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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

## SUMMARY OF PROGRESS

December 31, **1989**

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NATIONAL RESEARCH COUNCIL

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

## SUMMARY OF PROGRESS

December 31, **1989**

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### NOTICE TO READERS

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On December 31, 1988, a *special edition* of the Summary of Progress was published compiling information on all projects initiated under the NCHRP from its inception in 1962 through 1988. This 1989 publication, and subsequent editions, update the Summary of Progress series, including *only* those projects that were active, or for which some type of activity remained, after January 1, 1989. To obtain a copy of the *Summary of Progress Through 1988—Special Edition*, refer to the final page of this document for ordering information

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TRANSPORTATION RESEARCH BOARD  
NATIONAL RESEARCH COUNCIL 1989

MAY 4 1990

EB# 0147

## **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 av-

enues 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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## NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

# SUMMARY OF PROGRESS

## THROUGH 1989

### 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 on-going 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 1989 AASHTO referred the twenty-eighth program (FY '90) of research problems. From all programs

through FY '90, 565 research contracts have resulted (Table 3), totaling some \$91.5 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-ninth program (FY '91) was formulated in September 1989 by the Standing Committee on Research. Proposals will be solicited in March 1990. AASHTO's initial steps toward development of the thirtieth research program (FY '92) 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 '90 program were scheduled to begin in December 1989.

**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**

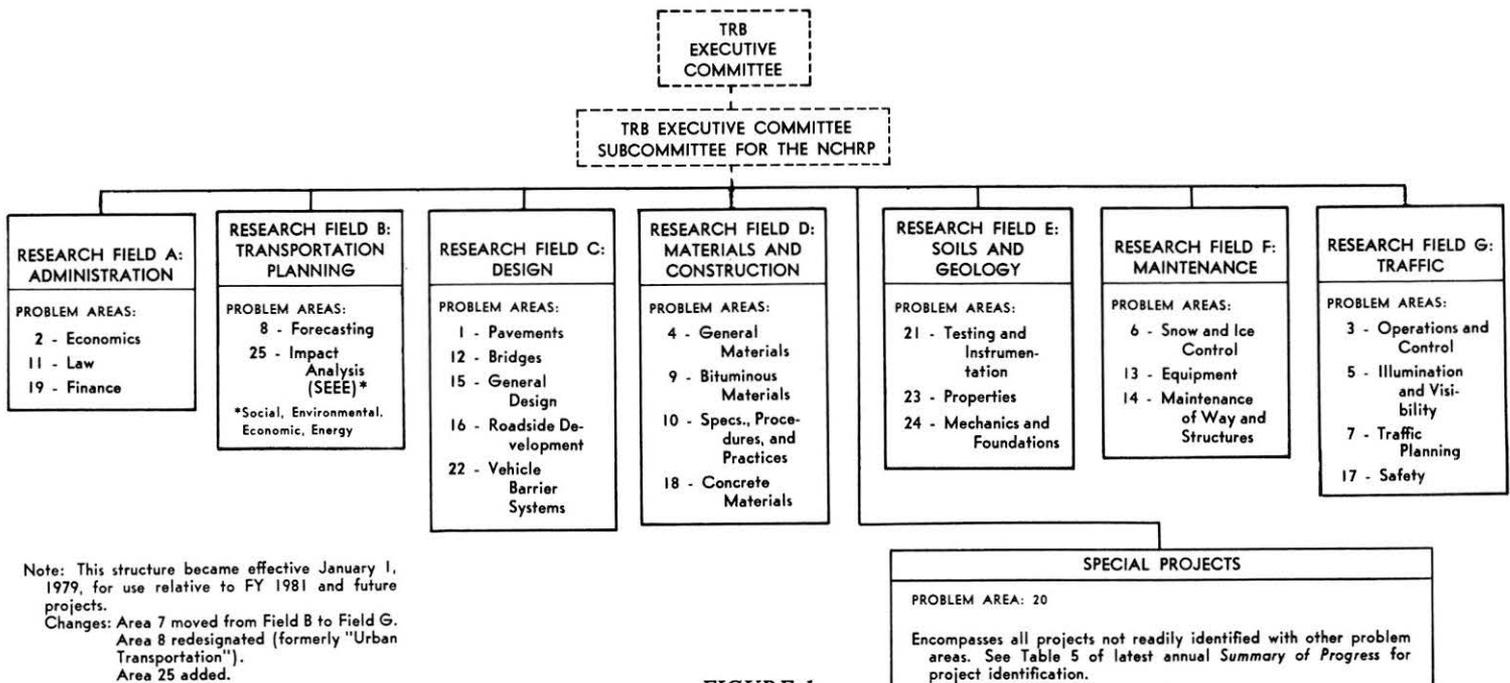


FIGURE 1

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.

TABLE 1  
DISTRIBUTION OF PROJECTS WITH  
RESPECT TO GENERALIZED SUBJECT AREAS

NO. OF PROJECTS	PERCENT OF FUNDS	GENERALIZED SUBJECT AREAS
53	9.0	Socio-economic and environmental issues
62	12.3	Urban issues
15	2.8	Multimodal issues
83	13.5	Safety and accident prevention
20	3.4	Legal studies
28	13.7	Special projects (including in-house)
32	5.0	Improved materials quality and performance
35	8.8	Highway maintenance
70	13.4	Specifications, tests, and construction control
102	18.1	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 1990 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	316	360
Federal Highway Administration*	35	48
Special transportation and other governmental agencies	65	73
Educational institutions	112	128
Research institutes	5	5
Industry, consultants, and trade associations	149	178
Professional societies and service organizations	10	12
All	692	804

\* Does not include liaison representatives

TABLE 3  
AGENCY DISTRIBUTION OF FY '63 THROUGH  
FY '90 PROJECTS

TYPE OF AGENCY	CONTRACTS	
	NO.	%
Educational institutions	192	34
Research institutes	86	15
Industry, consultants, and trade associations	263	46
Professional societies and service organizations	16	3
State highway and transportation departments	5	1
Special transportation and other governmental agencies	3	1
All	565	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 research 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. Re-

### **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).

search 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.

- 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 Offi-

cial 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, 1989 FOR FY '63 THROUGH FY '90 PROJECTS

PROJECT		RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST (\$)
NO.	TITLE		
<b>AREA ONE: DESIGN—PAVEMENTS</b>			
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*
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	499,942
1-27	Video Image Processing for Evaluating Pavement Surface Distress	Triple Vision	350,000
1-28	Laboratory Determination of Resilient Modulus for Flexible Pavement Design	—	425,000
<b>AREA TWO: ADMINISTRATION—ECONOMICS</b>			
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 Summary of Progress Through 1988	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 Summary of Progress Through 1988	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 Summary of Progress Through 1988	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 Summary of Progress Through 1988	1-15
6/3/74	10/31/81	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	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	Completed—Report not publ., for avail., see Summary of Progress Through 1988	1-25
9/1/88	8/31/91	Research in progress	1-25(1)
2/6/87	3/1/92	Research in progress	1-26
3/1/89	8/31/91	Research in progress	1-27
33 months		Contract pending	1-28
6/1/63	11/30/67	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	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		RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST (\$)
NO.	TITLE		
<b>AREA TWO (Continued)</b>			
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	225,000
2-15	Identifying, Measuring, and Evaluating the Benefits of Safety Roadside Rest Areas	KLD Associates	236,560
2-16	Relationships Between Vehicle Configurations and Highway Design	TRB	900,000
2-17(1)	Methodologies for Evaluating the Effects of Transportation Policies on the Economy	J. F. Hickling Mgmt	99,145
2-17(2)	Workshop on Research Needs in Transportation and Economic Development	Greenhorne & O'Mara	50,000
<b>AREA THREE: TRAFFIC—OPERATIONS AND CONTROL</b>			
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 Summary of Progress Through 1988	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	1/31/90	Phase I rept. published as NCHRP Report 307; Phase II research in progress	2-14
1/13/86	9/30/89	Completed—To be published as NCHRP Report 324	2-15
3/2/87	6/30/90	Research in progress	2-16
9/1/89	8/31/90	Research in progress	2-17(1)
9/1/89	7/31/90	Research in progress	2-17(2)
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 Summary of Progress through 1988	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 Summary of Progress through 1988	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 Summary of Progress Through 1988	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 Summary of Progress Through 1988	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 Summary of Progress Through 1988	3-18(3)
7/21/77	11/20/80	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	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 Summary of Progress Through 1988	3-20

TABLE 4 (Continued)

PROJECT		RESEARCH	CONTRACT
NO.	TITLE	AGENCY	AMOUNT OR CONTRACT COST (\$)
<b>AREA THREE (Continued)</b>			
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 E. 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 and Level of Service at Ramp-Freeway Junctions	—	450,000
3-38(1)	Assessment of Alternative Technologies for Relieving Urban Traffic Congestion	Castle Rock Consult	199,752
3-38(1A)	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 Associates	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	Metro Transportation	124,789
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	Texas A&M	250,000
3-41	Procedure for Determining Work Zone Speed Limits	Graham-Migletz	200,000
<b>AREA FOUR: MATERIALS AND CONSTRUCTION—GENERAL MATERIALS</b>			
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	VPI	20,000*
4-3(2)	Development of Methods to Identify Aggregate Particles Which Undergo Destructive Volume Changes When Frozen in Concrete	Penn State U	23,337*
4-4	Synthetic Aggregates for Highway Uses	Battelle Mem Inst	56,457*
4-5	A Study of the Mechanism Whereby the Strength of Bases and Subbases Is Affected by Frost and Moisture	Michigan Tech U	49,756*
4-6	Protective Coatings for Highway Structural Steel	Steel Str Paint	64,105*
4-7	Fatigue Strength of High-Yield Reinforcing Bars	PCA	25,000*
4-8	Research Needs Relating to Performance of Aggregates in Highway Construction	VPI	100,000*
4-8(2)	Density Standards for Field Compaction of Granular Bases and Subbases	Clemson U	50,000*
4-8(3)	Predicting Moisture-Induced Damage to Asphaltic Concrete	U of Idaho	55,254*
4-8(4)	Predicting Moisture-Induced Damage to Asphaltic Concrete—10-year Field Evaluation	U of Idaho	95,248*
4-9	Evaluation of Preformed Elastomeric Pavement Joint Sealing Systems and Practices	Utah DOT	190,177*
			70,860*
			24,402*
			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 Summary of Progress Through 1988	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 Summary of Progress Through 1988	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 Summary of Progress Through 1988	3-23
9/1/74	4/30/77	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	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 Summary of Progress Through 1988	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 Summary of Progress Through 1988	3-28
5/1/80	2/28/83	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	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 Summary of Progress Through 1988	3-28(2)
7/1/83	3/31/86	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	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., but available for loan	3-32
6/1/85	4/30/90	Report in review stage	3-33
11/1/85	9/30/88	Completed—Published as NCHRP Report 303	3-34
6/1/86	5/31/89	Report in review stage	3-35
2/16/87	8/16/89	Research in progress	3-36
	36 months	Contract pending	3-37
7/1/87	12/31/89	Report in review stage	3-38(1)
	18 months	In developmental stage	3-38(1)A
6/1/87	3/31/89	Completed—Published as NCHRP Report 323	3-38(2)
9/1/87	6/30/89	Report in revision stage	3-38(3)
10/1/87	7/31/90	Research in progress	3-38(4)
4/1/88	4/1/90	Research in progress	3-38(5)
5/15/88	2/28/90	Report in review stage	3-38(6)
5/15/89	11/15/90	Research in progress	3-38(7)
3/1/88	11/30/90	Research in progress	3-39
5/1/89	2/1/91	Research in progress	3-40
11/15/89	8/15/91	Research in progress	3-41
6/1/63	10/31/66	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	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 Summary of Progress Through 1988	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 Summary of Progress Through 1988	4-8(4)
10/1/68	6/30/71	Completed—Report included in Phase II report	4-9

TABLE 4 (Continued)

PROJECT		RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST (\$)
NO.	TITLE		
<b>AREA FOUR (Continued)</b>			
4-9(1)	Prefomed 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	249,973*
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*
<b>AREA FIVE: TRAFFIC—ILLUMINATION AND VISIBILITY</b>			
5-2(1)	Effects of Illumination on Operating Characteristics of Freeways—Traffic Flow, Driver Behavior, and Accidents	Yale University	124,319*
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*
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	475,325
5-11	Implementation Strategies for Sign Retroreflectivity Standards	Bellomo-McGee	200,000
<b>AREA SIX: MAINTENANCE—SNOW AND ICE CONTROL</b>			
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*
<b>AREA SEVEN: TRAFFIC—TRAFFIC PLANNING</b>			
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 Summary of Progress Through 1988	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 Summary of Progress Through 1988	4-13
4/1/78	9/30/79	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	4-13A
1/1/78	12/31/81	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	4-14
7/1/82	11/30/85	Completed—Published as NCHRP Report 313	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 Summary of Progress Through 1988	5-5A
9/1/71	12/31/74	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	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	8/1/90	Phase I completed; report not publ.; avail. on a loan basis; Phase II research in progress	5-10
2/15/89	4/30/91	Research in progress	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 Summary of Progress Through 1988	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 Summary of Progress Through 1988	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		RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST (\$)
NO.	TITLE		
<b>AREA SEVEN (Continued)</b>			
7-2	Traffic Attraction of Rural Outdoor Recreational Areas	IIT Research Inst	24,652*
7-3	Weighing Vehicles in Motion	Franklin Inst	24,844*
7-4	Factors and Trends in Trip Lengths	Voorhees & Assoc	73,391*
			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	Texas A & M	200,000
<b>AREA EIGHT: TRANSPORTATION PLANNING—FORECASTING</b>			
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 & Young	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 Summary of Progress Through 1988	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
2/1/89	1/31/91	Research in progress	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 Summary of Progress Through 1988	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 Summary of Progress Through 1988. Phase II report published as NCHRP Reports 216 and 217	8-11
9/3/74	12/31/75	Completed—Results published in 8-12A report	8-11
11/1/75	10/31/78	Completed—Published as NCHRP Reports 186 and 187	8-12
9/15/74	1/31/76	Completed—Phase I rep. not publ.; for avail., see Summary of Progress Through 1988	8-12A
5/1/76	12/31/80	Completed—Published as NCHRP Report 253	8-13
1/1/75	4/30/77	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	8-13(2)
1/1/78	6/30/82	Completed—Published as NCHRP Report 250	8-14
9/1/74	5/31/76	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	8-14A
10/1/77	3/31/80	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	8-15
1/1/76	12/31/80	Completed—Publ. as NCHRP Rep. 208, 209, 210, 211, 212	8-15A
7/15/75	2/15/77	Completed—Published as NCHRP Reports 177 and 178	8-16
9/1/75	6/30/78	Completed—Published as NCHRP Reports 179 and 199	8-17
12/1/76	11/30/78	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	8-18
1/2/78	7/31/80	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	8-19
3/1/79	6/30/81	Completed—Guidelines published as NCHRP Report 241; research rep. not publ.; for avail., see Summary of Progress Through 1988	8-20
			8-21
3/26/79	2/27/81	Completed—Published as NCHRP Report 231	8-21
4/2/79	9/1/80	Completed—Published as NCHRP Report 229	8-22
1/21/80	4/30/82	Completed—Published as NCHRP Report 266	8-23
4/1/87	1/1/90	Report in review stage	8-24
4/1/80	1/31/82	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	8-24A
5/15/81	12/31/82	Completed—Published as NCHRP Report 255	8-25
			8-26
9/1/81	4/30/83	Completed—Published as NCHRP Reports 261 and 262	8-27
6/1/87	7/31/89	Report in review stage	8-28

TABLE 4 (Continued)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST (\$)
<b>AREA NINE: MATERIALS AND CONSTRUCTION—BITUMINOUS MATERIALS</b>			
9-1	Asphalt Durability and Its Relation to Pavement Performance	American Oil	50,000*
9-2	Asphalt Durability and Its Relation to Pavement Performance—Adhesion	Montana College	50,000*
9-3	Evaluation of Pavement Joint and Crack Sealing Materials and Practices	Rensselaer	101,903*
9-4	Minimizing Premature Cracking of Asphaltic Concrete Pavements	Materials R & D	24,996*
9-4A	Bayesian Analysis Methodology for Verifying Recommendations to Minimize Asphalt Pavement Distress	Woodward-Clyde	99,560*
9-5	Design of Emulsified Asphalt Paving Mixtures	Asphalt Inst	204,194*
9-6A	Development of Asphalt Aggregate Mixture Analysis System: Phase I	ARE Inc	150,172*
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	25,000*
9-6(1)	Asphalt Aggregate Mixture Analysis System (AAMAS)	Brent Rauhut Eng	24,879*
			675,000
<b>AREA TEN: MATERIALS AND CONSTRUCTION—SPECIFICATIONS, PROCEDURES, AND PRACTICES</b>			
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	U of Washington	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	148,303*
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 Summary of Progress Through 1988	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	6/4/90	Research in progress	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 Summary of Progress Through 1988	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 Summary of Progress Through 1988	10-12
7/1/79	10/31/81	Completed—Published as NCHRP Report 242	10-13
10/1/82	8/31/85	Completed—Rep. not publ.; report avail. on a loan basis from NCHRP	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 Summary of Progress Through 1988	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	Laboratory phase published as NCHRP Report 274; field evaluation report in review stage	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	Report in editorial and publication process	10-20
8/21/89	2/28/92	Contract pending	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	Completed—Published as NCHRP Report 314	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 Summary of Progress Through 1988	10-24
10/13/83	9/5/86	Completed—Published as NCHRP Report 284	10-24
6/1/85	8/15/89	Report in review stage	10-25
6/15/83	9/14/84	Completed—Rep. not publ., for avail., see Summary of Progress Through 1988	10-25A
1/6/86	9/30/89	Report in review stage	10-26
9/17/84	8/31/89	Report in review stage	10-26A
11/1/85	12/31/87	Completed—Published as NCHRP Report 304	10-27
10/1/86	9/30/91	Research in progress	10-28
			10-29

TABLE 4 (Continued)

PROJECT		RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST (\$)
NO.	TITLE		
<b>AREA TEN (Continued)</b>			
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
<b>AREA ELEVEN: ADMINISTRATION—LAW</b>			
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, Mikkeltborg	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 RI 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*
<b>AREA TWELVE: DESIGN—BRIDGES</b>			
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*
12-8	Bridge Rail Service Requirements as a Basis for Design Criteria	Texas A & M	200,000*
			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 Summary of Progress Through 1988	10-30(1)
1/20/86	10/3/86	Completed—Rep. not publ., for avail., see Summary of Progress Through 1988	10-30(2)
7/1/87	8/31/90	Research in progress	10-30(3)
1/1/86	12/31/89	Report in review stage	10-31
1/6/86	7/5/87	Completed—Published as NCHRP Report 296	10-32
10/1/87	3/31/91	Research in progress	10-32A
1/6/86	12/15/88	Completed—Published as NCHRP Report 315	10-33
3/1/86	1/31/89	Completed—Published as NCHRP Report 317	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 Summary of Progress Through 1988	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 Summary of Progress Through 1988	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 Summary of Progress Through 1988	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 Summary of Progress Through 1988	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 Summary of Progress Through 1988	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 Summary of Progress Through 1988	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 Summary of Progress Through 1988	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	12/31/90	Research in progress	12-15(5)
9/1/74	11/30/77	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	12-16

TABLE 4 (Continued)

PROJECT		RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST (\$)
NO.	TITLE		
<b>AREA TWELVE (Continued)</b>			
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	Engr Comp Corp	100,000*
12-23	Recommended Revisions to the AASHTO <i>Manual for Maintenance Inspection of Bridges</i>	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	370,229*
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	191,024*
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	241,031
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	375,000
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	50,000
12-33B	Development of a Comprehensive Bridge Specification and Commentary—Concrete Structures	Imbsen & Assoc	50,000
12-33C	Development of a Comprehensive Bridge Specification and Commentary—Soil Structure Interaction Systems	D'Appolonia	45,000
12-34	Update of AASHTO <i>Standard Specifications for Highway Bridges: Division II—Construction</i>	Imbsen & Assoc	200,000
12-35	Recommended Specifications for the Design of Foundations, Retaining Walls, and Substructures	D'Appolonia	100,000
<b>AREA THIRTEEN: MAINTENANCE—EQUIPMENT</b>			
13-1	Equipment Rental Rates	Ernst & Ernst	22,800*
<b>AREA FOURTEEN: MAINTENANCE—MAINTENANCE OF WAY AND STRUCTURES</b>			
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	80,811

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 Summary of Progress Through 1988	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 Summary of Progress Through 1988	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 Summary of Progress Through 1988	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 in progress	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	Completed—Published as NCHRP Report 321	12-27
9/1/85	8/31/89	Phase I rept. published as NCHRP Report 301; Phase II report in review stage	12-28(1)
6/24/85	6/23/87	Completed—Published as NCHRP Report 300	12-28(2)
11/2/87	11/1/89	Report in review stage	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	11/30/89	Report in review stage	12-28(6)
5/5/86	11/30/89	Report in review stage	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	5/31/89	Completed—Published as NCHRP Report 319	12-28(10)
2/9/87	3/30/90	Report in review stage	12-28(11)
9/1/87	5/30/90	Research in progress	12-28(12)
10/4/87	9/30/89	Report in review stage	12-28(13)
8/26/85	5/31/88	Completed—Published as NCHRP Report 322	12-29
1/13/86	2/12/89	Report in review stage	12-30
9/1/87	8/30/90	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
7/24/89	12/31/91	Research in progress	12-33C
10/19/87	10/18/89	Completed—Rep. not publ.; see proj. writeup in latest Sum. of Prog.	12-34
1/4/88	7/3/89	Completed—Rep. not publ.; see proj. writeup in latest Sum. of Prog.	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	14-1
9/11/72	3/15/76	Completed—Published as NCHRP Report 202	14-2
4/15/74	3/24/76	Completed—Published as NCHRP Report 196	14-3
1/1/78	4/30/80	Completed—Published as NCHRP Report 223	14-4
9/15/81	8/31/84	Completed—Published as NCHRP Report 273	14-5
6/1/82	12/31/85	Completed—Published as NCHRP Report 285	14-5(2)
9/1/87	5/1/89	Report in review stage	14-6
			14-7

TABLE 4 (Continued)

PROJECT		RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST (\$)
NO.	TITLE		
<b>AREA FOURTEEN (Continued)</b>			
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
14-9(1)	Effective Maintenance Budget Strategies	Urban Institute	250,000
14-9(2)	Incorporation of Maintenance Considerations in Highway Design	—	190,000
14-9(3)	Maintenance Contracting	—	150,000
14-10	Improvements in Data Acquisition Technology for Maintenance Management Systems	Urban Institute	100,000
14-11	Effective Motivation of Highway Maintenance Personnel	Penn State U	200,000
<b>AREA FIFTEEN: DESIGN—GENERAL DESIGN</b>			
15-1	Guardrail Design	Cornell Aero Lab	19,723*
15-1(2)	Guardrail Performance and Design	Sw Research Inst	280,000*
15-2	Design to Control Erosion in Roadside Drainage Channels	U of Minnesota	100,000*
15-3	Rational Structural Analysis and Design of Pipe Culverts	U of Minnesota	97,300*
15-4	Estimating Runoff Rates from Small Rural Watersheds	Northwestern U	49,937*
15-5	Dynamic Characteristics of Heavy Highway Vehicles	Travelers Res Cen	299,902*
15-6	Development of Criteria for Safer Luminaire Supports	Gen Mot Corp	135,000*
15-7	Flow Modifications by Storage Loss Through Flood Plain Encroachment	Texas A & M	147,254*
15-8	Parameters Affecting Stopping Sight Distance and Vehicle Acceleration/Deceleration Characteristics	Dames & Moore	99,730*
15-9	Encasement of Pipelines Through Highway Roadbeds	U of Michigan	274,482*
15-10	Development of a Design/Graphics Interface System	Byrd, Tallamy et al	30,000
15-11	Computer-Aided Analysis of Highway Encroachments on Mobile Boundary Streams	Beilfuss & Assoc	500,000
15-12	Roadway Widths for Low Traffic Volume Roads	Simons & Assoc	249,360
15-13	Long-Term Performance of Geosynthetics in Drainage Applications	Jack E. Leisch Assoc	250,000
		—	500,000
<b>AREA SIXTEEN: DESIGN—ROADSIDE DEVELOPMENT</b>			
16-1	Effects of Deicing Compounds on Vegetation and Water Supplies	VPI	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*
<b>AREA SEVENTEEN: TRAFFIC—SAFETY</b>			
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
<b>AREA EIGHTEEN: MATERIALS AND CONSTRUCTION—CONCRETE MATERIALS</b>			
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*

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	Completed—Problem statements developed	14-9
11/15/89	11/15/91	Research in progress	14-9(1)
	24 months	Contract pending	14-9(2)
	18 months	Contract pending	14-9(3)
5/29/89	5/28/90	Research in progress	14-10
6/1/89	8/31/91	Research in progress	14-11
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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 Summary of Progress Through 1988	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 Summary of Progress Through 1988	15-7
5/1/82	5/31/84	Completed—Published as NCHRP Report 270	15-8
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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
5/1/89	10/31/91	Research in progress	15-12
	36 months	Contract pending	15-13
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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
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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
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12/16/88	5/15/89	Completed—Published as NCHRP Report 320	17-7
6/1/88	5/31/91	Research in progress	17-8
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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 Summary of Progress Through 1988	18-2(2)
5/1/80	4/29/83	Completed—Published as NCHRP Report 257	18-2(3)

TABLE 4 (Continued)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST (\$)
<b>AREA NINETEEN: ADMINISTRATION—FINANCE</b>			
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*
<b>AREA TWENTY: SPECIAL PROJECTS</b>			
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 <sup>a</sup>
20-3A	Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control	U of Michigan	505,631* 20,000 <sup>b</sup>
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	650,000 <sup>c</sup>
20-6	Legal Problems Arising out of Highway Programs	TRB	200,000 <sup>c</sup>
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 HUFSA	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	—

STARTING DATE	COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
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
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 Summary of Progress Through 1988	20-3C
5/15/77	12/31/78	Completed—Spec. publ.; for avail., see Summary of Progress Through 1988	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: Refer to Table 6 for topic reports published as NCHRP Syntheses	20-5
11/1/68	c	Research in progress: Refer to Tables 7 and 8 for publications	20-6
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 Summary of Progress Through 1988	(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 Summary of Progress Through 1988	(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 Summary of Progress Through 1988	(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 Summary of Progress Through 1988	(Task 21) 20-7
3/1/82	11/30/82	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	(Task 22) 20-7
7/26/82	4/17/84	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	(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 Summary of Progress Through 1988	(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 Summary of Progress Through 1988	(Task 28) 20-7
—	—	Conducted under Project 1-23(2)	(Task 29) 20-7

TABLE 4 (Continued)

PROJECT		RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST (\$)
NO.	TITLE		
<b>AREA TWENTY (Continued)</b>			
	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	50,000
	Task 35: Review of Traffic Signal Intensity Standards	JMJ Research	81,536
	Task 36: Critical Assessment of Tire Pressure Research	Harry A. Smith	15,000
	Task 37: Development of an Asphalt Paving Handbook	TRB	45,000 <sup>d</sup>
	Task 38: AASHTO Guidelines for Pavement Management Systems	ARE Inc	99,989
	Task 39: Revision of the AASHTO Pavement Overlay Design Procedures	Darter & Assoc	75,000
	Task 40: Analytical Support for the Highway Research Coordinating Council	L. G. Byrd	10,000 <sup>e</sup>
	Task 41: AASHTO Guide for Recruitment and Retention of Transportation Professionals	Herb Golden	\$18,200
	Task 42: Development of National Truck Size and Weight Policy Recommendations	TRB	\$50,000
	Task 43: Revision of the AASHTO Policy on Geometric Design of Highways and Streets	—	—
	Task 44: Division 100 Revision of the AASHTO Guide Specifications for Highway Construction	—	\$60,000
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	146,218
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
20-24(2)	Executive Management Information Systems for State Departments of Transportation	Andersen Consult	100,000
20-25	Training Needs for Highway Construction Personnel	U of Maryland	74,927
20-26	Bond and Insurance Coverages for Highway Construction Contractors	Texas A & M	100,000
20-27	Adaptation of Geographic Information Systems for Transportation	—	220,000

STARTING DATE	COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
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
12/15/88	3/14/90	Research in progress	(Task 35) 20-7
11/15/88	7/14/89	Report in review stage	(Task 36) 20-7
4/15/88	10/15/89	Report in review stage	(Task 37) 20-7
1/2/89	10/31/90	Research in progress	(Task 38) 20-7
6/1/89	5/31/90	Research in progress	(Task 39) 20-7
9/1/88	12/31/89	Research in progress	(Task 40) 20-7
7/1/89	6/30/90	Research in progress	(Task 41) 20-7
9/1/89	8/31/90	Research in progress	(Task 42) 20-7
—	—	Cancelled	(Task 43) 20-7
—	—	In developmental stage	(Task 44) 20-7
9/1/70	7/31/71	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	20-8
8/1/72	12/17/76	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	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 Summary of Progress Through 1988	20-11
9/1/75	11/30/76	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	20-11A
1/24/77	5/4/79	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988; sum. in NCHRP Res. Results Digest 114	20-11B
4/1/77	3/31/78	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	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 Summary of Progress Through 1988	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	12/31/89	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 Summary of Progress Through 1988	20-20(2)
3/15/85	1/31/86	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	20-20(3)
3/15/85	1/31/86	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	20-20(5)
3/15/85	1/31/86	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	20-20(6)
3/15/85	1/31/86	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	20-20(7)
4/12/85	2/26/86	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	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	Completed—Report distributed to program sponsors; sum. in NCHRP Research Results Digest 170	20-24
10/1/88	9/30/89	Report in review stage	20-24(1)
5/1/89	10/14/89	Report in review stage	20-24(2)
6/15/89	6/14/90	Research in progress	20-25
6/1/89	9/30/90	Research in progress	20-26
18 months		Contract pending	20-27

TABLE 4 (Continued)

PROJECT		RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST (\$)
NO.	TITLE		
<b>AREA TWENTY-ONE: SOILS AND GEOLOGY—TESTING AND INSTRUMENTATION</b>			
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*
21-3	Instruments for Measuring Scour at Bridge Piers and Abutments	Resource Consult Inc	299,824
<b>AREA TWENTY-TWO: DESIGN—VEHICLE BARRIER SYSTEMS</b>			
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*
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	Sw Research Inst	503,954*
22-5	Develop Performance Standards and Hardware for Low Service Level Guardrail Systems	Sw Research Inst	200,000
22-5A	Warrants for the Installation of Low Service Level Guardrail Systems	—	100,000
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”	Texas A & M	200,000
22-8	Evaluation of Performance Level Selection Criteria for Bridge Railings	Texas A & M	200,000
<b>AREA TWENTY-THREE: SOILS AND GEOLOGY—PROPERTIES</b>			
No Projects			
<b>AREA TWENTY-FOUR: SOILS AND GEOLOGY—MECHANICS AND FOUNDATIONS</b>			
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	459,152
24-5	Downdrag on Bitumen-Coated Piles	Texas A&M	200,000
<b>AREA TWENTY-FIVE: TRANSPORTATION PLANNING—IMPACT ANALYSIS</b>			
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	URS Consultants	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.

<sup>a</sup> 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.
8/25/69	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)
12/1/89	2/29/92	Research in progress	21-3
10/1/70	12/31/71	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	22-1
3/1/74	5/30/75	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988; summarized in NCHRP Res. Results Dig. 81	22-1A
1/1/72	9/30/73	Completed—Phase I and Phase II (Task 1) reports not published; for avail., see Summary of Progress Through 1988; summarized in NCHRP Res. Results Digests 84 and 102; Task 2 rep. publ. as NCHRP Rep. 153	22-1A
10/1/73	3/31/75	Completed—Phase I and Phase II (Task 1) reports not published; for avail., see Summary of Progress Through 1988; summarized in NCHRP Res. Results Digests 84 and 102; Task 2 rep. publ. as NCHRP Rep. 153	22-2
8/1/76	4/30/79	Completed—Agency reps. on Ph. I and Ph. II avail. for loan	22-2
1/1/79	5/31/81	Completed—Published as NCHRP Report 239	22-2(2)
5/1/79	2/28/81	Completed—Published as NCHRP Report 230	22-2(3)
1/1/74	2/15/75	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988; summarized in NCHRP Res. Results Dig. 76	22-2(4)
7/1/74	12/31/74	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988; summarized in NCHRP Res. Results Dig. 76	22-3
7/1/83	7/15/87	Completed—Published as NCHRP Report 289	22-3
5/1/85	1/31/89	Completed—Research continued as Project 22-5A	22-3A
	18 months	In developmental stage	22-4
6/1/85	11/30/88	Completed—Published as NCHRP Report 318	22-5
6/1/89	11/30/91	Research in progress	22-6
4/15/89	1/14/91	Research in progress	22-7
4/2/79	12/31/80	Completed—Report to be published by AASHTO	22-8
8/22/83	5/21/87	Completed—Published as NCHRP Report 290	24-1
1/6/86	8/31/88	Completed—Published as NCHRP Report 316	24-2
9/1/87	12/31/90	Research in progress	24-3
6/15/88	6/14/91	Research in progress	24-4
			24-5
2/16/81	3/16/84	Completed—Published as NCHRP Report 264	25-1
1/18/88	5/31/89	Completed—Published as NCHRP Report 311	25-2
4/1/89	6/30/91	Research in progress	25-3

<sup>b</sup> 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.

<sup>c</sup> Continuing activity. Amount shown is for latest fiscal year in which funding was provided.

<sup>d</sup> 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).

<sup>e</sup> 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. Conn. DOT	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. To design experimental pavement projects.
1-2	Report 7	N. Y. DOT Tallamy, Byrd,—	To develop a flexible pavement performance equation; in use June 1968. 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 Conn. DOT	Major equipment purchase based on successful use of similar equipment in conduct of project. In evaluating flexible experimental pavements.
1-7	Report 37	Nat'l. Hwy. Safety Bur. 92nd Cong., 1 Sess. Conn. DOT	In preparation of a <i>Highway Safety Program Manual</i> for issuance to the States. House of Representatives subcommittee hearings on highway safety and skidding. 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. Conn. DOT	In evaluation of proposed State legislation regarding use of studded tires. 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.
1-12	—	AASHTO 92nd Congress, 1st Sess.	Partly published as <i>Interim Guide for Design of Pavement Structures, 1972</i> 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 N. Y. DOT	As background information on skid-testing program. Leans heavily on the suggestions presented when purchasing or altering skid trailers and when modifying operational procedures.
1-12(3)	—	ASTM 92nd Cong., 1 Sess.	As basis for updating ASTM Method E274. 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 Japan Road Contractors Association	In the design of pavement rehabilitation programs. 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 Illinois DOT	As input to FHWA-AASHTO Long-Term Pavement Monitoring Program documents. As reference for identifying concrete pavement distress.
1-21	Agency draft guide, "Specs. for Joint Repair"	FHWA Penn. DOT	As input to internal publication titled, "Construction Handbook on PCC Pavement Rehabilitation." As a guide for developing policies and repair techniques.
2-5	Reports 13, 111	One State (unkn.)	To replace outdated material in AASHTO book, <i>Urban Freeway Design</i> .
2-5A	Report 111	AASHTO W. W. Rankin, I.T.E.	In draft of proposed AASHTO publication, <i>A Policy on Arterial Highways in Urban Areas</i> . In preparing textbook on traffic engineering.
2-6	Report 63	E. L. Grant, W. G. Ireson	In textbook, <i>Principles of Engineering Economy</i> .

\* Project titles, as well as project status, are given in Table 4. Publication titles are given in Tables 6, 7 and 8.

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 Agency report	Federal Supply Serv., Gen. Serv. Adm. J. Leisch & Assoc. AASHTO Colorado SHD	Vehicle operating cost data applied in review of Govt. employee automobile costs. As an aid in conducting a planning-design course for the South Carolina SHD in coordination with the Governor's Safety Program. Published by AASHTO as <i>A Manual on User Benefit Analysis of Highway and Bus Transit Improvements</i> . 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 Minn. DOH Calif. Div. of Hwys.	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. Steps taken toward implementation of the delay difference offset technique in an existing signal network. 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.
3-7	Agency final report Reports 78, 117 and "Illustrative Recording of Traffic Noise"	Goodell, Grivas and Assoc. Hwy. Depts., FHWA offices, universities, consulting firms, County Bd. of Educ. Georgia SHD Minnesota Legislature Virginia DOH Arizona cons. firm Natl. Assn. of Home-builders Missouri SH Comm. FHWA Louisiana DOH AASHTO Howard, Needles, et al. Express Hwy. Res. Fdn. (Japan)	Obtained contract to use model described in report on a network in Detroit. 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. Noise design guide used in design of urban freeway system. 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. 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. 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. In development of a <i>Builders' Acoustical Manual</i> that includes guidelines for prediction of site noise due to traffic. Highway traffic noise simulation program used to establish noise projections on new project designs. In developing highway noise level standards PPM 90-2, "Interim Noise Standards and Procedures for Implementing Section 109(I) 23 U.S.C." As primary texts in a "noise school" for parish (county) engineers. As source documents for new (1974) publication, "Guide on Evaluation and Attenuation of Traffic Noise." Model for predicting highway traffic noise validated under contract to a state highway department. Abridgment (8 pp.) published in April 1972 issue of <i>Expressways and Automobiles</i> (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.
	Agency final rep. draft	Minnesota DOH Envir. Protection Agency	Predictions for use in design of I-35W noise barrier in S. Minneapolis. In evaluating alternatives for truck noise emission regulations.
	Agency final rep.	Nat. Bur. Stand. Md.-Natl. Cap. Park and Plan. Comm.	Published a form of the Noise Prediction Nomogram adapted to an "L-equivalent" measure. Found to be useful and quite accurate as a tool in preparation of land-use plans.
3-8	Rep. 78, 117, 144 Report 50	Conn. DOT Orange Co. (Calif.) Traf. Eng. Council Illinois Div. of Hwys., Bur. of Design	As a basis for noise analyses. Extensive use as best available source of information for preparation of warrants for installation of protective devices at rail-grade crossings. 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.
3-9	Report 84	Conn. DOT Calif. Div. of Hwys.	Source reference for Railroad-Highway Safety Grade Crossing Program. 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 <u>You</u> 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 <i>Manual on Uniform Traffic Control Devices</i> .
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 <i>Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part II</i> , 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 Subcommittee 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 Oper.	Input (with Report 77, Proj. 15-6) to the March 1969 publication, <i>Informational Guide to Roadway Lighting</i> .
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 ( <i>Civil Eng.</i> , 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. U.S. Park Serv.	See Project 6-1. 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.
8-16	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.
	Agency final report Appendix, "Transportation Services for the Transportation Disadvantaged"	Am. Public Transit Assoc.	Testimony on proposed DOT regulations to implement Sec. 504 of the Older Americans Rehabilitation Act.
		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.
	Report 147	Conn. DOT	To change bridge design parameters in order to reduce fatigue cracking.
		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 <i>Standard Specifications for Highway Bridges</i> 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 <i>Manual for Maintenance Inspection of Bridges</i> .
12-32	Report 297	AASHTO	The corrosion protection requirements for reinforcing steel in the <i>Standard Specifications for Highway Bridges</i> 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.
14-5	Report 223	Conn. DOT Penn. DOT	In establishing Maintenance Management System. To determine tradeoffs between various maintenance 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 American Iron and Steel Inst. Illinois Div. of Hwys.	In planning, design, construction, maintenance, replacement of guardrails and median barriers. 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. 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 <i>Design Manual or Highway Standards</i> 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.
	Report 115	Nevada DOH Illinois DOT, Bur. Design	In evaluating acceptability of the Department's design criteria and standards. Findings have been found useful, and practice has been modified to conform with them.
	Report 118	Conn. DOT New York DOT	As a basis of guardrail systems currently used in Connecticut. 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 Wisconsin DOT Kansas SH Comm. Minnesota DOH Colorado DOH Soil Conserv. Serv., U.S. Dept. of Agr.	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. 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. As basis for publication, "Design of Stable Roadside Channels." 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. Method to size riprap protection included in Ch. 8 of Design Manual. Recommendations used in preparation of <i>SCS Tech. Release No. 59</i> , "Hydraulic Design of Riprap Gradient Control Structures."
	Report 108 and agency draft Report 108 and agency report	Hydr. Br., Bridge Div., FHWA Consultant, Madrid, Spain	As source documents for "Stable Channel Designs"; design procedures for riprap linings developed principally from Report 108. 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. California Div. of Hwys.	Input (with Report 20, Proj. 5-4) to March 1969 publication, <i>Informational Guide to Roadway Lighting</i> . 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.
15-7	Agency final report and User's Manual	Conn. DOT Wyoming Hwy. Dept.	As a basis for breakaway luminaires for highway lighting. As reference for guidance in determining flow modifications caused by storage losses on encroached flood plains.
16-1	Report 91	California Div. of Hwys. U.S. Government	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. 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
16-3	Agency report Report 221	Conn. DOT	In preparation of environmental impact statements.
		Iowa DOT	In a training program on erosion control for state personnel.
		Hittman Assoc. Inc.	Information and illustrations used in a field manual for the Office of Surface Mining, U.S. Dept. of Interior.
17-1	Reports 220 and 221 Report 79	Utah DOT Park City, Utah	To develop a manual. Developers are required by city ordinance to comply with provisions set forth in the reports.
		Robley Winfrey Calspan	In development of college textbook, <i>Economic Analysis for Highways</i> . As starting point for a Tri-Level Accident Research Program for NHTSA and the Motor Vehicle Mfrs. Assn.
17-2A	Agency report Report 162	Min. of Transp., Brazil	Translated into Portuguese.
		S. Dak. DOT., Div. of Hwys.	To assist in evaluating safety improvements accomplished under an ongoing safety program.
17-3	Report 219	Northwestern Univ. Office of Highway Safety, FHWA	As a reference and teaching aid in a graduate course in highway safety programming. By staff serving as instructors for a series of regional seminars on evaluation of safety improvements.
		FHWA Office of Traffic Operation	As source document for FHWA's Positive Guidance series on planning and collection of field data.
17-4	Report 236	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.
		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 <i>Highway Research in Progress</i> 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 Synthesis 2 Synthesis 4	Conn. DOT	As a basis for current signing patterns from Maintenance.
		Lab. de Eng., Angola	Translated into Portuguese.
Synthesis 5	Synthesis 5	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 <i>Instructional Memorandum 40-2-70</i> .
		N. Mex. SHD	In revising the Department's <i>Bridge Construction Manual</i> .
Synthesis 6 Synthesis 7	Synthesis 6 Synthesis 7	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 10 Synthesis 11	Synthesis 10 Synthesis 11	Conn. DOT	In project scheduling.
		92nd Cong., 1 Sess.	See Project 1-12.
Synthesis 12 Synthesis 14	Synthesis 12 Synthesis 14	Conn. DOT	Provided justification for motorist aid call-box system.
		Conn. DOT	By Maintenance in training personnel for equipment responsibilities.
Synthesis 16	Synthesis 16	AASHTO	As a text in Highway Management Course (conducted by the Highway Management Institute at the Univ. of Mississippi).
		Conn. DOT	As a basis for Maintenance Telecommunication System.
Synthesis 16	Synthesis 16	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.
		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.
	Syntheses 81 and 93	FHWA Univ. of Calif.— Berkeley	As source material in short courses on Organization and Management of Ridesharing. 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 <i>in toto</i> 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.
20-7	Res. Dig. 25	U. Wis., Dept. Eng.	As a text in short course on Urban Transportation Planning.
	—	92nd Congress, 1st Sess.	Task 4, "Lateral 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 <i>Guidelines on Citizen Participation in Transportation Planning</i> .
	Agency final report (Task 16)	North Central Council of Governments	As an aid in the validation of a survey regarding hazardous materials shipments.
	Agency final report (Task 18)	AASHTO	Published by AASHTO in 1983 as the 13th Edition of the <i>Standard Specifications for Highway Bridges</i> .
	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 <sub>TM</sub> (Task 28)	States, Counties, Cities, Consultants	This personal computer program for new pavement design is based on the <i>AASHTO Guide for Design of Pavement Structures</i> 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.

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**EXAMPLES OF UTILIZATION OF NCHRP RESULTS** (*Continued*)
 

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NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
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.
	Report 153	Federal Aviation Administration	To install breakaway cable terminals as part of a demonstration project on the Dulles Airport Access Highway.
		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.
22-2(4)	Report 230	State hwy. agencies, FHWA, and full-scale, crash-testing agencies	As the guide for developing and evaluating highway safety hardware.
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.

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TABLE 6  
PUBLISHED REPORTS OF THE NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NO.	REPORT TITLE, PROJECT, PAGES, PRICE	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	• 22	Factors Influencing Flexible Pavement Performance (Proj. 1-3(2)), 69 p., \$2.60
• 1	Evaluation of Methods of Replacement of Deteriorated Concrete in Structures (Proj. 6-8), 56 p., \$2.80	• 23	Methods for Reducing Corrosion of Reinforcing Steel (Proj. 6-4), 22 p., \$1.40
• 2	An Introduction to Guidelines for Satellite Studies of Pavement Performance (Proj. 1-1), 19 p., \$1.80	• 24	Urban Travel Patterns for Airports, Shopping Centers, and Industrial Plants (Proj. 7-1), 116 p., \$5.20
• 2A	Guidelines for Satellite Studies of Pavement Performance, 85 p.+9 figs., 26 tables, 4 app., \$3.00	• 25	Potential Uses of Sonic and Ultrasonic Devices in Highway Construction (Proj. 10-7), 48 p., \$2.00
• 3	Improved Criteria for Traffic Signals at Individual Intersections—Interim Report (Proj. 3-5), 36 p., \$1.60	• 26	Development of Uniform Procedures for Establishing Construction Equipment Rental Rates (Proj. 13-1), 33 p., \$1.60
• 4	Non-Chemical Methods of Snow and Ice Control on Highway Structures (Proj. 6-2), 74 p., \$3.20	• 27	Physical Factors Influencing Resistance of Concrete to Deicing Agents (Proj. 6-5), 41 p., \$2.00
• 5	Effects of Different Methods of Stockpiling Aggregates—Interim Report (Proj. 10-3), 48 p., \$2.00	• 28	Surveillance Methods and Ways and Means Communicating with Drivers (Proj. 3-2), 66 p., \$2.60
• 6	Means of Locating and Communicating with Disabled Vehicles—Interim Report (Proj. 3-4), 56 p., \$3.20	• 29	Digital-Computer-Controlled Traffic Signal System for a Small City (Proj. 3-2), 82 p., \$4.00
• 7	Comparison of Different Methods of Measuring Pavement Condition—Interim Report (Proj. 1-2), 29 p., \$1.80	• 30	Extension of AASHO Road Test Performance Concepts (Proj. 1-4(2)), 33 p., \$1.60
• 8	Synthetic Aggregates for Highway Construction (Proj. 4-4), 13 p., \$1.00	• 31	A Review of Transportation Aspects of Land-Use Control (Proj. 8-5), 41 p., \$2.00
• 9	Traffic Surveillance and Means of Communicating with Drivers—Interim Report (Proj. 3-2), 28 p., \$1.60	• 32	Improved Criteria for Traffic Signals at Individual Intersections (Proj. 3-5), 134 p., \$5.00
• 10	Theoretical Analysis of Structural Behavior of Road Test Flexible Pavements (Proj. 1-4), 31 p., \$2.80	• 33	Values of Time Savings of Commercial Vehicles (Proj. 2-4), 74 p., \$3.60
• 11	Effect of Control Devices on Traffic Operations—Interim Report (Proj. 3-6), 107 p., \$5.80	• 34	Evaluation of Construction Control Procedures—Interim Report (Proj. 10-2), 117 p., \$5.00
• 12	Identification of Aggregates Causing Poor Concrete Performance When Frozen—Interim Report (Proj. 4-3(1)), 47 p., \$3.00	• 35	Prediction of Flexible Pavement Deflections from Laboratory Repeated-Load Tests (Proj. 1-3(3)), 117 p., \$5.00
• 13	Running Cost of Motor Vehicles as Affected by Highway Design—Interim Report (Proj. 2-5), 43 p., \$2.80	• 36	Highway Guardrails—A Review of Current Practice (Proj. 15-1), 33 p., \$1.60
• 14	Density and Moisture Content Measurements by Nuclear Methods—Interim Report (Proj. 10-5), 32 p., \$3.00	37	Tentative Skid-Resistance Requirements for Main Rural Highways (Proj. 1-7), 80 p., \$3.60
• 15	Identification of Concrete Aggregates Exhibiting Frost Susceptibility—Interim Report (Proj. 4-3(2)), 66 p., \$4.00	• 38	Evaluation of Pavement Joint and Crack Sealing Materials and Practices (Proj. 9-3), 40 p., \$2.00
• 16	Protective Coatings to Prevent Deterioration of Concrete by Deicing Chemicals (Proj. 6-3), 21 p., \$1.60	• 39	Factors Involved in the Design of Asphaltic Pavement Surfaces (Proj. 1-8), 112 p., \$5.00
• 17	Development of Guidelines for Practical and Realistic Construction Specifications (Proj. 10-1), 109 p., \$6.00	40	Means of Locating Disabled or Stopped Vehicles (Proj. 3-4(1)), 40 p., \$2.00
• 18	Community Consequences of Highway Improvement (Proj. 2-2), 37 p., \$2.80	• 41	Effect of Control Devices on Traffic Operations (Proj. 3-6), 83 p., \$3.60
• 19	Economical and Effective Deicing Agents for Use on Highway Structures (Proj. 6-1), 19 p., \$1.20	42	Interstate Highway Maintenance Requirements and Unit Maintenance Expenditure Index (Proj. 14-1), 144 p., \$5.60
20	Economic Study of Roadway Lighting (Proj. 5-4), 77 p., \$3.20	• 43	Density and Moisture Content Measurements by Nuclear Methods (Proj. 10-5), 38 p., \$2.00
• 21	Detecting Variations in Load-Carrying Capacity of Flexible Pavements (Proj. 1-5), 30 p., \$1.40	• 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		REPORT	
NO.	TITLE, PROJECT, PAGES, PRICE	NO.	TITLE, PROJECT, PAGES, PRICE
	havior—Phase I Summary Report (Proj. 20-4), 71 p., \$3.20	• 74B	Protective Coatings for Highway Structural Steel—Current Highway Practices (Proj. 4-6), 102 p., \$4.00
• 50	Factors Influencing Safety at Highway-Rail Grade Crossings (Proj. 3-8), 113 p., \$5.20	• 75	Effect of Highway Landscape Development on Nearby Property (Proj. 2-9), 82 p., \$3.60
• 51	Sensing and Communication Between Vehicles (Proj. 3-3), 105 p., \$5.00	• 76	Detecting Seasonal Changes in Load-Carrying Capabilities of Flexible Pavements (Proj. 1-5(2)), 37 p., \$2.00
• 52	Measurement of Pavement Thickness by Rapid and Nondestructive Methods (Proj. 10-6), 82 p., \$3.80	• 77	Development of Design Criteria for Safer Luminaire Supports (Proj. 15-6), 82 p., \$3.80
• 53	Multiple Use of Lands Within Highway Rights-of-Way (Proj. 7-6), 68 p., \$3.20	• 78	Highway Noise—Measurement, Simulation, and Mixed Reactions (Proj. 3-7), 78 p., \$3.20
• 54	Location, Selection, and Maintenance of Highway Guardrails and Median Barriers (Proj. 15-1(2)), 63 p., \$2.60	79	Development of Improved Methods for Reduction of Traffic Accidents (Proj. 17-1), 163 p., \$6.40
• 55	Research Needs in Highway Transportation (Proj. 20-2), 66 p., \$2.80	• 80	Oversize-Overweight Permit Operation on State Highways (Proj. 2-10), 120 p., \$5.20
• 56	Scenic Easements—Legal, Administrative, and Valuation Problems and Procedures (Proj. 11-3), 174 p., \$6.40	• 81	Moving Behavior and Residential Choice—A National Survey (Proj. 8-6), 129 p., \$5.60
• 57	Factors Influencing Modal Trip Assignment (Proj. 8-2), 78 p., \$3.20	• 82	National Survey of Transportation Attitudes and Behavior—Phase II Analysis Report (Proj. 20-4), 89 p., \$4.00
• 58	Comparative Analysis of Traffic Assignment Techniques with Actual Highway Use (Proj. 7-5), 85 p., \$3.60	• 83	Distribution of Wheel Loads on Highway Bridges (Proj. 12-2), 56 p., \$2.80
• 59	Standard Measurements for Satellite Road Test Program (Proj. 1-6), 78 p., \$3.20	• 84	Analysis and Projection of Research on Traffic Surveillance, Communication, and Control (Proj. 3-9), 48 p., \$2.40
• 60	Effects of Illumination on Operating Characteristics of Freeways (Proj. 5-2), 148 p., \$6.00	• 85	Development of Formed-in-Place Wet Reflective Markers (Proj. 5-5), 28 p., \$1.80
• 61	Evaluation of Studded Tire—Performance Data and Pavement Wear Measurement (Proj. 1-9), 66 p., \$3.00	• 86	Tentative Service Requirements for Bridge Rail Systems (Proj. 12-8), 62 p., \$3.20
• 62	Urban Travel Patterns for Hospitals, Universities, Office Buildings and Capitols (Proj. 7-1), 144 p., \$5.60	87	Rules of Discovery and Disclosure in Highway Condemnation Proceedings (Proj. 11-1(5)), 28 p., \$2.00
• 63	Economics of Design Standards for Low-Volume Rural Roads (Proj. 2-6), 93 p., \$4.00	88	Recognition of Benefits to Remainder Property in Highway Valuation Cases (Proj. 11-1(2)), 24 p., \$2.00
• 64	Motorists' Needs and Services on Interstate Highways (Proj. 7-7), 88 p., \$3.60	• 89	Factors, Trends, and Guidelines Related to Trip Length (Proj. 7-4), 59 p., \$3.20
65	One-Cycle Slow-Freeze Test for Evaluating Aggregate Performance in Frozen Concrete (Proj. 4-3(1)), 21 p., \$1.40	90	Protection of Steel in Prestressed Concrete Bridges (Proj. 12-5), 86 p., \$4.00
66	Identification of Frost-Susceptible Particles in Concrete Aggregates (Proj. 4-3(2)), 62 p., \$2.80	91	Effects of Deicing Salts on Water Quality and Biota—Literature Review and Recommended Research (Proj. 16-1), 70 p., \$3.20
• 67	Relation of Asphalt Rheological Properties to Pavement Durability (Proj. 9-1), 45 p., \$2.20	92	Valuation and Condemnation of Special Purpose Properties (Proj. 11-1(6)), 47 p., \$2.60
• 68	Application of Vehicle Operating Characteristics to Geometric Design and Traffic Operations (Proj. 3-10), 38 p., \$2.00	• 93	Guidelines for Medial and Marginal Access Control on Major Roadways (Proj. 3-13), 147 p., \$6.20
• 69	Evaluation of Construction Control Procedures—Aggregate Gradation Variations and Effects (Proj. 10-2A), 58 p., \$2.80	• 94	Valuation and Condemnation Problems Involving Trade Fixtures (Proj. 11-1(9)), 22 p., \$1.80
• 70	Social and Economic Factors Affecting Intercity Travel (Proj. 8-1), 68 p., \$3.00	• 95	Highway Fog (Proj. 5-6), 48 p., \$2.40
• 71	Analytical Study of Weighing Methods for Highway Vehicles in Motion (Proj. 7-3), 63 p., \$2.80	• 96	Strategies for the Evaluation of Alternative Transportation Plans (Proj. 8-4), 111 p., \$5.40
72	Theory and Practice in Inverse Condemnation for Five Representative States (Proj. 11-2), 44 p., \$2.20	97	Analysis of Structural Behavior of AASHO Road Test Rigid Pavements (Proj. 1-4(1)A), 35 p., \$2.60
• 73	Improved Criteria for Traffic Signal Systems on Urban Arterials (Proj. 3-5), 55 p., \$2.80	• 98	Tests for Evaluating Degradation of Base Course Aggregates (Proj. 4-2), 98 p., \$5.00
74	Protective Coatings for Highway Structural Steel (Proj. 4-6), 64 p., \$2.80	• 99	Visual Requirements in Night Driving (Proj. 5-3), 38 p., \$2.60
• 74A	Protective Coatings for Highway Structural Steel—Literature Survey (Proj. 4-6), 275 p., \$8.00	• 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		REPORT	
NO.	TITLE, PROJECT, PAGES, PRICE	NO.	TITLE, PROJECT, PAGES, PRICE
102	Effect of Weldments on the Fatigue Strength of Steel Beams (Proj. 12-7), 114 p., \$5.40	130	Roadway Delineation Systems (Proj. 5-7), 349 p., \$14.00
• 103	Rapid Test Methods for Field Control of Highway Construction (Proj. 10-4), 89 p., \$5.00	131	Performance Budgeting System for Highway Maintenance Management (Proj. 19-2(4)), 213 p., \$8.40
104	Rules of Compensability and Valuation Evidence for Highway Land Acquisition (Proj. 11-1), 77 p., \$4.40	132	Relationships Between Physiographic Units and Highway Design Factors (Proj. 1-3(1)), 161 p., \$7.20
• 105	Dynamic Pavement Loads of Heavy Highway Vehicles (Proj. 15-5), 94 p., \$5.00	• 133	Procedures for Estimating Highway User Costs, Air Pollution, and Noise Effects (Proj. 7-8), 127 p., \$5.60
• 106	Revibration of Retarded Concrete for Continuous Bridge Decks (Proj. 18-1), 67 p., \$3.40	• 134	Damages Due to Drainage, Runoff, Blasting, and Slides (Proj. 11-1(8)), 24 p., \$2.80
107	New Approaches to Compensation for Residential Takings (Proj. 11-1(10)), 27 p., \$2.40	135	Promising Replacements for Conventional Aggregates for Highway Use (Proj. 4-10), 53 p., \$3.60
• 108	Tentative Design Procedure for Riprap-Lined Channels (Proj. 15-2), 75 p., \$4.00	• 136	Estimating Peak Runoff Rates from Ungaged Small Rural Watersheds (Proj. 15-4), 85 p., \$4.60
• 109	Elastomeric Bearing Research (Proj. 12-9), 53 p., \$3.00	• 137	Roadside Development—Evaluation of Research (Proj. 16-2), 78 p., \$4.20
• 110	Optimizing Street Operations Through Traffic Regulations and Control (Proj. 3-11), 100 p., \$4.40	• 138	Instrumentation for Measurement of Moisture—Literature Review and Recommended Research (Proj. 21-1), 60 p., \$4.00
• 111	Running Costs of Motor Vehicles as Affected by Road Design and Traffic (Proj. 2-5A and 2-7), 97 p., \$5.20	139	Flexible Pavement Design and Management—Systems Formulation (Proj. 1-10), 64 p., \$4.40
• 112	Junkyard Valuation—Salvage Industry Appraisal Principles Applicable to Highway Beautification (Proj. 11-3(2)), 41 p., \$2.60	140	Flexible Pavement Design and Management—Materials Characterization (Proj. 1-10), 118 p., \$5.60
113	Optimizing Flow on Existing Street Networks (Proj. 3-14), 414 p., \$15.60	• 141	Changes in Legal Vehicle Weights and Dimensions—Some Economic Effects on Highways (Proj. 19-3), 184 p., \$8.40
• 114	Effects of Proposed Highway Improvements on Property Values (Proj. 11-1(1)), 42 p., \$2.60	• 142	Valuation of Air Space (Proj. 11-5), 48 p., \$4.00
• 115	Guardrail Performance and Design (Proj. 15-1(2)), 70 p., \$3.60	143	Bus Use of Highways—State of the Art (Proj. 8-10), 406 p., \$16.00
• 116	Structural Analysis and Design of Pipe Culverts (Proj. 15-3), 155 p., \$6.40	• 144	Highway Noise—A Field Evaluation of Traffic Noise Reduction Measures (Proj. 3-7), 80 p., \$4.40
117	Highway Noise—A Design Guide for Highway Engineers (Proj. 3-7), 79 p., \$4.60	145	Improving Traffic Operations and Safety at Exit Gore Areas (Proj. 3-17), 120 p., \$6.00
• 118	Location, Selection, and Maintenance of Highway Traffic Barriers (Proj. 15-1(2)), 96 p., \$5.20	146	Alternative Multimodal Passenger Transportation Systems—Comparative Economic Analysis (Proj. 8-9), 68 p., \$4.00
• 119	Control of Highway Advertising Signs—Some Legal Problems (Proj. 11-3(1)), 72 p., \$3.60	147	Fatigue Strength of Steel Beams with Welded Stiffeners and Attachments (Proj. 12-7), 85 p., \$4.80
• 120	Data Requirements for Metropolitan Transportation Planning (Proj. 8-7), 90 p., \$4.80	148	Roadside Safety Improvement Programs on Freeways—A Cost-Effectiveness Priority Approach (Proj. 20-7), 64 p., \$4.00
• 121	Protection of Highway Utility (Proj. 8-5), 115 p., \$5.60	149	Bridge Rail Design—Factors, Trends, and Guidelines (Proj. 12-8), 49 p., \$4.00
• 122	Summary and Evaluation of Economic Consequences of Highway Improvements (Proj. 2-11), 324 p., \$13.60	• 150	Effect of Curb Geometry and Location on Vehicle Behavior (Proj. 20-7), 88 p., \$4.80
123	Development of Information Requirements and Transmission Techniques for Highway Users (Proj. 3-12), 239 p., \$9.60	151	Locked-Wheel Pavement Skid Tester Correlation and Calibration Techniques (Proj. 1-12(2)), 100 p., \$6.00
124	Improved Criteria for Traffic Signal Systems in Urban Networks (Proj. 3-5), 86 p., \$4.80	152	Warrants for Highway Lighting (Proj. 5-8), 117 p., \$6.40
125	Optimization of Density and Moisture Content Measurements by Nuclear Methods (Proj. 10-5A), 86 p., \$4.40	153	Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances (Proj. 22-2), 19 p., \$3.20
• 126	Divergencies in Right-of-Way Valuation (Proj. 11-4), 57 p., \$3.00	154	Determining Pavement Skid Resistance Requirements at Intersections and Braking Sites (Proj. 1-12), 64 p., \$4.40
127	Snow Removal and Ice Control Techniques at Interchanges (Proj. 6-10), 90 p., \$5.20	155	Bus Use of Highways—Planning and Design Guidelines (Proj. 8-10), 161 p., \$7.60
• 128	Evaluation of AASHO Interim Guides for Design of Pavement Structures (Proj. 1-11), 111 p., \$5.60	156	Transportation Decision-Making—A Guide to Social and Environmental Considerations (Proj. 8-8(3)), 135 p., \$7.20
• 129	Guardrail Crash Test Evaluation—New Concepts and End Designs (Proj. 15-1(2)), 89 p., \$4.80		

TABLE 6 (Continued)

NO.	REPORT TITLE, PROJECT, PAGES, PRICE	NO.	TITLE, PROJECT, PAGES, PRICE
157	Crash Cushions of Waste Materials (Proj. 20-7), 73 p., \$4.80		Alignment on Skidding (Proj. 1-14), 33 p., \$3.20
158	Selection of Safe Roadside Cross Sections (Proj. 20-7), 57 p., \$4.40	185	Grade Effects on Traffic Flow Stability and Capacity (Proj. 3-19), 110 p., \$6.40
159	Weaving Areas—Design and Analysis (Proj. 3-15), 119 p., \$6.40	186	Travel Estimation Procedures for Quick Response to Urban Policy Issues (Proj. 8-12A), 70 p., \$5.60
160	Flexible Pavement Design and Management—Systems Approach Implementation (Proj. 1-10A), 53 p., \$4.00	187	Quick-Response Urban Travel Estimation Techniques and Transferable Parameters—User's Guide (Proj. 8-12A), 229 p., \$10.20
161	Techniques for Reducing Roadway Occupancy During Routine Maintenance Activities (Proj. 14-2), 55 p., \$4.40	188	Fatigue of Welded Steel Bridge Members Under Variable-Amplitude Loadings (Proj. 12-12), 113 p., \$6.40
162	Methods for Evaluating Highway Safety Improvements (Proj. 17-2A), 150 p., \$7.40	• 189	Quantifying the Benefits of Separating Pedestrians and Vehicles (Proj. 20-10), 127 p., \$7.00
163	Design of Bent Caps for Concrete Box-Girder Bridges (Proj. 12-10), 124 p., \$6.80	• 190	Use of Polymers in Highway Concrete (Proj. 18-2), 77 p., \$5.60
164	Fatigue Strength of High-Yield Reinforcing Bars (Proj. 4-7), 90 p., \$5.60	191	Effect of Air Pollution Regulations on Highway Construction and Maintenance (Proj. 20-12), 81 p., \$7.00
165	Waterproof Membranes for Protection of Concrete Bridge Decks—Laboratory Phase (Proj. 12-11), 70 p., \$4.80	• 192	Predicting Moisture-Induced Damage to Asphaltic Concrete (Proj. 4-8(3)), 46 p., \$5.20
166	Waste Materials as Potential Replacements for Highway Aggregates (Proj. 4-10A), 94 p., \$5.60	193	Beneficial Effects Associated with Freeway Construction—Environmental, Social, and Economic (Proj. 20-13), 110 p., \$7.80
167	Transportation Planning for Small Urban Areas (Proj. 8-7A), 71 p., \$4.80	194	Traffic Control in Oversaturated Street Networks (Proj. 3-18(2)), 152 p., \$9.60
168	Rapid Measurement of Concrete Pavement Thickness and Reinforcement Location—Field Evaluation of Nondestructive Systems (Proj. 10-8), 63 p., \$4.80	195	Minimizing Premature Cracking in Asphaltic Concrete Pavement (Proj. 9-4), 51 p., \$6.00
169	Peak-Period Traffic Congestion—Options for Current Programs (Proj. 7-10), 65 p., \$4.80	196	Reconditioning Heavy-Duty Freeways in Urban Areas (Proj. 14-4), 60 p., \$6.40
170	Effects of Deicing Salts on Plant Biota and Soils—Experimental Phase (Proj. 16-1), 88 p., \$5.60	197	Cost and Safety Effectiveness of Highway Design Elements (Proj. 3-25), 237 p., \$10.60
171	Highway Fog—Visibility Measures and Guidance Systems (Proj. 5-6A), 40 p., \$4.00	198	State Laws and Regulations on Truck Size and Weight (Proj. 20-16), 117 p., \$7.20
172	Density Standards for Field Compaction of Granular Bases and Subbases (Proj. 4-8(2)), 73 p., \$4.80	199	Evaluating Options in Statewide Transportation Planning/Programming—Techniques and Applications (Proj. 8-18), 190 p., \$9.00
173	Highway Noise—Generation and Control (Proj. 3-7), 174 p., \$8.00	200	Monitoring Carbon Monoxide Concentrations in Urban Area (Proj. 20-14), 41 p., \$5.20
174	Highway Noise—A Design Guide for Prediction and Control (Proj. 3-7), 193 p., \$9.60	201	Acceptance Criteria for Electroslag Weldments in Bridges (Proj. 10-10), 44 p., \$5.20
175	Freeway Lane Drops (Proj. 3-16), 72 p., \$4.80	202	Improved Pavement-Shoulder Joint Design (Proj. 14-3), 103 p., \$7.20
176	Studded Tires and Highway Safety—Feasibility of Determining Indirect Effects (Proj. 1-13(2)), 42 p., \$4.00	203	Safety at Narrow Bridge Sites (Proj. 20-7, Task 7), 63 p., \$6.00
177	Freight Data Requirements for Statewide Transportation Systems Planning—Research Report (Proj. 8-17), 196 p., \$8.80	204	Bridge Deck Joint-Sealing Systems—Evaluation and Performance Specification (Proj. 10-11), 46 p., \$5.60
178	Freight Data Requirements for Statewide Transportation Systems Planning—User's Manual (Proj. 8-17), 155 p., \$7.40	205	Implementing Packages of Congestion-Reducing Techniques—Strategies for Dealing with Institutional Problems of Cooperative Programs (Proj. 7-10(2)), 128 p., \$7.60
179	Evaluating Options in Statewide Transportation Planning/Programming—Issues, Techniques, and Their Relationships (Proj. 8-18), 91 p., \$5.60	206	Detection and Repair of Fatigue Damage in Welded Highway Bridges (Proj. 12-15 & 12-15(2)), 85 p., \$6.80
180	Cathodic Protection for Reinforced Concrete Bridge Decks—Laboratory Phase (Proj. 12-13), 135 p., \$7.00	207	Upgrading of Low-Quality Aggregates for PCC and Bituminous Pavements (Proj. 4-12), 91 p., \$7.20
181	Subcritical Crack Growth and Fracture of Bridge Steels (Proj. 12-14), 82 p., \$5.60	208	Market Opportunity Analysis for Short-Range Public Transportation Planning—Procedures for Evaluating Alternative Service Concepts (Proj. 8-16), 80 p., \$6.80
182	Economic Evaluation of Ice and Frost on Bridge Decks (Proj. 6-11), 73 p., \$4.80	209	Market Opportunity Analysis for Short-Range Public Transportation Planning—Transportation Services for
183	Studded Tires and Highway Safety—An Accident Analysis (Proj. 1-13), 70 p., \$4.80		
184	Influence of Combined Highway Grade and Horizontal		

TABLE 6 (Continued)

NO.	REPORT TITLE, PROJECT, PAGES, PRICE	NO.	TITLE, PROJECT, PAGES, PRICE
	the Transportation Disadvantaged (Proj. 8-16), 52 p., \$6.00	232	Guidelines for Selection of Ramp Control Systems (Proj. 3-22A), 108 p., \$8.40
210	Market Opportunity Analysis for Short-Range Public Transportation Planning—Economic, Energy, and En- vironmental Impacts (Proj. 8-16), 45 p., \$6.00	233	Selecting Traffic Signal Control at Individual Intersec- tions (Proj. 3-27), 133 p., \$9.20
211	Market Opportunity Analysis for Short-Range Public Transportation Planning—Goals and Policy Develop- ment, Institutional Constraints, and Alternative Or- ganizational Arrangements (Proj. 8-16), 161 p., \$9.20	234	Galvanic Cathodic Protection for Reinforced Concrete Bridge Decks—Field Evaluation (Proj. 12-13A), 64 p., \$6.80
212	Market Opportunity Analysis for Short-Range Public Transportation Planning—Method and Demonstration (Proj. 8-16), 132 p., \$10.00	235	Effectiveness of Changeable Message Displays in Ad- vance of High-Speed Freeway Lane Closures (Proj. 3- 21(2)), 49 p., \$7.00
—*	Freeway Traffic Management (Proj. 20-3D), 68 p., \$4.00	236	Evaluation of Traffic Controls for Highway Work Zones (Proj. 17-4, 17-4(2)), 189 p., \$12.00
213	Bayesian Methodology for Verifying Recommendations to Minimize Asphalt Pavement Distress (Proj. 9- 4A), 52 p., \$6.00	237	Locating Voids Beneath Pavement Using Pulsed Elec- tromagnetic Wave Techniques (Proj. 10-14), 40 p., \$6.80
214	Design and Traffic Control Guidelines for Low-Volume Rural Roads (Proj. 20-7, Task 13), 41 p., \$5.60	238	Estimating Exceedances and Design Values from Data Collected by Urban Ozone Monitoring Networks (Proj. 20-14A), 121 p., \$9.60
215	Pavement Management System Development (Proj. 20- 7, Task 15), 32 p., \$5.20	239	Multiple-Service-Level Highway Bridge Railing Selec- tion Procedures (Proj. 22-2(3)), 161 p., \$10.40
216	The No-Action Alternative—Research Report (Proj. 8-11), 72 p., \$6.80	240	A Manual to Determine Benefits of Separating Pedes- trians and Vehicles (Proj. 20-10(2)), 56 p., \$7.20
217	The No-Action Alternative—Impact Assessment Guidelines (Proj. 8-11), 174 p., \$9.60	241	Guidelines for Using Vanpools and Carpools as a TSM Technique (Proj. 8-21), 154 p., \$10.40
218A	Ecological Effects of Highway Fills on Wetlands— Research Report (Proj. 20-15), 34 p., \$5.20	242	Ultrasonic Measurement of Weld Flaw Size (Proj. 10- 13), 76 p., \$8.00
218B	Ecological Effects of Highway Fills on Wetlands— User's Manual (Proj. 20-15), 99 p., \$7.20	243	Rehabilitation and Replacement of Bridges on Sec- ondary Highways and Local Roads (Proj. 12- 20), 46 p., \$6.80
219	Application of Traffic Conflict Analyses at Intersec- tions (Proj. 17-3), 109 p., \$7.60	244	Concrete Sealers for Protection of Bridge Structures (Proj. 12-19A), 138 p., \$10.00
220	Erosion Control During Highway Construction—Re- search Report (Proj. 16-3), 30 p., \$5.60	245	Methodology for Evaluating Highway Air Pollution Dispersion Models (Proj. 20-18), 85 p., \$8.40
221	Erosion Control During Highway Construction— Manual on Principles and Practices (Proj. 16-3), 108 p., \$14.40	246	Predicting Moisture-Induced Damage to Asphaltic Concrete—Field Evaluation (Proj. 4-8(3)) 50 p., \$7.20
222	Bridges on Secondary Highways and Local Roads— Rehabilitation and Replacement (Proj. 12-20), 132 p., \$9.20	247	Effectiveness of Clear Recovery Zones (Proj. 17-5) 68 p., \$7.20
223	Maintenance Levels-of-Service Guidelines (Proj. 14-5), 118 p., \$8.80	248	Elastomeric Bearings Design, Construction, and Ma- terials (Proj. 10-20), 82 p., \$8.40
224	Guidelines for Recycling Pavement Materials (Proj. 1-17), 137 p., \$9.20	249	Peak-Hour Traffic Signal Warrant (Proj. 3-20A), 71 p., \$7.60
225	Plastic Pipe for Subsurface Drainage of Transportation Facilities (Proj. 4-11), 153 p., \$9.60	250	New Approaches to Understanding Travel Behavior (Proj. 8-14A), 142 p., \$10.00
226	Damage Evaluation and Repair Methods for Pre- stressed Concrete Bridge Members (Proj. 12-21), 66 p., \$7.20	251	Assessment of Deficiencies and Preservation of Bridge Substructures Below the Waterline (Proj. 10-16), 80 p., \$8.40
227	Fatigue Behavior of Full-Scale Welded Bridge Attach- ments (Proj. 12-15(3)), 47 p., \$6.40	252	Adding Dust Collector Fines to Asphalt Paving Mix- tures (Proj. 10-19), 90 p., \$8.40
228	Calibration of Response-Type Road Roughness Mea- suring Systems (Proj. 1-18), 81 p., \$7.60	253	Application of Disaggregate Travel Demand Models (Proj. 8-13(2)), 207 p., \$12.40
229	Methods for Analyzing Fuel Supply Limitation on Pas- senger Travel (Proj. 8-23), 132 p., \$9.20	254	Shoulder Geometrics and Use Guidelines (Proj. 1- 22), 71 p., \$7.60
230	Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances (Proj. 22- 2(4)), 42 p., \$6.00	255	Highway Traffic Data for Urbanized Area Project Planning and Design (Proj. 8-26), 191 p., \$11.60
231	State Transportation Finance Within the Context of Energy Constraints (Proj. 8-22), 86 p., \$7.60	256	Partial Lighting of Interchanges (Proj. 5-9), 81 p., \$8.40
		257	Long-Term Rehabilitation of Salt-Contaminated Bridge Decks (Proj. 18-2(3)), 32 p., \$6.40
		258	Control of Air Content in Concrete (Proj. 10-18), 84 p., \$8.40

\* Special publication.

TABLE 6 (Continued)

REPORT		REPORT	
NO.	TITLE, PROJECT, PAGES, PRICE	NO.	TITLE, PROJECT, PAGES, PRICE
259	Design of Emulsified Asphalt Paving Mixtures (Proj. 9-5), 97 p., \$8.80	286	Evaluation of Fatigue Tests and Design Criteria on Welded Details (Proj. 12-15(5)), 66 p., \$8.40
260	Application of Statewide Freight Demand Forecasting Techniques (Proj. 20-17A), 210 p., \$12.80	287	Load Distribution and Connection Design for Precast Stemmed Multibeam Bridge Superstructures (Proj. 12-24), 137 p., \$11.80
261	Cost-Effectiveness of Transportation Services for Handicapped Persons—Research Report (Proj. 8-27), 130 p., \$9.60	288	Evaluating Grade-Separated Rail-Highway Crossing Alternatives (Proj. 3-31), 87 p., \$10.80
262	Planning Transportation Services for Handicapped Persons—User's Guide (Proj. 8-27), 74 p., \$8.00	289	Performance of Longitudinal Traffic Barriers (Proj. 22-4), 169 p., \$13.20
263	Simplified Procedures for Evaluating Low-Cost TSM Projects—User's Manual (Proj. 7-11), 209 p., \$12.80	290	Reinforcement of Earth Slopes and Embankments (Proj. 24-2), 323 p., \$40.00
264	Guidelines for the Management of Highway Runoff on Wetlands (Proj. 25-1), 166 p., \$10.80	291	Development of Pavement Structural Subsystems (Proj. 1-10B), 59 p., \$8.80
265	Removal of Lead-Based Bridge Paints (Proj. 10-23), 72 p., \$8.00	292	Strength Evaluation of Existing Reinforced Concrete Bridges (Proj. 10-15), 133 p., \$14.00
266	Forecasting Inputs to Transportation Planning (Proj. 8-24), 117 p., \$9.60	293	Methods of Strengthening Existing Highway Bridges (Proj. 12-28(4)), 114 p., \$12.00
267	Steel Bridge Members Under Variable Amplitude Long Life Fatigue Loading (Proj. 12-15(4)), 26 p., \$6.40	294A	Planning and Implementing Pedestrian Facilities in Suburban and Developing Rural Areas—Research Report (Proj. 20-19), 92 p., \$10.40
268	Influence of Asphalt Temperature Susceptibility on Pavement Construction and Performance (Proj. 1-20), 62 p., \$7.60	294B	Planning and Implementing Pedestrian Facilities in Suburban and Developing Rural Areas—State-of-the-Art Report (Proj. 20-19), 165 p., \$12.40
269	Paving with Asphalt Cements Produced in the 1980's (Proj. 1-20), 28 p., \$6.40	295	Automated Field Survey Data Collection System (Proj. 20-21), 107 p., \$13.20
270	Parameters Affecting Stopping Sight Distance (Proj. 15-8), 169 p., \$11.20	296	Durability of In-Place Concrete Containing High-Range Water-Reducing Admixtures (Proj. 10-32), 63 p., \$10.40
271	Guidelines for Evaluation and Repair of Damaged Steel Bridge Members (Proj. 12-17A), 64 p., \$7.60	297	Evaluation of Bridge Deck Protective Strategies (Proj. 12-32), 80 p., \$12.00
272	Performance of Weathering Steel in Bridges (Proj. 10-22), 164 p., \$12.00	298	Performance of Elastomeric Bearings (Proj. 10-20), 100 p., \$12.00
273	Manual for the Selection of Optimal Maintenance Levels of Service (Proj. 14-5(2)), 81 p., \$9.20	299	Fatigue Evaluation Procedures for Steel Bridges (Proj. 12-28(3)), 94 p., \$11.20
274	Use of Antistripping Additives in Asphaltic Concrete Mixtures—Laboratory Phase (Proj. 10-17), 50 p., \$7.60	300	Bridge Management Systems (Proj. 12-28(2)), 74 p., \$10.40
275	Pavement Roughness and Rideability (Proj. 1-23), 69 p., \$8.80	301	Load Capacity Evaluation of Existing Bridges (Proj. 12-28(1)), 104 p., \$11.60
276	Thermal Effects in Concrete Bridge Superstructures (Proj. 12-22), 99 p., \$9.60	302	Fatigue and Fracture Evaluation for Rating Riveted Bridges (Proj. 12-25), 86 p., \$11.20
277	Portland Cement Concrete Pavement Evaluation System (COPEs) (Proj. 1-19), 175 p., \$12.80	303	Feasibility of a National Heavy Vehicle Monitoring System (Proj. 3-34), 68 p., \$10.00
278	Cathodic Protection of Concrete Bridge Substructures (Proj. 12-19B), 60 p., \$8.40	304	Determining Deteriorated Areas in Portland Cement Concrete Pavements Using Radar and Video Imaging (Proj. 10-28), 107 p., \$14.00
279	Intersection Channelization Design Guide (Proj. 3-30), 153 p., \$25.00	305	Environmental Monitoring and Evaluation of Calcium Magnesium Acetate (CMA) (Proj. 4-17), 160 p., \$13.60
280	Guidelines for Evaluation and Repair of Damaged Prestressed Concrete Bridge Members (Proj. 12-21), 84 p., \$9.20	306	Correlation of Bridge Load Capacity Estimates with Test Data (Proj. 12-28(8)), 75 p., \$11.20
281	Joint Repair Methods for Portland Cement Concrete Pavements—Design and Construction Guidelines (Proj. 1-21), 83 p., \$9.20	307	Public and Private Partnerships for Financing Highway Improvements (Proj. 2-14), 83 p., \$11.20
282	Multilane Design Alternatives for Improving Suburban Highways (Proj. 2-13), 71 p., \$8.50	308	Pavement Roughness and Rideability—Field Evaluation (Proj. 1-23(2)), 48 p., \$9.00
283	Training Aid for Applying NCHRP Report 263—Simplified Procedures for Evaluating Low-Cost TSM Projects (Proj. 7-11A), 34 p., \$7.20	309	Protection of Pipelines Through Highway Roadbeds (Proj. 15-9), 21 p., \$8.00
284	Evaluation of Procedures Used to Measure Cement and Water Content in Fresh Concrete (Proj. 10-25), 76 p., \$9.20	310	Dealing with Hazardous Waste Sites—A Compendium for Highway Agencies (Proj. 20-22), 107 p., \$12.00
285	Evaluating Alternative Maintenance Strategies (Proj. 14-6), 86 p., \$10.40	311	Predicting Stop-and-Go Traffic Noise Levels (Proj. 25-2), 97 p., \$11.00
		312	Condition Surveys of Concrete Bridge Components—User's Manual (Proj. 12-28(5)), 84 p., \$11.00

TABLE 6 (Continued)

REPORT			
NO.	TITLE, PROJECT, PAGES, PRICE	NO.	TITLE, PROJECT, PAGES, PRICE
313	Corrosion Protection of Prestressing Systems in Concrete Bridges (Proj. 4-15) 25 p., \$8.00		Rating of Two-Girder Steel Bridges (Proj. 12-28(10)), 142 p., \$13.00
314	Guidelines for the Use of Weathering Steel in Bridges (Proj. 10-22), 98 p., \$16.00	320	Guidelines for Converting STOP to YIELD Control at Intersections (Proj. 17-7), 49 p., \$9.00
315	Potential Benefits of Geosynthetics in Flexible Pavement Systems (Proj. 10-33), 56 p., \$9.00	321	Welded Repair of Cracks in Steel Bridge Members (Proj. 12-27), 46 p., \$8.00
316	Laboratory Evaluation of Piles Installed with Vibratory Drivers (Proj. 24-3), 51 p., \$9.00	322	Design of Precast Prestressed Bridge Girders (Proj. 12-29), 97 p., \$11.00
317	Transient Protection, Grounding, and Shielding of Electronic Traffic Control Equipment (Proj. 10-34), 84 p., \$11.00	323	Travel Characteristics at Large-Scale Suburban Activity Centers (Proj. 3-38(2)), 106 p. \$11.00
318	Roadside Safety Design for Small Vehicles (Proj. 22-6), 70 p., \$10.00	324	Identifying, Measuring, and Evaluating Benefits of Roadside Rest Areas (Proj. 2-15), (In preparation)
319	Recommended Guidelines for Redundancy Design and	325	Low Temperature Behavior and Acceptance Criteria for Elastomeric Bridge Bearings (Proj. 10-20), (In preparation)

TABLE 6 (Continued)

SYNTHESIS OF HIGHWAY PRACTICE			
NO.	TITLE, PAGES, PRICE	NO.	TITLE, PAGES, PRICE
1	Traffic Control for Freeway Maintenance (Proj. 20-5, Topic 1), 47 p., \$2.20	29	Treatment of Soft Foundations for Highway Embankments (Proj. 20-5, Topic 4-09), 25 p., \$3.20
• 2	Bridge Approach Design and Construction Practices (Proj. 20-5, Topic 2), 30 p., \$2.00	30	Bituminous Emulsions for Highway Pavements (Proj. 20-5, Topic 6-10), 76 p., \$4.80
• 3	Traffic-Safe and Hydraulically Efficient Drainage Practice (Proj. 20-5, Topic 4), 38 p., \$2.20	31	Highway Tunnel Operations (Proj. 20-5, Topic 5-08), 29 p., \$3.20
• 4	Concrete Bridge Deck Durability (Proj. 20-5, Topic 3), 28 p., \$2.20	• 32	Effects of Studded Tires (Proj. 20-5, Topic 5-13), 46 p., \$4.00
• 5	Scour at Bridge Waterways (Proj. 20-5, Topic 5), 37 p., \$2.40	33	Acquisition and Use of Geotechnical Information (Proj. 20-5, Topic 5-03), 40 p., \$4.00
• 6	Principles of Project Scheduling and Monitoring (Proj. 20-5, Topic 6), 43 p., \$2.40	34	Policies for Accommodation of Utilities on Highway Rights-of-Way (Proj. 20-5, Topic 6-03), 22 p., \$3.20
7	Motorist Aid Systems (Proj. 20-5, Topic 3-01), 28 p., \$2.40	35	Design and Control of Freeway Off-Ramp Terminals (Proj. 20-5, Topic 5-02), 61 p., \$4.40
• 8	Construction of Embankments (Proj. 20-5, Topic 9), 38 p., \$2.40	36	Instrumentation and Equipment for Testing Highway Materials, Products, and Performance (Proj. 20-5, Topic 6-01), 70 p., \$4.80
• 9	Pavement Rehabilitation—Materials and Techniques (Proj. 20-5, Topic 8), 41 p., \$2.80	37	Lime-Fly Ash-Stabilized Bases and Subbases (Proj. 20-5, Topic 6-06), 66 p., \$4.80
10	Recruiting, Training, and Retaining Maintenance and Equipment Personnel (Proj. 20-5, Topic 10), 35 p., \$280	38	Statistically Oriented End-Result Specifications (Proj. 20-5, Topic 6-02), 40 p., \$4.00
11	Development of Management Capability (Proj. 20-5, Topic 12), 50 p., \$3.20	• 39	Transportation Requirements for the Handicapped, Elderly, and Economically Disadvantaged (Proj. 20-5, Topic 6-07), 54 p., \$4.40
12	Telecommunications Systems for Highway Administration and Operations (Proj. 20-5, Topic 3-03), 29 p., \$2.80	40	Staffing and Management for Social, Economic, and Environmental Impact Assessments (Proj. 20-5, Topic 7-02), 43 p., \$4.00
13	Radio Spectrum Frequency Management (Proj. 20-5, Topic 3-03), 32 p., \$2.80	41	Bridge Bearings (Proj. 20-5, Topic 6-09), 62 p., \$4.80
14	Skid Resistance (Proj. 20-5, Topic 7), 66 p., \$4.00	42	Design of Pile Foundations (Proj. 20-5, Topic 5-04), 68 p., \$4.80
• 15	Statewide Transportation Planning—Needs and Requirements (Proj. 20-5, Topic 3-02), 41 p., \$3.60	43	Energy Effects, Efficiencies, and Prospects for Various Modes of Transportation (Proj. 20-5, Topic 7-05), 57 p., \$4.80
16	Continuously Reinforced Concrete Pavement (Proj. 20-5, Topic 3-08), 23 p., \$2.80	44	Consolidation of Concrete for Pavements, Bridge Decks, and Overlays (Proj. 20-5, Topic 7-01), 61 p., \$4.80
17	Pavement Traffic Marking—Materials and Application Affecting Serviceability (Proj. 20-5, Topic 3-05), 44 p., \$3.60	45	Rapid-Setting Materials for patching of Concrete (Proj. 20-5, Topic 6-05), 13 p., \$2.40
18	Erosion Control on Highway Construction (Proj. 20-5, Topic 4-01), 52 p., \$4.00	46	Recording and Reporting Methods for Highway Maintenance Expenditures (Proj. 20-5, Topic 7-04), 35 p., \$3.60
19	Design, Construction, and Maintenance of PCC Pavement Joints (Proj. 20-5, Topic 3-04), 40 p., \$3.60	47	Effect of Weather on Highway Construction (Proj. 20-5, Topic 5-07), 29 p., \$3.20
20	Rest Areas (Proj. 20-5, Topic 4-04), 38 p., \$3.60	48	Priority Programming and Project Selection (Proj. 20-5, Topic 7-07), 31 p., \$3.20
21	Highway Location Reference Methods (Proj. 20-5, Topic 4-06), 30 p., \$3.20	49	Open-Graded Friction Courses for Highways (Proj. 20-5, Topic 8-09), 50 p., \$4.00
• 22	Maintenance Management of Traffic Signal Equipment and Systems (Proj. 20-5, Topic 4-03), 41 p., \$4.00	50	Durability of Drainage Pipe (Proj. 20-5, Topic 5-09), 37 p., \$3.60
23	Getting Research Findings into Practice (Proj. 20-5, Topic 11), 24 p., \$3.20	51	Construction Contract Staffing (Proj. 20-5, Topic 8-02), 62 p., \$6.00
24	Minimizing Deicing Chemical Use (Proj. 20-5, Topic 4-02), 58 p., \$4.00	52	Management and Selection Systems for Highway Maintenance equipment (Proj. 20-5, Topic 8-08), 17 p., \$4.40
25	Reconditioning High-Volume Freeways in Urban Areas (Proj. 20-5, Topic 5-01), 56 p., \$4.00	53	Precast Concrete Elements for Transportation Facilities (Proj. 20-5, Topic 8-05), 48 p., \$5.60
26	Roadway Design in Seasonal Frost Areas (Proj. 20-5, Topic 3-07), 104 p., \$6.00	• 54	Recycling Materials for Highways (Proj. 20-5, Topic 8-01), 53 p., \$5.60
• 27	PCC Pavements for Low-Volume Roads and City Streets (Proj. 20-5, Topic 5-06), 31 p., \$3.60	55	Storage and Retrieval Systems for Highway and Trans-
28	Partial-Lane Pavement Widening (Proj. 20-5, Topic 5-05), 30 p., \$3.20		

TABLE 6 (Continued)

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

TABLE 6 (Continued)

SYNTHESIS OF HIGHWAY PRACTICE			
NO.	TITLE, PAGES, PRICE	NO.	TITLE, PAGES, PRICE
111	Distribution of Wheel Loads on Highway Bridges (Proj. 20-5, Topic 14-22), 21 p., \$7.20	133	Integrated Highway Information Systems (Proj. 20-5, Topic 17-02), 31 p., \$7.60
112	Cost Effectiveness of Hot-Dip Galvanizing for Exposed Steel (Proj. 20-5, Topic 15-19), 28 p., \$7.20	134	D-Cracking of Concrete Pavements (Proj. 20-5, Topic 17-08), 33 p., \$7.60
113	Administration of Research, Development, and Implementation Activities in Highway Agencies (Proj. 20-5, Topic 14-11), 49 p., \$8.00	135	Pavement Management Practices (Proj. 20-5, Topic 17-10), 139 p., \$12.40
114	Management of Traffic Signal Maintenance (Proj. 20-5, Topic 14-02), 133 p., \$10.80	136	Protective Coatings for Bridge Steel (Proj. 20-5, Topic 15-09), 107 p., \$11.00
115	Reducing Construction Conflicts Between Highways and Utilities (Proj. 20-5, Topic 14-03), 72 p., \$8.80	137	Negotiating and Contracting for Professional Engineering Services (Proj. 20-5, Topic 18-05), 75 p., \$10.00
116	Asphalt Overlay Design Procedures (Proj. 20-5, Topic 14-04), 66 p., \$8.40	138	Pavement Markings Materials and Application for Extended Service Life (Proj. 20-5, Topic 18-06), 45 p., \$8.00
117	Toll Highway Financing (Proj. 20-5, Topic 15-01), 29 p., \$7.20	139	Pedestrians and Traffic-Control Measures (Proj. 20-5, Topic 17-11), 75 p., \$9.00
118	Detecting Defects and Deterioration in Highway Structures (Proj. 20-5, Topic 15-03), 75 p., \$8.80	140	Durability of Prestressed Concrete Highway Structures (Proj. 20-5, Topic 15-02), 65 p., \$9.00
119	Prefabricated Bridge Elements and Systems (Proj. 20-5, Topic 15-10), 75 p., \$8.80	141	Bridge Deck Joints (Proj. 20-5, Topic 16-10), 66 p., \$9.00
120	Professional Resource Management and Forecasting (Proj. 20-5, Topic 15-08), 14 p., \$6.80	142	Methods of Cost-Effectiveness Analysis for Highway Projects (Proj. 20-5, Topic 13-02), 22 p., \$7.00
121	Energy Conservation in Transportation (Proj. 20-5, Topic 14-09), 25 p., \$7.20	143	Uniformity Efforts in Oversize/Overweight Permits (Proj. 20-5, Topic 19-02), 79 p., \$10.00
122	Life-Cycle Cost Analysis of Pavements (Proj. 20-5, Topic 15-07), 136 p., \$10.80	144	Breaking/Cracking and Sealing Concrete Pavements (Proj. 20-5, Topic 17-09), 39 p., \$8.00
123	Bridge Designs to Reduce and Facilitate Maintenance Repairs (Proj. 20-5, Topic 12-11), 65 p., \$8.40	145	Staffing Considerations in Construction Engineering Management (Proj. 20-5, Topic 17-13), 42 p., \$8.00
124	Use of Weigh-In-Motion Systems for Data Collection and Enforcement (Proj. 20-5, Topic 16-02), 34 p., \$7.60	146	Use of Consultants for Construction Engineering and Inspection (Proj. 20-5, Topic 18-01), 64 p., \$9.00
125	Maintenance Activities Accomplished by Contract (Proj. 20-5, Topic 14-07), 42 p., \$8.00	147	Treatment of Problem Foundations for Highway Embankments (Proj. 20-5, Topic 18-04), 72 p., \$9.00
126	Equipment for Obtaining Pavement Condition and Traffic Loading Data (Proj. 20-5, Topic 15-04), 117 p., \$11.20	148	Indicators of Quality in Maintenance (Proj. 20-5, Topic 18-12), 114 p., \$11.00
127	Use of Fly Ash in Concrete (Proj. 20-5, Topic 16-07), 66 p., \$8.40	149	Partnerships for Innovation: Private-Sector Contributions to Innovation in the Highway Industry (Proj. 20-5, Topic 19-23), (In preparation)
128	Methods of Identifying Hazardous Highway Elements (Proj. 20-5, Topic 15-06), 80 p., \$10.00	150	Technology Transfer in Selected Highway Agencies (Proj. 20-5, Topic 19-08), (In preparation)
129	Freezing and Thawing Resistance of High-Strength Concrete (Proj. 20-5, Topic 16-05), 31 p., \$7.60	151	Process for Recapitalizing Highway Transportation Systems (Proj. 20-5, Topic 19-06), (In preparation)
130	Traffic Data Collection and Analysis: Methods and Procedures (Proj. 20-5, Topic 15-11), 58 p., \$8.40	152	Compaction of Asphalt Pavement (Proj. 20-5, Topic 19-04), 42 p., \$8.00
131	Effects of Permit and Illegal Overloads on Pavements (Proj. 20-5, Topic 15-05), 99 p., \$10.40	153	Evolution and Benefits of Preventive Maintenance (Proj. 20-5, Topic 18-11), (In preparation)
132	System-Wide Safety Improvements: An Approach to Safety Consistency (Proj. 20-5, Topic 17-01), 20 p., \$6.80	154	Recycling of Portland Cement Concrete Pavements (Project 20-5, Topic 17-06), (In preparation)

TABLE 7  
NCHRP RESEARCH RESULTS DIGESTS<sup>a</sup>

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 <sup>b</sup>	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 <i>Selected Studies in Highway Law</i> 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
169	10-24	Rapid Replacement of Portland Cement Concrete Pavement Segments 11 p. \$4.00
170	20-24	Research Program Design Administration of Highway and Transportation Agencies 5 p. \$3.00
171	10-20 <sup>b</sup>	Pot Bearings and PTFE Surfaces 14 p. \$4.00
172	20-5	Continuing Project to Synthesize Information on Highway Problems 7 p. \$4.00

<sup>a</sup> 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.

<sup>b</sup> Subsequent publication anticipated.

TABLE 8  
NCHRP LEGAL RESEARCH DIGESTS <sup>a</sup>

DIGEST NO.	PROJ. NO.	TITLE, PAGES, PRICE
2	20-6	Supplement to Liability of State Highway Departments for Design, Construction, and Maintenance Defects <sup>b</sup> 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 <sup>b</sup> 10 p. \$3.00
4	20-6	Supplement to Personal Liability of State Highway Department Officers and Employees <sup>b</sup> 9 p. \$3.00
5	20-6	Supplement to Labor Standards in Federal-Aid Highway Construction Contracts <sup>b</sup> 20 p. \$6.00
6	20-6	Impact of the Discretionary Function Exception on Tort Liability of State Highway Departments 25 p. \$6.00
7	20-6	Liability of Public Agencies Arising Out of Rejection of Bids and Misaward of Contracts 17 p. \$6.00
8	20-6	Continuing Project on Legal Problems Arising Out of Highway Programs 11 p. \$6.00

Note: Supplements reference papers published in *Selected Studies in Highway Law*, Volumes 1, 2, 3, 4.

<sup>a</sup> All items listed are final publications except where noted. Numbers missing from the series have been superseded by a later publication.

<sup>b</sup> Subsequent publication anticipated in Addendum to *SSHL*.

# PROGRESS BY PROJECT

## AREA 1: PAVEMENTS

**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.

The approach being used in the research is to integrate existing mechanistic models of trucks and pavement structures which have been selected into a cohesive vehicle/roadway simulation system that will allow systematic study of the interactions between these two elements. By virtue of the fact that the pavement is much stiffer than a truck, the two simulation models can be decoupled, allowing the truck dynamic loads to be computed from the vehicle model excited by road roughness. The calculated dynamic loads can then be used as input to the pavement model for independent calculations of the road response. The two models will then be combined into a system by which the results of the vehicle simulation are fed directly to the pavement response model for study of the interactive effects.

Limited field tests have been conducted and results are being analyzed.

**Project 1-26** FY '87 and FY '89

### Calibrated Mechanistic Structural Analysis Procedures for Pavements

*Research Agency:* University of Illinois  
*Principal Invest.:* Dr. Marshall Thompson  
*Effective Date:* February 6, 1987  
*Completion Date:* March 1, 1992  
*Funds:* \$499,942

During development of the revised *AASHTO Guide for Design of Pavement Structures*, the AASHTO Joint Task Force on Pavements decided to use the statistically based algorithms for traffic loading/pavement performance relationships developed from the AASHO Road Test data with modifications and improvements resulting from research and experience subsequent to the Road Test. It was further decided that research should be initiated immediately with the objective of developing mechanistic pavement analysis and design procedures suitable for use in future versions of the *AASHTO Guide*. The mechanistic technology will eventually be used to (1) increase ability to consider the influence of environmental factors, such as temperature and moisture content; (2) enable better use of existing and new pavement materials; (3) improve reliability of performance predictions; and (4) evaluate the influence of changing traffic loads and vehicle configurations to include axle spacing, number of tires, higher tire pressures, and non-uniform distribution of tire contact pressure.

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 first phase of the project, which has been completed, (1) selected from existing mechanistic technology those procedures suitable for accomplishment of the overall objective, (2) further developed and conducted 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) prepared a long-term plan for calibration and verification of the analysis procedure, and (4) prepared a research plan for future development of the analysis procedure to an implementable mechanistic pavement design method suitable for use in future versions of the *AASHTO Guide for the Design of Pavement Structures*.

Based on the framework for further development of the analysis procedure prepared in the first phase, continuation of the project has been approved, and the second phase of the project has commenced covering the tasks of: (1) input development, (2) structural modeling and transfer functions, (3) design reliability, (4) procedure packaging and presentation, (5) develop pilot implementation plan, and (6) prepare final report.

#### **Project 1-27**    FY '89

##### **Video Image Processing for Evaluating Pavement Surface Distress**

*Research Agency:*    Triple Vision, Inc.  
*Principal Invest.:*    Dr. Richard A. Fundakowski  
*Effective Date:*        March 1, 1989  
*Completion Date:*    August 31, 1991  
*Funds:*                    \$350,000

Measuring distress of both bituminous and portland cement concrete pavements is a primary means of evaluating 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.

The research agency has assessed 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 and have submitted an interim report describing a preliminary system design for processing these video images. The report specifies image resolution and other characteristics required for processing, and describes the equipment and conditions that would be needed for obtaining such images.

Remaining tasks required to complete the project are: (1) 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; (2) develop the video image processing system described in the Interim Report with consideration for user options on hardware and video parameters specific to an individual transportation agency; (3) validate system output by comparison with visual interpretations of video images; (4) modify the system based on these validations; (5) arrange to demonstrate the video image processing system to the NCHRP; (6) deliver the video image processing system software, program source codes, and user's and program manuals to the NCHRP; and (7) prepare a final report on the total research effort.

#### **Project 1-28**    FY '90

##### **Laboratory Determination of Resilient Modulus for Flexible Pavement Design**

*Research Agency:*    Contract Pending  
*Principal Invest.:*    (33 Months)  
*Effective Date:*        (33 Months)  
*Completion Date:*    \$425,000  
*Funds:*                    \$425,000

The resilient modulus of pavement materials and subgrades is an increasingly important input item for design of flexible pavement structures. Existing laboratory test procedures for determining resilient modulus vary in approach; they appear complex and ambiguous, and require a major investment in time and equipment, while providing questionable results. Even the term "resilient modulus," as used by highway design practitioners, differs from the "modulus of resilience" used in other engineering disciplines. Laboratory test procedures do not adequately simulate field conditions, and considerable differences exist between field-determined moduli and laboratory test results.

Resilient modulus is an essential input variable for pavement design using mechanistic concepts. In addition, the empirical design procedures presented in the 1986 *AASHTO Guide for Design of Pavement Structures* require the resilient modulus of the subgrade as a design input in place of the "soil support value" used in the previous editions. However, in the *AASHTO Guide*, an undue emphasis may be placed on the use of resilient modulus in determining structural coefficients. This may lead to the misinterpretation that resilient modulus is the only property of importance in this determination.

The primary objective of this study is to develop and recommend laboratory test procedures for determining resilient moduli of component materials in a flexible pavement structure. These procedures are intended for use in design of both new pavements and rehabilitation of existing pavements. The procedures must be able to account for varying field conditions, such as temperature of the asphalt surface layer and moisture content of a subbase or subgrade layer.

Another objective is to assess the applicability and constraints of using the resilient modulus to establish structural coefficients for the flexible pavement design procedure in the 1986 *AASHTO Guide*.

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

*Task 1. State of the art.* Review state-of-the-art procedures and equipment for laboratory resilient modulus testing and their interrelationships with current and emerging practices for design of flexible pavements.

*Task 2. Candidate procedures.* From the information obtained in Task 1, identify test procedures and equipment for further development under Task 4.

*Task 3. Interim report.* Submit an interim report within 6 months after initiation of the research. The interim report shall summarize the accomplishments of Tasks 1 and 2 and include a detailed plan for the laboratory work to be performed under Task 4. NCHRP approval of the interim report and the proposed plan will be required before commencing with the remaining tasks.

*Task 4. Test procedures.* Develop detailed laboratory test procedures for determining resilient modulus values suitable for use in flexible pavement design. This task may include either modifications of existing equipment and methods or development and fabrication of new equipment or both. The procedures should encompass the normal range of load and environmental factors and material characteristics, and should be suitable for testing both laboratory specimens and field samples. The validity and suitability of the test procedures should be confirmed with sufficient testing of materials encompassing the range of characteristics normally encountered in highway design. The goal of this task is to recommend laboratory test methods that are easily performed and yield consistent and realistic material characteristic values. Recommended test procedures should be in a format suitable

for adoption by AASHTO or ASTM. At the conclusion of this task, a second interim report shall be submitted containing the recommended test procedures and a detailed plan for the validation and study required in Tasks 5 and 6. NCHRP approval of this second interim report and the proposed plan will be required before proceeding with the remaining tasks.

*Task 5. Multi-lab validation.* Perform a validation analysis of the recommended test procedures through multi-lab testing. (It is not envisioned that a full "round-robin" laboratory test validation will be accomplished in this project.) The results of the validation analysis shall be used to refine test procedures.

*Task 6. Field study.* Conduct a limited study to compare and analyze field-determined modulus obtained by commonly used nondestructive testing devices and back-calculation procedures with laboratory-determined modulus using validated test procedures. The purpose of this study is to provide an indication of the magnitude of the difference between field and laboratory resilient modulus values.

*Task 7. AASHTO Guide.* Review the 1986 *AASHTO Guide for the Design of Pavement Structures* with particular emphasis on Chapter II, paragraphs 2.3.3 and 2.3.5. Assess the applicability and constraints of using resilient modulus values to establish structural coefficients for use in the flexible pavement design procedure. Recommend any revisions as appropriate.

*Task 8. Final report.* Prepare a final report documenting the research effort and the research findings.

## AREA 2: ECONOMICS

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:* January 31, 1990  
*Funds:* \$225,000

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 en-

couraging 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." Following publication of NCHRP Report 307, the project panel elected to conduct further work to disseminate the research findings through the preparation of a one-day workshop. The workshop, intended for State and local highway officials and developers, is being presented to panel members and invited participants. Following two or three presentations, the workshop materials will be revised and made available to State DOT officials who may be interested in presenting further dissemination efforts of their own. The publication type and availability will be determined after project panel review of the workshops and the workshop materials.

## **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 was 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 addressed both the benefits and disbenefits associated with rest area facilities.

The research included 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.

All research has been completed. The final report will be published as NCHRP Report 324, "Identifying, Measuring, and Evaluating Benefits of Roadside Rest Areas."

**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 has been completed on schedule. The study committee met for the final time on October 12, 1989 to review study results, conclusions, and recommendations. Publication of the final report is scheduled for April 1990.

**Project 2-17(1) FY '90**

**Methodologies for Evaluating the Effects of Transportation Policies on the Economy**

*Research Agency:* James F. Hickling Management Consultants, Ltd.  
*Principal Invest.:* Dr. David Lewis  
*Effective Date:* September 1, 1989  
*Completion Date:* August 31, 1990  
*Funds:* \$99,145

There is a growing concern that the nation's current transportation policies are not providing the necessary level, type, or quality of services that are required to maintain or improve national productivity and international competitiveness, or to enhance regional and state economic development.

In response to this concern, there is a need for research that will document and critically evaluate the quality and content of the current state of knowledge and research in progress, relating to transportation (all modes) and the local, regional, and national economies.

The objectives of this project are (1) to identify and describe methodologies available to analyze the relationships between transportation and economy, (2) to critically evaluate the methodologies and the state of knowledge resulting from their use, and (3) to develop a primer which documents economic analysis methods found useful in transportation policy decision-making.

To accomplish these objectives the following tasks will be performed:

*Task 1.* For all modes, conduct a literature survey, review research in progress, and inventory current practice to identify and describe the techniques, practices and research available to analyze the interrelationships between transportation and the economy. The types of analyses to be considered include but are not limited to:

- Input-output analysis
- Cost-benefit analysis
- Rate-of-return analysis
- Opportunity cost analysis
- Regional impact analysis models
- Macro-economic analysis
- Industrial locational decision-making models

Prepare a draft report, for review by the project panel, including recommendations for the scope of the Task 2 effort and the technical and practical criteria to be used in the evaluations.

*Task 2.* Following project panel review and approval of the draft report prepared in Task 1, perform the recommended evaluations in accordance with the approved plan and prepare a draft report of those results.

*Task 3.* Develop a primer that will document existing knowledge and useful avenues (either in theory, practical application techniques, or repackaging of existing knowledge) in economic analysis, to assist transportation policy decision-making. The primer shall be written in language suitable for use by state and local transportation decision-makers in explaining the economic effects of transportation infrastructure investment to legislators, interest groups and the public. A summary version of the primer, suitable for release to the media and the public, will also be prepared for project panel review and approval.

*Task 4.* Prepare a final report including recommendations for additional research needed to improve existing or proposed methodologies. The research needs shall be based on the Task 1 investigations, the Task 2 evaluations and the project panel review of the Task 3 primer.

For background on this project and others in the Project 2-17 series, readers are referred to "NCHRP Summary of Progress Through 1988," Transportation Research Board, Washington, DC, 1988, page 72.

**Project 2-17(2) FY ;90**

**Workshop on Research Needs in Transportation and Economic Development**

*Research Agency:* Greenhorne & O'Mara, Inc.  
*Principal Invest.:* Lowell B. Jackson, P.E.  
*Effective Date:* September 1, 1989  
*Completion Date:* July 31, 1990  
*Funds:* \$50,000

The objectives of this project are to assist NCHRP Project Panel A2-17 and the NCHRP staff in organizing, conducting, and documenting a workshop on research needs in transportation and economic development. The purpose of the workshop will be to critique the current thinking in this area, to identify the most critical gaps in knowledge, and to develop a research agenda to facilitate the bridging of these gaps.

To accomplish these objectives the following tasks will be performed:

*Task 1.* Develop Requirements for Commissioned Papers. In consultation with NCHRP staff, develop categories of breakout groups and plans for commissioned papers for each category. Tentative categories are: (1) The National Perspective, (2) The State/Regional Perspective, (3) The Metropolitan Perspective, and (4) The Rural Perspective.

*Task 2.* Prepare Preliminary List of Invitees. Criteria used to select invitees should not be limited to but should include for example:

*Private Sector*

Industrial  
Manufacturing  
Service (including  
transportation services)  
Consultants  
Universities

*Public Sector*

National  
State/Regional  
Metropolitan  
Rural  
Consultants  
Universities  
Research associations

A preliminary list of invitees drawn from the above categories shall be discussed at a NCHRP Panel meeting held in conjunction with the Williamsburg Conference in November 1989.

*Task 3. Secure Site.* In consultation with NCHRP staff, secure site for workshop and assist with preparations for other workshop details as indicated in the other work scope tasks.

*Task 4. Select Paper Authors.* In accordance with the subject matter for the various breakout sessions, select authors for "white papers." Papers shall cover author's view of the state-of-the-knowledge, gaps, and issues together with a suggested phased program of research projects.

*Task 5. Develop Preliminary List of Workshop Questions.* Prepare list of generic questions to be applied to the issues identified for each breakout group. The questions should be designed to provide group leaders with starting points for the group discussions.

*Task 6. Attend Williamsburg Conference and Meeting of NCHRP Panel A2-17.* Present to the panel preliminary lists of invitees and questions.

*Task 7. Finalize List of Invitees and Send Out Invitations.*

*Task 8. Refine Workshop Questions.*

*Task 9. Prepare List of Requirements for Physical Arrangements and Obtain Acceptance from Hotel Management.*

*Task 10. Paper Distribution.* Distribute workshop "white papers" to attendees for review and provide comments to authors to initiate interaction among workshop participants in advance of the workshop.

*Task 11. Select and Contact Breakout Group Chairpersons.*

*Task 12. Prepare Instruction to Chairpersons of Breakout Groups.*

*Task 13. Organize Initial and Final Plenary Session.*

*Task 14. Conduct Workshop.*

*Task 15. Organize Research Problems.*

*Task 16. Prepare Proceedings Document.*

For background on this project and others in the Project 2-17 series, readers are referred to "NCHRP Summary of Progress Through 1988," Transportation Research Board, Washington, DC, 1988, page 72.

## AREA 3: OPERATIONS AND CONTROL

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  
Dr. Daniel B. Fambro  
*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 in the form of a revised version of Table 9-13 (TRB Special Report 209) and 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 mea-

surement 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 research has been completed. The results have been incorporated into a revision of Chapter 9 of the Highway Capacity Manual which is being reviewed by the Highway Capacity Committee. A decision on publication of the final report on Project 3-28C is pending.

## Project 3-32 FY '85

### Temporary Pavement Markings for Work Zones

<i>Research Agency:</i>	Texas A & M Research Foundation
<i>Principal Invest.:</i>	Dr. Conrad L. Dudek
<i>Effective Date:</i>	May 1, 1985
<i>Completion Date:</i>	February 28, 1987
<i>Funds:</i>	\$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. The final report will not be published in the regular NCHRP report series. 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:*      April 30, 1990  
*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 except for a remaining effort to revise the Chapter 7 Highway Capacity Software (HCS). The final report and a revised Chapter 7 have been provided to the Highway Capacity Committee for review and a decision on inclusion in the Highway Capacity Manual. Following acceptance or revision by the Committee, a new version of the Chapter 7 HCS will be prepared.

### **Project 3-35**      FY '86

#### **Speed-Change Lanes**

*Research Agency:*      JHK & Associates  
*Principal Invest.:*      William R. Reilly  
*Effective Date:*        June 1, 1986  
*Completion Date:*      May 31, 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 per-

manent 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.

All research has been completed and the project panel has reviewed the final report and user design guidelines.

The research agency is completing revised documentation which will be provided to the AASHTO Geometric Design Task Force for consideration in revisions to the AASHTO "Green Book." A decision on publication of the final report is pending. Loan copies of the final report and the user design guidelines are available from NCHRP.

### **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 procurement. 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 7 have been completed. Design modifications to reduce the construction and repair costs of

the prototype delayed completion of the final report. Panel review and revision of all materials will require a time extension to about March 1990.

### **Project 3-37**      FY '90

#### **Capacity of Ramp-Freeway Junctions**

*Research Agency:*      Contract pending  
*Principal Invest.:*  
*Effective Date:*      (36 months)  
*Completion Date:*  
*Funds:*      \$450,000

A more definitive understanding of capacity and level of service (LOS) at ramp-freeway junctions is needed to properly design new freeway interchanges and improve existing freeway interchanges.

Chapter 5 of the 1985 *Highway Capacity Manual* (HCM) is based primarily on a Bureau of Public Roads study of lane distribution in the vicinity of merge and diverge areas conducted in the early 1960's. The procedure represents operating characteristics, such as vehicle fleet mix and driver and vehicle performance, that may no longer be valid and does not include a number of geometric and traffic factors that influence capacity and level of service (LOS).

The objective of this research is to develop and validate an appropriate methodology for determining capacity and LOS at freeway-ramp junctions. This could take the form of modifications to the 1985 HCM methodology or an entirely new methodology. In either case, the product of this research shall be a consistent and comprehensive approach treating a wide range of ramp-freeway configurations and traffic conditions.

This research will: (1) evaluate the state of the art in operational analysis of ramp-freeway junctions, (2) develop and test a revised or new methodology for analyzing capacity and LOS at these junctions, and (3) verify the proposed method with an extensive field data collection effort.

The deliverable items of the project shall be: (1) interim and final technical reports, (2) a new or revised Chapter 5 of the HCM, and (3) revisions to the Highway Capacity Software (HCS) module for Ramps and Ramp Junctions.

To accomplish this objective, the project shall be performed in two phases:

#### *Phase I*

*Task 1.* Evaluate the adequacy of the procedures in Chapter 5 of the 1985 HCM. Survey users to determine their experience in applying the procedures to identify deficiencies and needed improvements. Evaluate new information and procedures that should be considered. Appraise the ability of current procedures to predict traffic flow phenomena and identify any deficiencies. This task will not require major field data collection.

*Task 2.* Propose an improved model or models, where needed to overcome the deficiencies identified in Task 1.

The model(s) shall relate capacity and LOS to an appropriate set of site-specific characteristics. The research shall consider the characteristics used in the current methodology and, as a minimum, consider the following additional characteristics: (a) angle of convergence/divergence; (b) length of acceleration/deceleration lane and recovery zone; (c) tapered vs. parallel design; (d) ramp roadway geometrics (including curvature, grades, sight distance, operating speed and width); (e) ramp vehicle arrival patterns (specifically random arrivals, platoon arrivals, and ramp metered arrivals); (f) ratio of ramp to main line lane volumes; and (g) number of lanes and volume distribution on ramp and main line.

In addition, other characteristics identified as having a significant impact on capacity and LOS should be considered. The treatment of ramp configurations shown in Figure 5-1 and Table 5-2 of the HCM shall be extended to include those additional configurations identified in Task 1. The recommended model(s) shall reflect changes in driver behavior and vehicle fleet and performance. Those characteristics and relationships that can be demonstrated to have no significant influence on capacity or level of service may be eliminated from future consideration.

The proposed model(s) shall be based on a systematic approach which represents a rational and logical application of the principles of traffic flow. Modification or expansion of the current LOS criteria may be considered, if warranted.

*Task 3.* Prepare a field data collection and analysis plan to quantify the traffic flow relationships among the parameters identified in Task 2. The interval used for analysis shall not exceed 15 min. Investigate the existence of current usable field data before preparing the plan. To the extent possible, sites for data collection shall represent a variety of nationwide geographical locations, traffic demands, geometrics, and other key conditions. The plan shall identify the expected level of precision, sample size, specific costs, and priorities for each data collection category. A method for early identification of problems that may arise in the data collection and analysis shall also be included. The use of automated data collection techniques, such as video imaging, is allowed, but the development of such techniques is not an objective of this study.

An interim report shall be submitted for review by the NCHRP panel before proceeding with Task 4. The interim report shall discuss the proposed model(s) and support any substantial changes from the existing methodology. It shall also describe the plan for data collection and analysis in detail.

*Task 4.* Select a minimum of five representative sites for a pilot study and implement the data collection and analysis procedures developed in Task 3. Based on the data collected, evaluate the model(s) proposed in Task 2.

*Task 5.* Prepare a Phase I report including (1) a preliminary evaluation of the proposed model(s), (2) the pro-

posed data collection and analysis plan, and (3) a revised, detailed budget for Phase II. The data collection plan should include site selection for approximately 50 sites including those in the pilot study. The researchers shall meet with the NCHRP panel and appropriate members of TRB's Highway Capacity Committee for review and approval of the Phase I report before proceeding to Phase II. It is anticipated that a 60-day period will lapse between the submission and approval of the Phase I report.

#### *Phase II*

*Task 6.* Collect field data according to the approved plan. Data shall be collected under good weather conditions in daylight.

*Task 7.* Reduce and analyze the data collected under Task 6 to calibrate the model(s). Select the appropriate model(s) for inclusion in the final report.

*Task 8.* Prepare a final report describing the form and content of the capacity and level-of-service analysis procedures. This report shall include any procedural revisions necessitated by the data collection and analysis effort and the final values adopted for the relationships used in the analysis procedures. The level of precision and sensitivity of the procedures shall be estimated. This report will be subject to review and acceptance by the NCHRP panel and TRB's Highway Capacity Committee prior to starting Tasks 9 and 10.

*Task 9.* Prepare a new version of HCM Chapter 5, "Ramps and Ramp Junctions," containing the new analysis procedures. This material shall follow the style of the 1985 HCM and shall be suitable for use without any changes, other than typesetting. Figures, tables, and photographs shall be in final camera-ready form.

*Task 10.* Implement the procedures of this project in the HCS module for Ramp and Ramp Junctions which is currently distributed and maintained by the McTrans Center. This task will require modifying the existing module or preparing a new module. The modified or new module shall use the language, software standards, and "look and feel" of the HCS. Fully documented source code and modified user documentation shall be provided. The new version of the HCM Chapter 5 produced in Task 9, and the new version of the HCS produced in Task 10, will be reviewed and approved by the NCHRP project panel.

Research is expected to commence in January 1990.

#### **Project 3-38(1) FY '87**

#### **Assessment of Advanced Technologies for Relieving Urban Traffic Congestion**

<i>Research Agency:</i>	Castle Rock Consultants, Inc.
<i>Principal Invest.:</i>	Peter Davies
<i>Effective Date:</i>	July 1, 1987
<i>Completion Date:</i>	December 31, 1989
<i>Funds:</i>	\$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 en-*

*vironmental 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.*

All research has been completed and the final report is being reviewed by the project panel. It is expected that the final report will be published in the regular NCHRP report series.

Prior to completion of Project 3-38(1), TRB, with the concurrence of ASSHTO and FHWA, had initiated a broader, policy study of the issues being addressed in this project. 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**

<i>Research Agency:</i>	Transportation Research Board
<i>Principal Invest.:</i>	Robert E. Skinner, Jr.
<i>Effective Date:</i>	(18 months)
<i>Completion Date:</i>	
<i>Funds:</i>	\$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/NCR 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-chauffeur 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:* March 31, 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.

All research has been completed, and the final report has been published as NCHRP Report 323, "Travel Characteristics of Large-Scale Suburban Activity Centers."

**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).

*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.

*Task 5*—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.

All research has been completed, and the final report is being revised to reflect project panel comments. A decision on publication of the final report is pending.

A panel meeting is planned for late 1989 or early 1990 to consider an additional phase of research on improvements to traffic adaptive control systems, either through recommended improvements to CIC algorithms or possibly through development of entirely new control strategies.

**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:* July 31, 1990  
*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 the interim report and the plan for the Task 4 simulation testing. Because of extensive review periods for the interim report and the plan for the Task 4 testing, and the software problems with a major revision of the NETSIM program, the completion date has been extended. All problems have now been resolved and the Task 4 simulation runs are underway.

### **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 through 4 have been completed and work is underway on Task 5.

**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:*    February 28, 1990  
*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.

All research is completed, and the preliminary draft final report is under review.

**Project 3-38(7) FY '89****Access Management Policies and Guidelines for Activity Centers**

*Research Agency:* Metro Transportation Group, Inc.  
*Principal Invest.:* Frank J. Koepke  
 Herbert S. Levinson  
*Effective Date:* May 15, 1989  
*Completion Date:* November 15, 1990  
*Funds:* \$124,789

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 is 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.

Work on Task 1 is complete, and preparation of Task 2 synthesis is under way.

**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 through 3 have been completed but project delays have occurred due to difficulties in obtaining project panel approval of the Task 2 Interim Report and identifying suitable test sites to collect weigh-in-motion data. No time extension beyond November 30, 1990 is anticipated.

**Project 3-40**      FY '89

### **Single Point Urban Interchange Design and Operations Analysis**

*Research Agency:*    Texas A&M University Research Foundation

*Principal Invest.:*    Dr. Carroll J. Messer

*Effective Date:*        May 1, 1989  
*Completion Date:*      February 1, 1991  
*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 agencies 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.

Task 1 has been completed, and Task 2 is underway.

### **Project 3-41**    FY '90

#### **Procedure for Determining Work Zone Speed Limits**

*Research Agency:*    Graham-Migletz Enterprises, Inc.  
*Principal Invest.:*    James Migletz  
*Effective Date:*        November 15, 1989  
*Completion Date:*     August 15, 1991  
*Funds:*                    \$200,000

A recent poll of the members of the AASHTO Highway Subcommittee on Traffic Engineering confirmed that the nationwide safety problem in work zones is being aggravated by the lack of uniform guidelines for determining speed limits. Inconsistencies in the methods used to determine work zone speed limits, noncompliance with the posted speed limit by motorists, and the growing practice of setting work zone speed limits through administrative decisions without benefit of an engineering study are major contributors to this safety problem.

While the national *Manual on Uniform Traffic Control Devices* (MUTCD) presents uniform guidelines for determining the speed limit on roads free of work activities, it fails to provide a procedure for determining work zone speed limits. At their 1988 joint summer meeting in Jackson, Wyoming, the AASHTO Highway Subcommittee on Traffic Engineering and the Construction and Maintenance Technical Committee of the National Committee on Uniform Traffic Control Devices unanimously concurred that research is urgently needed to establish a procedure for determining work zone speed limits.

The objective of this project is to develop a uniform procedure for determining work zone speed limits. This procedure should be usable during both the design and construction phases of a roadway construction project and should be developed to accommodate, to the maximum extent possible, the often divergent interests of motorists, workers, and pedestrians.

This project shall consist of at least the following tasks:

*Task 1.* Using an extensive literature search, interviews with knowledgeable individuals, and other appropriate survey techniques, identify, from a broad spectrum of state and local agencies, current procedures and actual practices related to the determination of speed limits both generally and in work zones, and assess motorist compliance with speed limits in work zones.

*Task 2.* Based on the results of Task 1, develop a data collection and analysis plan to accomplish the project objective. Factors to be included in this plan shall include but not be limited to: (a) identification of work zone characteristics that should be included in a procedure for determining speed limits; (b) formulation of one or more potential procedures for determining work zone speed limits; (c) description of how the most effective procedure for determining work zone speed limits will be selected; and (d) identification of data collection sites. The data collection sites shall include a sampling by geographic region, by level of development (urban, suburban, rural), by roadway classification (e.g., freeway, expressway, divided arterial, undivided arterial), and by type and duration of work zone activity.

*Task 3.* Prepare an interim report documenting the research completed in Tasks 1 and 2. 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 scheduled for the purpose of providing panel members the opportunity to interact with the researchers in a detailed discussion on the contents of the interim report. NCHRP approval of the interim report will be required before proceeding with Task 4.

*Task 4.* Implement the data collection and analysis plan approved by the panel in Task 3. The final procedure for determining work zone speed limits shall be readily usable and easily applicable to most work zones.

*Task 5.* Prepare a final report documenting the research effort. It should contain language consistent with the format of the MUTCD to facilitate adoption of the recommended procedure for determining work zone speed limits into Part VI of the MUTCD. It should also contain an applications-oriented user's manual with a diversity of examples describing the use of the recommended procedure. The user's manual must be capable of serving as a stand-alone document. The researchers shall make presentations to the AASHTO Highway Traffic Engineering Subcommittee and National Committee on Uniform Traffic Control Devices describing the research effort and the recommended procedure for determining work zone speed limits.

### **AREA 4:    GENERAL MATERIALS**

#### **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:* \$249,973

The use of deicing salts or the existence of a marine environment presents a potential problem of chloride-induced corrosion of prestressing steel embedded in concrete bridge members—a problem that could ultimately lead to major structural damage. This potential problem is of particular concern in segmental bridges where the prestressing steel is located in close proximity to the deck or other exposed surface.

Good quality construction minimizes the potential corrosion of prestressing steel. Unfortunately, this is not always the case under actual field conditions and construction practices. Low permeable membranes and overlays, concrete sealers, and various methods of decreasing permeability of concrete are being used, but confidence in the long-term protection of prestressing steel is lacking. Therefore, more positive steps were needed to instill confidence in the use of prestressing steel in a chloride-potential environment.

Accordingly, techniques and materials to provide enhanced corrosion protection for prestressing steel and its associated metallic hardware in pretensioned and post-tensioned concrete bridges were reviewed. In addition, a year-long, accelerated corrosion test program on epoxy-coated strand, polyethylene duct, epoxy-coated steel duct, epoxy-coated anchorage hardware, grouts modified with silica fume and with calcium nitrate, and heat-shrink tubing for sealing post-tensioning duct joints, together with traditional materials was undertaken on pretensioned and post-tensioned members.

The research project is complete, and the principal findings have been published in NCHRP Report 313, "Corrosion Protection of Prestressing Systems in Concrete Bridges." Further detail is available in an agency report entitled *Supplement to NCHRP Report 313*, "Corrosion Protection of Prestressing Systems in Concrete Bridges, Appendices A,B,C,D,E,F." These appendices provide additional information on the literature search and the conduct of the various experiments. The supplemental report was distributed to NCHRP sponsors only. However, others may obtain loan copies or purchase ones for the cost of reproduction (see final page of this document for ordering information).

#### **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. A time extension will be required for panel review and revision of the submitted materials.

## AREA 5: ILLUMINATION AND VISIBILITY

**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:* August 1, 1990  
*Funds:* \$475,325

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 in-

adequate 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

Work on Tasks 1 through 6 was successfully completed and has been categorized as Phase I in the overall development of the mobile system. In Phase I, a laboratory model of the measurement system was developed and the proof-of-concept testing was successfully completed. Recommendations were made for a mobile prototype to be developed under a Phase II effort. The project panel met to review the Phase I results and consider the proposed Phase II effort. The panel agreed that the feasibility of a mobile system had been demonstrated and approved the Phase II effort.

Loan copies of the Phase I final report are available from the NCHRP.

The work to be conducted under Phase II is as follows:

*Task 1.* Produce a conceptual design for a prototype Mobile System for Measuring the Retroreflectance of Traffic Signs (MSMRTS) based on the Phase I breadboard system and results. Select/recommend a vehicle suitable for installation and testing of the MSMRTS, based on the mechanical and electrical design requirements of the prototype. Investigate measurement accuracy due to lowering the maximum retroreflectance capability of the system, and develop a mathematical model to predict overall measurement error based on individual component errors.

Prepare a presentation of the conceptual design for review and approval.

*Task 2.* Develop a plan for testing the mobile prototype. This plan will define the signing material, age, and category of sign samples to be tested. System operating modes and vehicle speeds shall also be considered.

*Task 3.* Build the prototype MSMRTS including: detailed design, fabrication, assembly, subsystem integration, and testing.

*Task 4.* Acquire a van-type vehicle including auxiliary generator and prepare vehicle for installation of the prototype MSMRTS.

*Task 5.* Install the MSMRTS on the vehicle and test the prototype system. Perform mobile and stationary measurements of street and highway signs. Evaluate the measurement accuracy of the mobile system while under way.

*Task 6.* Develop final system specifications. Present revised estimate of final system capital and operating costs.

*Task 7.* Prepare a final report and demonstrate the MSMRTS prototype.

Work on Task 1 is complete, and the panel met to review the conceptual design.

**Project 5-11**      FY '89

### **Implementation Strategies for Sign Retroreflectivity Standards**

*Research Agency:* Bellomo-McGee, Inc.  
*Principal Invest.:* Dr. Hugh W. McGee  
*Effective Date:* February 15, 1989  
*Completion Date:* April 30, 1991  
*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 rela-

tionships 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.

All work through Task 5 has been completed, and the panel has met and approved the data collection plan. The Task 6 data collection is in progress.

## **AREA 6: SNOW AND ICE CONTROL**

*(For projects in this Area, refer to Summary of Progress Through 1988—Special Edition)*

## **AREA 7: TRAFFIC PLANNING**

**Project 7-12** FY '89

### **Microcomputer Evaluation of Highway User Benefits**

<i>Research Agency:</i>	Texas A&M Research Foundation
<i>Principal Invest.:</i>	Dr. William F. McFarland
<i>Effective Date:</i>	February 1, 1989
<i>Completion Date:</i>	January 31, 1991
<i>Funds:</i>	\$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 micro-computer 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.

Tasks 1 through 5 have been completed.

## AREA 8: FORECASTING

**Project 8-24A** FY '83

### Forecasting the Basic Inputs to Transportation Planning at the Zonal Level

*Research Agency:* COMSIS Corporation  
*Principal Invest.:* David Levinsohn  
*Effective Date:* April 1, 1987  
*Completion Date:* January 1, 1990  
*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 tech-

niques 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 avail-

ability, 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.

All research is completed and the final report is being reviewed by the project panel. It is expected that the final report will be published in the regular NCHRP report series.

## **Project 8-28    FY '87**

### **Strategic Planning and Management for Transportation Agencies**

<i>Research Agency:</i>	Ernst & Young
<i>Principal Invest.:</i>	Gene Tyndall
<i>Effective Date:</i>	June 1, 1987
<i>Completion Date:</i>	July 31, 1989
<i>Funds:</i>	\$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 guidelines 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.

Draft final reports have been reviewed by the NCHRP; a final version is now under preparation by the agency.

## AREA 9: BITUMINOUS MATERIALS

Project 9-6(1) FY '85 and FY '90

### Asphalt-Aggregate Mixture Analysis System (AAMAS)

*Research Agency:* Brent Rauhut Engineering, Inc.  
*Principal Invests.:* L. Von Quintus  
*Effective Date:* January 5, 1987  
*Completion Date:* June 4, 1990  
*Funds:* \$675,000

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.

Phase II has been completed with the development of the AAMAS in accordance with the concepts and plans prepared during the preliminary Phase I, an investigation of the feasibility of the AAMAS. Major emphasis during development was on preparation, conditioning, testing, and analysis of asphalt-aggregate laboratory specimens that duplicate as nearly as possible the construction, environmental, and traffic conditions to which the pavement is likely to be subjected.

Asphalt concrete construction projects in Colorado, Michigan, Texas, Virginia, and Wyoming were selected 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 test methods to identify techniques for predicting traffic loading and environmental forms of distress.

After determining the most appropriate method for preparation of laboratory specimens to duplicate field samples, specimens were tested using a variety of methods to determine the best methods for predicting resistance to fatigue cracking, thermal cracking, rutting, and moisture damage. The proposed AAMAS was submitted in AASHTO format with a commentary fully describing its development. This has been reviewed by the project panel, and the final report of Phase II should be available in mid-1990.

The objective of the Phase III work effort, now underway, is twofold. The first part is to provide additional data and improve on selected areas studied in Phase II, which are time and traffic dependent. The second part is to take the mixture analysis system the next step to a mix design system, suitable for adoption and use by state highway agencies to optimize the structural and mix design process to produce the desired pavement performance at the least cost.

## AREA 10: SPECIFICATIONS, PROCEDURES, AND PRACTICES

**Project 10-13** FY '79 and FY '82

### Ultrasonic Measurement of Weld Flaw Size

<i>Research Agency:</i>	The Welding Institute (England)	
<i>Principal Invest.:</i>	Timothy J. Jessop	Peter J. Mudge
<i>Effective Date:</i>	July 1, 1979	October 1, 1982
<i>Completion Date:</i>	October 31, 1981	August 31, 1985
<i>Funds:</i>	\$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 reproducibility 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 Phase II objectives were to develop recommendations for applications of tandem-probe techniques for the characterization of vertical, planar defects and 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 Phase II final report will not be published, but copies of the agency's final draft report were distributed to NCHRP sponsors in early 1989. Copies are available on a loan basis from the NCHRP (see final page of this document for ordering information).

**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 nears completion. 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 adopted as ASTM D 4867, "Test Method for Effect of Moisture on Asphalt Concrete Paving Mixtures."

Also in this field evaluation phase, nineteen test sections were included in asphalt paving projects in eight states. Each project contained a control section without additive and a test section including additive. Materials from these projects have been tested. Field cores have also been taken and tested. To date there has been little evidence of moisture damage because the test projects have not been wet

enough nor are they old enough for moisture damage to have occurred. The principal investigator has submitted an "Interim Report" on the field evaluation phase and has recommended that field observations be continued on these test sections until original objectives are satisfied. Consideration is being given as to how this may best be accomplished.

**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 this 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 were to resolve design procedures for special applications of unconfined elastomeric bearings and provide a critical state-of-the-art review of design and construction procedures for pot bearings.

The Phase III research on unconfined elastomeric bearings included (1) an experimental investigation of the low temperature behavior of bearing elastomers; (2) development of guidelines for recommended manufacturing procedures and tolerances; (3) development of recommended bearing prequalification procedures and tests; and (4) revision of the specification developed in Phase II on the basis of the Phase III experimental work.

Phase III research has been completed. The pot bearing research has been summarized in the NCHRP Research Results Digest 171, "Pot Bearings and PTFE Surfaces." The report on unconfined elastomeric bearings will be published in early 1990, and the recommendations from that report are expected to be considered by the AASHTO Bridge Committee in mid-1990.

**Project 10-20A**    FY '88

### **High-Load, Multi-Rotational Bridge Bearings: Design, Materials, and Construction**

*Research Agency:* University of Washington  
*Principal Invest.:* Drs. C. W. Roeder and J. F. Stanton  
*Effective Date:* August 21, 1989  
*Completion Date:* February 28, 1992  
*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.

Through December 31, 1989, research on the project is progressing on schedule. A draft test plan has been prepared and will be finalized in the interim report, which is expected to be submitted at the end of February 1990.

**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 had as its specific objectives to fatigue test 8-year weathered A588 transverse stiffener specimens under constant loading in air and

aqueous environments, and to develop practical guidelines for design, construction, maintenance, and rehabilitation of weathering steel bridges.

Research on the second phase is also complete and has been published as NCHRP Report 314, "Guidelines for the Use of Weathering Steel in Bridges."

**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:* August 15, 1989  
*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 colorimetric procedure for identifying soluble silica in concrete to determine cement content; and a bromide ion-specific electrode, microwave oven technique, and an infrared method to determine water content.

Research is essentially complete; the agency preliminary draft final report has been reviewed by the NCHRP. A revised final report is expected in early 1990.

**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:* September 30, 1989  
*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 framework 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, reviewed, and should be available in mid-1990.

**Project 10-27**    FY '84

### **Determination of Asphaltic Concrete Pavement Structural Properties by Nondestructive Testing**

<i>Research Agency:</i>	Texas A & M Research Foundation
<i>Principal Invest.:</i>	Dr. Robert Lytton
<i>Effective Date:</i>	September 17, 1984
<i>Completion Date:</i>	August 31, 1989
<i>Funds:</i>	\$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 non-destructive 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 has been completed. Existing NDT devices and concepts for analyzing asphalt concrete pavements were identified and evaluated using utility theory. Generic categories of analysis methods for converting NDT deflection data to characteristics of pavement layers have been developed. A field test program for verification of recommended procedures for using NDT deflection data in the pavement design process was conducted. In-service asphalt concrete pavement sections have been selected in several different climatic regions of Texas and in Minnesota for field testing and material sampling. Deflection data were collected using the falling weight deflectometer to evaluate procedures for determining structural characteristics of pavement layers from NDT data. These have been compared with laboratory determination of layer characteristics from cores and material samples collected at the test sites. A computer program has been developed that will quickly back-calculate pavement layer moduli values. The project final report has been submitted, reviewed, and should be available in mid-1990, along with the computer program and users guide.

**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, 1989, research on the project has progressed on schedule. A draft report summarizing the Tasks 4A and 5A research was submitted for NCHRP panel review near the end of December 1989. The draft report also included recommendations for interim specifications for consideration by AASHTO. After panel review, the interim specification recommendations will be forwarded to AASHTO for consideration for adoption.

### **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:* August 31, 1990  
*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 has been focusing on the development of an ultrasonic technique to interrogate the condition of prestressing steel in concrete. A prototype device has been developed and will now be tested in the field, both in the United Kingdom and in the United States. Investigations of cable stayed and suspension cables will only be pursued if time and money permit.

### **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.

Research on the project has been completed. The draft final report has been submitted and reviewed by the

NCHRP project panel. The revised final report is expected to be submitted early in 1990. A decision on publication in the regular NCHRP report series will be made in early 1990.

**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, 1991  
*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 accom-

plish 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 begun under Task 3 continues.

### **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

This study was primarily concerned with the reinforcement of the aggregate base of a surfaced, flexible pavement system using geosynthetics (i.e., geotextiles and geogrids). Separation, filtration, and durability were also considered. Specific methods of reinforcement that were evaluated included: (1) placing the reinforcement within the base, (2) pretensioning a geosynthetic within the base, and (3) prerutting the aggregate base with and without reinforcement. Both large-scale laboratory tests and an analytical

sensitivity study were conducted. Recommendations were also made for full-scale field studies.

Research is complete, and the principal findings have been published in NCHRP Report 315, "Potential Benefits of Geosynthetics in Flexible Pavements." Additional details on the laboratory tests and the analytical study plus plans for full-scale field tests are available in an agency report titled, "Supplement to NCHRP 315, Potential Benefits of Geosynthetics in Flexible Pavements." The supplemental report was distributed to NCHRP sponsors only. However, others may obtain loan copies or purchase ones for the cost of reproduction (see final page of this document for ordering information).

### **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 op-

eration 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 1/2-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.

The final report has been published as NCHRP Report 317. Supplemental materials including the video training tape, "The Nuts and Bolts of Jolts," with an accompanying user guide, will be available from NCHRP in early 1990.

**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, 1989, research on the project has fallen about 4 months behind schedule. A time-only contract amendment will be required in early 1990. The laboratory testing is progressing as planned and should be completed by the middle of 1990.

**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, 1989, research on the project has progressed on schedule. The interim report was reviewed during a meeting of the project panel in August 1989. A revised laboratory test plan was developed by the agency and approved by the panel late in the year. Testing should begin in early 1990.

## AREA 11: LAW

(For projects in this Area, refer to *Summary of Progress Through 1988—Special Edition*)

## AREA 12: BRIDGES

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, 1990  
*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 tests have continued through December 31, 1989. Testing has fallen substantially behind schedule due to equipment problems, but should be completed in mid-1990. A time-only contract amendment will be processed in early 1990 to extend the project termination date.

**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 on-going 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.

Through December 31, 1989, research has progressed on schedule on the project. The interim report was received near the end of the year and is presently under review by the NCHRP project panel.

**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, 1989, research on the project has fallen somewhat behind schedule. An interim report was submitted near the end of the year and is presently under review by the NCHRP project panel. The report includes the results of a number of parameter studies and provides recommendations for new wheel load distribution formulas on the basis of the parameter studies.

#### **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:*                    \$370,229

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 and the final report published as NCHRP Report 321, "Welded Repair of Cracks in Steel Bridge Members." The report is presented in the form of a manual of recommended practice for repair welding and includes criteria for welder qualification and specific repair procedures depending on the type and location of cracks.

#### **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 primary objective of this research was to develop evaluation procedures for steel bridges of different types and for prestressed concrete girder bridges based on the load and resistance factor design (LRFD) methodology. These procedures were then combined with those developed in NCHRP Project 10-15 for reinforced concrete bridges in order to create comprehensive evaluation guidelines for all typical bridge types. The guidelines were

prepared in a format suitable for incorporation into the AASHTO *Manual for Maintenance Inspection of Bridges*.

The first phase of research (development of evaluation procedures for steel girder and prestressed girder bridges) was completed in 1987. The results from this phase of work were published as NCHRP Report 301, "Load Capacity Evaluation of Existing Bridges."

The second phase of research included the combination of the Project 10-15 and 12-28(1) guidelines, and the development of training materials and example problems demonstrating the use of the new guidelines. The combined guidelines were published in 1989 as AASHTO *Guide Specification for Strength Evaluation of Existing Steel and Concrete Bridges*.

The training materials were reviewed by the NCHRP project panel near the end of 1989, and it is expected that they will be published by TRB in 1990.

#### **Project 12-28(2)**    FY '85 and FY '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 was to develop a model form of effective bridge management at the network level.

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 had as its objective the further development and refinement of the model BMS. This phase resulted 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.

Research on the second phase has been completed. A beta-version computer program was submitted for NCHRP review in mid-September 1989. The revised software and user's manual was received just prior to the end of the year. A system for software duplication and distribution will be set up in early 1990.

**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 fatigue design provisions were adopted by AASHTO in 1988 and issued in 1989 as the AASHTO *Guide Specifications for Fatigue Design of Steel Bridges*. The recommended fatigue evaluation and remaining life estimation guidelines were adopted by AASHTO in 1989 and will be issued as a Guide Specification in early 1990.

**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:* November 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 dovetail 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.

Research on the project has been completed. The draft final report was submitted for NCHRP panel review in late October 1989. The revised final report was expected to be submitted by the end of December 1989. It is likely that the report will be published in the regular NCHRP report series in mid-1990.

**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:* November 30, 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 on the project has been completed. The draft final report was submitted in early September 1989 and reviewed by the NCHRP project panel. The revised final report was submitted near the end of the year. The final report includes guidelines for field inspection and office evaluation of corrosion damage, as well as recommended provisions for inclusion in the AASHTO *Manual for Maintenance Inspection of Bridges*. It is expected that the report will be published in the regular NCHRP report series in early 1990.

**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:* May 31, 1989  
*Funds:* \$299,995

The 13th Edition of the AASHTO Standard Specifications for Highway Bridges classifies all two-girder steel highway bridges as nonredundant load path structures. This classification is based on unrealistic concepts widely held by bridge engineers, resulting from the oversimplified assumptions normally used in design, and not on the realistic behavior of the as-built three-dimensional structure.

In this research project, an investigation into the after-fracture redundancy of simple span and continuous, composite and noncomposite steel two-girder highway bridges was conducted. A near full depth fracture was assumed to occur at any position along the length of one of the two girders. The fracture was assumed to penetrate the tension flange and full depth of the web, but not the compression flange. An analytical model was developed consisting of the fractured and unfractured girders together with a redundant bracing system consisting of top and bottom laterals and diaphragms. Results showed that (1) the fractured structure carries dead and live loads as a "pseudo space truss," (2) the after-fracture behavior of

the structure is primarily dependent on the strength and stiffness of the redundant bracing system and its connections to the girder flanges, and (3) a properly designed and configured bracing system provides effective and efficient redundancy to a two-girder highway bridge.

Procedures, equations, and worked examples were developed for application to the design of a new or retrofitted redundant bracing system for new or existing bridges and for application to the redundancy rating of a properly configured existing bracing system in terms of AASHTO truck loading.

Research is complete, and the final report has been published as NCHRP Report 319, "Recommended Guidelines for Redundancy Design and Rating of Two-Girder Steel Bridges."

Guidelines are provided for the design and rating of a redundant bracing system including suggested design and rating loads, allowable stresses, load factors, serviceability criteria, probable fracture locations, strength of connections and allowable fatigue stresses. Guidelines are provided for performing the retrofit of an existing bracing system, for the use of a composite deck as top lateral bracing, for special provisions for continuous two-girder bridges, and for the use of redundant tension cables or rods in lieu of a redundant bracing system for two-girder deck-type bridges and through girder bridges.

Guidelines, procedures, and equations are also presented for the redundancy design or rating of new or existing two-girder steel bridges using the results of a finite element computer analysis of the entire three-dimensional structure. They are intended for bridge engineers who wish to provide redundancy design or rating by computer rather than by using the simplified procedures and equations developed in the remainder of the report.

**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:* March 30, 1990  
*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 assembled 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 fell substantially behind schedule during 1989. The draft final report was not submitted until the end of the year and is presently under review by the NCHRP project panel. A decision on the acceptability of the report will be made in early 1990.

In addition, questions have been raised about the validity of the truck weight histograms that the recommended load models were based on. A review of the data and an assessment of the effect of any errors will be performed prior to report acceptance.

#### **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:*     May 30, 1990  
*Funds:*                    \$241,031

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 5A*—Perform shakedown and ultimate load tests on a one-third scale bridge model. The parameters to be studied shall include the inelastic lateral distribution factors, residual moment fields, and multi-component member behavior and damage. Compare model test results to the data obtained in Task 5.

*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, 1989, research on the project has progressed on schedule. A laboratory bridge model was made available to the research team for testing in early 1989. Task 5A was added to the scope of work in order to provide validation of the analytical models developed in Task 5. The model bridge tests produced results that were very close to those predicted by the analytical models.

## **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:* September 30, 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.

Research on the project has been completed. The draft final report was submitted in mid-August and reviewed by the NCHRP project panel. The revised final report was received near the end of the year and is presently under review for acceptability. It is likely that the report will be published in the regular NCHRP report series in mid-1990.

#### **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 objectives of this research were to investigate the behavior of precast prestressed bridge girders made continuous by connections using cast-in-place slabs and diaphragms at the piers, and 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 piers.

The research was completed and the results are reported in NCHRP Report 322, "Design of Simple-Span Precast Prestressed Bridge Girders Made Continuous." The report includes recommendations for positive and negative moment steel at the continuity connection, along with recommendations for changes to the design require-

ments in the AASHTO *Standard Specifications for Highway Bridges*. The report also includes the description of a simplified computer program that was developed to calculate the time-dependent forces and moments in the girders and at the connections.

#### **Project 12-30**    FY '86

### **Fatigue of Cables in Cable-Stayed Bridges**

*Research Agency:*    Acer Freeman Fox Ltd.  
*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 1989 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-1990.

## 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:* August 30, 1990  
*Funds:* \$375,000

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, 1989, research on the project is progressing on schedule. Most of the specimen fabrication and testing has been completed. Analysis of 1- and 2-inch plate data has been completed and is underway on the 4-inch plate material.

**Project 12-33** FY '88, FY '89, and FY '90

### **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 shortcomings 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, 1989, work on the project is proceeding on schedule. Three contractors and 43 consultants have been employed to work with the Principal Investigator and overall project manager, Dr. John Kulicki of Modjeski and Masters, on the development of the specification and commentary. A "strawman" specification has been completed and submitted to AASHTO for preliminary review. It is expected that the first complete specification draft will be submitted to AASHTO for review in mid-May 1990.

To date, \$799,570 has been obligated on the project. Included in this amount is \$440,000 for Projects 12-33, 12-33A, 12-33B, and 12-33C. The remainder of the obligated amount covers consultant fees and expenses.

**Project 12-33A** FY '88, FY '89, and FY '90**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:* \$50,000

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, FY '89, and FY '90**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:* \$50,000

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 12-33C** FY '88, FY '89, and FY '90**Development of a Comprehensive Bridge Specification and Commentary—Soil-Structure Interaction Systems**

*Research Agency:* D'Appolonia  
*Principal Invest.:* Dr. James L. Withiam

*Effective Date:* July 24, 1989  
*Completion Date:* December 31, 1991  
*Funds:* \$45,000

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 12-33C will act under the direction of the Principal Investigator on Project 12-33, Dr. John Kulicki. D'Appolonia will be responsible for developing specification provisions relating to soil-structure interaction systems such as culverts, anchored walls, mechanically stabilized earth walls, and prefabricated modular walls.

**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.

The objective of this project was to develop recommendations for a revised Division II-Construction specification that would reflect current practice in highway bridge construction. In addition, a companion commentary explaining the background and intent of the various provisions was also developed.

The project has been completed, and the recommended specification and commentary have been distributed to AASHTO for consideration for adoption. The agency report and recommended specification will not be published by TRB. However, if the recommended specification is adopted by AASHTO, it will be published by AASHTO in the near future.

**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* (14th Edition, 1989) 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 substructures.

The objective of this project was 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 project has been completed, and the recommended specification revisions have been distributed to AASHTO for consideration for adoption. The agency report and recommended specifications will not be published by TRB. However, if the recommended specification revisions are adopted by AASHTO, they will be published by AASHTO in the near future.

**AREA 13: EQUIPMENT**

*(For projects in this Area, refer to Summary of Progress Through 1988—Special Edition)*

**AREA 14: MAINTENANCE OF WAY AND STRUCTURES****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:* May 1, 1989  
*Funds:* \$80,811

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 prepared. Panel review and revision of all materials will require a time extension to about March 1990.

**Project 14-8** FY '87**Chip Seal Coats for High-Traffic-Volume Asphalt Concrete Pavements**

*Research Agency:* Intermountain Research Foundation, Inc.  
*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. The literature review has been completed, and an annotated bibliography has been prepared. A questionnaire is being utilized 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. 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 all desired field test projects. One site has been secured for a test project in Tulsa, OK, on U.S. 169. Four different treatments will be investigated, along with two speeds of the pilot car. This project has been constructed, and data are being analyzed.

**Project 14-9(1)** FY '90

### **Effective Maintenance Budget Strategies**

*Research Agency:* The Urban Institute  
*Principal Invest.:* Arlee Reno  
*Effective Date:* November 15, 1989  
*Completion Date:* November 15, 1991  
*Funds* \$250,000

The present condition of highway infrastructure in many parts of the United States is testimony that funding levels have not been adequate for maintenance. Effective communication of budget requests to chief administrative officers (CAOs), highway and transportation commissions, and legislative bodies is a key to funding highway maintenance operations at levels that will preserve investment in the highway system, minimize long-term replacement and user costs, and provide user services. However, many state highway agencies have not been successful in communicating such maintenance needs. This may be due to a number of factors, including consideration that benefits from maintenance operations are much less immediately visible to the public than those from construction, and the apparent inability of maintenance managers to convey to executive and legislative bodies the quantifiable benefits of adequate maintenance funding.

There is a critical need for appropriate guidelines to aid maintenance managers in developing effective maintenance budgeting strategies. Although maintenance will continue to compete with other transportation programs, the use of such guidelines will facilitate better recognition of maintenance needs, in the context of total transpor-

tation budget requirements, and it will increase the probability that the highway infrastructure will be preserved.

The objectives of the study are to (1) identify the state of the practice in formulating and justifying state highway maintenance budgets; (2) assess the strategic usefulness of the various approaches to achieve funding levels consistent with preserving and operating the highway system at acceptable standards; and (3) develop effective guidelines for conveying maintenance budget requests to CAOs, highway and transportation commissions, and legislative bodies.

This project shall consist of at least the following tasks:

*Task 1.* Identify key elements in developing and presenting maintenance budgets in an effective manner; in other words, focus on questions that need to be answered and how they should be addressed in successfully presenting maintenance budgets to CAOs, highway and transportation commissions, and legislative bodies.

*Task 2.* Survey and compare, in terms of similarities and differences, the methods currently used by state highway agencies to develop maintenance budgets and the procedures followed to justify and communicate budget needs to executive and legislative bodies. As part of this survey, variations from the definition of maintenance found in the *AASHTO Maintenance Manual* (1987) should be highlighted. The researchers shall have the survey instrument reviewed and approved by the project panel and, then, pilot tested in several states prior to distribution to all state DOTs. The researchers shall, in addition, select a sample of at least 10 states, including states using dedicated funds and states using general funds, to conduct in-depth field visits in order to identify in detail the best practices.

*Task 3.* Review and analyze the survey results to assess the effectiveness of various state maintenance budget request strategies, in relation to the key elements identified in Task 1. The assessment should include, but not be limited to, an identification of the strengths and weaknesses of existing practices, how legislative and public feedback is obtained, and how innovative or creative strategies are used.

*Task 4.* Document the findings of the previous tasks in an interim report. In addition, formulate a detailed work plan for the remaining tasks and incorporate this plan into the interim report. 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 scheduled for the purpose of providing the panel members the opportunity to interact with the researchers in a detailed discussion on the contents of the interim report. NCHRP approval of the interim report will be required before proceeding with the remaining tasks.

*Task 5.* Identify existing analytical techniques and data sources that can be used to determine road user

costs, safety costs, environmental impacts, tort liability, measured maintenance service levels, and other consequences of alternative maintenance budgets. This effort should draw primarily on published literature. Suggest procedures that can integrate and adapt the analytical techniques and data identified to generate information that can be used as enhancements to maintenance budgeting practices.

*Task 6.* On the basis of the work performed in the previous tasks, develop guidelines for alternative strategies that a maintenance manager can consider in effectively formulating, presenting, and defending maintenance budgets. The researchers shall also present the results of this research effort at a meeting of the AASHTO Highway Subcommittee on Maintenance.

*Task 7.* Prepare a final report documenting the research.

**Project 14-9(2)**      FY '90

### **Incorporation of Maintenance Considerations in Highway Design**

*Research Agency:*      Contract pending  
*Principal Invest.:*  
*Effective Date:*      (24 months)  
*Completion Date:*  
*Funds:*                    \$190,000

Designers are not normally required as part of the highway design process to indicate their assumptions regarding expected life and maintenance requirements for the facilities they are designing. Inadequate consideration for maintenance during design was recognized some years ago as evidenced by the following quotation from the Iowa Highway Maintenance Study (1959-1960, *HRB Special Report 65*): "From the beginning of highway maintenance, its heritage has included taking care of problems unknowingly or neglectfully perpetrated by design and construction engineers." This problem persists to this day and is a contributing cause of increased maintenance work and inconvenience to highway users.

A process is needed for designers to be routinely aware of the maintenance implications of their designs. Designs must be developed and evaluated, recognizing a number of assumptions affecting maintenance operations and requirements. Knowing the implications of these assumptions will permit the documentation of maintenance needs to ensure that maintenance personnel, equipment, materials, and funds will be available when needed.

Designers must also be aware of design details that create maintenance problems and be willing to incorporate improvements to increase the "maintainability" of the highway components. There is a need to specifically identify and communicate maintenance problems that can be addressed through better design. The need is accelerating because of the greatly increased volume of traffic that makes it difficult to close traffic lanes for routine

maintenance work. It would be desirable to design highway components (such as pavements, bridges, drainage features, and roadside appurtenances) with zero maintenance requirements, but because this is unlikely, designs should be developed to ensure maintainability at optimal costs. Designers must consider a variety of issues such as: (1) access for inspection and repair; (2) incorporation of sensing and monitoring devices; (3) future maintenance operations, for example, snow removal, street cleaning, and mowing; (4) life expectancy of various materials and designs; and (5) improved features and configurations.

The objectives of this study are threefold: (1) determine the current practice of incorporating maintenance concerns in the highway design process and identify successful techniques, weaknesses, and needed improvements; (2) recommend a design process that will achieve explicit recognition of the maintenance implications of each design; and (3) list and describe design details that create maintenance problems and improvements that overcome them, including opportunities for applying new technology. Attainment of these objectives will necessitate at least the following tasks.

*Task 1.* Through literature searches, interviews, and other appropriate means, determine current practices to do the following: (a) incorporate maintenance considerations in design procedures, (b) determine expected service life and future maintenance costs to support design decisions, and (c) identify details of specific problems and solutions to those problems. Select five agencies with successful programs, representing a variety of administrative structures, agency sizes, and geographical locations, for more detailed visits and interviews with maintenance and design engineers.

*Task 2.* Develop a process, taking into account the organizational structures of the agencies, to evaluate the maintenance implications of highway facility designs. The maintenance assumptions used in each design, for example, the expected service life of significant components, must be recognized. Such factors as future maintenance resource requirements and ease of future inspection and maintenance shall also be considered. Submit to the NCHRP for approval a recommended evaluation process and the name of a state willing to cooperate in the application of the process to a recently designed project. (Upon submission, it is anticipated that the necessary review and approval will be completed within 2 months.) On approval, apply the process to the selected state, document the results, and make modifications to the process if needed.

*Task 3.* Identify design features that will mitigate future maintenance, including techniques or devices that can be incorporated in the design of new facilities that will permit the monitoring or inspection of various components. Examples include techniques and devices to monitor or allow the inspection of the condition of post-

tensioned cables, corrosion of steel, scour around foundations, and deterioration of concrete. All recommendations should be limited to those that can be practically employed in the immediate future.

*Task 4.* Prepare a final report documenting the findings of the research effort. The report shall include the state of practice and a user's manual. The user's manual will include the suggested maintenance evaluation process for highway facility designs and descriptions of design features, techniques, and devices to reduce or improve the maintenance of highway-related facilities and operations.

**Project 14-9(3)** FY '90

### **Maintenance Contracting**

*Research Agency:* Contract pending  
*Principal Invest.:*  
*Effective Date:* (18 months)  
*Completion Date:*  
*Funds:* \$150,000

Highway departments are challenged by increasing levels-of-service demands and the deteriorating infrastructure at a time of constrained resources (funds, equipment, materials, and personnel). As the resulting workload enlarges, the contracting of maintenance activities is being used as an alternative to the expansion of in-house resources. However, limited in-house resources may not be the only reason for engaging in contract maintenance. Decisions for contracting can also be based on such factors as the need for specialized equipment and expertise, more cost-effective procedures or techniques, better quality, public demand for new services, statutory requirements, agency policies, seasonality of work, and contractor availability.

Most state highway departments have gained experience in various contracting relationships with private industry and, in some instances, other governmental agencies that collectively include many aspects of performing highway maintenance. Contract maintenance has been used to perform both functional contracting (e.g., guardrail repair) and general contracting (e.g., overall maintenance of a designated highway section). Contracts for maintenance can also be based on repair, restoration, or services connected with a single project or provided over a specified period of time. Current practices used for contract development (including the decision to contract), implementation, and administration need to be collected and shared through the preparation of practical guidelines for use by state highway departments.

The objective of this research is to prepare guidelines for the development, implementation, and administration of maintenance contracts. This objective will be accomplished by completing the following tasks:

*Task 1.* Through literature reviews, surveys, and interviews with contracting agencies and contractors, de-

termine current practices to include as a minimum: (a) methods of deciding whether maintenance activities should be performed with contractors or in-house personnel (special emphasis shall be placed on determinations of comparative costs); (b) procedures for evaluating minimum staffing requirements for contracting agencies; (c) types of maintenance contracts being used by public agencies and reasons why; (d) innovative funding methods and sources to support certain types of contract maintenance work; (e) recent developments and unique methods in contract administration that include such issues as pay items, methods of measurement, incentive and liquidated damage assessments, project acceptance, and final payments; (f) unique methods of contracting for maintenance; and (g) agency satisfaction with various types of maintenance contracts. (This research is intended to update and supplement two relevant documents, *NCHRP Synthesis of Highway Practice 125*, "Maintenance Activities Accomplished by Contract," and *A Guide for Methods and Procedures in Contract Maintenance* (prepared by the AASHTO Highway Subcommittee on Maintenance).)

**Project 14-10** FY '89

### **Improvements in Date Adjustment Technology for Maintenance Management Systems**

*Research Agency:* The Urban Institute  
*Principal Invest.:* William A. Hyman  
 Ancel Dan Horn  
*Effective Date:* May 29, 1989  
*Completion Date:* May 28, 1990  
*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.

Research is underway. A variety of potential tools and techniques have been identified and are now being evaluated for their applicability to maintenance management systems and the needs of first-level maintenance supervisors.

**Project 14-11** FY '89

### **Effective Motivation of Highway Maintenance Personnel**

*Research Agency:* The Pennsylvania State University  
*Principal Invest.:* Dr. H. Randolph Thomas

*Effective Date:* June 1, 1989  
*Completion Date:* August 31, 1991  
*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.

Tasks 1 and 2 have been completed.

## AREA 15: GENERAL DESIGN

**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 final report has been submitted, and appropriate methods for report distribution are under consideration. 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 Information Systems has indicated an interest in the project results for 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.

Research is nearing completion. The Task 6 workshop was held on December 4 and 5, 1989. Experts and lay persons critiqued the work thus far. Modifications to the computer software package are now being made based on the results of the workshop.

## **Project 15-12    FY '88**

### **Roadway Widths for Low Traffic Volume Roads**

*Research Agency:* Jack E. Leisch & Associates  
*Principal Invest.:* Charles V. Zegeer and Timothy R. Neuman  
*Effective Date:* May 1, 1989  
*Completion Date:* October 31, 1991  
*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.

Task 1 has been completed.

**Project 15-13** FY '90

### **Long-Term Performance of Geosynthetics in Drainage Applications**

*Research Agency:* Contract pending  
*Principal Invest.:*

*Effective Date:* (36 months)  
*Completion Date:*  
*Funds:* \$500,000

The use of geosynthetics in drainage-related applications has increased rapidly in the past 10 to 15 years. Geosynthetics, as used here, includes geotextiles, geotextile/aggregate, geotextile/pipe, and prefabricated drainage systems. Applications include, but are not limited to, pavement edge drains, underdrains, slope drains, drainage behind retaining walls, french drains, and interceptor drains. Wick drains are specifically excluded from the scope of this research. In general, geosynthetics are used rather than graded filters because of their lower initial cost and ease of construction.

There have been many publications, conferences, and short courses during the past few years extolling the advantages of geosynthetics and providing information on their design. However, there is little quantitative information regarding long-term performance of geosynthetics over the design life of the facility. The initial cost advantage of geosynthetics can be negated if they do not have a sufficiently long life and have to be replaced prematurely. Inadequate performance of geosynthetics may lead to failures of pavements, slopes, or retaining walls.

Questions about drainage performance of geosynthetics can be divided into four areas: (1) appropriateness of the application, (2) design methodology, (3) relationship of design properties to field performance, and (4) installation. Geosynthetics have been used where adequate performance was impossible or where specific site conditions severely restricted their performance. Design methods have not necessarily taken into consideration factors to improve long-term performance. Standardized tests and specifications for various applications have not been developed to ensure required performance life. Installation problems include inadequate understanding of how the installation method affects the performance of the geosynthetics.

The objectives of this project are: (1) to document the design and performance of existing installations of geosynthetics in drainage applications, including the appropriateness of use, construction techniques and related problems, failure mechanisms and their consequences, and factors affecting long-term performance; and (2) to recommend material properties, test methods, specification values, and design and construction criteria.

It is anticipated that the research will include, as a minimum, the following tasks:

*Task 1.* Review relevant literature, research findings, design methods, and performance data on geosynthetic drainage systems to assess the state of the art. This review should not be limited to highway or transportation-related projects, but should include applications in areas such as agriculture and buildings.

*Task 2.* Conduct a survey of state highway agencies and other appropriate organizations to develop a list of

candidate sites for in-service performance evaluation of geosynthetic drainage systems. This candidate list should include sites with failures and successes, sites with various soil conditions and geosynthetics applications, and sites that have been used by agencies for experimental purposes. This survey should also include any other information pertinent to this research.

*Task 3.* Submit an interim report within 6 months after initiation of the research. The interim report shall include a summary of the data collected in Tasks 1 and 2, and a detailed plan for a proposed field and laboratory investigation program to be conducted in Task 4. Sites shall be selected to obtain a reasonable balance between sites with documented successes and failures, and a variety of soil conditions, with particular emphasis on encompassing the full range of geosynthetic applications. NCHRP approval of the interim report and the proposed plan will be required before commencing with the remaining tasks.

*Task 4.* For selected sites, review design and construction records and conduct a field and laboratory investigation program to document: (a) the performance of the drainage system and compare it with design expectations and product claims; (b) the presence or absence of any system or component problems such as physical, chemical, or biological clogging, material deterioration, physical damage, construction failures, inadequate hydraulic capacity, or excessive core compression; (c) the causes and consequences of any problems noted in b; and (d) any other items that would be useful in preparing procedures and specifications for design and construction or in planning further research in this field. These investigations should be conducted and documented in a thorough and systematic manner in order to provide guidance to assist others to fully understand the basis for the recommendations made in Task 5.

*Task 5.* Analyze and compare the field and laboratory test results with the design and construction procedures, and specification values based on the results of this investigation. Recommended test procedures should be in a format suitable for adoption by AASHTO or ASTM.

*Task 6.* Prepare a final report documenting the research efforts and the research findings.

## AREA 16. ROADSIDE DEVELOPMENT

*(For projects in this Area, refer to Summary of Progress Through 1988—Special Edition)*

## AREA 17: SAFETY

**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 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 were to also place emphasis on the operational efficiency and cost-effectiveness of each treatment.

This research consisted of two phases. Phase I determined the state of the art 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 completed the Phase I effort. Because of staff changes at the research agency, Project 17-6 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.

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 were 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 were 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.

Research has been completed and the disposition of the final report is pending.

#### **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:*    May 15, 1989  
*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 were (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.

The research has been completed, and the final report has been published as NCHRP Report 320, "Guidelines for Converting STOP to YIELD Control at Intersections."

#### **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 iden-

tified 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 through 5 have been completed.

**AREA 18: CONCRETE MATERIALS**

*(For projects in this Area, refer to Summary of Progress Through 1988—Special Edition)*

**AREA 19: FINANCE**

*(For projects in this Area, refer to Summary of Progress Through 1988—Special Edition)*

**AREA 20: SPECIAL PROJECTS**

**Project 20-5** FY '68 and continuing

**Synthesis of Information Related to Highway Problems**

*Research Agency:* Transportation Research Board  
*Principal Invest.:* Herbert A. Pennock  
 Martin T. Pietrucha  
*Effective Date:* December 15, 1967

<i>Completion Date:</i>	Continuing	
<i>Funds:</i>	\$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 annually,	FY '86-'87
	\$650,000	FY '88
	\$550,000	FY '89
	\$650,000	FY '90

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.

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 172.

**Project 20-6** FY '69 and continuing

**Legal Problems Arising out of Highway Programs**

<i>Research Agency:</i>	Transportation Research Board
<i>Principal Invest.:</i>	Robert W. Cunliffe
<i>Effective Date:</i>	November 1, 1968
<i>Completion Date:</i>	Continuing
<i>Funds:</i>	
\$200,000 FY '69	\$85,000 FY '76
\$125,000 FY '72	\$75,000 FY '77
\$50,000 FY '73	\$100,000 Ann. FY '78-'79
\$185,000 FY '74	\$150,000 Ann. FY '80-'81
\$125,000 FY '75	\$100,000 FY '82

\$150,000 FY '83	\$200,000 FY '86 & '88
\$200,000 FY '84	\$100,000 FY '89
\$280,000 FY '85	\$200,000 FY '90

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.

Studies completed under this project prior to November 1988 have been published as *NCHRP Research Results Digests* (see Table 7). Subsequent studies will be published in a new series (see Table 8), the "Legal Research Digest." Like previous papers published in the NCHRP Research Results Digest series, each issue of the Legal Research Digest will focus on supplements and new papers which will be compiled and subsequently published as addenda to the 4-volume compendium, *Selected Studies in Highway Law*. Because the material presented in these Digests will still be of interest to individuals in the transportation community who are not necessarily in the legal profession, they will continue to be widely distributed through the Transportation Research Board's selective distribution process. For the convenience of those individuals possessing the compendium, the Legal Research Digest is 3-hole punched for retention in a binder, as a ready reference, pending receipt of subsequent addenda.

In addition, completed studies have also been included in the four-volume text, *Selected Studies in Highway Law*. Volumes 1 and 2, dealing primarily with the law of eminent domain, were published in 1976. Volume 3, dealing with contracts, torts, environmental and other areas of

highway law, was published in 1978. An addendum to *Selected Studies in Highway Law*, consisting of 5 new papers and updates of 8 existing papers, was issued during 1979; a second addendum, consisting of 2 new papers and 15 supplements was distributed early in 1981; a third addendum, consisting of 8 new papers, 7 supplements, and an expandable binder for Volume 4 was distributed during the first half of 1983; and 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.

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 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. Additional information on the project may be found in Legal Research Digest 8.

#### Project 20-7 FY '69 and continuing

#### Research for AASHTO Standing Committee on Highways

<i>Research Agency:</i>	Open
<i>Principal Invest.:</i>	Open
<i>Effective Date:</i>	December 2, 1968
<i>Completion Date:</i>	Continuing
<i>Funds:</i>	\$100,000 annually, FY '69-'85
	\$56,000 FY '86
	\$150,000 annually, FY '87-'88
	\$125,000 FY '89
	\$200,000 FY '90

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 current tasks completed after 1988 follows. For tasks completed prior to 1989, refer to the Summary of Progress Through 1988—Special Edition.

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 32, "Design and Construction Specifications for Segmental Concrete Bridges" (Post-Tensioning Institute). The objective of this research was 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 recommended specifications were adopted and published by AASHTO in 1989 as the *AASHTO Guide Specifications for Design and Construction of Segmental Concrete Bridges*.

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 the *ANSI/AASHTO/AWS D1.5-88 Bridge Welding Code*, a new welding code for steel highway bridges. The objectives of Task 34 are to develop a commentary to the new code and to incorporate the welding related provisions of the 1978 *AASHTO Guide Specifications for Nonredundant Fracture Critical Members* into the code. The recommended commentary has been completed and distributed to AASHTO for consideration for adoption. Work was initiated in late 1989 on the development of the welding provisions for fracture critical members.

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 will be completed in March 1990.

Task 36, "Critical Assessment of Tire Pressure Research" (Harry A. Smith). This task was requested by AASHTO Joint Task Force on Pavements. The objectives are to develop a synopsis and critical evaluation of completed and on-going research efforts pertaining to high pressure truck tires and to identify future research required to fill information gaps in this area. Research has been completed, and the final report is under review.

Task 37, "Development of An Asphalt Paving Handbook" (TRB Division B). This task was requested by AASHTO Subcommittee on Construction and the Sub-

committee 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 report is currently under review.

Task 38, "AASHTO Guidelines for Pavement Management Systems" (ARE, Inc.). 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. Research is complete, and the new *AASHTO Guidelines for Pavement Management Systems* has been delivered to AASHTO for publication consideration.

Task 39, "Revision of AASHTO Pavement Overlay Design Procedures" (Darter and Associates). 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. Research is underway.

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.

Task 41, "AASHTO Guide for Recruitment and Retention of Transportation Professionals" (Herb Golden). The objective of this study is to develop a comprehensive recruitment and retention program guide to assist AASHTO member departments in diagnosing the effectiveness of their current activities in (1) formulating a recruitment and retention strategy, (2) developing and promoting career opportunities, (3) cultivating university contacts, (4) producing attractive and effective marketing materials, (5) refining recruitment tactics, (6) providing

student employment, and (7) inventorying best practices. A draft of the *Guide* has been presented to the AASHTO Task Force on Transportation Professionals, Development and Recruitment for their review.

Task 42, "Development of National Truck Size and Weight Policy Recommendations" (TRB Division B). The objective of this study is to develop national truck size and weight policy recommendations. To accomplish this objective will require staff support to identify areas where research is needed, to initiate additional research to fill information gaps, and to coordinate research study schedules.

Task 43, "Revision of the AASHTO Policy on Geometric Design of Highways and Streets." Cancelled.

Task 44, "Division 100 Revision of the AASHTO Guide Specifications for Highway Construction." Several State highway agencies have in recent years revised their specifications to address the issues that have developed as a result of (1) legal interpretations of the issues coming from the courts; (2) changing methods of doing business in the fields of contract administration and construction inspection due to factors such as increased claims and new legislative requirements; (3) growing involvement of third parties in the control and inspection of construction activities; and (4) increased construction industry involvement in the control of material quality and construction procedures due to a decrease in the availability of experienced State field personnel. The AASHTO Highway Subcommittee on Construction has requested a synthesis of Division 100 example specifications addressing areas such as claims handling, design-construct contracts, bid escrow documentation, construction inspection by consultant, quality assurance, etc., including the ramifications of these specifications on the state highway agency and the contractor. Based on this synthesis, a revised version of Division 100 will be recommended.

**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:* December 31, 1989  
*Funds:* \$146,218

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 illustrate 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 completed on all tasks and the project panel is reviewing the video and all other documents. Publication and distribution decisions will be made early in

1990, and final products of the research will be published or available by mid-1990.

**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. A preliminary version of the computer software has been developed and is being used to evaluate data collected by several different equipment vendors. The data were obtained in July 1989 during a field demonstration over a predefined course in Santa Fe, New Mexico. Evaluations of the data will permit further refinements in the algorithms and software. Present indications are that the project will be successful in meeting its objective.

**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

Much of the research conducted by the NCHRP is designed to solve specific problems, experienced by practitioners, that are related to the operational and planning functions of state highway departments. Although top management is certainly affected by these problems and benefits from solutions through improved agency performance, this type of research does not necessarily address top management's most immediate needs. A research program designed from the perspective of top management would help provide a needed resource to support the decisions and improve the effectiveness of top managers. Such a program was initiated under this NCHRP project.

Through surveys and interviews, issues of greatest concern to top management were identified. Individual projects were developed to address these issues and then described to provide background information and suggested research plans. All of the projects were classified under one of three categories—resource development, decision support, or financial management.

Research is complete, and the principal findings and brief summaries of all the recommended projects have been published in NCHRP Research Results Digest 170, "Research Program Design, Administration of Highway and Transportation Agencies." Additional details on the

recommended program and the specific projects are available in the agency final report titled, "NCHRP Project 20-24, Research Program Design." The agency report was distributed to NCHRP sponsors only. However, others may obtain copies or purchase ones for the cost of reproduction (see final page of this section for ordering information).

**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 inter-related 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 design and implementation of transportation market research efforts.

The agency's preliminary draft final report has been reviewed by the NCHRP. Preparation of the revised final report based on suggestions from the review is now underway. The revised version is expected in early 1990.

**Project 20-24(2) FY '89**

**Executive Management Information Systems for State Departments of Transportation**

*Research Agency:* Andersen Consulting  
*Principal Invest.:* Roger A. Gelfenbien  
*Effective Date:* May 1, 1989  
*Completion Date:* October 14, 1989  
*Funds:* \$100,000

Providing relevant, accurate, and timely information in an easy-to-use format benefits any executive, primarily ones with the breadth of responsibilities found in transportation departments. Executive Management Information Systems (EMIS) are relatively new to departments of transportation and as such AASHTO requested a project to develop guidelines to assist member departments in the development and implementation of EMISs. The objectives of the project were to: (1) develop a prototype to assist DOT executives in understanding what an EMIS can do for their departments, and (2) outline the step-by-step process that would be needed to design, implement, and support an EMIS.

On behalf of the NCHRP, the contract research agency worked with an AASHTO task force to develop a guide for implementing executive management information systems in state DOTs. Work is completed, and the agency's final report has been submitted. Copies of the report were sent to all state DOTs. Further decisions on the publication and distribution of the report are pending discussions between AASHTO and NCHRP.

**Project 20-25 FY '89**

**Training Needs for Highway Construction Personnel**

*Research Agency:* University of Maryland  
*Principal Invest.:* Dr. Everett C. Carter  
*Effective Date:* June 15, 1989  
*Completion Date:* June 14, 1990  
*Funds:* \$74,927

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.

Research is underway to (1) develop a nationally applicable listing of job-related tasks (work elements) and job task descriptions for personnel involved in the highway construction process, (2) survey existing training and certification programs, (3) establish criteria for determining effectiveness of training and certification programs and assess existing programs, including areas of weaknesses and deficiencies, and (4) design a framework for a national training program that supports certification for highway construction personnel.

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:* Texas Transportation Institute  
*Principal Invest.:* Dr. Donn Hancher  
*Effective Date:* June 1, 1989  
*Completion Date:* September 30, 1990  
*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 pub-

lic 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.

Through December 31, 1989, research on the project is progressing on schedule. The Task 1 and Task 2 surveys have been distributed, and responses are being collected and analyzed.

**Project 20-27** FY '90

### **Adaptation of Geographic Information Systems for Transportation**

*Research Agency:* Contract pending  
*Principal Invest.:*  
*Effective Date:* (18 months)  
*Completion Date:*  
*Funds:* \$220,000

Administrators, engineers, and researchers are continually faced with transportation problems on which much information exists, often in the form of reports, computer data, and undocumented experience and practice. Because of the complexity of many transportation issues, both within and across modes, the information required to fully consider the various alternatives frequently resides in a number of units within local, state, and federal agencies and is not readily available for use in the decision process.

Geographic information systems (GIS), which have been successfully applied in many fields outside of the transportation industry, offer the potential to assemble and process data from a diversity of sources and present it in an easily understood graphical format. A GIS is a computerized data management system that is designed to capture, store, retrieve, analyze, and display spatially referenced data. The capabilities of a GIS in the transportation field, hereinafter referred to as GIS-T, will permit the assimilation, integration, and presentation of data collected and stored by each of the divisions within a highway agency. Additionally, it can accommodate information gathered and stored by other agencies.

To exploit the full capabilities of GIS-T, there is a need to identify current applications of GIS concepts and technologies in the transportation field, to identify transportation problems that can not be addressed by current GIS concepts and technologies and thus will require the development of new or extensions to existing concepts and technologies, to design a GIS-T that will provide comprehensive and timely information for management decision support, and to assess the impacts of implementing a GIS-T on the transportation industry.

The objectives of this research project are to: (1) identify and evaluate the state of practice and planned activities in GIS-T, (2) identify transportation problems requiring new capabilities or extensions to current GIS concepts and technologies, (3) design a GIS-T based on current and anticipated transportation agencies' needs, and (4) assess the impact of implementing the designed GIS-T on the transportation industry.

This research shall include at least the following tasks:

*Task 1.* Identify and assess current and planned activities in the design, development, implementation, and operation of GIS-T. Information gathered from transportation agencies, other agencies with data of interest to transportation agencies, and vendors of GIS and GIS-T products should include but not be limited to:

- GIS and GIS-T concepts and technologies; definitions of GIS-T; GIS-T structures; internal and external system components and relationships; analytical tools; standardization issues; data collection, conversion, and maintenance; map scales; location reference methods; accuracy/precision issues; use of expert systems; system outputs.
- Areas of application (e.g., accident analysis, hazardous material routing, highway performance monitoring systems, planning, project management, socioeconomic and environmental impact).
- Internal and external agency coordination; shared data (e.g., census, geological, land use, value and zoning, local traffic engineering and planning, utilities).
- Management support and involvement; training; institutional issues; procurement issues; copyrighting and licensing issues; costs and benefits.

*Task 2.* Based on the results of Task 1, design an idealized framework(s) for a GIS-T. The framework(s) should include each of the appropriate system characteristics identified in Task 1 and any other characteristics the researchers deem to be advantageous. The framework(s) developed should use modular component design to facilitate staged development and be independent of the computing environment. Within this task the researchers shall also identify transportation problems that will require the development of new or modified GIS and GIS-T concepts and technologies.

*Task 3.* Prepare an interim report documenting the research completed in Tasks 1 and 2. Soon after submission of the interim report for review by the NCHRP project panel, a meeting between the research team and the NCHRP project panel will be scheduled for the purpose of providing panel members the opportunity to interact with the researchers in a detailed discussion of the contents of the interim report. NCHRP approval of the interim report will be required before proceeding with Task 4.

*Task 4.* Design a GIS-T(s) based on the panel approved framework(s) in Task 3. The GIS-T(s) design shall contain sufficient detail to allow for the development of a GIS-T. For transportation problems that will require the development of new or modified GIS and GIS-T concepts and technologies, the researchers shall provide a detailed description of the problems and a brief description of potential concepts and technologies required to address these problems.

*Task 5.* Identify GIS-T implementation issues and how the introduction of GIS-T will potentially change the

transportation industry. Based on the results of this effort prepare a management guide to assist transportation agencies in the implementation of a GIS-T.

*Task 6.* Prepare 5- and 10-year forecasts of the potential applications of GIS-T. These forecasts shall address planned and anticipated advances in technology, how these advances will be applied, and their impact on the transportation industry. Within these forecasts the researchers shall also identify basic and applied research efforts needed to support GIS-T development during the forecast periods.

*Task 7.* Prepare a final report documenting the research effort.

#### **Project 20-28** FY '90

### **Guidance to Highway Agencies Encountering Hazardous Waste Sites in Highway Rights-of-Way**

*Research Agency:* Transportation Research Board  
*Principal Invest.:* Robert E. Skinner, Jr.  
*Effective Date:*  
*Completion Date:* (In developmental stage)  
*Funds:* \$300,000

When constructing or improving highway projects, state highway agencies are encountering hazardous waste sites in highway rights-of-way with increasing frequency. Although one or two states have considerable experience addressing these problems, few state highway officials are aware of the regulatory or technical issues raised. Little information is available to help highway officials assess the potential delays and costs likely to be encountered, or to suggest approaches to managing the problem. Accordingly, the states, acting through the American Association of State Highway and Transportation Officials (AASHTO), have requested guidance on how to assess the potential cost and delay of hazardous waste site cleanup to assist in their decision-making on whether and how to proceed with construction projects that involve a hazardous waste site. A study committee including experts in highway design and construction, hazardous waste remediation, environmental law, environmental health, and public policy will build on a previous NCHRP project (*NCHRP Report 310*) and commission a small number of case studies to examine and characterize the problems being encountered by state highway agencies. Drawing on these findings and the experience and expertise of its members, the committee will provide guidance to state highway officials on managing hazardous waste site problems. The committee may also identify areas where changes or improvements in state or federal procedures are justified. Aspects of this issue where uncertainty is high due to lack of technical knowledge will be indicated and research recommended. Aspects where uncertainty is high because of legal and regulatory requirements will also be discussed.

### **AREA 21: TESTING AND INSTRUMENTATION**

#### **Project 21-3** FY '90

### **Instrumentation for Measuring Scour at Bridge Piers and Abutments**

*Research Agency:* Resource Consultants, Inc.  
*Principal Invest.:* Dr. Everett V. Richardson  
 Dr. Peter F. Lagasse  
*Effective Date:* December 1, 1989  
*Completion Date:* February 29, 1992  
*Funds:* \$299,824

There are approximately 575,000 highway bridges in the nation's National Bridge Inventory. Of these, 85 percent are over streams or rivers. This level of exposure to the scouring action of floods dictates the need for expeditious development and implementation of reliable scour evaluation and related bridge inspection practices. The importance of this is supported by the 80 flood-related failures that have occurred in the past 3 years. Nationally, the annual cost for scour-related bridge failures has been determined to be \$30 million.

In late 1988, the FHWA issued a Technical Advisory titled "Scour at Bridges." The advisory is intended to provide guidance to the states for developing and implementing a scour evaluation program. The program is intended to be applicable to the design of new bridges, evaluation of existing bridges, and implementation of scour countermeasures.

In many cases, current scour evaluation procedures predict scour depths greater than indicated by experience. If a bridge is determined to be scour critical, a countermeasure is recommended by the Technical Advisory, but the cost of these countermeasures is often prohibitive. One alternative to conventional countermeasures is to monitor actual scour activity to determine if significant scour affecting bridge safety has occurred. A secondary benefit may be to provide site-specific data to determine if currently used scour equations are applicable to that site. However, no scour monitoring device has yet been demonstrated to be effective under the range of environmental conditions encountered at a bridge during a flood.

Research is needed to develop low-cost, reliable, scour monitoring devices that can be mounted to a bridge to indicate the maximum scour depth that occurs at bridge piers and abutments during floods.

The objective of this research is to develop, test, and evaluate instrumentation that would be both technically and economically feasible for use in monitoring maximum scour depth at bridge piers and abutments. It is anticipated that the research will include the following tasks:

*Task 1.* Review relevant current domestic and foreign practice, performance data, and research findings. The

review should be comprehensive and also consider technology transferable from sources other than the highway industry. Perform a survey of equipment that has been previously proposed for bridge scour monitoring.

*Task 2.* Identify electrical, mechanical, or other devices that can be adapted to measure maximum scour at bridge piers and abutments. These existing, proposed, or conceptualized devices must meet the following criteria:

- Capability for installation on or near a bridge pier or abutment.
- Ability to measure maximum scour depth within an accuracy of  $\pm 1$  foot.
- Ability to obtain scour depth readings from above the water or from a remote site.
- Operable during storm and flood conditions.

The following criteria are desirable for the devices:

- Capability to be installed on most existing bridges or during construction of new bridges.
- Capability to operate in a range of flow conditions.
- Capability to withstand ice and debris.
- Relatively low cost.
- Vandal resistant.
- Operable and maintainable by highway maintenance personnel.

*Task 3.* Evaluate each device identified in Task 2, noting its advantages, limitations, anticipated purchase and installation costs, and important features and considerations. Identify possible scenarios for equipment problems and failure. Select devices that show promise for further development and testing.

*Task 4.* Document 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. The interim report shall include a test plan for evaluating the devices selected at the conclusion of Task 3. Provide a cost estimate for developing and testing each identified device. NCHRP approval of the interim report and test plan will be required before proceeding with the remaining tasks.

*Task 5.* Develop prototypes of the devices approved by the NCHRP.

*Task 6.* Test and evaluate the prototype devices.

*Task 7.* Prepare a cost analysis for the fabrication, installation, operation, and maintenance for each prototype evaluated.

*Task 8.* Submit a final report documenting all research findings, including recommendations for a field evaluation program for prototypes that show promise. The final report should also include an estimate of the costs and time for performing field evaluations.

Research was initiated just prior to the end of 1989. It appears that the research has gotten off to a good start. Some preliminary hydraulic tests are expected to be performed in mid-1990.

## AREA 22: VEHICLE BARRIER SYSTEMS

**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 were: (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.

Four low-service-level barrier systems were developed and crash tested during this project. The correlation of the crash test conditions with field conditions will take place as part of NCHRP Project 22-5A.

**Project 22-5A** FY '87

### Warrants for the Installation of Low Service Level Guardrail Systems

*Research Agency:* In developmental stage  
*Principal Invest.:*  
*Effective Date:* (18 months)  
*Completion Date:*  
*Funds:* \$100,000

Most operational guardrail systems in the United States have been developed to contain a 4,500-lb vehicle impacting at 60 mph and 25 deg. The use of design criteria based on these test conditions has resulted in relatively expensive guardrail installations. For low-service-level roads, there is a need to determine the conditions under which less stringent guardrail requirements are warranted in order to avoid excessive expenditures and provide safety performance based on demonstrated need.

Four low-service-level barrier systems were developed under NCHRP Project 22-5 to address this need. Through full-scale crash testing, these systems were shown to contain a 3,400-lb vehicle impacting at 50 mph and 20 deg. It is anticipated that these barriers can be used to improve the level of safety on low-service-level roads; however,

correlation of the crash test conditions with field conditions is required. In addition, a user's guide is needed to provide design details for the systems developed and specific warrants for their placement on low-service-level roads.

The objectives of NCHRP Project 22-5A are to develop warranting procedures for the placement of the barrier systems developed under NCHRP Project 22-5, and to prepare a user's guide which contains design drawings for these systems and warranting procedures for their placement.

This research shall include at least the following tasks:

*Task 1*—Determine the range of roadway characteristics for which it would be appropriate to install the barrier systems designed and crash tested under Project 22-5. In addition, estimate the installed cost for each of these barrier systems. A letter report containing the findings of this task shall be submitted to NCHRP. Panel approval of the letter report is required before proceeding to Task 2.

*Task 2*—Using the findings of Task 1, develop specific warranting criteria for the placement of the barrier systems developed under Project 22-5. The product to be delivered by this effort will be warranting procedures in table and/or chart form to guide the placement of these low-service-level barrier systems.

*Task 3*—Prepare a user's guide which contains the warranting procedures developed under Task 2 and design drawings for the barrier systems developed under Project 22-5. The guidelines shall also include estimated life-cycle cost data for each barrier system.

*Task 4*—Prepare a final report documenting the research conducted under NCHRP Projects 22-5 and 22-5A.

#### **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:* November 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 were (1) to assess the performance of selected existing highway safety appurtenances and roadside features with passenger vehicles be-

low 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.

Research has been completed and the project report has been published as NCHRP Report 318, "Roadside Safety Design for Small Vehicles."

#### **Project 22-7**    FY '89

##### **Update of "Recommended Procedures for Safety Performance Evaluation of Highway Appurtenances"**

*Research Agency:* Texas A&M University Research Foundation  
*Principal Invest.:* Dr. Hayes E. Ross, Jr.  
*Effective Date:* June 1, 1989  
*Completion Date:* November 30, 1991  
*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.

Task 1 has been completed.

## **Project 22-8    FY '89**

### **Evaluation of Performance Level Selection Criteria for Bridge Railings**

*Research Agency:* Texas A&M University Research Foundation  
*Principal Invest.:* King K. Mak  
*Effective Date:* April 15, 1989  
*Completion Date:* January 14, 1991  
*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.
- Tasks 1, 2, and 4 have been completed.

## AREA 23: SOILS PROPERTIES

No projects

## AREA 24: SOIL MECHANICS AND FOUNDATIONS

**Project 24-3** FY '86

### Laboratory Evaluation of Piles Installed with Vibratory Drivers

*Research Agency:* University of Houston  
*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. Laboratory studies were 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 would also assist in the design of future field tests and the analysis of results.

The overall objective of this study was to evaluate the load-deformation behavior of piles installed in the laboratory with vibratory drivers. Specific objectives included: (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.

Research is complete, and the principal findings have been published in NCHRP Report 316, "Laboratory Evaluation of Piles Installed with Vibratory Drivers." Additional detail on the various experiments is available in an agency report titled, "Supplement to NCHRP 316, Laboratory Evaluation of Piles Installed with Vibratory Drivers, Appendices B-Q." The supplemental report was distributed to NCHRP sponsors only. However, others may obtain loan copies or purchase ones for the cost of reproduction (see final page of this document for ordering information).

**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:* December 31, 1990  
*Funds:* \$459,152

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 research 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.

The project scope of work was increased during 1989 through the addition of a task requiring the development of a series of 5 stand-alone engineering manuals, one each for driven piles, drilled piers, spread footings, abutments and retaining walls, and tolerable settlements. Each manual will contain the code and commentary information for a specific foundation type, along with a discussion on the methods and procedures assumed in the development of the provisions. The manuals will also provide examples on the use of the recommended code provisions.

Through December 31, 1989, research on the project has progressed on schedule. The engineering manual on spread footings is nearing completion, and work has been initiated on the development of the remaining manuals.

#### **Project 24-5      FY '88**

#### **Downdrag on Bitumen-Coated Piles**

<i>Research Agency:</i>	Texas A&M Research Foundation
<i>Principal Invest.:</i>	Dr. Jean-Louis Briaud
<i>Effective Date:</i>	June 15, 1988
<i>Completion Date:</i>	June 14, 1991
<i>Funds:</i>	\$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.

Research is underway. Current practice and literature on methods of reducing downdrag forces in piles using bituminous (and other viscous) coatings have been re-

viewed and a background summary and a complete bibliography have been prepared. A preliminary Design and Construction Manual based on the present state of the art has been submitted and is under review. Laboratory and field testing programs to verify design and construction recommendations are 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 25-2 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:* May 31, 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 was 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 was to develop a procedure for predicting stop-and-go traffic noise levels that could be input into the STAMINA 2.0 noise model.

Research is complete, and the principal findings and a prediction methodology have been published in NCHRP Report 311, "Predicting Stop-and-Go Traffic Noise Levels." Additional detail on the test sites and data and the

evaluation techniques is available in an agency report titled, "Supplement to NCHRP 311, Predicting Stop-and-Go Traffic Noise Levels." The supplemental report was distributed to NCHRP sponsors only. However, others may obtain loan copies or purchase ones for the cost of reproduction (see final page of this section for ordering information).

### Project 25-3 FY '89

#### Guidelines for the Development of Wetland Replacement Areas

*Research Agency:* URS Consultants  
*Principal Invest.:* Thomas J. Denbow  
 Dr. Edgar W. Garbish  
*Effective Date:* April 1, 1989  
*Completion Date:* June 30, 1991  
*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.

Tasks 1 and 2 are complete; the results will soon be submitted for NCHRP review.

## HOW TO ORDER

### **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 (\$7.00 per report). Price may change without notice. See latest Summary of Progress for current cost.
4. Other TRB publications.

A check or money order, payable to *Transportation Research Board*, must accompany orders totaling \$20.00 or less. Mail to:

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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: *Cooperative Research Programs, 2101 Constitution Avenue, N.W., Washington, DC 20418*
2. Loan requests for films and tapes should be directed to:

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### **Summary of Progress Through 1988—Special Edition**

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