michigan Transportation Research Institute
Principal Invest.: Dr. Paul L. Olson
Effective Date: May 1, 1982
Completion Date: May 31, 1984
Funds: $274,482

The primary objective of this research was to evaluate those parameters affecting stopping sight distance including: (1) perception and reaction time; (2) driver eye height; (3) height of an object in the roadway; and (4) braking distance as affected by tire performance, brake system

performance, pavement skid resistance, and grades. A second objective of this research was to update vehicle acceleration and deceleration rates to be representative of the current vehicle fleet.

The final report has been published as: NCHRP Report 270, "Parameters Affecting Stopping Sight Distance."

Project 15-9 FY '85

Encasement of Pipelines Through Highway Roadbeds

Research Agency:	Byrd, Tallamy, MacDonald, and Lewis
Principal Invest.:	R. A. Koenig, Jr.
Effective Date:	October 1, 1986
Completion Date:	June 30, 1988
Funds:	$30,000

Many states and railroads, to varying degrees, require the encasement of pipelines through their roadbeds. This policy is predicated on the premises that the pipeline is protected from the associated loading, that the pipeline can be removed and reinstalled from the casing in the event of failure, and that liquids would be discharged out the ends of the casing in the event of rupture, thereby protecting the integrity of the roadbeds. The pipeline owners contend that the pipe designs and strengths available today can accept loadings without casing, that welds on road crossings are x-rayed, that the casing may interfere with cathodic protection systems, and that casing installation/maintenance is costly and unnecessary. Existing policies are extremely varied in that requirements for casing may be based on soil type, method of installation, products being transported, and/or operating pressures of the system. In many cases the validity of current policy is unknown leading to excessive or insufficient protection as the case may be. A study under NCHRP 20-7, Task 22 entitled "Encasement of Pipelines Through Highway Roadbeds," completed a review of the present state of the art of pipeline encasement on a national basis. Research findings show that states have developed and maintained their own utility accommodation policy within AASHTO policy and Federal Pipeline Safety Regulations. Pipeline operators, utility companies, and railroads have developed their own guidelines and policies; however, no comprehensive national standards exist for the encasements or for conditions warranting encasement or nonencasement.

The objectives of this project were to (1) assess the consequences of the failure and maintenance costs of various types of pipeline protection through highway roadbeds and (2) develop guidelines for pipeline protection. Research has been completed and the project final report has been published as: NCHRP Report 309, "Protection of Pipelines through Highway Roadbeds." The report contains guidelines to assist in the selection of appropriate protection of pipelines through highway roadbeds taking into account such factors as pipe location, construction methods, available cover, corrosion potential, and an assessment of the consequences of failure.

Project 15-10 FY '85

Development of a Design/Graphics Interface System

Research Agency:	C.W. Beilfuss & Associates, Inc.
Principal Invest.:	Charles W. Beilfuss Roy R. Guess
Effective Date:	August 1, 1985
Completion Date:	November 30, 1988
Funds:	$500,000

Transportation organizations are currently faced with the problem of handling an accelerated design workload caused in part by the recent increase in federal funding levels to upgrade the nation's transportation network. Most of these organizations use computer-aided design systems, such as the Roadway Design System, COGO-ROADS, and other systems developed by individual states. These design systems, while providing productivity gains, make limited use of the latest technology available in computer-aided graphics.

A number of proprietary interactive graphics drafting systems have been developed that provide drafting productivity increases from 3:1 to 6:1. Some of the interactive roadway design systems use features from proprietary interactive graphics drafting systems. These systems have shown productivity gains to the designer on the same or higher order than those obtained in the drafting field. The interactive graphics roadway design systems use only minimal features of the drafting software. However, they must rely on expensive terminals and support computers that are required for the drafting functions, but are not necessary for design.

Consequently, there is a need to develop an interface system that will allow interactive compatibility between existing design systems and graphics systems having varying degrees of complexity and costs. Such an interface system will provide flexibility in the types of hardware and software used and at the same time provide a standardization for computerized communication within, and between, state highway departments and consultants in the design of highway facilities. This interface system will permit the designers and draftpersons to interact in much the same way traditional, manual highway design is handled.

The objective of the project is to provide a nonproprietary interface between highway facilities design systems and generally accepted graphics systems. The interface shall include all requirements to allow transfer of the highway facilities design graphics files to and from a standard graphics file that can be processed by available graphics systems. Additionally, the interface should allow

for the inherent performance characteristics of the interfaced graphics devices to be used.

Research is complete; the agency's preliminary draft final report is under review. The final report contains recommended specifications for standard interfacing files that will facilitate the exchange of roadway design and graphic data between various computerized systems. The report also contains the preliminary documentation for selected transfer programs to demonstrate the utility of interfacing files. The AASHTO Administration Subcommittee on Computer Technology will be kept informed of the project results for possible use in the activity of its Joint Development Task Force.

Project 15-11 FY '87

Computer-Aided Analysis of Highway Encroachments on Mobile Boundary Streams

Research Agency: Simons and Associates, Inc.
Principal Invest.: D. B. Simons and A. Molinas
Effective Date: July 1, 1987
Completion Date: March 31, 1990
Funds: $249,360

More than 85 percent of the 571,000 bridges in the National Bridge Inventory are constructed over waterways that are subject to various degrees of scour and lateral stream migration (erosion) during floods. In addition, many miles of highways are built along and encroach on streams. Although there are no accurate statistics, a great deal of damage to bridges and highways is caused each year by degradation, aggradation, and scour. Conversely, in an attempt to avoid these problems, some highways and bridges may be designed too conservatively. For example, some bridge foundations may be deeper than necessary, which increases costs.

Engineers realize that streams can degrade, aggrade, and change location within flood plains and that the actual construction of a bridge or highway may initiate additional morphological changes in the behavior of a stream. However, existing design procedures for highway structures assume for the most part that streams have fixed boundaries. Although state-of-the-art analyses are available for the mobile boundary stream condition, they are seldom used, and if assessments are accomplished at all, they are based primarily on the designer's judgment and experience.

The principal reason for the current situation is that available analytical procedures are difficult to use and have not been adapted to highway applications. After a thorough review of existing computer models to aid in analyzing mobile boundary streams, a conclusion was reached, during a session of the Transportation Research Board's Second Bridge Engineering Conference at Minneapolis in September 1984, that none of the existing computer models would be totally suitable to aid either in the design of highway bridges or in determining the effects of longitudinal encroachments. For example, some existing models apply only to long stream reaches; others are not detailed enough for bridge openings and do not predict lateral erosion of streams; and many are not user-friendly.

The objective of this research project is to develop and test a practical computer model that is based on sound physical principles of flow and sediment interaction and is designed to estimate water-surface profiles, aggradation, degradation, scour, and bank widening due to bridges and longitudinal encroachments located on mobile boundary streams. The estimates are to be used to aid in the design of highway crossings or other encroachments of streams. To accomplish the objective the following tasks will be performed:

Task 1—Finalize basic concepts, algorithms, flow charts, rationale for the stream classification system of Task 2, and program structure for the computer model.

Task 2—Develop a system to classify streams by size, bed and bank material stability, planform geometry, and other hydrological and morphological features, as needed to optimally select specific algorithms for use in an analysis. Submit an interim report containing the proposed algorithms, logic, and the classification system developed under Tasks 1 and 2.

Task 3—Develop a computer model that provides the necessary information for use in the design of highway stream crossings and encroachments, and contains the following features:

a. Computes changes in width and bed elevations in streams associated with general degradation and aggradation, contraction scour, and local scour.

b. Predicts the scour, fill, and water-surface profile resulting from the construction of highway embankments, bridges, longitudinal encroachments, and protective measures that may be used in the vicinity of a stream crossing also taking into account effects caused by other man-made changes upstream and downstream, such as streambed mining, channel realignment, storage reservoirs, and augmented stream flow.

c. Predicts the short and long term effects of relatively steady or unsteady flows.

d. Accommodates irregular channel cross sections and multichannel systems.

e. Includes procedures to isolate and superimpose the various components of scour and fill to arrive at composite estimates of stream widths and bed elevations for design of foundation depths and determination of water-surface profiles.

f. Incorporates an automated classification of stream processes and selection of appropriate algorithms based on physical description of a stream with provisions for user intervention.

g. Operates on a fully IBM-compatible microcomputer at a reasonable speed and with a manageable amount of input data.

h. Is written in user-friendly terms for use by a highway hydraulics engineer.

i. Includes an option that accepts user-provided sediment and hydraulic resistance functions.

Task 4—Make sensitivity analyses and develop guidelines for calibrating the model with emphasis on the most important data needs for calibration.

Task 5—Test and demonstrate the adequacy of the model by comparing the predicted results to measured field data.

Task 6—Conduct a 2-day critique workshop for 10 highway hydraulic engineers.

Task 7—Prepare the final report documenting the research effort, including a user's manual and a program documentation manual.

Tasks 1 and 2 are comlete. Work on the computer program progresses under Task 3. To accomplish Tasks 4 and 5, the agency is also in search of case studies and field data.

Project 15-12 FY '88

Roadway Widths for Low Traffic Volume Roads

Research Agency: In developmental stage
Principal Invest.:
Effective Date: (30 months)
Completion Date:
Funds: $250,000

The objectives of this research are to develop an engineering analysis procedure for determining roadway width for the construction and reconstruction of low volume roadways (less than 2,000 ADT) and, based on this analysis, to develop "minimum width of traveled way and shoulder" recommendations for consideration by the Geometric Design Task Force of the AASHTO Highway Subcommittee on Design for inclusion in future editions of the *Greenbook.*

This project will consist of at least six tasks as follows:

Task 1. Conduct a critical review of all pertinent literature dealing with safety, operations, and geometrics of low volume roads as they pertain to and impact on roadway width.

Task 2. Based on the results of Task 1, develop a data collection and analysis plan for acquiring the additional data needed to accomplish the project objectives. Variables to be included in this analysis shall include but not be limited to traffic volume, vehicle speed, percent trucks, geometrics, roadway functional classification (arterial, collector, and local), level of service (Reference: *Greenbook,* Table II-6, p. 96), traffic accident data, and associated costs (i.e., traffic accident and roadway construction, renovation, and maintenance). Prepare and distribute to the NCHRP Project Panel an interim report describing the results of this task.

Task 3. Implement the plan developed in Task 2.

Task 4. Based on the analysis of information obtained in previous tasks, develop an engineering analysis procedure for determining roadway width for roadways with an ADT of less than 2,000. This procedure shall incorporate an optimization of the costs and safety benefits for various roadway widths. Using the engineering analysis procedure, develop recommended roadway widths related to site conditions. It is anticipated that the traffic volume variable will require a minimum of three categories below 2,000 ADT. Prepare and distribute to the NCHRP Project Panel an interim report describing the results of this task.

Task 5. Apply the recommended roadway widths developed in Task 4 and the current width criteria found in the *Greenbook* to low traffic volume roadways constructed or reconstructed in three states and two counties during the last 5 years. The states and counties will be selected by NCHRP. Based on this analysis, determine the number of additional miles of roadway that could have been constructed or reconstructed in these 5 jurisdictions using the recommended roadway widths. In addition, determine the associated safety impact of applying the recommended roadway widths.

Task 6. Prepare a final report documenting the results of Task 1 through Task 5.

AREA 16. ROADSIDE DEVELOPMENT

Project 16-1 FY '66

Effects of Deicing Compounds on Vegetation and Water Supplies

Research Agency: Virginia Polytechnic Institute
Principal Invest.: Dr. R. E. Blaser
Effective Date: March 1, 1966
Completion Date: April 30, 1972
Funds: $217,300

The objectives of this study were to identify the detrimental effects of deicing salts on roadside vegetation and water supplies and to seek means for counteracting these detrimental effects.

The first phase of the study was an extensive literature review and survey of experience with regard to deicing salt use on roadways and the effects of this use on roadside vegetation, water, and wildlife. It also included identification of research needs in this problem area. This was followed by an experimental program covering the actual effects of deicing salts on specific types and species of vegetation and on soils along highways. Efforts were made to evaluate methods of counteracting certain detrimental effects.

Research has been completed, and the results of the first phase of the study have been published as: NCHRP Report 91, "Effects of Deicing Salts on Water Quality and Biota—Literature Review and Recommended Research."

The results of the experimental phase have been published as: NCHRP Report 170, "Effects of Deicing Salts on Plant Biota and Soils—Experimental Phase."

Project 16-2 FY '68

Evaluation of Research on Roadside Development

Research Agency:	Western States Landscape Association
Principal Invest.:	Wayne O. Earley
Effective Date:	October 1, 1967
Completion Date:	March 31, 1969
Funds:	$100,000

The objective of this project was to review, interpret, and evaluate past and present research on roadside development, describe areas where additional or continued research is needed, and recommend procedures for resolving these needs. The study included, but was not limited to, consideration of the relationship of roadside development and (1) highway location and design; (2) vegetation (planning, establishment, and management by plant growth zones is consideration of erosion control and roadside plantings); (3) resource conservation; (4) rest areas, scenic turnouts, and overlooks; (5) safety; and (6) right-of-way, scenic areas, and adjacent land use. Recognition was given to research under way or accomplished in legal authority, but it was not evaluated in this project.

The research has been completed, and the project report has been published as: NCHRP Report 137, "Evaluation of Research on Roadside Development."

Project 16-3 FY '73

Erosion Control During Highway Construction

Research Agency:	Utah State University	
Principal Invest.:	Dr. Calvin G. Clyde	
	Dr. C. Earl Israelsen	
	Paul E. Packer	
Effective Date:	Nov. 1, 1973	Mar. 1, 1978
Completion Date:	June 30, 1976	Nov. 30, 1979
Funds:	$179,224	$70,776

Uncontrolled water and wind erosion resulting from construction activities causes significant damage to the environment. The sediment produced pollutes surface water, restricts drainage, fills reservoirs, damages adjacent land, and destroys the natural ecology of lakes and streams. Besides harming the environment, soil erosion during construction increases costs and causes extensive delays and repairs.

Research is needed to develop more effective techniques, devices, and materials to control erosion during construction activities. This need was documented in NCHRP Synthesis 18, "Erosion Control on Highway Construction."

The synthesis study, while focusing attention on the need for a major research effort, also uncovered a large quantity of information, often fragmented or underevaluated, on known erosion control measures likely to have application in highway construction. Because of the existence of this information, the urgency of the problem, and research funding limitations, a logical first step in the eventual solution of the total problem was the development of recommendations for an interim set of specific guidelines for erosion control based on existing information.

Research has been completed, and project objectives have been accomplished. The Universal Soil Loss Equation was used as the basis for estimating soil loss. Existing maps that divide the country into areas of varying soil erosion potential were updated for use in application of the equation. An experimental program was planned and conducted for verifying the applicability of the equation for estimating soil loss from a construction site and for limited testing of erosion control products. An erosion control manual has been prepared for use by highway and transportation agencies and others for estimating soil loss from a specific construction site and assessing the effectiveness of erosion control procedures.

The project report has been published in 2 volumes as: NCHRP Report 220, "Erosion Control During Highway Construction—Research Report"; and NCHRP Report 221, "Erosion Control During Highway Construction—Manual on Principles and Practices."

AREA 17: SAFETY

Project 17-1 FY '66

Development of Improved Methods for Reduction of Traffic Accidents

Research Agency:	Cornell Aeronautical Laboratory
Principal Invest.:	John W. Garrett
Effective Date:	February 1, 1966
Completion Date:	May 31, 1968
Funds:	$247,847

The objective of this research was to develop motor vehicle accident investigation procedures, records, and statistics, which will more accurately reveal accident causation than the current accident record system. An extensive review of the state of the art revealed that the current data collection forms and procedures do not meet research requirements; few statisitcally trained personnel are employed for data analysis. Also, safety findings are assimilated slowly by the agencies responsible for the design, maintenance, and operation of the highway system. Long-

term recommendations included an improved centralized accident record system in which accident data were integrated with appropriate nonaccident data. Also proposed was a multilevel accident reporting scheme providing minimum data on all accidents, intensive investigative data on a small percentage of accidents, and special study data collected for a statistical sample of accidents. Improved cooperation between operating agencies with similar objectives was regarded as essential. Short-term recommendations included increased dissemination and utilization of current safety knowledge; utilization of modern technology at all levels of the system through the initiation of continuing education seminars and a safety review board; use of trained statistical personnel and techniques for better utilization of data; and use of accurate accident location methods. Location methods were reviewed and evaluated for guidance. Demonstration studies were performed to illustrate the feasibility of the proposed system and the techniques required. The study demonstrated the use of police to gather factual data in a study where they were provided with special report forms, written instructions, special training, and equipment. Utilization of intensive accident investigation procedures and the use of both accident and nonaccident data in a study also were demonstrated.

The project report has been published as: NCHRP Report 79, "Development of Improved Methods for Reduction of Traffic Accidents."

Project 17-2 FY '72

Methods for Evaluating Highway Safety Improvements

Research Agency: Operations Research Incorporated
Principal Invest.: Harry Denning
Effective Date: January 10, 1972
Completion Date: June 20, 1972
Funds: $29,973

The objective of the research was to provide a detailed technique in the form of guidelines from which calculations could be made that would allow officials to judge the effectiveness of highway improvements in terms, not only of reduced accidents, but also of cost-benefit of such improvements.

Activities prior to the contract's termination included detailed planning for the project and preparation of a detailed working plan. This research was resumed under 17-2A.

17-2A FY '72

Methods for Evaluating Highway Safety Improvements

Research Agency: Roy Jorgensen Associates
Principal Invest.: John C. Laughland
Effective Date: February 1, 1973
Completion Date: July 31, 1974
Funds: $98,403

The objective of the research was to provide a detailed technique in the form of guidelines from which calculations can be made that will allow officials to judge the effectiveness of highway improvements in terms, not only of reduced accidents, but also of cost-benefit of such improvements.

The research has been completed, and the final report has been published as: NCHRP Report 162, "Methods for Evaluating Highway Safety Improvements."

Project 17-3 FY '78

Application of Traffic Conflicts Analysis at Intersections

Research Agency: Midwest Research Institute
Principal Invest.: Dr. William D. Glauz
Effective Date: December 15, 1977
Completion Date: October 31, 1979
Funds: $190,000

The objective of this research was to develop a procedure for collecting and using traffic conflicts data to diagnose safety and operational deficiencies and to evaluate the effectiveness of improvements at intersections. This objective was achieved through an examination of present use of traffic conflicts analysis, development of new procedures, and field testing.

The final report was published as: NCHRP Report 219, "Application of Traffic Conflict Analysis at Intersections." Examples that illustrate the methods of data collection, data analysis, and application of the traffic conflicts technique are presented.

Project 17-4 FY '78

Evaluation of Traffic Controls for Street and Highway Work Zones

Research Agency: BioTechnology, Inc.
Principal Invest.: Dr. Hugh W. McGee
Effective Date: January 2, 1978
Completion Date: June 30, 1979
Funds: $200,000

The objective of this project was to determine the effectiveness of selected work-zone traffic control devices and to determine how these devices should be designed and used. The research was restricted to stationary work zones and did not consider moving operations.

Research has been completed; the findings were combined with the results of NCHRP Project 17-4(2) and published as: NCHRP Report 236, "Evaluation of Traffic Controls for Highway Work Zones."

Project 17-4(2) FY '80

Evaluation of Traffic Cones and Tubes for Street and Highway Work Zones

Research Agency: BioTechnology, Inc.
Principal Invest.: Dr. Richard F. Pain
Effective Date: April 23, 1980
Completion Date: September 30, 1981
Funds: $125,000

The first phase of this research (NCHRP Project 17-4) investigated the effectiveness of selected traffic channelizing devices and device markings in stimulating driver awareness of work-zone situations. Because of limited funding, Phase I did not cover the full range of device types and applications. Therefore, additional research was needed to extend the evaluation to other device types and applications and to determine the usefulness of each type under various work zone situations.

The objective of this continuation phase was to evaluate various types of cones and tubes and to determine the effects of size, spacing, reflectorization, and illumination on driver performance. The research was restricted to stationary zones and did not consider moving operations.

Research has been completed, and the combined findings from Projects 17-4 and 17-4(2) have been published as: NCHRP Report 236, "Evaluation of Traffic Controls for Highway Work Zones."

Project 17-5 FY '80

Effectiveness of Clear Recovery Zones

Research Agency: Midwest Research Institute
Principal Invest.: Jerry L. Graham
Effective Date: April 1, 1980
Completion Date: April 30, 1982
Funds: $200,000

The objective of this research was to investigate and quantify the effectiveness of clear recovery zones of differing slopes and widths in reducing the number and severity of run-off-the-road accidents. The frequency and severity of run-off-the-road accidents were compared on highways with and without clear zones. Highway sections in Missouri, Illinois, and Minnesota served as the primary data base, supplemented with data collected previously by MRI for a skid-reduction study. Highway sections compared had similar characteristics, (e.g., traffic volume and composition, functional classification, and alignment). Included in the sample were freeways and non-freeways and both left- (including median) and right-side encroachments. Excluded from the study were low-volume roadways (less than 750 ADT), intersections, interchanges, and urban facilities.

Research has been completed. The final report, including illustrative examples describing potential applications of the clear area safety relationships in design practice, has been published as: NCHRP Report 247, "Effectiveness of Clear Recovery Zones."

Project 17-6 FY '80 and FY '83

Service Vehicle Lighting and Traffic Control Systems for Short-Term and Moving Work Zones—Phase I

Research Agency: BioTechnology, Inc.
Principal Invest.: Dr. Richard F. Pain
Effective Date: November 1, 1982
Completion Date: July 24, 1984
Funds: $85,069

The objective of this project was to develop guidelines for warning systems on service vehicles and for traffic control in short-term, intermittent moving, and continuously moving work zones. In addition to considering the basic traffic and safety requirements, the guidelines will also place emphasis on the operational efficiency and cost-effectiveness of each treatment.

The state of the art was determined through a literature review and a review of current practice. Existing literature was reviewed to identify currently recommended standards, actual practice, and potential improvements. The MUTCD, the FHWA utilities handbook, ITE publications, SAE Handbook, representative state and local manuals, utilities operating practices, and research reports related to vehicle signal lighting and traffic control systems were reviewed. Selected organizations were contacted to obtain more detailed information on the most promising techniques, problems with current practice, and the feasibility and desirability of developing standards.

Typical situations were identified for which service vehicle warning and traffic control systems are needed, and those situations having similar traffic control requirements were combined to reduce the number of alternative treatments to be developed. Short-term, intermittent moving, and continuous moving activities were included. Some of the variables considered included: type of facility; roadway width, number of lanes, shoulder characteristics; urban or rural; traffic volume and speed; physical sight restriction; adverse visibility; activity period (e.g., day or night, peak or off-peak); duration of activity; length of work zones; extent of lane encroachment; lane blockage; and speed of operation.

Service vehicle warning and traffic control systems were developed for each work-type situation. For signal lighting, consideration was given to the effects of color, flash characteristics, number, size, and intensity, as well as the environment in which the vehicle is operating. Other vehicle warning devices such as arrow boards, flags, and vehicle paint schemes were also considered. The traffic control systems include the use, as appropriate, of flagmen, vehicles (e.g., barrier, shadow), and traffic control devices (e.g., signs, channelizing devices, arrow panels).

Spacing and size of devices, as well as the placement and number of all elements, are included. In development of the alternatives, consideration was given to the information needs of the motorist, equipment availability, characteristics of service vehicles, cost-effectiveness, portability, traffic operations, and motorist and worker safety (including the added hazard due to the placement and removal of devices).

The above activities complete the Phase I effort. Because of staff changes at the research agency, this contract had to be terminated at this point. Phase II is being conducted under a new contract as NCHRP Project 17-6A. The research findings from both phases will be published together at the end of Project 17-6A.

Project 17-6A FY '80 and FY '83

Service Vehicle Lighting and Traffic Control Systems for Short-Term and Moving Work Zones (Phase II)

Research Agency: Transportation Research Corp.
Principal Invest.: Fred R. Hanscom
Effective Date: October 15, 1984
Completion Date: May 16, 1988
Funds: $252,277

The objective of this project is to develop guidelines for warning systems on service vehicles and for traffic control in short-term, intermittent moving, and continuously moving work zones. In addition to considering the basic traffic and safety requirements, the guidelines will also place emphasis on the operational efficiency and cost-effectiveness of each treatment.

This research consists of two phases—Project 17-6 and Project 17-6A. Please refer to the Project 17-6 description for details regarding Phase I.

In Phase II, indoor laboratory studies were conducted to evaluate and optimize the vehicle warning and traffic control systems. Closed field studies were conducted in Maryland to further test the most promising systems. Field tests will be conducted in early 1986, under actual highway conditions, using real or simulated work activities, in New York and Louisiana as a final validation of each system.

A final report and an operations guide have been prepared describing recommended vehicle warning and traffic control systems developed under this project. This guide is designed to facilitate direct incorporation into state and local manuals used by service personnel in short-term and moving work zones.

The final draft report is currently being reviewed.

Project 17-7 FY '86

Guidelines for Converting STOP to YIELD Control at Intersections

Research Agency: Bellomo-McGee, Inc.
Principal Invest.: Dr. Hugh W. McGee
Effective Date: December 16, 1985
Completion Date: December 16, 1988
Funds: $200,000

Studies of low-volume intersections have concluded that control type has no appreciable effect on accident experience. These studies indicate YIELD control is more economical than STOP control because of the reduced delay and road user costs. For higher traffic volume intersections, however, insufficient accident data have been collected to demonstrate the relative safety of STOP versus YIELD control.

The objectives of this research are (1) to determine the accident experience when STOP-controlled intersections are converted to YIELD control, and (2) to develop guidelines for converting STOP control to YIELD control.

In order to meet these objectives, the following tasks will be performed:

Task 1—Determine the current traffic engineering practice and safety experience at STOP- and YIELD-controlled intersections through a review of the technical literature and contacts with State and local highway agencies.

Task 2—Prepare a study design to determine the safety consequences of converting STOP control to YIELD control for the full range of applicable volumes.

Submit an interim report on the findings of Task 1 and the study design developed in Task 2.

Task 3—Collect existing accident data and/or conduct new field studies.

Task 4—Relate the accident findings to intersection and operating characteristics. Interpret the results to explain the meanings associated with the statistical findings.

Task 5—Obtain the results from previous studies of user costs and benefits related to STOP and YIELD control. Integrate the safety results obtained from this project and develop criteria for converting from STOP control to YIELD control. Develop improved warrants for STOP and YIELD control.

Task 6—Prepare a final report including the guidelines for converting STOP control to YIELD control and suggested wording for improved STOP and YIELD control warrants for potential inclusion in the MUTCD.

Tasks 1 through 5 have been completed and the final report is being prepared.

Project 17-8 FY '88

Traffic Barrier and Control Treatments for Restricted Work Zones

Research Agency: Texas A&M Research Foundation
Principal Invest.: Dr. Hayes E. Ross, Jr.
Effective Date: June 1, 1988
Completion Date: May 31, 1991
Funds: $450,000

Many construction projects require the use of traffic barriers to adequately protect the motoring public and construction workers. Geometric and operational restrictions in these work zones frequently preclude the use of the same design standards for these barriers and terminals that normally apply to permanent systems.

One common example involves two-lane, two-way bridges where one-half of the bridge is repaired while maintaining alternating one-way traffic in the remaining lane (usually with temporary traffic control signals). The most common method of traffic control is to install a concrete barrier on the bridge approaches and across the bridge to protect the motorists and workers. While this practice normally provides an acceptable measure of safety for motorists and workers, problems occur when an intersecting highway or driveway that cannot be closed exists near the end of the bridge. In this example, and in other restricted situations, there is often inadequate room to install either the barrier runout at the specified flare rate, an impact attenuator, or other terminal treatments meeting the performance standards for permanent barrier systems.

The objective of this research is to develop improved and treatments for temporary traffic barriers, traffic control plans, and user guidelines for restricted work-zone situations. The following tasks will be conducted:

Phase I

Task 1—Identify types of existing work-zone situations where standard barrier terminal treatments and traffic control plans cannot be installed because of restricted conditions. Examples include bridge ends near an adjacent intersecting street, temporary traffic barriers with roadway/driveway openings, end treatments for barriers on narrow medians, and locations having restricted space for barrier deflection. Selected highway agencies, manufacturers, and other organizations are to be surveyed to determine common problem situations and current treatments.

Task 2—Classify the specific situations identified in Task 1 into groups having similar characteristics. Factors that should be considered include traffic parameters, site features (highway geometrics, terrain), and anticipated frequency of the problem situations.

Task 3—Develop conceptual designs for barrier terminal and traffic control treatments for the groups identified in Task 2. Factors to consider include: design vehicle, approach speed, barrier flare rate, safety, and roadway geometrics. Sloped terminals for concrete barriers under low approach speed conditions will be included as one of the end treatments.

Task 4—Evaluate the proposed treatments for typical situations. Evaluation criteria include safety, traffic capacity, user delay, costs, and ease of implementation.

Task 5—Prepare a report on the findings of the above tasks. This report will contain a detailed work plan for Phase II, including recommendations for the development and evaluation of the proposed barrier terminal treatments through analysis and crash tests.

Phase II

Task 6—Develop detailed designs for barrier terminal treatments.

Task 7—Evaluate the terminal treatments developed in Task 6 through full-scale crash tests.

Task 8—Develop a user's manual including detailed design drawings for recommended barrier terminal treatments and special traffic control plans, and guidelines for their use. This manual will be in sufficient detail and in a format suitable for consideration by AASHTO for incorporation into its design criteria.

Task 9—Prepare final research report.

Tasks 1 and 2 have been completed.

AREA 18: CONCRETE MATERIALS

Project 18-1 FY '68

Revibration of Retarded Concrete for Continuous Bridge Decks

Research Agency: University of Illinois
Principal Invest.: Dr. H. K. Hilsdorf
Effective Date: September 1, 1967
Completion Date: December 1, 1969
Funds: $103,895

This research had the objectives of (1) conducting a survey to determine the extent to which either delayed vibration or revibration has been used in placing bridge deck concrete, including the purpose, conditions, and results; (2) determining by laboratory and/or field tests if transverse and longitudinal cracking can be significantly reduced by revibration after retarded concrete has been placed over the entire deck of a continuous bridge or a complete segment of several spans supported by a continuous girder system; (3) determining the effect of revibration and subsequent finishing on the durability of bridge deck surfaces exposed to deicing chemicals; and (4) determining the most effective and practical means of revibration in the field.

The research has been completed, and the final report has been published as: NCHRP Report 106, "Revibration of Retarded Concrete for Continuous Bridge Decks."

Project 18-2 FY '73

Use of Polymers in Highway Concrete

Research Agency: Lehigh University
Principal Invest.: Dr. John A. Manson
Effective Date: October 1, 1972

Completion Date: September 30, 1975
Funds: $300,000

The over-all objective of this project was to develop the technology for the economical use of polymers to improve the serviceability of concrete in highways. The immediate goal concerned economically feasible methods for polymer impregnation of concrete bridge decks in place.

The program was conducted jointly by Lehigh University and The Pennsylvania State University.

The study included a state-of-the-art survey, laboratory development of engineering data on the penetration of candidate materials, testing of drying techniques and prototype impregnation equipment, durability studies, and experimental impregnations of two bridge decks. Final work centered on the use of methyl methacrylate and trimethylolpropane trimethacrylate (MMA/TMPTMA) as the monomer system. Two methods of drying (propane-fired infrared and propane torch units), two methods of monomer application (soaking and pressure), and two methods of polymerization (hot water and steam) were used. Polymer penetration to depths of more than 4 in. was achieved. Extreme dryness was found to be the key to deep penetration. This was obtained with temperatures of about 250 F at 4-in. depths. The first successful penetrations of a bridge deck were achieved with equipment covering areas of only a few square feet. Field equipment was enlarged and up-graded, and successful impregnations were achieved over several 36-sq ft areas on two bridge decks—one a test-track deck and the other a deck in regular service. A field manual describing the techniques that were developed and including suggested safety precautions and acceptance criteria is included in the final report.

Research has been completed, and the final report has been published as: NCHRP Report 190, "Use of Polymers in Highway Concrete."

Project 18-2(2) FY '78

Polymer Concrete in Highway Bridge Decks

Research Agency: Lehigh University
Principal Invest.: Dr. John A. Manson
Effective Date: January 1, 1978
Completion Date: March 15, 1979
Funds: $30,000

NCHRP Project 18-2 demonstrated the feasibility of polymer impregnation of salt-contaminated, but structurally sound, bridge decks to depths sufficient to encase the upper layer of steel reinforcement (about 4 in.) as a possible means of arresting or preventing corrosion. It was concluded that additional research and development work will be needed to refine the method and to extend its applicability beyond the range of variables of the completed investigation. Polymer impregnation includes a high-temperature drying process whose effects on the durability and structural integrity of the deck concrete are not now understood. It has been noted that the process causes fine cracks to appear in the concrete, but little else is known. The authors of NCHRP Report 190 concluded that research is needed to (1) measure the extent of this problem and provide a solution if required; (2) provide additional information on the long-term effectiveness of the impregnation process in preventing or arresting corrosion: and (3) determine the economics of the use of polymer impregnation. Determination of long-term effectiveness and economics will require consideration of the relative merits of various processes for impregnation as well as other methods of prevention and repair of bridge deck corrosion problems. Research is also needed to determine whether corrosion in a contaminated deck can be controlled by sealing with a shallow polymer impregnation, or complete encapsulation of the top reinforcement is necessary.

NCHRP Project 18-2(2) was not intended to provide answers to all of these specific questions. Its objective was more general: to clarify the state of knowledge with regard to polymer concrete in bridge decks. It did not involve extensive investigations to develop new research findings but was intended to outline what is already known, what additional information is needed, and what new research needs to be undertaken. The final report provides guidance for decisions on future research in this area.

Research has been completed. Copies of the agency's report may be obtained on a loan basis upon written request to the NCHRP. A limited number of copies are available to NCHRP sponsors for permanent retention, and others may purchase microfiche of the report (see final page of this section for ordering information).

Project 18-2(3) FY '78

Long-Term Rehabilitation of Salt-Contaminated Bridge Decks

Research Agency: Lehigh University
Principal Invest.: Dr. John A. Manson
Effective Date: May 1, 1980
Completion Date: April 29, 1983
Funds: $199,900

A critical review and experimental work were conducted on methods for the rehabilitation of salt-contaminated bridge decks. Emphasis was given to improving techniques for the impregnation of concrete with poly(methyl methacrylate) and to the concept of scarification to remove the top layer of concrete, followed by impregnation with a polymer or corrosion inhibitor, and overlaying with a low-permeability concrete. Exploratory research with electrochemical removal of salt was also conducted.

Resistance to freezing and thawing and to corrosion

was determined for several combinations of substrate treatment and overlay (latex-modified concrete, low-slump dense concrete, and polymer concrete) after scarification was simulated. Treatments of the concrete with methyl methacrylate consistently gave superior performance with respect to durability and corrosion resistance provided the concrete was dry prior to impregnation. Two impregnated inhibitors (calcium nitrite and a commercial rust inhibitor) and a hydrophobic silane improved corrosion resistance, but durability under freezing and thawing conditions was decreased. Sulfur gave variable or poor results. A new technique for impregnation was also developed, based on deeply grooving the concrete to facilitate drying and the impregnation process.

Research has been completed, and the final report has been published as: NCHRP Report 257, "Long-Term Rehabilitation of Salt-Contaminated Bridge Decks." The published report contains an appendix detailing the deep grooving technique as a means to facilitate deep polymer impregnation, i.e., impregnation to a depth to include the encapsulation of the top reinforcing steel in bridge decks. An agency "Supplement to NCHRP 257" containing several additional appendixes was distributed to NCHRP sponsors only. It is available to others on a loan basis or a purchase basis for the cost of reproduction (see final page of this section for ordering information). The appendixes in the supplemental report detail the laboratory investigations and present the development and use of an economic model for comparing cost-effectiveness of various alternatives.

AREA 19: FINANCE

Project 19-1 FY '68

Budgeting for State Highway Departments

Research Agency: Ernst & Ernst
Principal Invest.: F. W. Hinck, Jr.
Effective Date: September 5, 1967
Completion Date: September 4, 1968
Funds: $45,000

Although budget plans of varying effectiveness now exist in the several State highway departments, there is no indication that highway administration recognizes and utilizes the budget process to its full potential.

Research is needed with the long-range objective of devising a concisely defined framework of budget systems, together with detailed documentation for implementing policies and procedures. To meet this need, the researchers analyzed the organization plans and funding arrangements controlling State highway departments. They determined in detail the prerequisites which must be satisfied and the problems requiring resolution for effective State highway budgetary systems to be instituted. Documented recommendations were developed for devising a concise universal State highway budgeting system with detailed aids for implementing appropriate policies and procedures.

Research has been completed. The project report will not be published in the regular NCHRP report series, but the essential findings from the report have been published in NCHRP Research Results Digest 20.

Project 19-2(1) FY '69

Develop Performance Budgeting System to Serve Highway Maintenance Management

Research Agency: Booz • Allen & Hamilton
Principal Invest.: H. L. Wilsey
Effective Date: September 2, 1968
Completion Date: October 31, 1968
Funds: $6,000

With highway maintenance expenditures rapidly increasing due to completion of the Interstate System, rising traffic volumes, trends toward higher standards of physical maintenance, and more traffic services, it becomes increasingly important that maintenance operations be based on reasonable and effective maintenance budgets.

The scope of this project was to develop independent work plans to be used as the research plan for the second-phase work. The work plan has been received but will not be published. Refer to Project 19-2(4) for description of the over-all project objectives and details of Phase II of this study.

Project 19-2(2) FY '69

Develop Performance Budgeting System to Serve Highway Maintenance Management

Research Agency: Ernst & Ernst
Principal Invest.: F. W. Hinck, Jr.
Effective Date: September 2, 1968
Completion Date: October 31, 1968
Funds: $6,000

With highway maintenance expenditures rapidly increasing due to completion of the Interstate System, rising traffic volumes, trends toward higher standards of physical maintenance, and more traffic services, it becomes increasingly important that maintenance operations be based on reasonable and effective maintenance budgets.

The scope of this project was to develop independent work plans to be used as the research plan for the second-phase work. The work plan has been received but will not be published. Refer to project 19-2(4) for description of the over-all project objectives and details of Phase II of this study.

Project 19-2(3) FY '69

Develop Performance Budgeting System to Serve Highway Maintenance Management

Research Agency: Roy Jorgensen & Associates
Principal Invest.: J. L. Garner
Effective Date: September 2, 1968
Completion Date: October 31, 1968
Funds: $6,000

With highway maintenance expenditures rapidly increasing due to completion of the Interstate System, rising traffic volumes, trends toward higher standards of physical maintenance, and more traffic services, it becomes increasingly important that maintenance operations be based on reasonable and effective maintenance budgets.

The scope of this project was to develop independent work plans to be used as the research plan for the second-phase work. The work plan has been received but will not be published. Refer to Project 19-2(4) for description of the over-all project objectives and details of Phase II of this study.

Project 19-2(4) FY '69

Develop Performance Budgeting System to Serve Highway Maintenance Management

Research Agency: Roy Jorgensen & Associates
Principal Invest.: Roy E. Jorgensen
J. L. Garner
Effective Date: February 1, 1969
Completion Date: November 30, 1971
Funds: $220,000

The objectives of this project were to develop a model highway maintenance performance budgeting system and to pilot test the installation of the system in a State highway department.

The objectives have been accomplished in terms of the development of a model system that can be adapted for use by a State highway department to make most effective use of available maintenance funds and to assist in the process of highway budget and management planning. Pilot installation of the model system in cooperation with the State Highway Department of Georgia indicates that implementation is feasible.

The research has been completed, and the project report has been published as: NCHRP Report 131, "Performance Budgeting System for Highway Maintenance Management."

Project 19-3 FY '71

Economic Effects of Changes in Legal Vehicle Weights and Dimensions on Highways

Research Agency: Wilbur Smith and Associates
Principal Invest.: R. E. Whiteside
Effective Date: September 15, 1970
Completion Date: June 14, 1972
Funds: $96,728

The objectives of this research were: (1) to critically review past and current research and methodologies relating to the consequences of possible changes in legal vehicle weight; (2) to evaluate methodologies and procedures identified in the review as to their reliability, adequacy, ease of application, and other attributes; (3) to assemble from existing knowledge a recommended methodology or methodologies identifying all decision points involved in reaching a conclusion regarding costs and benefits associated with changes in legal weights and dimension limits for vehicles; and (4) to recommend additional research and development as may be found necessary to fill gaps in present knowledge.

The research has been completed, and the project report has been published as: NCHRP Report 141, "Changes in Legal Vehicle Weights and Dimensions—Some Economic Effects on Highways."

AREA 20: SPECIAL PROJECTS

Project 20-1 FY '65, FY '66, and FY '67

Highway Reserch Information Service

Research Agency: Highway Research Board
Principal Invest.: Dr. Paul E. Irick
Effective Date: March 16, 1964
Completion Date: October 31, 1967
Funds: $455,000

The objectives of the Highway Research Information Service were: (1) to select and store input information from current and past highway research that will be of value to users of highway information, (2) to disseminate current information to users, and (3) to retrieve relevant information on request.

All storage and retrieval procedures are now operational. The service, available to anyone interested, includes abstracts of publications, new reports on research in progress, and the updating of previously stored reports for ongoing research.

Project 20-2 FY '66

Research Needs in Highway Transportation

Research Agency: Bertram D. Tallamy Associates
Wilbur Smith and Associates
Principal Invest.: Lloyd G. Byrd
Paul E. Conrad
Effective Date: April 1, 1966
Completion Date: December 31, 1967
Funds: $98,760

This project developed a coordinated framework of needed short- and long-range research in the field of highway transportation. Major areas of needed research were

identified and arranged in the general framework. Technical priorities of need and an estimate of the appropriate level of funding for each are included. The framework was designed in such a manner as to permit updating with minimal effort.

The project report gives method or concept for structuring research as developed by the research, which includes a method for assigning priorities and costs to proposed research. The methods developed under this research were applied to 900 proposed research project statements considered in the study to formulate an example research program.

The final report has been published as: NCHRP Report 55, "Research Needs in Highway Transportation."

Project 20-3 FY '67 and FY '68

Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control

Research Agency:	Texas A & M University Research Foundation	
Principal Invest.:	Dr. J. A. Wattleworth Kenneth G. Courage	
Effective Date:	Dec. 15, 1966	Jan. 1, 1967
Completion Date:	Jan. 31, 1969	Dec. 31, 1968
Funds:	$394,016	$200,540*

To meet present and future traffic demands, the combined freeway and surface street system must operate more efficiently. Practical measures for increasing operational efficiency by judicious application of traffic surveillance, communication, and control were studied for the heavily traveled corridor of the John C. Lodge Freeway in Detroit.

The initial research program included an evaluation of the effectiveness of the existing National Proving Ground surveillance, communication, and control system, and its individual components. Methods were determined for increasing the effectiveness of the freeway and surface street system, and equipment configurations were recommended to improve the system based on a cost-effectiveness study.

A technical report, "An Evaluation of Two Types of Freeway Control Systems," covering the 1967 research work was submitted and accepted. The report includes an evaluation of the initial NPG television and advisory speed and lane-control signs and a description and evaluation of the ramp-metering system. Six additional reports were prepared covering the 1967 research work.

The major work items proposed for completion in 1968 were a pilot study of a freeway-frontage road driver information system, further freeway operations studies using improved detection and refined control techniques, environmental effects studies, pilot equipment studies for traffic-responsive signal control throughout the corridor, and a preliminary design for a more extensive driver-communication system to include the surface streets within the corridor. The project report for the 1968 work, "A Freeway Corridor Surveillance, Information, and Control System," was accepted but not published. A summary of the work has been provided in the report prepared under Project 20-3C.

At the end of 1968 the research agency requested, due to extensive other research commitments, to be relieved of further work. A continuation proposal was requested from the University of Michigan. The research was continued under Project 20-3A.

Project 20-3A FY '69 and FY '70

Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control

Research Agency:	University of Michigan	
Principal Invest.:	Dr. Donald E. Cleveland	
Effective Date:	Nov. 20, 1968	Jan. 1, 1969
Completion Date:	May 31, 1971	Dec. 31, 1969
Funds:	$505,631	$20,000†

This project was a continuation of the 1967 and 1968 research conducted by the Texas Transportation Institute under Project 20-3.

The basic tasks and their respective components of the 1969 research work were designed to develop information required for the ultimate synthesis of a traffic surveillance, driver information, and control system capable of real-time control of traffic throughout an entire network of arterial streets and freeways. The topics included (1) detection of capacity-reducing incidents, (2) improved ramp control techniques and environmental effects, (3) pilot studies of freeway-frontage road informational system, (4) an experiment in traffic routing within the freeway corridor, and (5) observation of freeway operations. Draft reports on the topics of the 1969 research work have been accepted by the project committee.

The 1970 research had the general objective of improving the combined level-of-service on the Freeway and the supporting street network. The work was divided into four principal tasks, all of which were completed: (1) improvement of ramp metering and freeway corridor flow; (2) improvement of Davison-Lodge interchange operation; (3) determination of the effect of weather on freeway corridor operations; and (4) long-term motorist response to the information system.

Draft final reports on the results from the work under the tasks were accepted and are available on a loan basis upon written request to the NCHRP. They, along with the 1969 reports, have not been published, but are summarized in the report prepared under Project 20-3C.

*NCHRP funds obligated under the $314,340 four-way agreement among the National Academy of Sciences, Michigan Department of State Highways, Wayne County, and the City of Detroit.

†NCHRP funds obligated under the $70,000 five-way agreement among the National Academy of Sciences, Michigan Department of State Highways, Wayne County, the City of Detroit, and the University of Michigan.

Project 20-3B FY '70

Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control—Summary Reporting

Research Agency: Patrick J. Athol
Principal Invest: Patrick J. Athol
Effective Date: July 1, 1972
Termination Date: September 27, 1974
Funds: $31,116

Because a substantial body of knowledge relative to more efficient operation of systems made up of freeways and adjacent streets has been acquired through NCHRP Projects 20-3, 20-3A, and studies under other programs, Project 20-3B was established with the following objectives:

1. Preparation of a report summarizing the main findings of freeway surveillance and control on the John C. Lodge Freeway in Detroit. The end product of this synthesis was to have been one report that summarized all historic and technical activities of the research conducted by the State of Michigan and under the NPG and NCHRP Projects 20-3 and 20-3A. The major emphasis was to be placed on reporting on usable results that have been found to be practical on the Lodge project.
2. Preparation of a report in the vein of "Getting the Most Service from Freeways," using published research reports and the experience available from past and ongoing freeway traffic operations projects.

Objective 1 was advanced only to the point of a preliminary report that was submitted to the NCHRP project panel for an acceptance review. Based on this review, extensive revisions were required. They were begun but were never completed; therefore, a revised report was never submitted. Some work was carried out toward Objective 2, but, although the original completion date had been overrun by a year, it was not substantial and never progressed to the point of a preliminary report. Still another extension was imminent; however, the contractor chose to quit without fulfilling the objectives set forth in his proposal. By mutual agreement, the project was terminated. This research was resumed under Project 20-3C.

Project 20-3C FY '70

Summary of the Lodge Freeway Research

Research Agency: Asriel Taragin
Principal Invest.: Asriel Taragin
Effective Date: November 15, 1975
Completion Date: July 15, 1976
Funds: $10,183

This project was initiated to prepare a summary report outlining the main findings from a long series of freeway surveillance and control studies on the John C. Lodge Freeway in Detroit. The historical research has been completed, and a report has been submitted. It covers the objectives, organization, and data, as well as the results, conclusions, and recommendations associated with each stage of the traffic research studies. References to all published and unpublished reports as well as file documents pertinent to the background of the studies have been appropriately identified.

The agency's final report has been distributed to the sponsoring agencies; microfiche of the report may be purchased (see final page of this section for ordering information).

Project 20-3D FY '70

Summary of All Freeway Surveillance, Communication and Control Experience

Research Agency: Alan M. Voorhees & Associates
Principal Invest.: Dr. Donald G. Capelle
Effective Date: May 15, 1977
Completion Date: December 31, 1978
Funds: $40,000

This project complements Project 20-3C. It was established to prepare a summary report of all experience with the surveillance, communications, and traffic control aspects of freeway operations. Published reports and other experience available from relevant research projects were reviewed. The final report provides a synthesis of past and present practices to aid highway administrators in decisions related to freeway operation problems.

Research has been completed. Because the final report is of a nontechnical nature and is directed to top-level administrators, it was published as a special publication rather than in the regular NCHRP series. The report, "Freeway Traffic Management," is available for $5.00 (see final page of this section for ordering information).

Project 20-4 FY '68

Public Preference for Future Individual Transportation

Research Agency: Chilton Research Services (CRS)
National Analysts (NA)
Principal Invest.: Robert K. McMillan
James M. Marshall
Effective Date: May 2, 1967
Completion Date: January 21, 1969 (CRS)
January 2, 1968 (NA)
Funds: $279,171

The objective of this research was to determine the attitudes and behavior of the public related to transportation and identify the factors that influence such attitude and behavior.

A first-phase report was published in 1968 as: NCHRP Report 49, "National Survey of Transportation Attitudes and Behvior—Phase I Summary Report." This report

presents a preliminary analysis of the nationwide survey data. It includes a comparison of household and individual characteristics for both survey samples and a question-by-question analysis of the total sample.

A second-phase report has been published as: NCHRP Report 82, "National Survey of Transportation Attitudes and Behavior—Phase II Analysis Report." This report presents results of a more advanced statistical analysis of the data. This analysis is multi-variant in nature; that is, it considers many variables simultaneously to obtain a comprehensive view of transportation attitudes, their relation to behavior and demographic characteristics, and profiles of people holding these views.

The report includes 16 charts that indicate attitudes, according to eight demographic variables, toward spending for roadways and highways and public transportation. The report deals comprehensively with data by describing the methodology, statistical methods used, and the detailed findings.

Project 20-5 FY '68 and continuing

Synthesis of Information Related to Highway Problems

Research Agency:	Transportation Research Board	
Principal Invest.:	T. L. Copas	
	H. A. Pennock	
Effective Date:	December 15, 1967	
Completion Date:	Continuing	
Funds:	$100,000 annually,	FY '68-'71
	$200,000 annually,	FY '72-'75
	$300,000 annually,	FY '76-'77
	$330,000	FY '78
	$360,000 annually,	FY '79-'83
	$380,000	FY '84
	$650,000	FY '85
	$600,000	FY '86
	$600,000	FY '87
	$650,000	FY '88
	$550,000	FY '89

Administrators, practicing engineers, and researchers are continually faced with highway problems on which much information exists, either in documented form or in terms of undocumented experience and practice. Unfortunately this information is often fragmented, scattered, and unevaluated. As a consequence, full information on what has been learned about a problem is frequently not brought to bear on its solution. Costly research findings may be unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

In this project, particular highway problems, or sets of closely related problems, will be designated as topics for information synthesis.

For each topic the objectives are:

1. To locate and assemble documented information.
2. To learn what engineering practice has been used for solving or alleviating the problem.
3. To identify all ongoing research.
4. To learn what problems remain largely unsolved.
5. To organize, evaluate, synthesize, and document the useful information that is acquired.
6. To evaluate the effectiveness of the synthesis after it has been in the hands of its users for a period of time.

The 143 published syntheses of highway practice that have been prepared under this project are listed in Table 6. Additional information on the project may be found in Research Results Digest 168.

Project 20-6 FY '69 and continuing

Legal Problems Arising out of Highway Programs

Research Agency:	Transportation Research Board	
Principal Invest.:	Robert W. Cunliffe	
Effective Date:	November 1, 1968	
Completion Date:	Continuing	
Funds:		
$200,000	FY '69	$100,000 Ann. FY '78-'79
$125,000	FY '72	$150,000 Ann. FY '80-'81
$50,000	FY '73	$100,000 FY '82
$185,000	FY '74	$150,000 FY '83
$125,000	FY '75	$200,000 FY '84
$85,000	FY '76	$280,000 FY '85
$75,000	FY '77	$200,000 FY '86 & '88
		$100,000 FY '89

A major and continuing need of State highway departments involves the assembly, analysis, and evaluation of operating practices and the legal elements of special problems involving right-of-way acquisition and control and highway law in general. Individual State experiences need to be compared and made available for possible application nationally. Need exists with respect to both immediate and longer-range right-of-way and legal problems.

In spite of this critical need, there has been no present mechanism that is capable of responding in time to be of practical assistance to State highway departments. The Right-of-Way and Legal Affairs Committee of the American Association of State Highway Officials has tried all of the known channels in an effort to initiate such research, but the response has been negative for one reason or another.

Accordingly, State highway officials have agreed that an appropriate mechanism be initiated under which needed research of the type suggested can be undertaken and with dispatch. Prototypes of such a device may be found in the various AASHO and HRB road-test projects that have been undertaken and, perhaps more closely

related, in the 1956-60 special HRB Highway Laws Project.

NCHRP Project 20-6 has been established to meet the aforementioned need and is a continuing effort involving research on a priority listing of topics selected by the cognizant NCHRP project committee. The topics of concern to date are:

Study No. 1— Relocation Assistance Under Chapter Five of the 1968 Federal-Aid Highway Act (Research Results Digest No. 3)

Study No. 2— Standing to Sue for Purposes of Securing Judicial Review of Exercise of Administration Discretion in Route Location of Federal-Aid Highways (Research Results Digest No. 6)

Study No. 3— Valuation Changes Resulting From Influence of Public Improvements (Research Results Digest No. 11)

Study No. 4— Advance Acquisition Under the 1968 Federal-Aid Highway Act (Research Results Digest No. 19)

Study No. 5— Valuation in Eminent Domain as Affected by Zoning (Research Results Digest No. 22)

Study No. 6— Federal Environmental Legislation and Regulations as Affecting Highways (Research Results Digest No. 25)

Study No. 7— Changes in Existing State Law Required by the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970 (Research Results Digest No. 32)

Study No. 8— Proposed Legislation to Authorize Joint Development of Highway Rights-of-Ways (Research Results Digest No. 31)

Study No. 9— Legal Effect of Representations as to Subsurface Conditions (Research Results Digest No. 39)**

Study No. 11— Personal Liability of State Highway Department Officers and Employees (Reserch Results Digest No. 79)**

Study No. 12— Tort Liability of Highway Departments Arising Out of Skidding Accidents (Research Results Digest Nos. 83 and 95)**

Study No. 13— Appeal Bodies for Relocation Assistance (Research Results Digest No. 40)

Study No. 15— Trial Strategy and Techniques to Exclude Noncompensable Damages and Improper Valuation Methods in Eminent Domain Cases (Research Results Digest No. 41)

Study No. 16— Supplemental Condemnation: A Discussion of the Principles of Excess and Substitute Condemnation (Research Results Digest No. 42)

Study No. 17— Liability of State Highway Departments for Design, Construction, and Maintenance Defects (Research Results Digest No. 80)**

Study No. 23— Exclusion of Valuation Changes Resulting from Influence of Public Improvement: A Study of the Provisions of 42 U.S.C. 4651 (3) (Research Results Digest No. 45)

Study No. 24— Eminent Domain: An Overview*

Study No. 25— Where Does Police Power End and Eminent Domain Begin?*

Study No. 26— Just Compensation and the Doctrine of Damnum Absque Injuria*

Study No. 27— The Meaning of Highway Purpose (Research Results Digest No. 68)*

Study No. 28— Valuation of Outdoor Advertising Rights*

Study No. 30— Liability for Drainage Damage*

Study No. 31— Trial Strategy and Techniques Using the Income Approach to Valuation (Research Results Digest No. 54)*

Study No. 32— Trial Strategy and Techniques Using the Comparable Sales Approach to Valuation (Research Results Digest No. 47)*

Study No. 33— Trial Strategy and Techniques Using the Reproduction Cost Less Depreciation Approach to Valuation*

Study No. 34— Trial Aids in Highway Condemnation Cases* (Research Results Digest No. 111)

Study No. 35— Model Airspace Act: A Vehicle for Joint Development*

Study No. 36— Formation of the Contract** (Research Results Digest No. 109)

Study No. 37— Effect of Mistakes in Bids, Plans and Specifications**

Study No. 38— Legal Problems Arising from Changes, Change Clauses and Changed Conditions**

Study No. 39— Contract Completion Time: Damages for Delay; Liquidated Damages; Work Stoppage Under Court Order**

Study No. 40— Administrative Settlement and Disposition of Claims**

Study No. 41— Trial Strategy and Techniques in Contract Litigation** (Research Results Digest No. 108)

Study No. 42— Environmental Litigation: Rights and Remedies**

Study No. 43— Trial Strategy and Techniques in Environmental Litigation**

Study No. 44— Legal Interrelationship of the Federal and State Governments**

Study No. 45— Review of the One-Offer System of Right-of-Way Acquisition (Completed)

Study No. 46— Liability of Governmental Agencies for Improper Traffic Control Devices, Signs, and Pavement Markings** (Research Results Digest No. 110)
Study No. 47— Supplementation of Studies 15, 31, 32 and 33, and Project 11-1(2)***
Study No. 48— Supplementation of Studies, 3, 4, and 5.***
Study No. 49— Inverse Condemnation***
Study No. 50— Payment of Attorney Fees and Other Costs in Condemnation and Environmental Litigation*** (Research Results Digest No. 103)
Study No. 51— Appraisal of Property Damages Due to Highway Noise*** (Research Results Digest No. 99)
Study No. 54— Outdoor Advertising Control and Acquisition (Completed)
Study No. 57— Legal Aspects of Access Control on Unlimited-Access Highways*** (Research Results Digest No. 112)
Study No. 60— Relocation of Public Utilities† (Research Results Digest No. 116)
Study No. 61— Right to Compensation in Eminent Domain for Abrogation of Restrictive Covenants*** (Research Results Digest No. 113)
Topic No. 2-03 —Condemnation Blight† (Research Results Digest 119)
Topic No. 2-04 —Legal Aspects of Historic Preservation in Highway Programs†† (Research Results Digest 138)
Topic No. 2-05 —Local Land-Use Regulations in Relation to Highway Programs (Completed)††
Topic No. 2-08 —"State Highway Programs Versus the Spending Powers of Congress"†† (Research Results Digest 136)
Topic No. 2-09 —Procedural Aspects of Inverse Condemnation Actions (Completed)††
Topic No. 2-10 —The Effect of Federal and State Public Information Acts on Highway and Transportation Department Activities†† (Research Results Digest 137)
Topic No. 2-13 —Update of Five Tort Liability Papers in Chapter VIII, SSHL†
Topic No. 2-14 —Update of "Legal Effect of Representations as to Subsurface Conditions"†
Topic No. 2-15 —Update of "Valuation and Condemnation of Special Purpose Properties" (Completed)††
Topic No. 2-16 —Update of "Environmental Litigation: Rights and Remedies" (Completed)††
Topic No. 2-17 —Update of "Damnum Absque Injuria and the Concept of Just Compensation in Eminent Domain"†
Topic No. 2-18 —Update of "Supplemental Condemnation: A Discussion of the Principles of Excess and Substitute Condemnation"†
Topic No. 2-19 —Update of "Liability for Delay in Completion of Highway Construction Contracts"†
Topic No. 2-21 —Legal Implications of Highway Department's Failure to Comply with Design, Safety, or Maintenance Guidelines†† (Research Results Digest 129)
Topic No. 2-22 —Update of "Legal Problems Arising from Changes, Changed Conditions, and Disputes Clauses in Highway Construction Contracts"†
Topic No. 2-23 —Update of "Where Does Police Power End and Eminent Domain Begin"†
Topic No. 2-24 —Update of "The Meaning of Highway Purpose"†
Topic No. 2-25 —Update of "Liability of the State for Highway Traffic Noise"†
Topic No. 2-26 —Update of "Right of Compensation in Eminent Domain for Abrogation of Restrictive Covenants"†
Topic No. 2-27 —Update of "Liability for Highway Drainage Damage"†
Topic No. 2-28 —Update of "Valuation nd Condemnation Problems Involving Trade Fixtures (Completed)††
Topic No. 2-29 —Update of "Valuation and Condemnation of Advertising Signs and Related Property Interests Under the Highway Beautification Act" (Completed)††
Topic No. 2-30 —Update of "Payment of Attorney Fees in Eminent Domain and Environmental Litigation" (Completed)††
Topic No. 2-31 —Update of "Rules of Discovery and Disclosure in Highway Condemnation Proceedings" (Completed)††
Topic No. 2-32 —Update of "Legal Implications of Control of Access to Uncontrolled-Access Highways" (Completed)††
Topic No. 2-33 —Liability of the State for Injury Producing Defects in Highway Surface†† (Research Results Digest 135)
Topic No. 2-36 —Liability of State Highway Departments for Defects in Design, Construction, and Maintenance of Bridges†† (Research Results Digest 141)
Topic No. 2-37 —Liability of Highway Agencies for Failure to Remove Obstructions In or

*Published in *Selected Studies in Highway Law*, Vols. 1 and 2.
**Published in *Selected Studies in Highway Law*, Vol. 3.
***Published in first addendum to *SSHL*.
†Published in second addendum to *SSHL*.
††Published in third addendum to *SSHL*.
†††Published in fourth addendum to *SSHL*.

Near the Highway (Completed)††† (Research Results Digest 151)

Topic No. 2-37A—Liability of the State for Injuries Caused by Obstruction on Defects in Highway Shoulder or Berm (Completed)††† (Research Results Digest 153)

Topic No. 3-01 —Disposition of Minerals on Highway Rights-of-Way (Research Results Digest 147)†††

Topic No. 3-02 —Legal and Procedural Issues Related to Relocation Assistance (Research Results Digest 158)†††

Topic No. 3-04 —First Amendment Aspects of Control of Outdoor Advertising (Research Results Digest 145)†††

Topic No. 3-05 —Liability of a Public Agency for Planning Blight: The "De Facto" Taking (Completed)††† (Research Results Digest 150)

Topic No. 3-06 —Exaction of Right-of-Way by the Exercise of Police Power (Completed)††† (Research Results Digest 149)

Topic No. 3-07 —Trial Strategy and Techniques in Handling Tort Claims Arising Out of Highway Operations (Completed)

Topic No. 3-09 —Trial Strategies and Techniques in Establishing Violations of Size and Weight Laws (Completed)††† (Research Results Digest 154)

Topic No. 3-10 —Enforceability of the Requirement of Notice in Highway Construction Contracts (Completed)††† (Research Results Digest 152)

Topic No. 3-19 —Minority Business or Enterprise Requirements in Public Contracts (Research Results Digest 146)†††

Topic No. 4-02 —Liability of Highway Agencies for Failure to Provide or Maintain Highway Barriers, Guardrails and Similar Devices (Incorporated into Topic 4-07)

Topic No. 4-03 —Liability of Public Agencies Arising Out of Rejection of Low Bids and Misaward of Contracts (In progress; was 3-13)

Topic No. 4-04 —Use of Guarantee or Warranty Clauses in Highway Construction Contracts (Completed; was 3-14)

Topic No. 4-06 —Update of "Payment to Public Utilities for Relocation of Facilities in Highway Right-of-Way" (Completed; was 3-21)†††

Topic No. 4-07 —Update of "Liability of State and Local Governments for Negligence Arising Out of the Installation and Maintenance of Warning Signs, Traffic Lights, and Pavement Markings" (Completed; was 3-22)†††

Topic No. 4-08 —Legal Techniques for Reserving Right-of-Way for Future Projects including Corridor Protection (Research Results Digest 165)†††

Topic No. 4-09 —Flooding and Water Problems Involving Highways (Completed)†††

Topic No. 4-10 —Land Use Laws and Effect on Highway Construction, Including Police Power Taking by Zoning, Freezing, Dedication, etc. (Completed)†††

Topic No. 4-11 —Beautification (Update of Study No. 54 "Outdoor Advertising Control Under the Highway Beautification Act of 1965") (Completed)†††

Topic No. 4-12 —Legal Implications of Penalty and Bonus Provisions For Quality Control and the Use of Incentive–Disincentive Clauses in Construction Contracts (Completed)†††

Topic No. 4-13 —The Use of Alternative Design Specifications and Value Engineering Clauses in Highway Contracts (Pending)

Topic No. 4-14 —Liability to Abutting Property Owner for Loss or Impairment of Access Due to Conversion of Conventional Road Into Limited Access Highway (Research Results Digest 164)†††

Topic No. 4-15 —Update of Five Papers in Contract Law (In Progress; was 3-20) (1) Licensing and Qualifications of Bidders (Research Results Digest 157)†††; (2) Competitive Bidding and Award of Highway Construction Contracts (Research Results Digest 163)†††; (3) Indemnification and Suretyship In Highway Construction Contracts (Completed)†††; (4) Labor Standards in Federal-Aid Construction Contracts (In progress); (5) Control of Conflicts of Interest in Highway Administration (Pending)

Topic No. 4-17 —Acquisition of Uneconomic Remnants Under 23 U.S.C. 109f (Research Results Digest 160)†††

Topic No. 4-18 —Liability for Delay in Completion of Highway Construction Contracts (Completed)†††

Topic No. 4-19 —Wetlands and Floodplain Protection and the Federal-Aid Highway Program (In progress)

Topic No. 4-20 —What Constitutes the Administrative Record in Highway Cases (In progress)

Topic No. 4-21 —Effect of Clean Air Act Requirements on Regional Transportation Planning (Pending)

Topic No. 4-22 —Suspension and Debarment of Highway Construction Contractors (Pending)
Topic No. 4-23 —Public/Private Partnerships for Financing Highway Improvements (Completed) (Research Results Digest 161)†††
Topic No. 4-24 —Update of Chapter in SSHL on "Legal Aspects of Historic Preservation in Highway Transportation Programs (Pending)
Topic No. 4-25 —Impact of Civil Rights Act on Departments, Programs and Officials (In progress)
Topic No. 4-26 —Legal Aspects of Hazardous Waste Containments in Highway Programs (Pending)
Topic No. 5-01 —Impact of Discretionary Exemption of Tort Liability (In Progress)
Topic No. 5-02 —Condemnation Blight and Project Enhancement (Pending)
Topic No. 5-03 —Application of National Environmental Policy Act to Highway Planning and Highway Programs (Pending)
Topic No. 5-04 —Public Duty Defense to Tort Liability (Pending)
Topic No. 5-05 —Legal Obligation of States to Permit Highway Occupancy of New Technologies (e.g. Fibre Optics and CATV) (Pending)
Topic No. 5-06 —State Highway Liability for and Ability to Recover Attorney Fees and Costs (Pending)
Topic No. 5-07 —Obligation of State Highway Departments in Coastal Zones (Pending)
Topic No. 5-08 —Update Paper in *SSHL* on "Liability of the State for Highway Traffic Noise" (Pending)
Topic No. 5-09 —Racketeer Influenced and Corrupt Organizations Act—RICO Cases (Civil) in the Highway Program (Pending)
Topic No. 5-10 —The Use, Implementation, and Enforcement of Liquidated Damage Provisions in Highway Construction Contracts (Pending)
Topic No. 5-11 —Supplement to "Legal Implications of Highway Departments Failure to Comply with Design, Safety, or Maintenance Guidelines" (Pending)
Topic No. 5-12 —Supplement to "Liability of the State for Injury Producing Defects in Highway Surface" (Pending)
Topic No. 5-13 —Supplement to "Liability of State Highway Departments for Defects in Design, Construction, and Maintenance of Bridges" (Pending)
Topic No. 5-14 —Supplement to "Liability of State and Local Governments for Snow and Ice Control" (Pending)
Topic No. 5-15 —Supplement to "Liability for Wet-Weather Skidding Accidents and Legal Implications of Regulations Directed to Reducing Such Accidents on Highways" (Pending)
Topic No. 5-16 —Supplement to "Valuation Changes Resulting from Influence of Public Improvements" (Pending)
Topic No. 5-17 —Supplement to "Planning and Precondemnation Activities as Constituting a Taking Under Inverse Law" (Pending)
Topic No. 5-18 —Supplement to "Minority and Disadvantaged Business Enterprise Requirements in Public Contracting" (Pending)

Studies completed under this project have been published as NCHRP Research Results Digests (see Table 7). The most recent of which have also been included in the text, *Selected Studies in Highway Law.* Volumes 1 and 2, dealing primarily with the law of eminent domain, were published in 1976, and Volume 3, dealing with contracts, torts, environmental and other areas of highway law, was published in early 1978. All three volumes have been distributed on a limited basis to selected state and federal offices. Information on obtaining copies of this text may be found in the newly created NCHRP Legal Research Digest 1 (see Table 8) or by contacting the Transportation Research Board Publications Office.

The first addendum to Selected Studies in Highway Law, consisting of five new papers and supplements to eight existing papers, was issued during 1979. A second addendum with two new papers and 15 supplements was distributed early in 1981. A third addendum consisting of eight new papers, seven supplements, and an expandable binder for Volume 4 was distributed during the first half of 1983.

A fourth addendum, consisting of 14 new papers, 8 supplements, and an index was published in June 1988. The four volumes now total about 3,000 pages comprising 67 papers, 38 of which have been supplemented over the years. All four volumes have been distributed on a limited basis to selected state and federal offices.

Through December 31, 1988, research continues on topics listed as being "In Progress," and preparations are underway to proceed with studies on additional topics. Future work in this continuing project will include research on new topics of current interest in the legal field. Updating and supplementing the text book will continue

*Published in *Selected Studies in Highway Law,* Vols. 1 and 2.
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†††Published in fourth addendum to *SSHL.*

to include the preparation of a new Volume 5 in *Selected Studies in Highway Law.* The primary purpose of Volume 5 will be to address new areas, not previously covered.

Project 20-7 FY '69 and continuing

Research for AASHTO Standing Committee on Highways

Research Agency:		
Principal Invest.:	Open	
Effective Date:	December 2, 1968	
Completion Date:	Continuing	
Funds:	$100,000 annually,	FY '69-'85
	$56,000	FY '86
	$150,000 annually,	FY '87-'88
	$125,000	FY '89

The American Association of State Highway and Transportation Officials (AASHTO) Standing Committee on Highways is called on continually to rule on engineering and operations policies as a guide for State highway and transportation departments to follow. The Committee desires to obtain guidance on a reasonably prompt schedule through a continuing research program geared to the needs and wishes of the Committee in the development of guides, standards, policies, and other AASHTO activities. In earlier years, objectives of the Committee were attained through the establishment of a continuing research capability at the Texas Transportation Institute (TTI) of Texas A&M University. In June 1973, the Committee stipulated that accomplishment of task research could be through any agency deemed by the NCHRP to possess the necessary expertise, provided the research could be initiated quickly.

The project includes a series of tasks specified by the Committee to obtain data required by the Committee to fulfill its responsibilities.

The status of each of the tasks undertaken in this project is as follows:

Task 1, "Development of a Cost-Effectiveness Approach to the Programming of Roadside Safety Improvements" (TTI). Research has been completed, and the task report published as NCHRP Report 148, "Roadside Safety Improvement Programs on Freeways—A Cost-Effectiveness Priority Approach." The report describes a hazard model that can be used to evaluate the effectiveness of a roadside safety improvement program.

Task 2, "The Relation of Side Slope Design to Highway Safety" (TTI). Research has been completed, and the task report published as NCHRP Report 158, "Selection of Safe Roadside Cross Sections." Tentative criteria for the selection of safe side slopes and safe slope and ditch combinations are proposed.

Task 3, "Development of an Effective Earth-Berm Vehicle Deflector" (TTI). The final report has been completed, and the results summarized in NCHRP Research Results Digest 77. The study was exploratory in nature, and further research is recommended.

Task 4, "Lateral Accelerations and Lateral Tire-Pavement Forces in a Vehicle Traversing Curves Relative to Available Pavement Skid-Resistance Measures (TTI). The final report has been completed and accepted by the AASHTO Standing Committee. NCHRP Research Results Digest 55 summarizes the results of the study. The study found that, although more needs to be known about the limitations of the existing AASHTO curve design policy, the present policy will in most instances provide safe, conservative designs for highway curves.

Task 5, "Effect of Curb Geometry and Location" (TTI). Research has been completed, and the task report published as NCHRP Report 150, "Effect of Curb Geometry and Location on Vehicle Behavior." The study provides recommendations regarding curb configuration and placement.

Task 6, "Development of Impact Attenuators Utilizing Waste Materials" (TTI). Various used-tire configurations and a fiberized aluminum product were examined in the laboratory and analytically, and by full-scale field testing in some instances, to determine feasibility and to develop design information regarding the use of these materials for vehicle impact attenuation. Research has been completed, and the task report published as NCHRP Report 157, "Crash Cushions of Waste Materials." Designs are proposed for attenuators using two different configurations of scrap tires.

Task 7, "Safety at Narrow Bridge Sites" (TTI). Research has been completed. A bridge hazard index is proposed for assessing the degree of hazard of narrow bridges. Guidelines are offered for remedial treatments at narrow bridges. The essential findings have been published in NCHRP Research Results Digest 98. The revised agency report has been published as NCHRP Report 203, "Safety at Narrow Bridge Sites."

Task 8, "Energy and Transportation Systems" (California Department of Transportation). This study was designed to establish "energy factors" for the various elements of energy use in constructing, maintaining, and operating transportation systems; to develop procedures for evaluating the energy use by such systems by applying the established energy factors; and to develop a rational method for reporting the results. Research has been completed, and copies of the agency report have been distributed to the Program sponsors. Microfiche of the report may be purchased (see final page of this section for ordering information).

Task 9, "Review of Highway Management Studies Co-Sponsored by AASHTO and HUFSAM" (Management and Transportation Associates, Inc.) This was an evaluation of the Highway and Transportation Management Institute and the National Highway and Transportation Management Conference that have been offered annually over the past several years to improve the management

skills of highway department personnel. The study findings indicate that there is a continuing need within highway and transportation agencies for management training, but it is becoming increasingly difficult to justify the travel, time, and expenses required by the courses currently being scheduled. As an alternative, the report recommends development of a two-week course to be presented once each year in each of the four AASHTO regions. Research has been completed, and copies of the agency report distributed to the Program sponsors.

Task 10, "Review of Vehicle Weight/Horsepower Ratio as Related to Passing-Lane Design Criteria" (The Pennsylvania State University). The current AASHTO publications on highway geometrics use a loaded truck with weight/horsepower ratio of 400:1 as the design vehicle in determining the need for passing lanes on hills. The objective of this task was to evaluate the currently used design vehicle. Research has been completed. A recommendation is made that a truck with a weight/horsepower ratio of 300:1 be used where truck traffic is the controlling factor. An automobile pulling a travel trailer with a combined weight/horsepower ratio of 60:1 is recommended as the design vehicle on sections of highway not subjected to truck traffic but heavily used by recreation vehicles. Research has been completed, and copies of the agency report have been distributed to the Program sponsors.

Task 11, "Longitudinal Occupancy of Freeways by Utilities" (Byrd, Tallamy, MacDonald and Lewis). The objective of this task was to determine the over-all feasibility and practicality of joint occupancy of freeway ROW by trunk-line and transmission-type utility facilities. Research has been completed. Interviews have been conducted with highway and utility personnel. Existing joint occupancy sites have been studied for identification of potential problems. Possible benefits to the general public have been assessed. Copies of the agency report have been distributed to the Program sponsors.

Task 12, "Guidelines for Citizen Participation in Transportation Planning" (Kathleen Stein Hudson). The AASHTO Standing Committee on Planning has compiled material for preparation of guidelines for citizen participation in transportation planning. The objective of this task was to prepare draft guidelines from the materials that have been compiled. The project report has been published by AASHTO as: "Guidelines on Citizen Participation in Transportation Planning."

Task 13, "Guidelines for Safety Criteria for Low-Volume Roads" (John C. Glennon). The objective of this task was to evaluate and suggest modifications for existing safety criteria with regard to their applicability and relevancy for roads carrying less than 400 vehicles per day at normal and reduced speeds. Research has been completed, and the report has been published as NCHRP Report 214, "Design and Traffic Control Guidelines for Low-Volume Rural Roads."

Task 14, "A Policy on Geometric Design of Highways and Streets" (John F. Holman & Co., Inc.). The objective of this task was the preparation of an edited version of a new AASHTO publication being compiled by the Task Force on Geometric Design of the AASHTO Subcommittee on Design. The new publication will replace the current AASHTO publications, *A Policy on Geometric Design of Rural Highways—1965* (Blue Book) and *A Policy on Design of Urban Highways and Arterial Streets—1973* (Red Book). Research has been completed, and the new book, *A Policy on Geometric Design of Highways and Streets,* has been published by AASHTO.

Task 15, "Development of a Simplified Pavement Management System" (ARE, Inc.). The objectives of this task are to (1) prepare a synthesis report on pavement management system (PMS) research and development and (2) develop a simplified PMS suitable for assisting highway agencies in rehabilitation programming of existing pavements. The synthesis report has been completed and the report published as NCHRP Report 215, "Pavement Management System Development."

A simplified PMS has been developed as accomplishment of item 2. Research has been completed and copies of the agency report have been distributed to the program sponsors.

Task 16, "Regulation of Movement of Hazardous Cargoes" (D. M. Baldwin). Mr. Baldwin was retained as a consultant to prepare a report on the current state of the art on the task subject and to suggest specific objectives for further study. Research has been completed, and copies of the consultant's report have been distributed to the Program Sponsors.

Task 17, "Evaluating AASHO Road Test Satellite and Environmental Studies" (Texas A&M University). The objectives of this task were to (1) compile available data and information from satellite road tests and from sections of the AASHO Road Test subsequent to the completion of the road test and (2) determine the feasibility of using the information to propose revisions to the "AASHO Interim Guide for Design of Pavement Structures, 1972." Research has been completed on the initial phase and a report submitted indicating little feasibility of using satellite road test data to revise the pavement design guides developed from the AASHO Road Test data. However, it was found that overlay design procedures could be developed from satellite road test data on a climatic region basis. Additional funding was provided for a second phase of the study to develop such overlay design procedures for at least two climatic regions. Research has been completed, and copies of the agency report have been distributed to Program Sponsors.

Task 18, "Standard Specifications for Highway Bridges" (Howard Needles Tammen & Bergendoff). The objective of this task is the preparation of a completely reorganized and edited version of Standard Specifications for Highway Bridges and Structures for publication by

AASHTO. Research has been completed, and the reorganized and edited version, Standard Specifications for Highway Bridges, has been published by AASHTO.

Task 19, "The Engineering Aspects of Highway Traffic Safety in an Age of Limited Resources" (TRB). A conference on the above subject was jointly sponsored by AASHTO, FHWA, and others and was held in St. Louis, Mo., November 2-5, 1981. The AASHTO funding support in the amount of $25,000 was allocated from Project 20-7. The TRB was responsible for the planning and conduct of the conference. Proceedings of the conference have been distributed to the conference sponsors.

Task 20, "Vehicle Acceleration and Deceleration Characteristics" (University of Michigan). The objective of this task is to evaluate the influence of changes in vehicle size, weight, power, and brake systems on acceleration and deceleration capability. The results will be used during future revisions of highway geometric design. The task was being combined with Project 15-8, "Parameters Affecting Stopping Sight Distance and Vehicle Acceleration/Deceleration Characteristics." Research has been completed, and the findings included in NCHRP Report 270, "Parameters Affecting Stopping Sight Distance."

Task 21, "Need for Pavement Markings on Low-Volume Roads" (John C. Glennon). The objective of this task was to verify or modify the suggested warrants for centerline and no-passing markings of low-volume roads as described in NCHRP Report 214. Research has been completed, and copies of the agency report have been distributed to Program Sponsors.

Task 22, "Encasement of Pipelines Through Highway and Railroad Roadbeds" (Byrd, Tallamy, MacDonald and Lewis). The objective of this task is to develop procedures for determining the need for pipeline encasement based on (1) a review of literature on underground pipeline design and performance, (2) a limited stress analysis of underground pipelines, and (3) an evaluation of field experience by highway, railroad, and utility agencies of encased and unencased pipelines under roadbeds. Research has been completed, and copies of the agency report have been distributed to Program sponsors.

Task 23, "Contracting Policies and Payment Procedures" (Bergstralh-Shaw-Newman, Inc.). The objectives of this task were to evaluate current contracting practices and methods of determining pay-quantities for highway construction work in the United States and to suggest any appropriate improvements. Research has been completed, and copies of the agency report have been distributed to program sponsors.

Task 24, "AASHTO Pavement Design Guide" (Dr. Frank McCullough—Mr. Fred Finn). NCHRP Project 1-24 is funded from the FY '84 program in the amount of $500,000 with the objective being the preparation of a revised and expanded pavement design guide for consideration by AASHTO to replace the current publication, *AASHTO Interim Guide for Design of Pavement Structures—1972 (Chapter III Revised 1981).* In the interest of expediting this work, the entire project was conducted as Task 24 of Project 20-7. Research has been completed, copies of the proposed new *AASHTO Guide for Design of Pavement Structures* have been distributed to program sponsors, and the document has been published by AASHTO.

Task 25, "STRS Support Task" (Various consultants). The purpose of this task was to respond to the desires of the Executive Committee of AASHTO to obtain preliminary study designs for the six research areas identified in the Strategic Transportation Research Study (STRS) report. Nine consultants were retained by NCHRP to assist in preparation of the study designs. Work has been completed and the report distributed to the STRS Task Force and program sponsors.

Task 26, "Research and Development Needs in Construction Engineering Management" (Bergstralh-Shaw-Newman, Inc.). The objective of this task was to update the research and development program for highway construction engineering recommended in the *FHWA Report No. FHWA-HO-79-1,* assess the accomplishments since publication of the report, and evaluate the need for additional recommendations. Research has been completed, and copies of the agency report have been distributed to program sponsors.

Task 27, "Relationships Between Vehicle Configurations and Highway Design" (Transportation Research Board). The overall objective of research on this problem is to develop recommendations for coordination of heavy vehicle configurations and pavement, bridge, and highway geometric design to produce the most practical and efficient transportation of goods and services over the highway system. The objective of the initial phase of the research (NCHRP Project 20-7/27) was intended to (1) collect, review, and evaluate available information pertaining to the problem, (2) conduct a pilot analytical study involving the more significant factors and sample data, and (3) assess the feasibility and practicality of further development of an optimum solution. Research has been completed with the finding that it appears feasible and practical to produce both short-term improvements in interactions of heavy vehicles with the existing highway system and long-term optimization of heavy vehicle-highway design interaction. Recommended research will be conducted under NCHRP Project 2-16. The agency report has been distributed to program sponsors.

Task 28, "AASHTO Guide for Design of Pavement Structures-Training Program" (Dr. Frank McCullough and Mr. Fred Finn). The objective of this task was to develop and conduct a training program for users of the *AASHTO Guide for Design of Pavement Structures* to encourage early implementation of the new publication. Research has been completed including the development of a computer program for the "AASHTO Guide for Design of Pavement Structures." The computer program

is available from AASHTO, 444 North Capitol Street, N.W., Suite 225, Washington, D.C. 20001.

Task 29, "Pavement Roughness and Rideability—Field Evaluation" (JMJ Research). Research on Project 1-23(2) was accelerated by initial contracting with available funds from Project 20-7. See Project 1-23(2) for project status.

Task 30, "Manual on Subsurface Investigations" (Adrian Pelzner). The objectives of this task are to prepare the draft document developed under Project 24-1 for publication by AASHTO and to prepare a draft AASHTO standard for conduct of subsurface investigations. Research has been completed and the revised document delivered to AASHTO for publication consideration.

Task 31, "Development of Comprehensive Bridge Specifications and Commentary" (Modjeski and Masters). The objectives of this research are to develop a comprehensive outline for an updated AASHTO bridge specifications that will provide a framework to ensure that future modifications and additions be done in a coherent manner and to determine the feasibility of introducing the limit-states philosophy into the AASHTO bridge specifications. Research has been completed and the agency report was distributed to the program sponsors. NCHRP Project 12-33 was initiated based on the recommendations in the report.

Task 32, "Design and Construction Specifications for Segmental Concrete Bridges" (Post-Tensioning Institute). The objective of this research is to develop design and construction specifications for segmental concrete bridges. Research has been completed and the agency report was distributed to the program sponsors. The AASHTO Highway Subcommittee on Bridges and Structures adopted the specification provisions as a guide specification during 1988. AASHTO will publish the document in 1989.

Task 33, "Study of FHWA Research Program" (L. G. Byrd). It was suggested that operation of the FHWA Turner-Fairbank Highway Research Center be carried out by contract with a non-federal agency. The AASHTO Standing Committee on Highways (SCOH) recommended that the Select Committee on Research (SCOR) conduct a study of this privatization suggestion to determine its impact on the member departments of AASHTO and the nation's highway research program. The final report, "Assessment of National Programs of Highway Research," was approved and distributed to program sponsors.

Task 34, "AASHTO/AWS Bridge Welding Code Commentary and Draft Fracture Control Plan" (Warren G. Alexander). In 1988, AASHTO and AWS jointly adopted and published a new welding code for highway bridges. The objectives are to develop a commentary that will explain the background and proper use of the provisions of the new code, and to incorporate the welding related provisions of the 1978 AASHTO *Guide Specifications for Nonredundant Fracture Critical Members* into the AASHTO/AWS Bridge Welding Code. Research was initiated in late 1988. A draft of the commentary is expected to be completed by the end of April 1989.

Task 35, "Review of Traffic Signal Intensity Standards." This task was requested by the AASHTO Subcommittee on Traffic Engineering. The objectives are to review existing traffic signal intensity standards and to prepare a report which can serve as a basis for the Institute of Transportation Engineers (ITE) to update and/or revise their standards on *Vehicle Control Signal Heads* to better meet in-service performance requirements. The *Manual on Uniform Traffic Control Devices* (MUTCD) incorporates the intensity, light distribution, and color standards by reference to this ITE standard. This 12 month task is in the developmental stage and is expected to start in January 1989.

Task 36, "Critical Assessment of Tire Pressure Research." This task was requested by AASHTO Joint Task Force on Pavements. The objectives are to develop a synopsis and critical evaluation of completed and ongoing research efforts pertaining to high pressure truck tires and to identify future research required to fill information gaps in this area. This 8 month task is in the developmental stage and is expected to start in December 1988 or January 1989.

Task 37, "Development of An Asphalt Paving Handbook" (TRB Division B). This task was requested by AASHTO Subcommittee on Construction and the Subcommittee on Materials. The objective is to develop an asphalt paving manual geared to the needs of public agency field personnel and contractors involved in highway and airport construction. This effort is being jointly funded by the National Asphalt Pavement Association (NAPA), AASHTO, FHWA, US Army Corps of Engineers, and the Federal Aviation Administration (FAA). The completion date for this project is October 15, 1989.

Task 38, "AASHTO Guidelines for Pavement Management Systems." This task was requested by AASHTO Task Force on Pavement Management. The objective is to completely revise and expand the AASHTO *Guidelines on Pavement Management* (1985), incorporating the latest theory and practices. The new guide will give effective guidance to states that are in the early phase of Pavement Management Systems (PMS) development, guide states with existing systems toward state-of-the-art practices, identify and encourage areas of uniformity of certain practices and data, and assist states in providing guidance to local transportation agencies. This 9 month project is in the developmental stage and is expected to start in December 1988 or January 1989.

Task 39, "Revision of AASHTO Pavement Overlay Design Procedures." This task was requested by AASHTO Joint Task Force on Pavements. The objective is to revise Chapter 5 of Part III of the AASHTO *Guide for Design of Pavement Structures* so that pavement overlay design procedures will yield valid and acceptable designs. Chapter 5 addresses the subject of pavement design procedures for the rehabilitation of existing pavements with overlays. This 12 month project is in the develop-

mental stage and is expected to start in December 1988 or January 1989.

Task 40, "AASHTO Contribution to Support of the Highway Research Coordinating Council" (Mr. Lloyd G. Byrd). The objectives of this study are to assist the Highway Research Coordinating Council (HRCC) in analyzing the research activities of the major institutions involved in national highway research programs in the United States, to develop ways to display information for comparison of programs, to identify strategies for establishing and operating an Industry-HRCC, and to recommend improvements to the HRCC. This effort is being jointly funded by AASHTO, FHWA, and the US Army Corps of Engineers. The completion date for this project is August 31, 1989.

Project 20-8 FY '71

Interactive Graphic Systems for Highway Design

Research Agency: Control Data Corporation
Principal Invest.: C. W. Beilfuss
Effective Date: September 1, 1970
Completion Date: July 31, 1971
Funds: $49,672

This project was a feasibility study to determine the costs and benefits associated with the development of an Interactive Graphics Road Design System (IGRDS). The agency determined that IGRDS is feasible and produced cost and benefit figures to support that finding. The final report was not published in the NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 20-9 FY '73

Socioeconomic Consequences of Right-of-Way Acquisition Induced Resident Dislocation

Research Agency: RMC Research Corporation
Principal Invest.: Jon E. Burkhardt
Effective Date: August 1, 1972
Completion Date: December 17, 1976
Funds: $202,579

The objectives of the research were to (1) develop techniques to predict the dislocation consequences of alternate route and design proposals and (2) identify related legislative or regulatory constraints and recommend modifications to assume equity to the displacees.

Analyses of data collected before and after moving at six sites geographically distributed throughout the United States showed that the consequences of residential dislocation do not vary significantly among socioeconomic and demographic groups except for the elderly. Relocation process characteristics, rather than socioeconomic characteristics, were shown to be related to measures of happiness and satisfaction. The research was successful in identifying ways in which the highway planning process could be improved by (1) increasing the planners ability to forecast the dislocation consequences of particular location and design decisions and (2) suggesting techniques for more adequately compensating persons adversely affected by right-of-way acquisition. Very few recommendations to modify existing legislation or regulations are made because modifications in most instances were found to be unnecessary. Rather, changes in the way regulations are administered were found to be more appropriate and such changes are recommended under three categories: (1) changes in compensation, (2) changes in relocation practice and (3) changes in the highway planning process.

The agency's final draft report is a complete description of theory related to the subject, the research plan, the data obtained, data anlyses, findings, and recommendations. Microfiche of the report may be purchased (see final page of this section for ordering information). A condensation of the research results may be found in the paper, "Residential Dislocation: Costs and Consequences," published by the Transportation Research Board in Transportation Research Record 716. For this paper, the author, Mr. Jon E. Burkhardt, received the 1980 Pyke Johnson Award from the Transportation Research Board.

The data are available in tape form to other investigators who may wish to pursue further data analysis. Inquiries should be made in writing to the NCHRP. For a copy of the tape, a blank 9-track 1600 BPI tape should be provided by the inquirer. Copies of the coding book and data printouts can be made available for the cost of reproduction and handling.

Project 20-10 FY '73

The Benefits of Separating Pedestrians and Vehicles

Research Agency: Stanford Reserch Institute
Principal Invest.: Ronald L. Braun
Marc Roddin
Effective Date: August 26, 1974
Completion Date: April 30, 1976
Funds: $100,000

The general objective of this research was to identify and quantify the benefits related to separation of pedestrians and vehicles and develop techniques for relating these benefits to the evaluation of proposals for separation.

Four categories of direct and indirect benefits of separating pedestrians from roadway traffic were identified. These were (1) transportation; (2) safety, health, environment; (3) residential/business; and (4) environmental/institutional. The beneficiaries of these benefits were defined. A methodology was developed to weight the benefits identified according to values held by decision-makers and/or the community at large. The methodology was

tested at field sites in Seattle, Wash. (a highway overpass); Brooklyn, N. Y. (a mall); and Ottawa, Ont. (a mall).

Results of the research were published as: NCHRP Report 189: "Quantifying the Benefits of Separating Pedestrians and Vehicles."

Research was continued under Project 20-10(2).

Project 20-10(2) FY '78

The Benefits of Separating Pedestrians and Vehicles

Research Agency: SRI International
Principal Invest.: Ronald L. Braun, Marc F. Roddin
Effective Date: September 1, 1978
Completion Date: July 31, 1981
Funds: $100,000

A comprehensive method for evaluating the transportation, safety/environment/health, and residential/business benefits of proposals for facilities separating pedestrians and vehicles was developed and demonstrated during the course of NCHRP Project 20-10, and described in NCHRP Report 189. The objective of this continuation research was to update, refine, and extend the usefulness of the previously developed techniques for quantifying all of the significant direct and indirect benefits associated with the separation of pedestrians and vehicles.

This objective was met by the simplification of the method and the preparation of audiovisual materials to supplement a technical user guide. The method was simplified by reducing the number of variables from 36 to 27, without loss of precision or detail. Scoring for some of the variables was simplified also. The technical user guide was revised and simplified.

Audiovisual materials consisted of a slide show and a videotape. The slide show, with accompanying music, narration, and sound effects, was prepared for use by those interested in evaluating pedestrian facilities (such as elected officials, merchants, and the general public) but who would not be involved with details of the method. For those who would personally use the method, a videotape has been prepared that illustrates an application to problems encountered by suburban railroad commuters walking to and from the train station.

During this project, the feasibility of applying the evaluation method for use in pedestrian traffic warrants was evaluated. The purpose was to quantify pedestrian conditions to the extent that requirements for specific separate pedestrian facilities could be established. Seven existing pedestrian warrant systems were studied and classified. It was found that a subset of the evaluation method, using only ten variables, can be used for warrant purposes. Scores for these variables are computed, multiplied by an appropriate set of weights, and combined to obtain a score ranging between -1000 and $+1000$. For scores of $+300$ or lower, pedestrian separation from vehicles may be warranted, depending on pedestrian traffic volume. For weighted scores of -500 or less, only five pedestrians per hour are necessary to warrant separation. Potential users should note with caution that this proposed warrant has not been field tested.

The project report has been published as: NCHRP Report 240: "A Manual to Determine Benefits of Separating Pedestrians and Vehicles." The slide show and videotape are available on a loan basis (see final page of this section for ordering information). Borrowers may copy the audiovisual materials to retain sets.

Project 20-11 FY '73

Toward Environmental Benefit/Cost Analysis—Measurement Methodology

Research Agency: Polytechnic Institute of New York
Principal Invest.: Dr. Edmund J. Cantilli
Effective Date: September 1, 1972
Completion Date: May 31, 1974
Funds: $100,000

The basic objective of this project was to develop methods that are readily understood by the public for the qualitative evaluation of environmental values. Moreover, the methods should be practical and immediately implementable by responsible agencies.

The specific research objectives were to:

1. Identify and categorize environmental elements that are affected by the provision and operation of transportation facilities. These elements may be positive and/or negative, local and/or regional, long- and/or short-term.
2. Determine the significant elements and the relationships among these elements that may be altered by transportation facilities.
3. Develop quantitative scales for measuring quality levels of those environmental elements or categories, as appropriate, that have been identified as significant in Item 2.
4. Develop a method to identify threshold level(s) of adverse and beneficial effects on the quality scales defined in Item 3 for selected environmental elements and/or categories as appropriate.

The scope and direction of this project were modified to restrict the definition of "environment" to ecological and physical considerations. In addition, an energy concept was pursued by the research team, and attempts were made to develop it for use. This concept is a numerical means of calculating the energy lost by an ecosystem when a facility destroys part or all of given system. The energy approach also permits comparisons to be made on various levels—such as nationwide, regional, statewide, and local—between energy lost, energy used in building the facility, and energy to be used in operating the facility. The procedure allows for a comparison of the ecological impacts for transportation alternatives. The concept was

applied to the Oyster Bay Bridge (New York) and U.S. Route 29 (Kansas).

The research was completed. The final report was not published, but the agency's unedited final draft may be obtained on a loan basis upon written request to the NCHRP. Microfiche of the report may be purchased (see final page of this section for ordering information).

Project 20-11A FY '74

Toward Environmental Benefit/Cost Analysis—Measurement Methodology

Research Agency: Cornell University
Principal Invest.: Dr. Arnim H. Meyburg
Mitchell J. Lavine
Effective Date: September 1, 1975
Completion Date: November 30, 1976
Funds: $27,212

The general objective of this research was to identify and describe programs of research being undertaken or completed that use the energy-flow concept to measure impacts of man-made changes in ecosystems. Specifically, the following tasks were completed:

1. The identification and description of relevant research programs, including a literature search, a description of each of the research programs, and a description of supportive research information.
2. Evaluation of potential applications to transportation facilities planning.
3. The formulation of recommendations identifying particularly promising programs or findings and recommendations necessary for further development and implementation of an energy-flow analysis methodology for transportation-facilities planning.

Research on this project has been completed, resulting in initiation of Projects 20-11B and 20-11C. Microfiche of the agency's draft final report, "Toward Environmental Benefit/Cost Analysis: Measurement Methodology," is available (see final page of this section for ordering information).

Project 20-11B FY '74

Toward Environmental Benefit/Cost Analysis—Energy-Flow Analysis (Manual)

Research Agency: Cornell University
Principal Invest.: Dr. Arnim H. Meyburg
Mitchell J. Lavine
Effective Date: January 24, 1977
Completion Date: May 4, 1979
Funds: $140,450

The general objective of this research was to develop a user-oriented manual to assist any state or local transportation agency in conducting environmental analyses using the energy-flow concept. This work builds on the findings of NCHRP Project 20-11A and other related research efforts. The manual is designed for direct use in project development and system analysis for the movement of people and goods and emphasizes simplified techniques not requiring computer application. It includes:

1. A step-by-step description of the procedure for energy-flow analyses.
2. A checklist and brief discussion of specific parameters (e.g., productivity rates) for which data are required.
3. Methods for obtaining needed data, including a list of sources for data that do not require direct field collection.
4. Case studies that demonstrate the step-by-step methodology as it applies to transportation problems.
5. An explanation of the relationship between the step-by-step procedure contained in the manual and accepted theories of energy flow.
6. A discussion of the application and the limitations of the methodology to the planning, construction, operation, maintenance, and regulation of transportation facilities and services.

Research has been completed. The agency's draft final report will not be published but is available on a loan basis upon written request from the NCHRP. Microfiche of the report may be purchased (see final page of this section for ordering information). A summary of the research findings is provided in NCHRP Research Results Digest 114.

Project 20-11C FY '74

Toward Environmental Benefit/Cost Methodology—Energy-Flow Analysis (Study Design)

Research Agency: The Cannon Group
Principal Invest.: W. E. Kirksey
J. C. Kraft
Effective Date: April 1, 1977
Completion Date: March 31, 1978
Funds: $14,786

A start has been made in developing a usable methodology for assessing environmental impacts of transportation facilities using the energy-flow concept, including an evaluation of theoretical energy-flow concepts. It is now necessary to explore in some considerable detail the application of such concepts to transportation planning. The required exploration involves practical application in (a) measuring and interpreting transportation-related impacts and (b) assessing sensitivity to the variety of situations encountered in the planning of transportation facilities and services.

In view of the complex nature of these research requirements and the apparent broad application of energy-flow analysis to transportation systems and project planning, further specific research on the application of the

methodology required careful preparation of study designs.

The objective of this project was to develop study designs for a program of research that will provide evaluations of the application of the energy-flow methodology to the planning of transportation facilities and services. Particular attention to the social-cultural and esthetic considerations that have not been adequately accounted for in preceding studies is provided in the study designs.

The final report will not be published; copies of the study designs are available on a loan basis (see final page of this section for ordering information).

Project 20-12 FY '74

Effects of Air Pollution Regulations on Highway Construction and Maintenance

Research Agency:	Howard, Needles, Tammen and Bergendoff
Principal Invest.:	Orrin Riley
Effective Date:	April 1, 1974
Completion Date:	July 31, 1975
Funds:	$80,446

This research evaluated the effect of air pollution regulations for fugitive particulates and hydrocarbons on the highway construction and maintenance industry. Research was limited to the on-site construction process rather than off-site materials processing.

Research has been completed, and the report has been published as: NCHRP Report 191, "Effect of Air Pollution Regulations on Highway Construction and Maintenance."

Project 20-13 FY '75

Beneficial Environmental Effects Associated with Freeway Construction

Research Agency:	The Pennsylvania State University
Principal Invest.:	Hays B. Gamble Dr. Thomas B. Davinroy
Effective Date:	September 3, 1974
Completion Date:	August 2, 1975
Funds:	$49,965

It is necessary to discuss both positive and negative environmental aspects of a project during preparation of the environmental impact statement. The positive aspects have not previously been documented to any degree. This study provides an evaluation of environmental improvements attributable to freeways in order to place present and future freeways in proper perspective.

The objective of this project was to determine the long- and short-range positive aspects of freeway construction. These were differentiated, where necessary, for urban and rural freeways. The literature was searched, analyzed, and evaluated. The investigators were concerned with studies such as:

1. Improved emergency ambulance, fire, and police services.
2. Movement of goods and services.
3. Influence on land-use planning.
4. Influence on economic growth.
5. Accessibility to recreational and other activities.
6. Pollution control.
7. Energy utilization.
8. Effects on plants and wildlife.

A matrix approach was used to catalogue and classify beneficial environmental effects. Literature reviews and surveys conducted by a multi-disciplinary team were carried out to develop the required information for the matrix.

The project report has been published as: NCHRP Report 193, "Beneficial Effects Associated with Freeway Construction—Environmental, Social, and Economic."

Project 20-14 FY '77

Monitoring Carbon Monoxide Concentrations in Urban Areas

Research Agency:	Technology Service Corporation
Principal Invest.:	William S. Meisel Yuji Horie
Effective Date:	October 1, 1976
Completion Date:	March 31, 1978
Funds:	$99,973

The general objective was to develop a methodology (1) to estimate urban background CO concentrations from incomplete monitoring data sets for three types of areas (a) where urban background monitoring stations already exist, (b) where source-affected monitoring stations exist, and (c) where there are no existing stations; and (2) to determine the precision of the estimates.

The first step in the development of such a methodology was preparation of a high-quality data base for cities representing a wide geographical distribution throughout the U.S. Once the data base was established, the interrelationships among the CO concentrations at the target site, the CO concentrations at the auxiliary stations, and meteorological data were explored. The preliminary relationships determined were then refined to determine methods for extrapolating the CO concentrations at the target site to estimate the two critical annual statistics: the annual second 8-hour maximum and the annual second 1-hour maximum. From the analysis of CO concentrations, it was found that the 8-hour running average violated the air quality standard when the second-highest-reading-of-the-year standard was violated. This finding allowed research to concentrate on the extrapolating of 8-hour running averages.

The main result of this study was the following: As long as it is possible to monitor during a part of the CO season (October to January, possibly February), the two

statistics mentioned can be accurately estimated from one month of sampling. Restriction of monitoring to the CO season represented a change from practice in 1978. The most accurate of the methods tested was the simplest—use the highest 8-hour average observed during the period of monitoring at the highway site as the estimate of the annual second maximum. It must be verified that the monitoring period contained enough meterologically adverse days to make the estimate valid. Such adverse days must be determined using an existing monitoring station nearby which has been operating for at least a year, by a meteorological index, or, less persuasively, by typical rates of occurrence of adverse days for the months encompassed by the monitoring period.

An approach based on using an estimated statistical distribution to estimate the annual statistics from limited measurements was less accurate than the observed-maximum approach.

The degree to which the error in the estimation process creates uncertainty in the estimate was quantified. Means for assessing confidence intervals were recommended.

The project report has been published as: NCHRP Report 200, "Monitoring Carbon Monoxide Concentrations in Urban Areas."

Research was continued as Project 20-14A.

Project 20-14A FY '79

Statistical Analysis of Ozone Data for Transportation/Air Quality Planning

Research Agency:	SRI International Inc.
Principal Invest.:	Frank Ludvig
Effective Date:	September 15, 1979
Completion Date:	December 18, 1981
Funds:	$193,907

Federal and state regulations mandate air quality studies to develop strategies for achieving compliance with ozone standards. These air quality studies must frequently include monitoring programs to determine ozone concentrations and the degree of compliance with the air quality standards. However, use of historical data, wherever possible, is a more efficient and practical means to quantify ozone problems and minimize requirements for special monitoring. The major objective of this study was to develop the methods needed to analyze existing data and obtain as much information as possible from those data. Corollary objectives were to provide information about additional data needs and ways in which those needs can be met with the least additional monitoring, and to develop methods that provide information necessary for developing effective control strategies. No procedures were developed for designing control strategies, which is a major topic where further research will be fruitful.

All the objectives of the study were met. The rather specialized definitions of "design value" and "expected number of exceedances" that were developed by the U.S. Environmental Protection Agency (EPA) for the case of a single monitor have been broadened for application to regionwide conditions. The approach was to use available data to estimate numbers of exceedances and design values for points throughout the region of interest. Initially, points are very widely spaced in order to provide an overall picture of the distribution of these two parameters in the area. The points for which estimates are obtained are then more densely spaced in those areas where the highest design values and the greatest numbers of exceedances have been estimated. In this way it has been possible to estimate the maximum numbers of exceedances and the highest design values occurring in the area and the region in which they are found. These values satisfy the definitions of expected number of exceedances and design value that were derived for a network. Computer programs have been written for processing data to obtain the estimates discussed above. These computer programs and the directions for their use are among the major products of this study.

The deterministic approach to the estimation of regional design values and expected numbers of exceedances described above served as the basis for a probabilistic approach, which used the day-to-day estimates for each grid point of values generated by the deterministic method as a basis for developing conditional probability distributions of ozone concentration. Monte Carlo simulations were used to generate daily estimates of peak-hour ozone concentrations at key locations (those areas where higher design values and greater numbers of exceedances were expected and which had no nearby monitors), based on observed data. This probabilistic method provides a measure of the uncertainty and variability in the deterministic approach. The computer program, and directions for its use to obtain the probabilistic estimates of design value and expected numbers of exceedances are included in the final report.

The methods that have been developed here not only provide estimates of design value and expected numbers of exceedances for the region, but also identify those days when the highest concentrations occurred, which, in turn, allows the analyst to determine the meteorological conditions associated with high ozone concentrations in the region. The air quality data and meteorological information for the high-ozone days can be examined and used to estimate the transported background-ozone concentrations entering the region. The estimation methods are fully described in the report. The determination of the origins of the precursors to the transported ozone through air trajectory analysis is also discussed.

The methods described above were applied to data from four urban regions: Houston, St. Louis, Philadelphia, and Los Angeles. Each of these areas had relatively dense ozone-monitoring networks that had been operated for at least a few months. With the availability of data from these unusually dense monitoring networks, the method

could be applied to determine the sensitivity of the results to the number of stations in the monitoring network. A network of about 10 sites was found to be adequate, if the sites are properly located. There is a tendency to underestimate the expected number of exceedances when the number of monitoring sites is reduced. However, the design-value estimates are generally within the range of estimates for a single site, as derived from different EPA-recommended methods.

Studies have shown that a complete monitoring network need not be operated throughout the year. There is a close relationship between peak-ozone value and maximum temperature; if data are collected for all days when the maximum temperature in the region exceeds about 20° C, then the estimates of design value and expected numbers of exceedances will be accurate. It appears that the most efficient way to collect adequate ozone-monitoring data in an urban region is to operate about five fixed stations: one in the central part of the city and four in different directions a few tens of kilometers outside the highly urbanized region. This fixed network should be supplemented by mobile monitors operated during warm weather to fill-in the area between the central monitor and the peripheral monitors in the downwind direction.

The project report was published as: NCHRP Report 238, "Estimating Exceedances and Design Values From Urban Ozone Monitoring Network Data." The computer tape containing all programs developed during the course of the project may be obtained by request to the NCHRP; a 9-inch diameter (or greater) ASCII 9-track tape (or equivalent) with a density of 800 BPI must be supplied.

Project 20-15 FY '77

Ecological Effects of Highway Fills on Wetlands

Research Agency:	University of Massachusetts
Principal Invest.:	Dr. Paul W. Shuldiner
	Prof. Carl A. Carlozzi
Effective Date:	December 1, 1976
Completion Date:	December 31, 1979
Funds:	$152,085

The over-all objective of this project was to determine the ecological effects of placing highway fills on wetlands and associated flood plains and to develop initial guidelines as a management tool for the decision-making process regarding routes, fills, bridges, and other design alternatives.

Research has been completed. Based on a thorough literature review and the experience of the researchers, a state-of-the-art report on the ecological effects of highway fills on wetlands has been prepared and distributed to state highway and transportation agencies. The final report, including manual on the assessment of ecological effects, is scheduled to be published as: NCHRP Report 218A, "Ecological Effects of Highway Fills on Wetlands—Research Report." NCHRP Report 218B, "Ecological Effects of Highway Fills on Wetlands—User's Manual."

Project 20-16 FY '77

State Laws and Regulations on Truck Size, Weight, and Speed

Research Agency:	R. J. Hansen Associates, Inc.
Principal Invest.:	Ralph D. Johnson
	John C. Laughland
Effective Date:	October 11, 1976
Completion Date:	September 1, 1978
Funds:	$281,975

The objectives of the research were to:

1. Identify and describe the effects of current state size, weight, and speed laws, regulations, and interstate agreements on trucks and the highway systems they use.
2. Investigate the potential benefits and disadvantages of increased uniformity in truck size, weight, and speed limits among states.
3. List and evaluate the available alternatives for eliminating or minimizing the differences in truck size, weight, and speed limits among states.

The research was originally envisioned in two phases. This first phase was intended to synthesize the present system of state regulation of truck size, weight, and speed and to describe its effects. Dependent on the findings of Phase I, a second phase was planned to identify and evaluate alternatives to eliminate or minimize the adverse effects of states' nonuniformities of truck size, weight, and speed limits.

After completion of part of Phase I, the research agency proposed and the project panel approved a plan to merge both phases of the research.

Research has been completed, and the final report has been published as: NCHRP Report 198, "State Laws and Regulations on Truck Size and Weight."

Project 20-17 FY '79

Statewide Freight Demand Forecasting Procedures

Research Agency:	Cambridge Systematics, Inc.
Principal Invest.:	Dr. Paul O. Roberts
	Dr. Brian C. Kullman
Effective Date:	April 1, 1979
Completion Date:	July 31, 1980
Funds:	$73,151

NCHRP Project 8-17, "Freight Data Requirements for Statewide Transportation Systems Planning," identified many current state planning issues related to freight transportation, described existing analysis techniques that address those issues, and catalogued a wide variety of available data sources and collection procedures to sup-

port those techniques. Projects 20-17 and 20-17A extend this preliminary effort to provide operational freight forecasting techniques for use in policy, system, and project planning at the state level.

The objective of Phase I (20-17) was to propose appropriate, cost-effective, policy sensitive, multiregional and state freight demand forecasting techniques that utilize available information and data, while recognizing the issues states face in freight planning.

In Phase I, the uses of freight demand forecasts in statewide planning, the freight forecasting procedures available, the population and economic activity information necessary as input to freight forecasting procedures, the extent to which the existing procedures meet statewide planning needs, and the types of new procedures required to meet these needs were addressed. The most appropriate techniques to provide the needed levels of forecast detail were determined, and preliminary specifications for statewide freight demand forecasting procedures were prepared.

Loan copies of the agency's final report on Phase I are available (see final page of this section for ordering information).

Project 20-17A FY '81

Application of Statewide Freight Demand Forecasting Techniques

Research Agency: Roger Creighton Associates, Inc.
Principal Invest.: Frederick W. Memmott
Effective Date: June 1, 1981
Completion Date: January 31, 1984
Funds: $193,500

The first phase of this research (Project 20-17) identified freight transportation issues that need to be addressed by demand forecasting techniques and proposed a comprehensive research approach to develop a spectrum of such techniques. However, because of limited funding, extensive development work is not possible in this continuation phase.

The objective of Project 20-17A was to demonstrate the applicability of a freight demand forecasting technique for direct use by state agencies. The technique has been designed to develop freight flows by highway, rail, and water for the current year; forecast the likely annual freight volumes and shifts among the modes over the short term (5 years or less); and provide origins and destinations by commodity within a corridor or region at the substate, state, or multi-state level. The technique uses generally available data and methods to facilitate application to specific problems (e.g., deregulation and rate changes).

A user's manual has been developed setting forth how to apply the technique to problems such as the effects of deregulation, energy availability, industry shifts, infrastructure development and maintenance, or financing availability on modal competition. The user's manual provides a step-by-step set of procedures for state agencies to follow in obtaining data and techniques, modifying them if necessary, and applying them to yield appropriate freight forecasts. The user's manual describes (1) the level of analysis to be conducted (i.e., system, network, corridor, etc.); (2) the time frame involved (i.e., the base year and forecast years); (3) the modes included; (4) the commodities to be considered; (5) the specificity of origins and destinations to be developed (e.g., county-to-county); (6) the output of the techniques to be applied; (7) the usefulness of the techniques for various analysis problems; and (8) the role of available demographic and economic forecasts.

Case studies have been completed describing the analysis of commodity flow changes on the New York State Barge Canal System, of grain movements in Montana, and of the technique's applicability in forecasting changes in truck travel. The final report (user's manual) has been completed and published as: NCHRP Report 260, "Application of Statewide Freight Demand Forecasting Techniques."

Project 20-18 FY '79

Evaluation of Highway Air Pollution Dispersion Models

Research Agency: SRI International
Principal Invest.: W. F. Dabberdt
Effective Date: March 15, 1979
Completion Date: February 28, 1982
Funds: $207,509

The general objective of the research was to develop methods for evaluating the performance of highway air pollution dispersion models, assemble and document a data base to be used to assess model performance, and perform a preliminary evaluation of selected models to demonstrate the application of the methodology.

All of the study objectives were met. The evaluation methodology comprises both statistical analysis and sensitivity analysis. A comprehensive data base was assembled, which includes data from (1) at-grade, elevated, and depressed roadways; and (2) five data sets provided by SRI International, Texas A&M University, New York State Department of Environmental Conservation, California Department of Transportation, and General Motors Corporation. The application of the evaluation methodology was demonstrated by performing a preliminary assessment of the performance of six selected models, four Gaussian and two numerical.

The final report has been published as: NCHRP Report 245, "Methodology for Evaluating Highway Air Pollution Dispersion Models." The computer tape containing the model evaluation method and the comprehensive data base may be obtained by request to the NCHRP; a 12

inch diameter and an 8 inch diameter ASCII 9-track tape (or equivalent) with a density of 1600 BPI must be supplied.

Project 20-19 FY '85

Pedestrian Convenience and Safety on Suburban and Rural Highways

Research Agency: JHK & Associates
Principal Invest.: Steven A. Smith
Effective Date: May 1, 1985
Completion Date: December 31, 1986
Funds: $160,000

The general objective of this research was to develop a planning and implementation methodology to assist planners, designers, decision-makers, and the public in providing convenient and safe pedestrian movement for suburban areas having a heavy traffic corridor with adjacent pedestrian magnets, and in rural areas that are in, or likely to be in, transition to suburban areas. The planning methodology should have application to the creation of coherent (usable, understandable, continuous) pedestrian circulation for high activity subareas with the potential for connection to communitywide systems, but not dependent on their presence. The following tasks were performed:

Task 1—Structure the pedestrian problem for suburban and rural areas and conduct a literature review of solutions that provide convenient and safe movement of pedestrians.

Task 2—Define success and failure of existing pedestrian circulation systems. Identify and document examples of success and failure in providing coherent pedestrian circulation. Documentation should cover site-specific conditions, including institutional arrangements (public and private sector roles and responsibilities, and citizen participation) associated with success and failure.

Task 3—Based on an analysis of pedestrian needs, identify possible solutions which have not been discovered in the literature or in field studies but which may be feasible in the current context. Evaluate their effectiveness.

Task 4—Synthesize and evaluate the state of the art and state of practice from the knowledge gained in Tasks 1, 2, and 3. Prepare a synthesis report containing the following major components:

- *Literature Review:* critical evaluation of research related to pedestrian circulation systems in suburban and rural areas.
- *State-of-the-Art:* description of guidelines and procedures currently used in planning for pedestrian systems.
- *State-of-the-Practice:* results of the case study and data collection effort. A review of successful and unsuccessful systems, specifically the applicability of various potential solutions to the various development settings.
- *Alternative Solutions:* a description of new and innovative approaches to problems in pedestrian circulation systems.

Task 5—Develop guiding principles and design considerations that will assist planning and design professionals to provide coherent pedestrian circulation. Formulate these principles and considerations into a planning and implementation methodology.

The final two-part report has been published as NCHRP Report 294A (Research Report) and NCHRP Report 294B (State-of-the-Art Report).

Project 20-19(2) FY '86

Pedestrian Safety and Convenience on Suburban and Rural Highways—Implementation Phase

Research Agency: JHK and Associates
Principal Invest.: Steven A. Smith
Effective Date: September 1, 1987
Completion Date: March 31, 1989
Funds: $125,000

The objective of NCHRP Project 20-19 was the development of planning and implementation methodologies and principles. The objective of this continuation phase, Project 20-19(2), is on the implementation of the findings of the first phase. As stated in the 20-19 findings, many of the deficiencies noted are due to flaws in the implementation process. The continuation phase is envisioned primarily as an effort to support the implementation process. Accomplishing the objective will require the following tasks:

Task 1—Develop Teaching Modules. Task 1 will develop teaching modules that can be integrated into highway and planning courses at universities and colleges, at other training courses for planners and engineers, and even at professional meetings where this topic is appropriate. The modules will consist of alternative course segments of one, two or four hours in length.

Task 2—Develop an "Other Markets" Publication. The "other markets" publication will be developed as a condensed and more focussed version of the final report from the initial phase, to be oriented primarily toward the planning and development community. The emphasis will be on the planning and implementation process, with case study material interwoven to illustrates points.

Task 3—Prepare Advocacy Articles. Eight articles for publication in trade journals or periodicals on topics relating to pedestrian planning, design and implementation will be prepared. The articles will serve to bring pedestrian needs and planning solutions to the attention of readers of the publications and to effectively advocate the integration of pedestrian planning into other phases of planning and engineering practice. Tentative article titles are:

1. Pedestrian Planning—An Integral Part of the Local Planning Process.
2. Improving Suburban Pedestrian Mobility Through Medians and Refuge Islands.
3. Pedestrian-Sensitive Zoning and Subdivision Regulations.
4. Site Planning, Traffic Circulation and the Pedestrian.
5. On Planning, Building and Maintaining Sidewalks.
6. Accommodating the Pedestrian in Highway Design.
7. The Hazards of Walking in Suburbia: What Can You Do About It?
8. Practical Ideas for Improving Pedestrian Mobility and Safety.

Task 4—Develop "Think Pedestrian" Video. A video tape will be prepared, between 15 and 20 minutes in length. The video will be suitable for a variety of audiences, ranging from citizens who want to know more about good pedestrian planning and design practices to planning and engineering professionals who may not deal with pedestrians every day but yet require a basic knowledge of planning and design practices.

Task 5—Prepare Practitioners Manual. This will be a resource document to the training material prepared in Task 1, but will also be a stand-alone document which can be used by planning and engineering practitioners. It will consist of a collection of planning and design ideas that have been used by various agencies or in various development projects.

Research is nearing completion on all tasks. A time extension of approximately 5 months will be processed while the project panel reviews the substantial number of written and audio-visual products which have been developed.

Project 20-20 FY '83

STRS Pre-Implementation Research

Research Agency: AASHTO
Principal Invest.: L. Gary Byrd
Effective Date: October 1, 1984
Completion Date: September 30, 1986
Funds: $500,000

The Strategic Transportation Research Study (STRS) conducted by the Transportation Research Board and published in *TRB Special Report 202,* "America's Highways—Accelerating the Search for Innovation," detailed a concerted research effort needed to produce major innovations for increasing the productivity and safety of the nation's highway system. The American Association of State Highway and Transportation Officials (AASHTO), under NCHRP Project 20-20, has overall responsibility for conducting a pre-implementation effort that will produce a plan for carrying out the research identified as, "The Strategic Highway Research Program (SHRP)."

Three major tasks were undertaken. First, a plan was developed to provide the institutional requirements needed to organize, administer, and coordinate the research program. Second, detailed research plans were prepared and coordinated for each of the six research areas identified in the STRS report. Third, the institutional arrangements and research plans were implemented.

In addition to the primary contract with AASHTO, the following NCHRP projects were conducted between March 15, 1985 and May 31, 1986:

Project: 20-20(2)
Title: Overview and Integration Planning, SHRP
Research Agency: University of Maryland
Principal Invest.: Lowell K. Bridwell—*Funds:* $90,000

Project: 20-20(3)
Title: Detailed Planning for Research on Asphalt Properties
Research Agency: ARE Inc.
Principal Invest.: Fred N. Finn—*Funds:* $115,000

Project: 20-20(5)
Title: Detailed Planning for Research on Maintenance Effectiveness
Research Agency: Texas Research & Development Foundation
Principal Invest.: Bertell C. Butler, Jr.—*Funds:* $90,000

Project: 20-20(6)
Title: Detailed Planning for Research on Bridge Component Protection
Research Agency: David G. Manning
Principal Invest.: Dr. David G. Manning—*Funds:* $80,000

Project: 20-20(7)
Title: Detailed Planning for Research on Cement and Concrete
Research Agency: Construction Technology Laboratories
Principal Invest.: Paul Klieger—*Funds:* $75,000

Project: 20-20(8)
Title: Detailed Planning for Research on Snow and Ice
Research Agency: U.S. Army Cold Regions Research and Engineering Laboratory
Principal Invest.: David Minsk—*Funds:* $73,781

In addition to the above six NCHRP contracts, the FHWA funded and conducted Project 20-20(4), "Detailed Planning for Research on Pavement Performance."

The objective of each project was to develop a detailed research plan to provide the basis for a major research effort to be conducted following the pre-implementation project. The detailed research plans were guided by the budget and schedule shown for the subject research area in *Special Report 202.* The plans include a detailed description of each individual research project including the

tasks, level of effort, required resources, schedule, and budget. The research plans show the interrelationships of the projects, the timing and sequencing of each, and the assumptions or dependent conditions for each project.

Each study was guided by the NCHRP Project Panel SP20-20 and the SHRP Interim Director, as well as by input from advisory committees and other resources. Each agency was responsible also for obtaining input from a wide spectrum of the highway community including public, private, domestic, and foreign organizations.

This project has been completed and the final report, "Strategic Highway Research Program—Research Plans," is available from the TRB Publications Office. This report served as the basis for the SHRP program initiated in FY '87.

Project 20-21 FY '86

Development of an Automated Field Survey Data Collection System

Research Agency:	ARE Inc./Cooper Technology
Principal Invest.:	Hubert Henry Frank F. Cooper
Effective Date:	February 3, 1986
Completion Date:	May 5, 1987
Funds:	$200,000

In the past, few transportation agencies performed comprehensive analyses of survey operations within their organizations. However, with a diversity of high-tech "total stations" and "data collectors," and various software systems now available, many agencies are faced with problems of integrating these components into their surveying operations. Unfortunately, there is uncertainty as to how to best accomplish this integration. In addition, field survey data must be suitable for fast, efficient transfer to and from other engineering systems, such as computer-aided design and drafting programs. These issues, coupled with an increase in transportation construction projects nationwide, and an increased need for more accessible survey data, create pressure on agencies to provide "quick fix" purchases and approaches. This, in turn, results in possible wasted time and duplicated effort, as similar, but incompatible, systems are developed and tested.

Because of the demand for field survey information in varying formats and accuracies for projects and records, there is a need to integrate the different phases in handling survey information and to automate as many tasks as possible. An initial step in dealing with this problem is to develop an automated field survey data collection system that includes preprocessing and storage of the data in a standard file for subsequent electronic transfer to engineering design systems.

The objective of this research project was to define, develop, and demonstrate an automated system for collecting, preprocessing, and storing field survey data in a standard file format.

Research is complete; the final report has been published as NCHRP Report 295, "Automated Field Survey Data Collection System."

Project 20-22 FY '87

Factors to be Considered by Highway Agencies in the Identification and Remediation of Hazardous Waste Sites

Research Agency:	HMM Associates
Principal Invest.:	David J. Friend; Jan L. Connery
Effective Date:	November 1, 1986
Date:	July 1, 1988
Funds:	$148,015

Many state highway agencies are beginning to encounter problems caused by the discovery of hazardous waste on existing or soon to be acquired rights-of-way. These problems affect highway agencies in many ways. Environmental specialists, right-of-way officials, project development engineers, construction contract administrators and engineers, and legal counsels can all be involved, depending on the agency's organizational structure and the particular point at which the problems associated with hazardous waste are encountered.

Improper disposal and management of hazardous wastes, hazardous substances, and toxic chemicals have created substantial problems for state highway and transportation agencies in the planning, design, construction, and operation of highway facilities. For example, parcels purchased or considered for purchase by state highway agencies are sometimes contaminated by hazardous waste. Such sites, in addition to having been used as dumps, frequently reflect improper management of hazardous materials by former businesses. Federal and state regulations require that state highway agencies develop and implement plans for resolving these problems. Hazardous waste problems and their solutions have far reaching impacts on highway programs by increasing costs, creating time delays, and providing greater opportunities for litigation.

Problems associated with hazardous wastes are critical, yet fairly new for many highway agencies. The presence or suspected presence of hazardous waste sites creates a multitude of problems. Solutions to these concerns involve an intricate array of regulations, and require interactions with other agencies and individuals as well as with the general public. Therefore, the objective of the research was to compile the principal, relevant information describing the administrative, technical, and legal considerations that highway agency officials must be sensitive to when developing and implementing highway programs. The information provided is a useful resource in the challenging, complex process of dealing with hazardous waste sites.

Research is complete; the final report has been published as NCHRP Report 310, "Dealing with Hazardous Waste Sites, A Compendium for Highway Agencies."

Project 20-23 FY '88

Kinematic Differential GPS Satellite Surveying

Research Agency:	GPS Services Inc./National Geodetic Survey
Principal Invest.:	Dr. Gerald L. Mader
Effective Date:	September 15, 1988
Completion Date:	September 14, 1990
Funds:	$298,793

Although the Navigation Satellite Timing and Ranging system (NAVSTAR), also known as the Global Positioning System (GPS), is a satellite system being developed by the Department of Defense under Air Force management, some civilian applications are allowed. Presently, six satellites providing positioning information are in orbit. This six-satellite constellation can be used for measurements only during a limited time each day. An eighteen-satellite constellation providing 24-hour coverage is expected to be fully operational between 1990 and 1992; this will then provide very precise three-dimensional information on a continuous basis.

Equipment presently on the market can provide coarse-point-positions (positioning with a single receiver) in real-time with accuracies ranging from an estimated 10 to 30 meters. Improvements in coarse GPS real-time point-positioning are expected to evolve within private industry because of the potential for widespread commercial applications. Coarse-point-positioning data can be used by DOTs with a geographic information system (GIS) for such activities as highway inventories, accident locations, and maintenance operations. Because systems that may provide levels of accuracy acceptable for some of these activities already exist or are expected soon, no research is proposed in this area. However, opportunities do exist in the area of precise relative positioning using GPS.

Use of the present satellite constellation has shown that relative positioning measurements with accuracies of a few parts per million are possible in 30 minutes or less of data acquisition. Preliminary work involving the use of GPS for rapid differential (kinematic) positioning of ground-based survey points has indicated the feasibility of greatly reducing the time required to accomplish the equivalent of geodetic traversing. This process uses the differential GPS measurement mode where the time needed for static data collecting over each point is measured in seconds instead of minutes or hours. The benefits of such a process are great when considering the amount of geodetic traverses being conducted by the DOTs.

Another application of kinematic differential GPS is the positioning of moving sensors, such as aerial mapping cameras. A prime potential benefit of this application is that of greatly reducing the need for establishing and targeting ground control points for photogrammetric mapping. Preliminary altimetry experiments have substantiated GPS-determined vertical positions to 10-cm accuracy. Current experiments are expected to show similar results for horizontal positioning. The benefits of this procedure could greatly reduce surveying costs for photogrammetric mapping. More work is necessary if state DOTs are to realize these benefits as soon as possible. Consequently, the objective of this research will be to determine appropriate algorithms and develop operational software for kinematic differential GPS positioning at the 1-cm to 2-cm accuracy level.

Research is underway.

Project 20-24 FY '88

Research Program Design—Administration of Highway and Transportation Agencies

Research Agency:	Apogee Research Inc.
Principal Invest.:	Richard R. Mudge John A. Clements
Effective Date:	May 11, 1987
Completion Date:	September 30, 1988
Funds:	$125,000

At a special session held during the 1986 Annual Meeting of the Transportation Research Board (TRB), a number of Chief Administrative Officers (CAO's) from state departments of transportation identified areas of concern in the management of transportation agencies. Economic considerations and management of financial resources were judged to be the most important areas. Others included the management of people, information systems, public affairs, and technology transfer. In each area discussed, problems were identified that are in need of research. At the same Annual Meeting, members of the academic community reported the findings of the NSF seminar on "Transportation Research: The State of the Art and Research Opportunities." Although their recommendations call for more fundamental research, some of the problems identified are very similar to those listed by the CAO's. Concurrently, TRB committees concerned with the planning and administration of transportation systems developed their views on needed research in their areas of expertise.

Additional work is required to develop a research program, specifically directed to the management, administration, and policy planning needs of highway agencies. The objectives of NCHRP Project 20-24 are to identify the most critical problems faced by top management officials in state highway and transportation agencies and to design a well-defined, comprehensive research program to address those problems.

The initial step of the research effort was to award a contract for Task 1 with the following scope of work:

Task 1—Determine the most critical management, administration, and policy planning problems of common concern to the CAO's and other top managers in state highway and transportation agencies and identify those

that can be addressed through research. Because of the anticipated broad range and diverse nature of the problems to be identified, similar types will be classified into groups that individually or in combination would provide a logical base for structuring a coherent research program.

Some of the identified problems will require new research, but others may be best treated through the better use of existing methods from within the transportation community and from other public and private organizations. Although the detailed analysis of existing techniques will be accomplished in Task 2, as part of Task 1 a preliminary assessment will be conducted of the extent to which information is currently available to address specific problems.

Submit a report presenting one or more preliminary concepts for a research program to address the high priority areas. The concept(s) should identify (1) recommended research areas including priorities, (2) specific major products of the proposed program, (3) relative roles of new research and synthesis-type efforts, and (4) preliminary cost estimates.

It is anticipated that the following tasks will be conducted subsequently:

Task 2—Review state-of-the-art techniques used in governmental and private agencies and assess potentially useful techniques emerging from current research to determine their applicability to the problems identified in Task 1. Evaluate the more promising techniques for transferability and wider application.

Task 3—Design a research program to develop or adapt techniques that are needed to address the more critical problems identified in Task 1. The program plan will include primary emphasis areas (e.g., financial management) and, within each area, a list of specific research projects (e.g., development of a cash flow model).

Task 4—Develop a detailed scope statement for each project. Identify the highest priority projects for all proposed projects.

Research on Task 1 was completed, and the following research areas were identified for further attention: (1) Finance Resource Development, (2) Financial Management, (3) Decision Support, (4) Long-Term Policy Development, (5) Implementation, (6) Understanding of Industry, and (7) Public/Political Interactions. NCHRP Panel SP20-24 selected the first three areas for primary emphasis in the remaining work.

All research is now complete, and the agency preliminary draft final report has been submitted and is under review. The draft report presents a program of projects and recommended means for accomplishing those projects. A meeting of NCHRP Panel SP20-24 is scheduled to decide on future actions for conducting research in the management and administration of highway agencies. The final report will then be modified accordingly.

Project 20-24(1) FY '89

Using Market Research to Improve the Management of Transportation Systems

Research Agency: Apogee Research, Inc.
Principal Invest.: Dr. Richard R. Mudge
Effective Date: October 1, 1988
Completion Date: September 30, 1989
Funds: $200,000

Transportation programs must survive in an increasingly competitive world of public policy, where tough choices must be made among public works, social programs, tax cuts, and a variety of other public functions. Budget pressures are merely the most obvious outward sign of these political and financial battles.

Developing a political consensus for the funding of transportation programs requires both an in-depth knowledge of what the public knows about transportation and what their attitudes are about the transportation problems they face every day. Modern market research techniques, including public opinion surveys and focus groups, may offer a systematic way to help provide CAOs with answers to these questions.

Private firms make considerable efforts to identify their customers' general likes and dislikes as well as to identify specific needs. Based on this information, firms design a product or service to meet the potential customer's perceived needs and then work to convince them to purchase these products or services. As with other areas of modern life, marketing has become more sophisticated and technically advanced. How can these advances be adapted to help solve the problems of state DOTs?

While the focus of recent efforts in market research has been on surveys of public feelings in general, some of the same techniques could be used to survey and assess the needs and understanding of firms or groups with a direct interest in transportation. Most such information is now presented to DOTs by trade groups, but use of the ideas discussed here might make it possible to obtain information from the public at large.

The object of this research is to help the CAOs of state DOTs to add modern market research techniques to their program development and evaluation methods. Five interrelated tasks are called for:

Task 1. Review and summarize existing transportation public opinion research surveys and results.

Task 2. Review modern market research techniques used by private and public agencies.

Task 3. Design and conduct a national public opinion survey.

Task 4. Prepare policy guidance document on how these methods and information could be used most effectively to develop and implement transportation policy.

Task 5. Prepare a handbook that summarizes the de-

sign and implementation of past transportation opinion/market research and current efforts under way.

Project 20-25 FY '89

Training Needs for Highway Construction Personnel

Research Agency: In developmental stage
Principal Invest.:
Effective Date:
Completion Date: (12 months)
Funds: $75,000

There is a continuing need to improve the management of the quality of highway construction and to reduce life cycle costs. Budget restrictions, loss of skilled personnel, increased responsibility placed on quality assurance personnel, changing role of the contractor in the area of quality control, and demands to construct projects faster have all affected the highway construction process in the United States.

An approach for meeting this need is improved training programs for field and office personnel at the highway construction site. Current training programs for these personnel are not comprehensive, are localized in their application, and lack national acceptance. A national training program for highway agency, consultant, and contractor personnel will respond to this need.

The ultimate goal of this research is the development of a nationally acceptable training program that specifically supports certification for agency, consultant, and contractor personnel involved in highway construction. The objective of this project is to provide a needs assessment and design a framework for a training program to improve the quality of highway construction.

Accomplishment of this objective will require, as a minimum, the following tasks:

Task 1. Review existing listings of job-related tasks (work elements) that have been prepared for highway construction personnel and develop a nationally applicable listing of job task descriptions for personnel involved in the highway construction process.

Task 2. Survey existing training and certification programs for the job-related tasks (work elements) defined in Task 1.

Task 3. Establish criteria for determining the effectiveness of the training and certification programs surveyed under Task 2. Provide an assessment of existing training and certification programs, including areas of weakness and deficiencies.

Task 4. Based on the results of Tasks 2 and 3, design a framework for a national training program that supports certification for highway construction personnel.

Task 5. Prepare a final report on the total research effort.

NOTE: Funds are earmarked for a research project to follow in this area to develop a comprehensive training program that will lead to nationally accepted certification based on the results of this project.

Project 20-26 FY '89

Bond and Insurance Coverages for Highway Construction Contractors

Research Agency: In developmental stage
Principal Invest.:
Effective Date:
Completion Date: (16 months)
Funds: $100,000

Highway construction contractors typically need to obtain bid, performance, and payment bonds, as well as insurance coverages in order to undertake public highway construction contracts. In recent years, a number of contractors have complained that the cost of insurance has risen dramatically or the needed insurance coverages are not available. The cost and availability of surety bonds are also mentioned as problems for small, less experienced contractors and especially for Disadvantaged Business Enterprises (DBE) that are attempting to break into public construction. In turn, there is concern that these problems may have reduced competition and increased costs for highway construction.

It is not clear to what extent various factors influence the cost and availability of bonds and insurance. Some of these factors may fall into such categories as: highway agency design and construction practices; cyclical nature of the insurance industry; shifts in the type of construction toward rehabilitation and reconstruction; social issues; legal climates; environmental issues; OSHA requirements; changes in range and types of insurance coverage; size and number of projects; quality control; state and federal laws, rules, and regulations; risk management; safety programs; and loss prevention techniques.

Research is needed to enable the industry to deal with the primary short- and long-term factors that affect bond and insurance costs and create availability problems for contractors that need such coverages.

The objective of this research is to identify, analyze, and prioritize the factors that affect the cost and availability of bonds and insurance on public highway construction contracts. At a minimum, it is anticipated that the research will include the following tasks:

Task 1. Survey the highway and utility contracting industries including prime contractors, subcontractors, DBEs, State contracting agencies, and contractor and construction associations to determine the actual extent and cause of problems related to cost and availability of bonds and insurance. Solicit from these firms, agencies, and associations, suggestions for ways to increase the availability or reduce the cost of bonds and insurance.

Task 2. Survey bond and insurance companies and associations to obtain the results of their experience with highway contractors. This survey should address, as a minimum, the cost and availability of bonds and insurance, the impact of business failures within the bond and insurance industry, and any industry plans, suggestions, or potential changes that would influence the industry and serve to increase the availability or reduce the cost of bonds and insurance.

Task 3. Based on the results of Tasks 1 and 2, provide an analysis and a prioritization of the primary factors that affect cost and availability of bonds and insurance.

Task 4. Submit an interim report within 9 months after the start of research. The interim report shall summarize the results of Tasks 1 through 3 and include an outline for accomplishment of Task 5. NCHRP approval will be required before commencing Task 5.

Task 5. Develop recommendations for actions to solve the problems associated with the factors prioritized in Task 3. Develop research plans for those factors that require additional research. Provide an estimate of cost and duration for accomplishing each research plan.

Task 6. Submit a final report documenting all research findings.

AREA 21: TESTING AND INSTRUMENTATION

Project 21-1 FY '70

Instrumentation for Measurement of Moisture

Research Agency: Research Triangle Institute
Principal Invest.: Dr. L. F. Ballard
Effective Date: August 25, 1969
Completion Date: February 24, 1971
Funds: $35,027

The objective of this project was to evaluate, on the basis of a comprehensive literature review, the suitability of existing instrumentation and techniques to measure the amount and state of water in highway components such as embankments, subgrades, base courses, and structures.

The research has been completed, and the project report has been published as: NCHRP Report 138, "Instrumentation for Measurement of Moisture—Literature Review and Recommended Research."

Project 21-2 FY '71

Instrumentation for Moisture Measurement—Bases, Subgrades, and Earth Materials (Sensor Development)

Research Agency: Southwest Research Institute
Principal Invest.: Dr. C. G. Gardner
Effective Date: February 1, 1972
Completion Date: January 31, 1974
Funds: $64,976

The objectives of this project were to design, build prototype models, and conduct laboratory verification programs for one or more sensors capable of measuring moisture in granular and soil materials that would be suitable for highway needs. During the initial phase of the study, nuclear magnetic resonance (NMR) and microwave absorption approaches were investigated independently. In general, satisfactory performance was achieved using the NMR approach, but considerable difficulty was encountered with the microwave technique. As a result, the experimental verification phase was limited to the NMR sensor.

Research has been completed, and an NMR sensor has been developed for measurement of moisture in fine-grained soils. The prototype model has undergone laboratory testing and is considered suitable for further development and field evaluation.

The technology on which the prototype sensor is based is described in a paper by Gardner & Matzkanin, published in TRB Record 532. Information contained in the project report is included in the Project 21-2(3) report.

Project 21-2(2) FY '72

Instrumentation for Moisture Measurement—Bases, Subgrades, and Earth Materials (Sensor Development)

Research Agency: State U. of New York at Buffalo
Principal Invest.: Dr. E. T. Selig
Effective Date: April 1, 1972
Completion Date: September 30, 1973
Funds: $29,953

The objectives of this project were to design, build a prototype model, and conduct a laboratory verification program for a sensor capable of measuring moisture in granular and soil materials that would be suitable for highway needs.

Research has been completed, and a sensor has been developed based on the use of electrical capacitance as a measure of soil moisture. The prototype model has undergone laboratory testing and is considered suitable for further development and field evaluation.

The technology on which the prototype sensor is based is described in a paper by Selig, Wobschall, Mansukhani, and Motiwala published in TRB Record 532. Information contained in the project report is included in the Project 21-2(3) report.

Project 21-2(3) FY '75

Instrumentation for Moisture Measurement—Bases, Subgrades, and Earth Materials (Sensor Evaluation)

Research Agency: Southwest Research Institute
Principal Invest.: George A. Matzkanin
E. T. Selig (SUNY)
Effective Date: September 3, 1974

Completion Date: December 31, 1979
Funds: $154,452

The objective of this project was further refinement and field evaluation of the two prototype moisture sensors developed under Projects 21-2 and 21-2(2). This included fabrication of the sensors and readout instrumentation, their installation in the subgrade portions of pavements in Arizona and Pennsylvania, and evaluation of data collected at the field sites.

Research has been completed, with accomplishment of the intended tasks. Although neither sensor meets all of the desired criteria, the research indicates that each has some potential for practical applicaton to the soil moisture measurement problem. Operational problems encountered during the field evaluation should be resolved during the development of production models. A production model of the dielectric sensor is available from Ecotec Corp., Needham Heights, Mass.

The essential findings of the study have been published as NCHRP Research Results Digest 121. The agency report has been distributed to the Program sponsors and other interested persons. It will not be published in the regular NCHRP report series but is available on a loan basis (see final page of this section for ordering information).

AREA 22: VEHICLE BARRIER SYSTEMS

Project 22-1 FY '69

Concepts for Improved Traffic Barrier Systems

Research Agency: Walter W. White
Principal Invest.: Walter W. White
Marvin A. Shulman
Effective Date: October 1, 1970
Completion Date: December 31, 1971
Funds: $25,000

The objective of the research was to produce one or more traffic barrier system designs, described with sketches and narrative to the degree necessary to convey understanding, that offer promise of: preventing penetration by a standard-size U.S. automobile weighing 4,000 to 5,000 lb and impacting at 25° and 65 mph; smoothly redirecting errant vehicles relatively parallel to traffic flow; providing a range of controlled dynamic deflections by varying design parameters; retaining longitudinal continuity following a collision; permitting adequate visibility; being capable of quick and easy repair; performing satisfactorily in various foundation conditions; limiting decelerations at the center of gravity of the vehicle to 5g lateral, 10g longitudinal, and a total of 12g when averaged over any 200-millisec period; having reasonably low first cost and pleasing appearance; and minimizing vehicle damage. The design was analyzed and technical information was presented to demonstrate the degree of achievement of the foregoing. Working drawings suitable for fabrication and installation of a prototype were prepared for each barrier system.

The final report was not published in the NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 22-1A FY '73

Testing and Evaluation of Bridge Rail Concepts

Research Agency: Texas A & M University Research Foundation
Principal Invest.: T. J. Hirsch
Effective Date: March 1, 1974
Completion Date: May 30, 1975
Funds: $40,000

The objectives of NCHRP Project 22-1, "Concepts for Improved Traffic Barrier Systems," were accomplished by the development of a traffic barrier system that was analyzed using the Barrier IV computer program. The results of this analysis indicate that the proposed system meets the desired criteria.

The objective of Project 22-1A was to evaluate the prototype of the proposed barrier by full-scale impact tests.

The accomplishment of this objective included the following tasks:

1. Fabrication and construction of the barrier system shown in Figure 6 of the final report on Project 22-1 (Pages 148 to 173, *NCHRP Summary of Progress Through 1972*).
2. Testing and evaluation of the system under the following impact conditions:

(a) A passenger vehicle impacting the bridge rail at 60 mph and 25°.
(b) A passenger vehicle impacting the bridge rail at 60 mph and 7°.
(c) A passenger vehicle impacting the approach railing-bridge rail transition at 60 mph and 25°.

Research has been completed, and the essential findings have been summarized in NCHRP Research Results Digest 81, "Crash Testing and Evaluation of Attenuating Bridge Railing System."

Microfiche of the agency's final report may be purchased (see final page of this section for ordering information).

Project 22-2 FY '69, FY '72 and FY '73

Traffic Barrier Performance and Design

Research Agency:	Southwest Research Institute	
Principal Invest.:	M. E. Bronstad J. D. Michie	
Effective Date:	Jan. 1, 1972	Oct. 1, 1973
Completion Date:	Sept. 30, 1973	Mar. 31, 1975
Funds:	$125,000	$80,000

Among the most important of current needs in the area of vehicle barrier systems is a safer terminal design. The work of Project 22-2 was structured to emphasize the systematic experimental development of terminal treatments to fulfill this need. Terminal treatments for a number of selected guardrail systems were investigated. This study built on earlier preliminary NCHRP efforts that are described in NCHRP Reports 118 (1971) and 129 (1972).

The initial task in Phase I included a review of terminal concepts previously developed under Project 15-1(2), the development of several new concepts, and an examination of concepts developed outside the NCHRP. More than 20 of these concepts have come under consideration. This work was covered in an interim report. Although the report will not be published, it is available on a loan basis.

Based on the interim report, the project panel selected designs and established priorities for full-scale testing of several terminal systems. The experimental program consisted of some 26 full-scale crash tests. Interest in this testing was concentrated on a breakaway cable terminal (BCT) in combination with the W-beam guardrail and median barrier systems most often used. Ten crash tests were carried out on the BCT with the flared W-beam guardrail. The second part of the experimental program, comprising some 16 tests, was concentrated on the development of a crash-cushioning terminal for use with median barriers. Microfiche of the agency's Phase I report may be purchased (see final page of this section for ordering information).

Phase II research has been completed. Task 1 led to the refinement of BCT designs to provide more safety to smaller cars and to improve economy relative to the first cost, maintenance, and repair. Findings from the Phase II research were reported in NCHRP Research Results Digest 84 (March 1976). Microfiche of the agency's final report on Phase II may also be purchased (see final page of this section for ordering information).

Subsequently, the Federal Highway Administration sponsored additional tests on the median barrier BCT. NCHRP Research Results Digest 102 summarized the findings of these and previous tests and clarified recommended details for both guardrail and median barrier terminals with either steel or timber posts.

A separate task of Phase II, funded at $20,000, was intended to develop uniform barrier testing criteria and procedures. Research has been completed on this task, and the final report has been published as: NCHRP Report 153, "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances."

Project 22-2(2) FY '73

Multiple Service Level Highway Bridge Railings—Performance and Design Criteria

Research Agency:	Southwest Research Institute
Principal Invest.:	M. E. Bronstad
Effective Date:	August 1, 1976
Completion Date:	April 30, 1979
Funds:	$195,000

The initial objective of this project was to identify and document realistic performance criteria and correlated design criteria for bridge railing systems on roadways providing various (at least three—normal, higher, and lower) levels of service. The major objective was to develop at least one design based on criteria for the lower service level and to validate this system using analytical and full-scale testing methods.

The research included the following tasks:

1. Identify traffic and other parameters for use in defining appropriate categories of roadway service levels.
2. Establish reasonable performance criteria for bridge railings to be employed in each category.
3. Propose bridge railing design criteria for each category.
4. Develop and validate, through analytical simulation and full-scale testing (in accordance with the relevant provisions in NCHRP Report 153), at least one lower service level bridge railing design with first cost and maintenance advantages over normal service level systems. The railing will be designed according to the criteria proposed in Task 3, to give performance consistent with the criteria developed in Task 2. Bridge railing designs considered in this task may include some already in use.
5. Through analytical simulation, evaluate the performance of this railing when struck by a 25,000-lb (11,340 kg) school-type bus under various impact conditions.
6. Compare the developed bridge railing design with the present AASHTO static-elastic bridge railing design requirements.
7. Recommended appropriate modifications to current bridge railing design practice based on this study.

Research has been completed, and loan copies of the final reports on Phase I (Tasks 1-3) and Phase II (Tasks 4-7) may be obtained from the NCHRP upon written request.

Project 22-2(3) Fy '78

Multiple Service Level Highway Bridge Railings—Selection Procedures

Research Agency: Southwest Research Institute
Principal Invest.: Maurice E. Bronstad
Effective Date: January 1, 1979
Completion Date: May 31, 1981
Funds: $200,000

The concept of multiple service level bridge railings was developed in NCHRP Project 22-2(2). The objective of Project 22-2(3) was to further refine these procedures to make them more usable and accurate with respect to the needs of the highway community. Certain improvements had already been indicated from comments received on the initial studies.

Several aspects of the Multiple Service Level Approach (MSLA) were controversial and more comprehensive investigations were needed. The following steps were carried out in this program:

1. Perform a sensitivity analysis and refine MSLA procedures accordingly.
2. Develop bridge railing systems for a number of service levels.
3. Determine total costs of bridge railing systems for a number of service levels.
4. Based on cost, determine number of service levels needed.
5. Develop an upgrading strategy using MSLA.
6. Prepare a users' manual for practicing engineers.
7. Assess the legal implication of MSLA and make modifications as indicated.

Research has been completed, and the final report published as: NCHRP Report 239, "Multiple-Service-Level Highway Bridge Railings Selection Procedures." The findings of a small side study on the breakaway cable terminal have been published as Research Results Digest 124.

Project 22-2(4) FY '79

Procedures for Testing Highway Appurtenances

Research Agency: Southwest Research Institute
Principal Invest.: Jarvis D. Michie
Effective Date: May 1, 1979
Completion Date: February 28, 1981
Funds: $30,000

In 1962, the first procedures for full-scale vehicle crash testing of guardrails were published in *Highway Research Correlation Services Circular 482.* The one-page document delineated vehicle mass, impact speed, and approach angle. Although *Circular 482* did bring some some order to traffic barrier research being performed at several research agencies, a number of questions arose that were not addressed.

Under NCHRP Project 22-2, SwRI addressed these questions and developed NCHRP Report 153, "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances" (1974), which provided testing and research agencies with recommended procedures to vehicle crash test highway appurtenances. The procedure represented technical input from more than 70 individuals and agencies and the results of extensive deliberation of a special ad hoc panel. It was recognized then that several parts of the procedures were based on inadequate experience or research. It was decided, however, to retain coverage of these areas in order to provide a more complete testing procedure.

These procedures have gained wide acceptance since their publication in 1974. It was recognized at that time that periodic updating would be needed, and, in January 1976, TRB Committee A2A04 accepted the responsibility of maintaining the efficacy of the procedures. Questionnaires were submitted to committee members in late 1976 to ascertain areas of the document that needed revision. The responses generally fell into two categories: (1) minor changes that would require expanded discussions of certain provisions and problem areas and the addition of more detailed guidelines; and (2) major changes that would require broadening the scope to include testing with trucks and buses, reevaluating the criteria for impact severity, and treating special highway appurtenances such as construction barriers. The committee agreed to address the minor changes through special committee action; this was done, and *Transportation Research Circular No. 191* is the product of TRB Committee A2A04. For the major changes, the committee felt that the task was beyond its resource and requested TRB/NCHRP to investigate the possibility of having the work performed under a funded research contract. Project 22-2(4) was intended to address these major changes. Its objective was to review, revise, and expand the scope of *Transportation Research Circular No. 191* to reflect current technology. This study permitted research on points needing more in-depth analysis than could be provided by the TRB Committee.

Research has been completed, and the final report has been published as: NCHRP Report 230, "Recommended Procedures for Safety Performance Evaluation of Highway Appurtenances."

Project 22-3 FY '73

Field Evaluation of Vehicle Barrier Systems

Research Agency: Calspan Corporation
Principal Invest.: J. W. Garrett
N. J. DeLeys
Effective Date: January 1, 1974
Completion Date: February 15, 1975
Funds: $25,000

The objective of this project was to determine the degree to which accident data currently being accumulatd by various agencies meet the needs of those concerned with the effectiveness of vehicle barrier systems and, to the extent warranted, to recommend new approaches that may better serve those needs.

Research has been completed, and the essential findings from the final report have been summarized in NCHRP Research Results Digest 76, "Field Evaluation of Vehicle Barrier Systems." Microfiche of the agency's final report may be purchased (see final page of this section for ordering information).

Project 22-3A FY '73

Field Evaluation of Vehicle Barrier Systems

Research Agency: Arthur L. Elliott
Principal Invest.: Arthur L. Elliott
Effective Date: July 1, 1974
Completion Date: December 31, 1974
Funds: $10,000

The relative in-service performance of most guardrail systems is unknown. Although over-all performance of guardrail installations, in general, might be determined from state and national efforts in accident investigations, limitations in the data preclude the analysis of specific guardrail systems in terms of safety and cost. Accordingly, the relative merits of two or more systems must be evaluated on the basis of idealized laboratory experiments (including full-scale crash tests) and gross accounting procedures. The use of accident data to evaluate the field performance of barrier systems would be very desirable. The use of formal accident reports had been investigated under NCHRP Project 22-3.

At the same time, Project 22-3A was concerned with an investigation of a less formal approach to barrier evaluation. This approach consisted of personal interviews with highway agency maintenance, safety, and traffic operations personnel to obtain any data they may have had and to solicit their subjective opinions on the performance of various barriers. Five representative states were visited for this purpose.

Research has been completed, and the essential findings from the final report have been summarized in NCHRP Research Results Digest 76, "Field Evaluation of Vehicle Barrier Systems." Microfiche of the agency's final report may be purchased (see final page of this section for ordering information).

Project 22-4 FY '83

Performance of Longitudinal Traffic Barriers

Research Agency: Southwest Research Institute
Principal Invest.: J. D. Michie, M. E. Bronstad
Effective Date: July 1, 1983
Completion Date: July 15, 1987
Funds: $503,954

Existing crash test performance of longitudinal barrier systems was reviewed for compliance with NCHRP Report 230. Based on this review a matrix of five guardrail, two median barrier, and four bridge systems was evaluated with full-scale crash tests for occupant risk with 1,800-lb sedans. The results were evaluated using the recommended values of NCHRP Report 230 to which all systems were essentially in compliance.

In addition, evaluation of five guardrail and one median barrier systems was performed with an 1,800-lb sedan impacting at 60 mph and a 20-deg angle (test S13 of NCHRP Report 230). The purpose of these tests was to provide further insight into the performance of the barrier systems. Six insight tests using vans to determine barrier performance thresholds for this type of vehicle were performed. Seven transition tests were performed as follows: three guardrail/bridge rail transitions, two guardrail/guardrail transitions; and two median barrier/median barrier transitions. Finally, two additional insight tests were performed. The first was a van impacting a G1 cable guardrail system mounted at a 24-in. height. The second test evaluated a blocked-out W-beam system with round wood posts.

The final report, published as NCHRP Report 289, includes the crash test results, design drawings for the systems tested in this research as well as for systems tested in other studies, and recommended changes to the test criteria.

Project 22-5 FY '84

Develop Performance Standards and Hardware for Low Service Level Guardrail Systems

Research Agency: Southwest Research Institute
Principal Invest.: L. R. Calcote and K. Hancock
Effective Date: May 1, 1985
Completion Date: January 31, 1989
Funds: $200,000

Currently operational guardrail systems have been developed for 60-mph, 25-degree impacts with 4,500-lb vehicles. The use of design criteria based on this severe test condition has resulted in relatively expensive installations (e.g., high-cost terminal anchorage systems). For low service level roads, there is a need to determine the conditions under which less stringent guardrail requirements are warranted in order to reduce costs while providing safety performance based on demonstrated need.

The objectives of this project are: (1) to examine the need for guardrails on low service level roads and develop performance standards for guardrails, transitions, and terminals and (2) to design, test, and develop low-cost guardrail systems based on these performance standards.

This project consists of two phases:

Phase I

Task 1—Review, evaluate, and document available data in order to establish performance standards for low service level guardrail systems including transitions and terminals. Establish and, if necessary, develop general warranting criteria for use of such systems.

Task 2—Using the performance standards from Task 1, develop conceptual and preliminary designs with working drawings of the guardrails, terminals, and transitions using structural analysis, computer simulation, or other techniques. Existing hardware and systems in widespread use with demonstrated effective field performance will be fully considered. Make estimates of initial and maintenance (life cycle) costs for these guardrail systems.

Task 3—Prepare a letter report on the findings of Tasks 1 and 2 for review by the NCHRP. This report will also contain a detailed work plan for Phase II including recommendations for further development of the guardrail system(s).

Phase II

Task 4—Test and develop the guardrail systems selected by NCHRP using the approved performance standards.

Task 5—Prepare a final report including the following:

a. Low service guardrail performance standards.
b. Documentation of the design and development of low service level guardrail systems.
c. Recommended low service level guardrail drawings and specifications.
d. Estimated life cycle costs of the guardrail systems.
e. General warrants for use of low service level guardrail.

Research has been completed, and the draft final report is being reviewed.

Project 22-6 FY '85

Roadside Safety Design for Small Vehicles

Research Agency:	Texas A & M Research Foundation
Principal Invest.:	Dr. Hayes E. Ross, Jr.
Effective Date:	June 1, 1985
Completion Date:	June 30, 1988
Funds:	$350,000

Most current roadside safety appurtenances were designed and tested with passenger vehicles ranging from 4,500 down to 2,250 lb. Research is currently in progress to investigate the performance of hardware and roadside features with vehicles in the 1,800-lb range. Under some conditions, barrier impacts become increasingly hazardous for smaller vehicles; however, little is known about the performance of current hardware and roadside safety features with vehicles smaller than 1,800 lb.

The objectives of this project are (1) to assess the performance of selected existing highway safety appurtenances and roadside features with passenger vehicles below 1,800 lb and (2) to project the limits of vehicle characteristics that can be safely accommodated through improvements in current hardware and roadside features.

This research includes the following tasks:

Phase I:

Task 1—Review, evaluate, and document foreign and domestic information on the performance of safety appurtenances and roadside features with passenger vehicles weighing 1,800 lb and less.

Task 2—Identify all types of 4-wheel sedans below 1,800 lb that may constitute a significant portion of the vehicle fleet in the United States within the next 10 years. For the vehicle types identified, acquire, measure, or, where necessary, estimate the dynamic properties and other characteristics required for the computerized simulation of their reactions with safety hardware and roadside features.

Task 3—Select specific appurtenances for study in this project. The following items will be included: a rigid longitudinal barrier; a flexible longitudinal barrier; a breakaway support; a base-bending support; an impact attenuator; and a guardrail terminal.

Task 4—Select specific roadside features for study to identify performance limits when traversed by small cars. As a minimum, these features will include slopes, ditches, and curbs.

Task 5—Using available data from crash tests with the lightest vehicles tested, calibrate selected existing computer programs for simulation of impact performance, and use the calibrated programs to simulate occupant-risk tests for the selected hardware and roadside features with a 1,500-lb sedan.

Task 6—Prepare an interim report on the findings of Tasks 1 through 5. This report will contain a detailed working plan for the remainder of the study.

Phase II

Task 7—Conduct full-scale crash tests using vehicles in the 1,200 to 1,500-lb range to recalibrate the model and to demonstrate the validity of the computerized simulation to be carried out concurrently in Task 8.

Task 8—Using existing simulation models for a variety of appurtenances and roadside features (including potential improvements), vehicle types (including projections down to the lowest conceivable weight range), and crash test conditions, delineate the limiting values of particular vehicle characteristics for which feasible designs

are capable of providing satisfactory performance according to the guidelines in *NCHRP Report 230.* When these evaluation criteria are not satisfied, determine the changes in impact conditions that would be required to achieve compliance.

Task 9—Identify design modifications to hardware and roadside features to improve performance for vehicles at the low end of the weight spectrum. Such modifications will be supported by computerized simulation.

Task 10.—Prepare a final report.

Research has been completed and the final report is being revised, in preparation of its publication in early 1989.

Project 22-7 FY '89

Update of "Recommended Procedures for Safety Performance Evaluation of Highway Appurtenances"

Research Agency: In developmental stage
Principal Invest.:
Effective Date: (30 months)
Completion Date:
Funds: $200,000

The objective of this study is to update the recommended procedures for the safety performance evaluation of both temporary and permanent highway appurtenances in such a manner as to reflect advances in technology and to accommodate current and anticipated roadway and vehicle characteristics.

This project will consist of two phases to be performed consecutively, with a review required at the completion of Phase I on which authorization to proceed with Phase II will be based.

Phase I

Task 1. Develop a comprehensive list of topics to be examined in updating the recommended procedures. This list shall be based on a critical review of past and on-going research, and input from knowledgeable individuals involved with and interested in the subject area.

Task 2. Evaluate the relative importance of each of the topics cited in Task 1 and identify important issues within each topic.

Task 3. Prepare an interim report documenting the efforts completed in Tasks 1 and 2. The interim report shall also include an annotated outline of the final report and a detailed work plan describing the activities required in Phase II. Submit the interim report to the NCHRP Project Panel for review and approval. A meeting between the research team and the NCHRP Project Panel will be planned at the completion of Task 3 to discuss the results of Phase I and the work planned for Phase II. The investigators shall prepare a revised interim report to reflect the outcome of the meeting and distribute it to the project panel members.

Phase II

Task 4. Using the information generated in Phase I, prepare a first draft of the final report and document, under separate cover, how each of the issues identified was resolved. The investigators shall also prepare a proposed list of reviewers from the highway community-at-large for approval by the panel. A second meeting between the research team and the project panel will be planned at the completion of Task 4 to discuss the first draft of the final report, the list of issues identified and how they were resolved, and the proposed list of reviewers. The investigators shall prepare a second draft of the final report to reflect the outcome of the second meeting and distribute the revised document to the project panel members and to the reviewers approved by the project panel in this task.

Task 5. Evaluate the reviewers' comments and prepare a brief discussion of the comments and their disposition. Based on the results of this effort, prepare a third draft of the final report. A third meeting between the researchers and the NCHRP Project Panel will be scheduled at the completion of Task 5 to discuss the comments received from the community-at-large, the disposition of those comments, and the third draft of the final report.

Task 6. A final report shall be prepared based on the outcome of the third meeting between the researchers and the NCHRP Project Panel.

Project 22-8 FY '89

Evaluation of Performance Level Selection Criteria for Bridge Railings

Research Agency: In developmental stage
Principal Invest.:
Effective Date: (21 months)
Completion Date:
Funds: $200,000

The objectives of this research are (1) to determine the adequacy and validity of the performance levels and the performance-level selection procedures contained in the "Guide Specifications," (2) to estimate the impact of implementing the "Guide Specifications" on state and local agencies, (3) to recommend appropriate improvements to the "Guide Specifications," and (4) to evaluate the feasibility of extending the multiple performance-level approach to all longitudinal barrier systems.

This research shall include four phases. Phase I corresponds to the first objective; Phase II, to the second and third objectives; and Phase III, to the fourth objective. Phase IV encompasses the preparation of the final report.

Accomplishment of the objectives will require at least the following tasks:

- *Phase I*—Evaluate and Validate the "Guide Specifications"

Task 1. Review the literature for information on the multiple performance-level concept, barrier warrants, barrier design, vehicle crash testing, car and truck accident studies involving vehicle contact with bridge railings and other longitudinal barrier systems, and any other related subjects deemed appropriate by the researchers. In addition, identify accident data bases that can be used to validate the criteria used to develop the performance levels identified in the "Guide Specifications."

Task 2. Evaluate the information assembled in Task 1 and develop a working plan for evaluating and validating the performance levels and performance-level selection procedures contained in the "Guide Specifications." Prepare and distribute to the NCHRP Project Panel a letter report describing the results of Tasks 1 and 2.

Task 3. Implement the working plan developed in Task 2. Also identify potential modifications to the "Guide Specifications" along with the advantages and disadvantages of implementing each modification. Prepare and distribute to the NCHRP Project Panel an interim report describing the results of this task.

- *Phase II*—Assess Implementation of the "Guide Specifications"

Task 4. Develop a detailed working plan for applying the performance-level selection procedures to a representative sample of state, county, and city roadways in a minimum of 5 states, to be selected by NCHRP, for the purposes of: (a) estimating the impact of implementing the "Guide Specifications"; (b) assessing the effects of implementing the potential modifications to the "Guide Specifications" identified in Task 3; and (c) evaluating the sensitivity of the performance-level selection procedures to variations in actual roadway and traffic characteristics. Submit the working plan developed in this task to the NCHRP Project Panel for review and approval. Approval of the working plan is required before initiation of Task 5.

Task 5. Implement the working plan developed in Task 4. Also develop recommended modifications to the "Guide Specifications." Prepare and distribute to the NCHRP Project Panel an interim report documenting the findings of this task.

- *Phase III*—Extend The Multiple Performance-Level Concept

Task 6. Evaluate the feasibility of extending the multiple performance-level concept to all longitudinal barriers. Based on this evaluation, draft a detailed working plan for development of a roadside-appurtenance design guide. This plan shall include, but not be limited to, the identification of variables involved, the methodologies for accommodating these variables, and a strategy for validating the approach.

- *Phase IV*—Prepare the Final Report

Task 7. Prepare a final report documenting the results of Tasks 1 through 6.

AREA 23: SOILS PROPERTIES

No projects

AREA 24: SOIL MECHANICS AND FOUNDATIONS

Project 24-1 FY '79

Manual on Subsurface Investigations

Research Agency: Haley and Aldrich, Inc.
Principal Invest.: Dr. A. W. Hatheway
Effective Date: April 2, 1979
Completion Date: December 31, 1980
Funds: $75,000

The over-all objective of this project was preparation of a manual on subsurface investigations applicable to the general transportation field that could be considered for publication by AASHTO.

Research has been completed, and the final report has been published by AASHTO. Copies of the new manual, *AASHTO Manual on Subsurface Investigations,* are available from AASHTO, 444 North Capitol Street, N.W., Suite 225, Washington, D.C. 20001.

Project 24-2 FY '83

Reinforcement of Earth Slopes and Embankments

Research Agency: Dames & Moore
Principal Invest.: Dr. Willem C. B. Villet
Effective Date: August 22, 1983
Completion Date: May 21, 1987
Funds: $150,000

The problem of economically constructing and maintaining stable slopes within limited right-of-way is a continuing concern. Where increasing traffic requires the addition of lanes within the same right-of-way, earth retaining structures are often necessary. Such structures are required also where existing or proposed slopes are unstable and flattening of the slope is not feasible.

In recent years, some of the most noteworthy advances in geotechnology have been in the area of earth reinforce-

ment. Earth reinforcement systems are comprised of reinforcement material, backfill or in-place soil, and facing elements. Innovative techniques have been initiated and are being developed here and abroad that have the potential for improving stability at reasonable cost. Some techniques are proprietary, and information on many of the innovative methodologies has not been widely distributed. Therefore, a need existed to collect, evaluate and disseminate the current state of the art to realize the full potential of their use and determine their applicability.

Research is complete. The final report for the project provides a comprehensive compilation of information on various earth reinforcement systems used to construct embankments and stabilize existing slopes. The report includes an all-inclusive overview of earth reinforcement and details on specific earth reinforcement systems covering their mechanisms, behavior, applications, designs, and durability. The guiding objective in the preparation of this document was to make it sufficiently complete to be a valuable handbook-type reference source for the researcher and the practicing engineer in considering applications of earth reinforcement. The final report has been published as NCHRP Report 290, "Reinforcement of Earth Slopes and Embankments."

Project 24-3 FY '86

Laboratory Evaluation of Piles Installed with Vibratory Drivers

Research Agency:	University of Houston-University Park
Principal Invest.:	Drs. Michael W. O'Neill and Cumaraswamy Vipulanandan
Effective Date:	January 6, 1986
Completion Date:	August 31, 1988
Funds:	$200,000

State Departments of Transportation often are requested by contractors to use vibratory drivers rather than the more conventional impact hammers to install piles. Vibratory pile drivers can provide substantial savings by reducing the amount of driving time to final penetration under certain soil conditions. However, the lack of a reliable dynamic method of estimating bearing capacity limits their usefulness. Presently, the most common method to determine capacity is to restrike the pile with an impact hammer, but the validity of this method is unproven and the extra operation reduces the potential savings.

Developing a reliable method for dynamically determining bearing capacity of piles installed with vibratory drivers is a complex problem. To supplement current activity, laboratory studies are needed to provide insight into the basic behavior of piles installed with vibratory drivers compared to impact hammers and the influence of various soil parameters on the behavior of piles. Laboratory studies will also assist in the design of future field tests and the analysis of results.

The overall objective of this study is to evaluate the load-deformation behavior of piles installed in the laboratory with vibratory drivers. Specific objectives include: (1) a comparison of load deformation behavior of piles installed with vibratory drivers and impact hammers; (2) the identification of soil parameters that significantly affect load-deformation behavior of piles installed with vibratory drivers; (3) a comparison of load-deformation behavior of piles installed by vibratory drivers with and without restriking using an impact hammer to evaluate the effect of restriking; and (4) the development of a recommended predictive method of determining bearing capacity for further field verification. The research will include the following tasks:

The agency preliminary draft report has been submitted and revised. The agency will now respond to that review and furnish the revised final report in early 1989.

Project 24-4 FY '87

Load Factor Design Criteria for Highway Structure Foundations

Research Agency:	Virginia Polytechnic Institute and State University
Principal Invest.:	Richard M. Barker, James M. Duncan, Kamal B. Rojiani
Effective Date:	September 1, 1987
Completion Date:	May 31, 1990
Funds:	$375,000

Until the early 1970's all transportation structure design was performed using the working stress design method. Then, in the mid-1970's, AASHTO adopted load factor design into the *AASHTO Standard Specifications for Highway Bridges* as an approved design method for those portions of the bridge structure above the foundation. Many states have adopted AASHTO's load factor design criteria for bridge superstructures. As a result, engineers have been faced with the inconsistency of designing those portions of the structure above the foundation by the load factor method while still designing the foundations by working stress.

This inconsistency in design format requires the designer to perform considerable duplication in compiling design forces for the highway structure and its foundation. The development of suitable load factor design criteria for highway structure foundations would eliminate this inconsistency, saving time and money. Additionally, this would lead to a more uniform margin of safety for all the structural components in a highway structure and should result in a more consistent and efficient use of materials.

Research is needed so that designers of highway structures may take advantage of the load factor design concept for the design of highway structure foundations. The re-

search needs to consider both the loading and the resistance sides of the strength design equation.

The objective of this research is to develop load factor design criteria for highway structure foundations. The design criteria shall be developed for, but not necessarily limited to, drilled piles and shafts, driven friction piles, driven end-bearing piles, spread footings on rock, spread footings on soil, and rigid retaining walls. The loadings to be considered shall include vertical loads, horizontal loads, moments, and combinations thereof.

The research will include the following tasks:

Task 1—Review relevant current domestic and foreign practice, performance data, and research findings. This information shall be assembled from both technical literature and the unpublished experiences of bridge and geotechnical engineers, consultants, and owners of highway structures.

Task 2—Analyze and evaluate the information generated in Task 1 to establish a framework for the development of the load factor design concept as it should be applied to the design of highway structure foundations. This shall include a description of the proposed methodology for the development of the load factor design criteria.

Task 3—Develop a comprehensive outline of the anticipated load factor design criteria for highway structure foundations. Discuss the significance of each topic in the proposed outline.

Task 4—Present the findings of Tasks 1 through 3 in an interim report to be submitted not later than 12 months after initiation of the research. The interim report shall include a detailed research plan for Tasks 5 through 9. NCHRP approval of the interim report will be required before commencing Tasks 5 through 9.

Task 5—Develop values for appropriate load and resistance factors and loading combinations for all foundation types from the information obtained in the preceding tasks. These factors should be based on the reliability of load prediction, probability of load occurrence, soil or rock parameter characterization, bearing capacity, and deformation criteria. Serviceability criteria considering the total structure shall be addressed. Specific consideration should be given to soil-structure interaction and time-dependent soil behavior.

Task 6—Develop detailed load factor design criteria for highway structure foundations in a format suitable for consideration by the AASHTO Subcommittee on Bridges and Structures. The recommended criteria shall be accompanied by a detailed commentary and examples of specific applications intended to facilitate understanding and use of the criteria.

Task 7—Perform appropriate calibrations of the criteria developed in Task 6 against existing working stress design procedures. The calibration will be performed to establish the accuracy of the proposed criteria, to provide a comparison of the results obtained by the load factor and working stress designs, and to rationalize the differences between these results. This shall be done for as many of the load and resistance criteria that were developed as is necessary to validate the criteria.

Task 8—Identify and comment on other sections of the AASHTO Bridge Specifications that may be affected by the proposed changes in the foundation design criteria.

Task 9—Prepare and submit a final report containing the research findings and proposed load factor design criteria. Define the limits of applicability of the criteria. Identify additional research that may be needed for future development and refinement of the proposed criteria.

Through December 31, 1988, research on the project is proceeding on schedule. The interim report was reviewed and approved near the end of 1988. The scope of work was modified towards the development of a load and resistance factor design (LRFD) based specification. This will provide compatibility with the comprehensive bridge specification being developed under NCHRP Project 12-33.

Project 24-5 FY '88

Downdrag on Bitumen-Coated Piles

Research Agency:	Texas A&M Research Foundation
Principal Invest.:	Dr. Jean-Louis Briaud
Effective Date:	June 15, 1988
Completion Date:	June 14, 1991
Funds:	$200,000

Foundation piles are subject to downdrag forces whenever the soil surrounding them settles. The settlement of thick compressible soils under embankments can cause downdrag forces significantly larger than the structural load the pile must carry. This additional load may result in unacceptable settlements of the piles or even failure of part of the pile group.

Downdrag forces have been reduced by coating the piles with bitumen. Several approaches for predicting and reducing downdrag forces have been published but little verification of design methods and material properties is available.

Research is needed to verify and improve the present state of the art in both design and construction techniques for using bitumen-coated piles. This research is expected to improve design and testing procedures for practical use and to provide a basis for design confidence.

The overall objective of this research is to develop practical guidelines for use of bitumen-coated piles including: (1) coating material specifications and tests, (2) design techniques, and (3) construction practices. It is

anticipated that accomplishment of this objective will involve the following tasks:

Phase I

Task 1. Review the current practice and literature on methods of reducing downdrag forces in piles using bituminous (and other viscous) coatings. This review should analyze concepts, assumptions and limitations of each design and construction method. Prepare a background summary and a complete bibliography.

Task 2. Prepare a preliminary Design and Construction Manual based on the present state of the art. This manual should contain but not be limited to:

a. Recognition of downdrag problems on uncoated piles and the justification for using bituminous coatings.
b. Methods of calculating downdrag forces.
c. Mechanics of reducing downdrag with bituminous materials.
d. Information on consistency and other relevant characteristics of bituminous materials.
e. Evaluation of the soil-coating interaction on the magnitude of the downdrag force.
f. Methods of design and selection of appropriate bitumen from types commonly available.
g. Methods of applying, measuring, and protecting bituminous coatings.
h. Recommended material and construction specifications for bitumen-coated concrete, steel, and timber piles.

Task 3. Identify the shortcomings, if any, in current knowledge that inhibit the use of bitumen-coated piles.

Task 4. Prepare a proposal for laboratory and field testing programs to verify the methods recommended under Task 2 and to resolve any shortcomings cited in Task 3.

Phase II

Task 5. Perform suitable laboratory and field tests to verify bitumen-coating design methods identified in Phase I.

Task 6. Finalize the Design and Construction manual.

Task 7. Prepare a report summarizing test results and conclusions.

Research has been initiated and review of literature and current practice is underway.

AREA 25: IMPACT ANALYSIS

This area became effective January 1, 1979, and includes only those projects beginning with the FY 1981 program. Refer to Areas 7, 8, and 20 for previous projects in the realm of Impact Analysis.

Project 25-1 FY '81

Effects of Highway Runoff on Wetlands

Research Agency: Rexnord, Inc.
Principal Invest.: Dr. Nicholas P. Kobriger
Effective Date: February 16, 1981
Completion Date: March 16, 1984
Funds: $162,189

The objectives of this research were to identify the interactions between wetland systems and highway runoff, to identify the effects of highway runoff on wetlands, and to develop guidelines for the practical management of highway runoff on wetlands. Although no one situation is exactly like another, the results of this research provide excellent background for understanding the characteristics of wetlands, their functions, and the effects of highway runoff. Practical guidance for the management of runoff from highways in close proximity to wetlands was developed and should be of considerable interest and use. This guidance includes the management of runoff from the highway to and in the wetlands. A possibility also addressed is the use or creation of wetlands to mitigate the effects of highway runoff.

Research has been completed. The project report is comprised of two documents: the main research report and the guidelines. The research report titled, "Effects of Highway Runoff on Wetlands," was not published in the regular NCHRP series. However, a copy of the report was distributed to all Program Sponsors, and the report is available to others on a loan basis or for purchase of Xerox copies (see final page of this section for ordering information). This research report provides an excellent, comprehensive resource document on the subject and related areas.

The guidelines emanating from Project 25-1 were published as: NCHRP Report 264, "Guidelines for the Management of Highway Runoff on Wetlands." This report, in addition to providing guidelines for the practical management of highway runoff in wetlands, highlights the significant findings of the research and includes an extensive bibliography categorized by the following subject areas: processes and pathways, runoff constituents and aquatic ecosystems, runoff characteristics; state and federal regulations, wetland creation, wetland monitoring, assessing the interactions of highway runoff and wetlands, wetland vegetation and classification, and case studies.

Project 25-2 FY '88

Predicting Stop-and-Go Traffic Noise Levels

Research Agency: Vanderbilt University
Principal Invest.: Dr. William Bowlby
Effective Date: January 18, 1988
Completion Date: January 17, 1989
Funds: $64,999

STAMINA 2.0 has become the standard computer-based noise prediction model to aid in the assessment of existing and future noise levels on highway projects. It has the versatility to use several ranges of factors (or data) to predict noise levels for many types of conditions. However, STAMINA deals with free flowing traffic traveling at least 30 miles per hour. It does not have the capability of dealing with stop-and-go conditions that are frequently encountered in urban areas and can be very different from normal free flow traffic conditions.

Noise analysts using STAMINA have been attempting to predict noise levels for stop-and-go conditions by using various approximations and engineering judgments, such as varying average vehicle speeds and emission levels. The analyst who assesses existing and future noise levels for environmental impact statements (EIS's) or environmental assessments (EA's) using STAMINA has no formally recognized basis for adjusting the program to adequately reflect stop-and-go conditions. Consequently, the error resulting from the use of these approximations can be significant. Research is needed to develop a standard procedure for accurately assessing stop-and-go noise levels by adding additional emission level characteristics and other relevant factors to the STAMINA model. Therefore, the objective of this project is to develop a procedure for predicting stop-and-go traffic noise levels that can be input into the STAMINA 2.0 noise model. The agency preliminary draft final report has been submitted and is now under review.

Project 25-3 FY '89

Guidelines for the Development of Wetland Replacement Areas

Research Agency:	Contract Pending
Principal Invest.:	
Effective Date:	(27 months)
Completion Date:	
Funds:	$299,711

Planning for highway projects frequently involves consideration of several mitigative alternatives to address adverse impacts to wetland resources. One alternative often used requires the development of wetland replacement areas as compensation for wetlands lost due to highway development projects. Although considerable information is available on the subject of wetland replacement, both in documented form and undocumented experience or practice, much of this information is fragmented and dispersed throughout the country, or has not been fully evaluated. Therefore, current information cannot be easily used for locating, designing, constructing, or monitoring wetland replacement areas. However, to ensure effective implementation of this important mitigative alternative, transportation planners, designers, environmental staff, and other users must have this information readily available. Therefore, there is a need to synthesize the present state of the art and from this synthesis develop a recommended process for replacing wetlands.

The objective of this research is to develop a manual containing a well-defined wetland replacement process, including guidelines and techniques for locating, designing, constructing, monitoring, and maintaining wetland replacement sites. The guidelines and techniques shall be organized on a geographic or ecological basis as appropriate. This objective will be accomplished by completing the following tasks:

Task 1. Examine existing wetland replacement data. Locate, assemble, and evaluate all available technical information and current research projects pertaining to the subject of wetland replacement.

Task 2. Interview personnel having wetland replacement experience. Meet with personnel from transportation and natural resource agencies, environmental and engineering consultants, and other organizations, who have been or currently are involved in wetland replacement efforts. These interviews shall determine the various wetland replacement processes; design and construction techniques; construction plans, specifications, and special provisions; and cost information now being used to develop wetland replacement areas. Problems, constraints, and special monitoring and maintenance requirements associated with these wetland replacement efforts are also to be identified.

Task 3. Collect field data. A detailed plan shall be developed to collect data to validate or supplement the information from Tasks 1 and 2. The plan must include a list of proposed types of data to be collected on existing wetland replacement projects considered successful and unsuccessful in terms of functions and values. A rationale for the data to be collected must also be provided. It is beyond the scope of this study to perform comprehensive field sampling. The detailed plan shall be submitted to NCHRP for review and approval. Upon approval, the plan shall be implemented.

Task 4. Develop wetland replacement process manual. Using the information collected under Tasks 1 through 3, develop a wetland replacement manual. The manual will provide a detailed process for determining the steps and factors that need to be considered in the location and general design of wetland replacement areas to fulfill regulatory and policy needs. On an ecological or a geographical basis, as appropriate, the manual shall also provide guidelines and techniques for site selection, analysis, and design; construction plans, specifications, special provisions, and cost estimates; monitoring; and maintenance.

Task 5. Preparation of final report. Prepare a final report that documents the research effort. As a minimum, the report shall include the following: (a) a description of the current state of the art on wetland replacement techniques, their effectiveness and practicality, using a combination of concise narrative, tables, and illustrations; (b) a discussion of the problems and constraints frequently encountered in the location, design, construction, monitoring, and maintenance of wetland replacement areas; (c) recommendations for policy changes and additional research; and (d) an assessment of the feasibility for developing a "knowledge-based expert system" based on the Task 4 manual. The Task 4 manual shall be part of the total final report package.

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Items for Sale

1. NCHRP Series Reports, Syntheses, and Research Results Digests (see Tables 6, 7, and 8 for prices).
2. Research agencies' final reports (see project summaries for prices).
3. Microfiche ($5.95 per report). Price may change without notice. See latest Summary of Progress for current cost.
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A check or money order, payable to *Transportation Research Board,* must accompany orders totaling $20.00 or less. Mail to:

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Washington, DC 20418

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1. Some research agencies' final reports, manuals, videotapes, etc., are identified in the project summaries and are available on a loan basis upon written request to the *NCHRP, 2101 Constitution Avenue, N.W., Washington, DC 20418.*
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