National Cooperative Highway Research Program

NCHRP Report 349

Maintenance Considerations in Highway Design

Transportation Research Board
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Maintenance Considerations in Highway Design

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

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FOREWORD

By Staff
Transportation Research Board

This report contains a summary of the current practice for considering maintenance concerns in the highway design process, a recommended procedure for explicitly recognizing the maintenance implications of design, and a series of suggested improvements in design details that alleviate maintenance problems. Engineers responsible for maintenance, design, and specifications and managers throughout a highway agency will find the report of interest.

Inadequate consideration for maintenance during design was recognized some years ago in the Iowa Highway Maintenance Study (1959-1960, *HRB Special Report 65*). The 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 systematically 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 highway components. There is a need to specifically identify and communicate maintenance problems that can be addressed through better design. This need is gaining importance because of the greatly increased volume of traffic that makes it difficult to close traffic lanes for routine maintenance work. Although it would be desirable to design highway components (such as pavements, bridges, drainage features, and roadside appurtenances) with zero-maintenance requirements, this is not usually possible; therefore, designs should be developed to ensure maintainability at minimum life-cycle costs.

Under NCHRP Project 14-9(2), "Incorporation of Maintenance Considerations in Highway Design," Daniel, Mann, Johnson & Mendenhall and its subcontractor, Bergstralh-Shaw-Newman, Inc., were selected to address three objectives: (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 designs; and (3) list and describe design details that create maintenance problems and suggest improvements to overcome them. These objectives have been accomplished through a research approach that involved a literature search, a survey of practices, interviews in selected state transportation agencies, and a demonstration. However, in applying the research results, two caveats should be emphasized.

- Variations on a process for considering the implications of future maintenance on designs have been recommended. For the greatest success, highway agencies should adapt such recommendations to their existing organizational structures and cultures. Revolutionary changes are probably unnecessary in most cases.

- Improvements to design features that accommodate maintenance concerns have also been suggested. Although the researchers tried to ensure conformance with various design and safety standards, standards do change and will vary from jurisdiction to jurisdiction. Therefore, applicable standards and regulations must be checked before incorporating any suggestions into actual designs.

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ACKNOWLEDGMENTS

This research and the guideline preparation were performed under NCHRP Project 14-9(2) by Daniel, Mann, Johnson & Mendenhall (DMJM) and Bergstralh-Shaw-Newman, Inc. (BSN). DMJM was the prime contractor, and BSN was a subcontractor.

Turan Ceran (DMJM) served as the principal investigator and Robert B. Newman (BSN) as the co-principal investigator. Donald Cross and Thomas Monchak (DMJM) assisted with the research, formulation of processes, and reviews of all writings. Thomas Cain (BSN) reviewed and commented on the process and reports for the project.

The authors wish to express their appreciation to all those who responded to the questionnaires and to the officials of the five agencies selected for in-depth interviews.

We particularly want to thank the Utah Department of Transportation for conducting the pilot test and the staff members who assisted in that test. We appreciate the cooperation of top Department managers: Mr. E. H. Findlay, Director; Mr. Howard Richardson, Assistant Director; Mr. Sheldon McConkie, Operations Engineer; Mr. Gerald Barrett, Engineer for Maintenance; Mr. Lester Jester, Engineer for Preconstruction; Mr. Gene Sturzenegger, District Engineer for the Salt Lake district; and Mr. Dale Peterson, Engineer of Standards and Review, in consenting to conduct the pilot test and for supporting the effort.

We especially wish to thank Mr. Tracy Conti, Value Analysis Engineer, who acted as coordinator for the pilot test. We also appreciate the assistance of the design improvement committees. The members of the Central Design Improvement Committee were: James McMinimee, Operations Engineer for Maintenance; Byron Parker, Assistant Chief for Roadway Design; Kim Schvaneveldt, Engineer for Construction; David Nazare, Structural Engineer; and Michael Roshek, Research and Development Engineer.

The District Two Design Improvement Committee members were: LaMar Richins, Maintenance Supervisor, East Area; John Maurer, Design Engineer; Dana Meier, Resident Construction Engineer; and DeLoy Dye, District Materials Engineer.

MAINTENANCE CONSIDERATIONS IN HIGHWAY DESIGN

SUMMARY

Inadequate consideration for design-related maintenance concerns has been a persistent problem for highway maintenance supervisors. Aging highway facilities, greatly increased traffic volumes, tighter budgets, and limitations on available staff have compounded the problem. Designers need to be aware of maintenance problems caused by their designs so they may improve them. In some cases, a slightly lower initial construction cost may result in excessive annual maintenance costs for years. To minimize the impacts on maintenance, designers must consider how each facility can be maintained and the total cost of the facility over its expected life.

NCHRP Project 14-9(2) was initiated in response to the need for a routine process to improve communications between designers and maintenance personnel during the design process. The study was undertaken to meet the following objectives: (1) determine the current practices of incorporating maintenance concerns into the highway design process and identify successful techniques, weaknesses, and needed improvements; (2) recommend a design process that will ensure recognition of the maintenance implications of each design; and (3) list and describe design details that cause maintenance problems and suggest improvements to overcome them. Key research findings are summarized in the next section.

Findings

1. While maintenance is considered in the design of highway facilities by nearly all agencies, over 70 percent of those responding to the maintenance questionnaires reported having significant maintenance problems that resulted from insufficient consideration of maintenance in the design process. Few designers have had an opportunity to gain experience in maintaining highway facilities.

The majority of maintenance engineers thought these problems could be overcome through improved communications between design and maintenance personnel — especially by more involvement of maintenance supervisors in project scoping and plan reviews.

Relatively few agencies have formal processes for ensuring that maintenance is considered in design. Most have informal procedures that rely on personal contact between designers and maintenance supervisors.

2. The research found that two processes were needed to ensure that maintenance is considered in design: one for project-specific problems and one for general problems. Either process may be used for both central design and district design. The processes are quite similar because the same basic procedure is needed to identify and resolve

problems. The processes were designed to improve communications between design and maintenance personnel.

3. The process for addressing project-specific problems provides for maintenance participation at the project scoping meeting and at each plan review. The designer is required to respond to all maintenance suggestions, either by incorporating the suggestion in the design plans or by providing a written response explaining the reasons that the suggestion cannot be incorporated. An appeal procedure is included to ensure that maintenance requests receive adequate consideration. Flow charts were developed to show the differences in the process in the design responsibilities and the appeal procedures for central design and district design.

4. General problems are those that affect a number of projects within a district or the agency. Resolution of these problems usually requires changes in design standards and specifications. The process provides for the establishment of district design improvement committees (where design is decentralized) and a central design improvement committee. In larger agencies, separate committees may be appointed for each major specialty. Frequently the standards review committee(s) can also serve as the design improvement committee(s). Maintenance should be represented on all committees. A sample checklist of maintenance concerns is included to acquaint designers with problems related to designs. Each agency should prepare its own checklist to address problems specifically encountered by maintenance within the agency. Problems should be removed from the checklist as they are resolved by design.

5. To ensure that the process was practical and to identify any improvements needed, the process was pilot tested in the Utah Department of Transportation. Following the test, the process was revised to reflect the needed improvements.

6. Each agency will need to adapt the process to fit its particular organization, operating conditions, and design procedures. The process should be incorporated into the agency's procedures rather than being handled as a separate function. Implementation should be initiated through meetings with designers and maintenance supervisors. A firm commitment from top management is needed to ensure that maintenance is considered in the design process.

Design features

Maintenance problems and suggested designs to resolve those problems are described in Chapter Four under two major headings: highway design and bridge design. The section on highway design includes suggestions for design of roadways, drainage systems, appurtenances, and roadsides to alleviate maintenance problems. The bridge design section addresses all components, from pilings and footings to handrails.

Conclusions and recommendations

The impact that designs have on maintenance must be given more consideration in the design procedures. Because few designers have maintenance experience, the design procedures must provide for input from maintenance supervisors. The process described in this report, if adapted and implemented, will provide for improved communications between design and maintenance personnel.

CHAPTER 1

INTRODUCTION AND RESEARCH APPROACH

INTRODUCTION

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:

> From the beginning of highway maintenance, its heritage has included taking care of problems unknowingly or neglectfully perpetuated by design and construction engineers (*1*).

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. This need is accelerating because of the greatly increased volume of traffic that makes it difficult to close traffic lanes for routine maintenance work. Additionally, maintenance managers in most agencies are faced with imposed limitations on manpower and aging highway facilities that require greater maintenance effort.

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 factors, such as: access for inspection and repair; incorporation of sensing and monitoring devices; future maintenance operations—snow removal, street cleaning and mowing, for example; life expectancy of various materials and designs; and improved features and configurations.

OBJECTIVES

The objectives of this research project were threefold: (1) determine the current practice of incorporating maintenance concerns into 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 suggest improvements to overcome them, including opportunities for applying new technology. The remainder of this chapter discusses the approach taken to meet these objectives.

RESEARCH APPROACH

The research involved a literature search, a survey of the present practices in highway agencies, and interviews in selected state transportation agencies.

A *literature search* of TRIS (Transportation Research Information Service) records was made through an electronic connection. Publications identified through the search, including those from the U.S. Department of Transportation, Transportation Research Board, and company libraries, were reviewed for pertinent information. Of the 32 entries, all but 5 were found at one of the libraries. Relatively few publications, however, addressed the problem of maintenance considerations in design.

Three *survey questionnaires*—one each for maintenance, road design, and bridge design—were prepared for data collection. All 3 questionnaires were sent to the highway and transportation agencies for all 50 states plus the District of Columbia and Puerto Rico and 10 Canadian provinces. Questionnaires were also sent to several federal, regional, and county agencies.

Over 75 percent of the agencies responded. The number of responses is given in Table 1. The agencies listed as "Others" include 2 counties, 1 regional agency, and 1 federal agency. The responses to the questionnaires are summarized in Appendix A.

Interviews in selected agencies were conducted following a review of the completed questionnaires. Of special interest were those agencies that reported having formal processes for considering maintenance problems in the design stage. The project work plan provided for visiting five agencies to collect detailed information on the processes that are used to ensure that the impact on maintenance is considered in design. The following criteria were established for selecting the five agencies: (1) agencies should have a formal process in place; (2) both centralized and decentralized organizations should be represented; and (3)

Table 1. Questionnaire responses.

Agency	Maintenance	Road Design	Bridge Design
States	40	40	42
Provinces	6	7	7
Others	3	4	4
Total	49	51	53

each geographical section of the country should be represented, if possible.

The information in the questionnaires and any supplemental materials submitted by the agencies were reviewed, along with the type of organization, in selecting the five agencies. Those selected were California, Connecticut, Florida, Illinois, and Texas.

The principal investigator and the co-principal investigator of NCHRP Project 14-9(2) visited each of the agencies to learn exactly how its process functioned. They met with representatives of central maintenance, road design, bridge design, and research; where design is decentralized, they met with district maintenance and design personnel.

Process Development

As a part of the project, a process for including maintenance considerations in the design procedures was developed. First, a draft process was developed and, to ensure practicality, it was piloted tested by the Utah Department of Transportation. The results of that test are described in Appendix B.

The process was then revised as necessary according to recommendations from Utah department personnel who were directly involved with the pilot test. That process is described in Chapter Three.

CHAPTER 2

FINDINGS

SURVEY QUESTIONNAIRES

Maintenance Consideration in Design

The responses from the questionnaires indicate that maintenance is considered in the design of highway facilities. All 51 of those agencies who responded from road design and all but 1 of the 53 from bridge design reported that they do consider maintenance. However, only 36 of the 49 agencies that completed the maintenance questionnaire reported that maintenance is considered in design. Seven agencies were not certain whether maintenance was considered and six do not believe it is considered.

Maintenance Problems

Over 70 percent (35 of 49) of those completing the maintenance questionnaires reported having significant maintenance problems resulting from insufficient considerations during design. (A listing of the specific problems can be found in Appendix A.) From these responses, it appears that improvements are needed in the design process.

The major recommendation by maintenance (26 responses) to resolve these problems is to improve communication between maintenance and design personnel through more involvement of maintenance during scoping and design. The next most frequent response (5 responses) suggested that designers should consider how the facility will be maintained. Clearly, maintenance should be given more consideration by designers in many agencies.

Processes for Consideration of Maintenance in Design

In most agencies, the process is informal. Somewhat fewer agencies reported having formal processes for evaluating design-related maintenance problems and communicating needed changes to designers. Those agencies that reported having formal processes are listed in Table 2. Note that the responses varied depending on which division completed the questionnaire.

Overall, the responses indicated that the processes vary considerably—from informal contacts initiated by maintenance or design to complete reviews by maintenance personnel who sign off on the final plans.

Maintenance Involvement

The actual involvement of maintenance supervisors in the design process varies from no participation to participation in reviews at all stages of design. The role of maintenance supervisors may include: advising design of maintenance problems and answering designers' questions on an informal basis; participating in project scoping; reviewing plans at various stages of completion—scoping, preliminary design, 60-percent to 90-percent complete, and final design; attending field reviews of designs at the various stages; reviewing and approving final project plans (by the district maintenance engineer); participating in post-construction reviews; and serving on design standards and specifications committees.

The management level of the maintenance supervisors involved also varies. The district maintenance engineer (or the equivalent) usually has the most involvement of field personnel. However, district engineers, area engineers, resident engineers, superintendents, and foremen may also have a role. The chief maintenance engineer has the major role in central office.

AGENCY ORGANIZATIONS

The process for considering maintenance in design must be adaptable for use by all highway agencies. Consequently, the organizations for all of the state highway and transportation agencies were reviewed (*2*) to determine the organizational relationships between maintenance and design and to identify the level of management with responsibility for both design and maintenance. An analysis of the resulting flowcharts (Figures 1 and 2) summarizes the two basic organization types with some variations in each type.

Table 2. Agencies with formal processes for considering maintenance in design.

Agency	Maintenance	Road Design	Bridge Design
California	X		X
Connecticut	X	X	X
Florida	X	X	
Hawaii		X	
Illinois		X	
Kansas	X		
Maine			X
Maryland	X		
Minnesota			X
Montana		X	
Oregon		X	X
Pennsylvania	X		
Texas	X	X	
Alberta	X	X	
Ontario			X
Saskatchewan	X		
Bureau of Indian Affairs		X	
Total	9	9	6

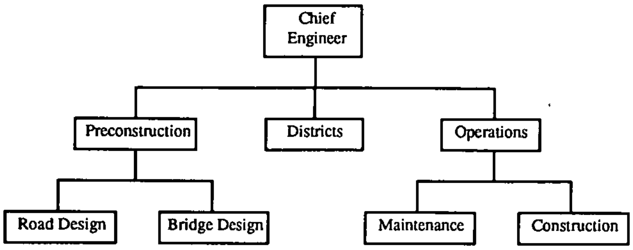

Figure 1. Typical organization — type 1.

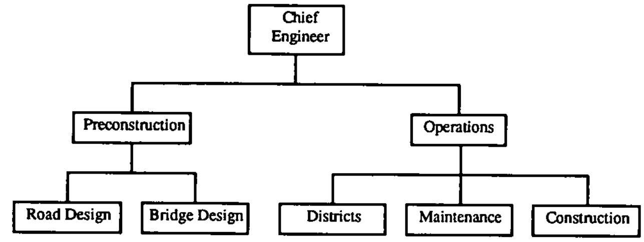

Figure 2. Typical organization — type 2.

1. In the most common type (about two-thirds of the states), preconstruction, operations, and the districts all report to the chief engineer or some similar position. (See Figure 1.) Design, construction, and maintenance may report directly to the chief engineer instead of through the preconstruction and operations division heads. Design may be *centralized* or *decentralized.* Road design, bridge design, maintenance, and construction may all report directly to the chief engineer in some agencies. Under a variation of this type, preconstruction is assigned to operations; operations and the districts report to the chief engineer.

2. In the second type of organization (Figure 2), the districts are assigned to operations; operations and preconstruction report to the chief engineer. Most agencies using this type of organization have *centralized* design. In a variation of this organizational type, traffic is assigned to operations along with the districts.

Alternative Designs

The major factors used by road and bridge designers in evaluating alternative designs are listed in Table 3. Eighty percent of the responses from road design and 68 percent of those from bridge design indicate that operations and maintenance costs are included as one of the factors in evaluating alternative designs. Generally, the designer or the design division makes the evaluation of the alternatives and decides which alternative will be selected.

Life Expectancy in Design

In the area of road design, 49 of the 50 agencies (98 percent) that responded do consider the life expectancy of some materials and components. The major items for consideration include the selection of pavement type, culverts, pavement markings, guardrail and barriers, shoulder type, and sign material. However, few agencies consider life expectancy of all of these items.

Forty-three of the 53 agencies (81 percent) that responded to the bridge design questionnaire consider life expectancy of some materials and components. These considerations include structure type selection, evaluation of coating systems, epoxy-coated versus bare rebar, class of concrete, selection of expansion joints, waterproofing and protective coatings for concrete, A588 structural steel versus regular steel, and design of bearings.

Table 3. Summary of major factors used for evaluating alternative designs.

Factor	No. of Responses	
	Road Design	Bridge Design
Construction costs	46	46
Operation & maintenance costs	41	36
Traffic disruptions — maintenance	35	28
User costs	28	15
Design costs	25	20
Environmental concerns	8	2
Traffic handling during construction	6	2
Life-cycle costs	5	1
Right of way costs	4	
Safety	4	

Value Engineering

Nearly two-thirds of the agencies reported having a value engineering (VE) review process in place. Maintenance personnel serve as VE team members in about half of the agencies and are consulted in reference to specific problems in many others.

Computer Software

The study identified four computer programs for evaluating alternatives.

HDM III, developed by the World Bank, makes comparative cost estimates and economic evaluations of different construction and maintenance options, either for a given road section or for an entire network. It is available from the McTrans Center for Microcomputers in Transportation, at the University of Florida (*3*).

Highway User Cost Accounting helps address questions concerning the user benefits associated with highway capacity improvements as compared with the costs of their implementation. The program uses techniques from the 1985 *Highway Capacity Manual,* the 1977 AASHTO *Manual of User Benefit Analysis,* and the 1982 *ITE Traffic and Transportation Engineering Handbook.* The program was developed by the New York State Department of Transportation. It is also available from McTrans.

Microcomputer Decision Support System assists in the economic analysis of proposed highway reinvestment or modest new highway investment projects. It performs benefit-cost ratios and net annualized and present worth computations. The benefits are evaluated based on savings from vehicle travel time, fuel cost, and accident reductions. The program is available from PC-Trans at the University of Kansas Transportation Center.

The Structural Financial Analysis Manual, developed by the Ontario (Canada) Ministry of Transportation, was designed to make rational choices regarding competing options both at the project and network levels. The techniques include completing present value analyses at the project level and incremental benefit-cost ratio analyses at the project and network levels (*4*).

Management Systems

Nearly all of the agencies surveyed have maintenance management systems. Over 80 percent have pavement management systems, 16 agencies (about one-third) have bridge management systems and 7 are developing systems, and about 45 percent have roadside management systems. All of these systems can provide data for value engineering and life-cycle cost analyses.

Communications

A need for three types of communication between designers and maintenance personnel was identified: (1) obtaining information from maintenance personnel about the existing facility and any special maintenance problems to help with the design; (2) communicating special maintenance needs of designs to those who must perform the maintenance—operation of traffic controllers, locations of underdrains, and care of bridge bearings, for example; and (3) making designers aware of maintenance problems caused by specific designs so future designs can be improved.

Obtaining Information

Designers need information about maintenance problems that may exist before starting the design—especially when the new project is on the existing alignment. Unfortunately, many agencies reported that no input is requested or received from maintenance personnel before or during the design process. Those agencies that do receive information use the following methods: open communication through the predesign and scoping process; field inspections with district personnel during design; personal contacts; plan reviews by maintenance personnel; and bridge safety inspection reports.

Communicating Maintenance Needs

It is essential that maintenance be aware of any special servicing required to get the anticipated life from a particular design. Even a simple task such as cleaning the underdrain outlets can be overlooked if their locations are not easy to find. Methods identified for communicating special maintenance needs include: (1) preparing operating and maintenance manuals for complex facilities, such as major bridges, large drainage or vehicular tunnels, and freeway control systems; (2) providing notes on the plans and in special provisions; (3) making "as-built" plans available to maintenance; (4) having maintenance foremen attend field reviews; (5) having direct communication by telephone or memorandum; (6) placing steel witness markers at the roadside to mark culvert and underdrain locations; (7) having a formal transfer of projects from design to construction to maintenance, providing opportunities to identify special project features; and (8) incorporating the information into regular maintenance manuals.

In about one-fifth of the agencies, designers do not advise maintenance at all; several others try to eliminate items that require special maintenance.

Problems with Designs

Designers must learn of maintenance problems associated with specific designs if they are to improve the designs on future projects. Methods in use include: (1) communication from central maintenance and districts; (2) personal contact; (3) cross-training among engineering disciplines; (4) participation of maintenance in developing and updating standards; (5) attendance by design engineers at maintenance superintendent meetings and district staff meetings; (6) sending copies of bridge safety inspection reports to design; (7) assigning engineers in the bridge division to obtain information about problem areas from maintenance for use in correcting designs; (8) use of the bridge management system; and (9) post-construction reviews with maintenance.

INTERVIEWS

The project work plan provided for visits to five agencies to collect more detailed information on the current processes in use to ensure that maintenance is considered in design. The results of those interviews are presented in this section.

Selection of Agencies

The following criteria were established for selecting the five agencies: (1) agencies should have a formal process in place; (2) agencies should represent both centralized and decentralized organizations; and (3) each section of the country should be represented if possible.

The information in the questionnaires and any supplemental materials attached were reviewed, along with the organization types, to select the five agencies. Those selected were California, Connecticut, Florida, Illinois, and Texas. All design is centralized in Connecticut. Road design is decentralized in the other four states. Bridge design is centralized in California and Illinois and partially decentralized in Florida and Texas.

The principal investigator and the co-principal investigator visited each of the agencies to learn exactly how its process functioned. They met with representatives of central maintenance, road design, bridge design, and research; where design is decentralized, they met with district maintenance and design.

Interview Findings

The process found in each agency is summarized in the following sections, along with a brief description of the agency organization. The communication procedures between maintenance and design are also discussed.

California

Organization. Road design is decentralized to the districts. There is a road design unit (Office of Project Planning and Design, or OPPD) in Sacramento but its main functions are formulating policies, preparing manuals, and monitoring quality assurance. The Office of Central Design (under OPPD) provides design services to balance the workloads for the smaller districts. The responsibility for all design work rests with the district whether it is performed by the district, Central Design, or a consultant. Road maintenance is decentralized to the districts.

Bridge design is centralized in Sacramento. In addition to design, the Chief of the Division of Structures is responsible for construction and maintenance although personnel for the latter two functions are located in the districts throughout the state.

Procedures. The procedures for communicating maintenance concerns to design are summarized as follows:

1. A scoping team appointed by the district engineer conducts a field review and prepares a Project Scope Summary Report (PSSR) for all major and minor rehabilitation projects. The use of this procedure was expanded in 1989 to all projects on the candidate list for the 1992 Highway System Operation and Protection Plan. Maintenance is always represented on rehabilitation projects but may not be on other types of projects.
2. The Project Development Team holds monthly meetings to plan and coordinate the work on the project with team members. Maintenance can attend these meetings, but because the focus of the meetings is frequently directed to keeping the project on schedule, most maintenance representatives do not attend. Actual input at meetings depends on the individuals in attendance. The key is the willingness of the design project manager to solicit and accept constructive suggestions from maintenance. Designers may not be inclined to solicit suggestions because of time constraints to complete designs.
3. A safety review is held at the 75-percent-complete stage. Few significant changes can be made when the plans are this far along.
4. A road design P.S. & E. (plan, specifications, and estimate) review is conducted at about the 95-percent-complete stage. Maintenance is invited. This is the first review where plans are available.
5. There is a small maintenance design staff in central bridge maintenance. Bridge maintenance problems are identified by that group and bridge design is alerted.
6. The trend is to design bridges to minimize maintenance needs and disruption of traffic.
7. Bridge safety inspection and maintenance needs are combined into one annual list. Projects on the Structures Rehabilitation and Improvement Needs List are funded through the State Transportation Improvement Program rather than through maintenance.
8. Maintenance developed a checklist to ensure that designers are aware of maintenance concerns.

Communications. The methods of communication between maintenance and design are described as follows:

1. Each district has a senior engineer's committee to review problems. (Senior engineers in project development supervise the design squads.) The committee meets as needed. Design, construction, traffic, right-of-way, and transportation planning are represented on the committee. Maintenance is invited only if maintenance-related problems are on the agenda. Any recommendations for resolution of general problems identified by maintenance go through regular channels. Project-specific recommendations go directly to the designer.

   Output from the committee meetings is a procedure to resolve each problem that surfaced at the meeting. The procedure manuals are directed more toward the processes than actual procedures. A copy of each procedure is sent to OPPD in Sacramento. Because that division is responsible for statewide uniformity, it decides whether to distribute district procedures to other districts.

   Suggestions for improvements on specific projects can result in not only plan changes but ultimately changes in standards. Some designers are rotated through maintenance in the Department's training program.
2. Technical committees have been formed to: (a) develop statewide technical policies and standards; (b) propose and review changes to AASHTO specifications, design manuals, standard plans and details, standard specifications, and special provisions; and (c) review items submitted by construction, maintenance, materials, and industry. All committees meet as needed.

   The Structures Division has 11 technical committees covering such areas as bridge deck protection, detailing, earthquakes, joint seals, bearings and approach slabs, and prestressed concrete. Maintenance is represented on five of these committees. Road design (Project Development) has a similar group of committees. Maintenance is represented on the pavement and rehabilitation committee (which is responsible for determining the pavement structural section) and on the culvert committee. Traffic has a new products evaluation committee.
3. The Department's employee suggestion program provides cash awards for approved suggestions. Suggestions are evaluated by a merit award review board.
4. Reviewers for both design and maintenance in central office monitor problems and work quality control into their respective areas of responsibility. Both reviewers are in a position to transmit successful solutions of problems to their assigned districts.
5. Two annual district maintenance meetings are held each year: one for the deputy district directors for maintenance and one for senior engineers in maintenance. The meetings provide a forum for districts to share concerns, problems, and solutions. Design holds similar meetings.

Connecticut

Organization. All design is centralized. No design is performed in the districts. There are four maintenance districts, each headed by a maintenance manager who reports to the Director of Maintenance in the central office. A senior engineer is assigned to each maintenance district to assist with bridge maintenance and plan reviews. There are also four construction districts headed by district engineers who report to the Director of Construction.

Vendor-in-place resurfacing projects, drainage adjustment contracts, and other "no plan" projects are handled by maintenance. Two liaison consultants assist the Department staff in supervising design consultants for bridge rehabilitation projects.

Procedures. Various project design reviews are held.

1. Project scoping is a Planning responsibility. Maintenance has no involvement except for resurfacing projects and bridge maintenance projects. Maintenance develops the scope for bridge maintenance work that it does not have the capability or funds to perform.
2. The designer presents the project in a central office meeting at the preliminary engineering stage. District maintenance is invited to attend.
3. A central office review meeting is conducted by the designer at the preliminary design stage—i.e., 30-percent complete. District maintenance is invited to attend, but plans are not available before the meeting.
4. A drainage review is held in central office at the 60-percent-complete stage for selected projects. The field review has been discontinued.
5. At the final plans review, plans are sent to the district engineer and the district maintenance manager. Review comments are sent directly to design with copies to Construction or Maintenance as appropriate. Time is limited for the reviews. Design does not have to wait for review comments to proceed with design.
6. The final submissions review is conducted by design in the central office at the 90-percent-complete stage. District maintenance is invited to attend. However, if the project is on fast-track scheduling, there is insufficient time to incorporate comments.
7. Bridge design requests input from maintenance on selected bridge rehabilitation projects, usually high-cost projects.
8. Extensive use is made of consultants to supplement in-house design staff. The same review procedures are used for both in-house and consultant designs.

Communications. Communications between maintenance and design are achieved through: (1) the *Geometric Highway Design Committee,* which includes representatives from design, traffic, environmental planning, central maintenance, and central construction; (2) the *Standard Specifications Committee,* which includes representatives from design, traffic, research and materials, central maintenance, and central construction; (3) the *Pavement Type Selection Committee,* which includes representatives from materials, pavement management, soils and foundations, engineering, and central maintenance; and (4) the *Project Status Review Committee,* which meets monthly to review the status of projects scheduled for letting in the next 12 to 18 months. Membership includes, among others, the chief engineer, the assistant chief engineer for construction and maintenance, and the assistant chief engineer for preconstruction.

Additionally, the bridge maintenance engineer reviews bridge safety inspection reports, identifies common problems, and writes memos requesting changes in design standards to correct problems.

Florida

Organization. Roadway design is decentralized to the districts. District design is responsible for all roadway designs in the district. The primary responsibility of central road design is quality assurance. District designs are spot-checked for conformance with standards. Standards that are not followed are reviewed to identify problems.

Bridge design is partially decentralized. Minor structures are designed in the districts and reviewed by district maintenance. Major structures are designed in the head office. Central maintenance receives plans for review. A maintainability review is conducted for all major structures.

Maintenance is all decentralized. As with design, a major responsibility of central maintenance is quality assurance.

Procedures. Candidate projects are nominated through a statewide process. The work program is set with input from traffic, maintenance, and so forth. Maintenance has a significant role in selecting candidate projects. The pavement inventory is controlled by maintenance.

1. A district task team scopes the projects. The team includes representatives from maintenance, design, safety, construction, and traffic operations. A preprinted checksheet is used to ensure that all items are addressed.
2. Review committees conduct phase reviews at the 30-percent-, 60-percent-, and 90-percent-complete stages. The committees also conduct the P.S. & E. (plan, specifications, and estimate) reviews. Most maintenance involvement is after the 60-percent review. Plans lack sufficient detail at the 30-percent stage and changes are too difficult at 90 percent. At least one review is conducted in the field. The district area maintenance engineer reviews the plans at each of these stages and meets with the designers in the office or at the project site to discuss the plans.
3. The district structures and facilities engineer reviews plans prepared by central bridge design or consultants at each of the review stages. He or she also has the responsibility for conducting the bridge safety inspections.
4. Comments by central maintenance are submitted to the designers in writing.
5. A post-construction review process is being implemented. Reviews will be conducted on all projects with construction costs over $10 million; on one-half of those with costs between $2 million and $10 million; and on one-tenth of the projects below $2 million. Maintenance will be represented on the review team.
6. Value engineering (VE) is conducted on all projects with estimated construction costs of over $2 million. Smaller projects are selected randomly for value engineering. Maintenance is represented on all VE teams. Value engineering is outside the formal design process, so it is not subject to the same pressure to meet deadlines as design. Any employee is allowed to make suggestions for consideration by the VE teams.
7. A special bridge research section evaluates new materials, equipment, and systems. Maintenance is one of the evaluation criteria.

Communications. Drainage and pavement designers in the districts have the opportunity to work with maintenance on specific maintenance problems to gain maintenance experience.

Illinois

Organization. Except for bridge design, all central office bureaus—road design, construction, maintenance, planning, etc.—have counterparts in each district. Road design is 99 percent decentralized; bridge is 100 percent centralized. A district bridge maintenance engineer reports to the district maintenance engineer.

Procedures. Bridge design has a procedure for evaluating alternatives for bridge deck repairs (patching, rehabilitation, etc.). There are 7,856 state bridges. About half are steel and half concrete. Nearly all (95 percent) of larger bridges (those with spans over 120 ft) are steel. Alternate designs are required on major bridges. About 40 percent of bridges are designed inhouse and 60 percent by consultants. (There are also 16,000 local bridges owned by cities, counties, and townships. These are coordinated through the Local Roads Bureau.) The administrative policy is to resurface every 7 to 10 years.

The procedure for bridge project approvals and maintenance input is as follows:

1. Approval of the Scope of Work for the projects in the 5-year program is the responsibility of district planning or district road design, depending on the district. A worst-case scenario is used to get more accurate projected cost estimates. Each bureau looks at projects individually, and then a meeting is held to discuss the scope. For bridges, two reports are used in the scoping: the bridge inspection report from the 2-year inspection cycle and a bridge condition report prepared for each specific project. The District Bridge Maintenance Engineer prepares this report, which includes recommendations. The report influences priorities. District 6 design has a checklist used in scoping to ensure that all items are addressed.
2. Bimonthly coordination meetings are held with FHWA to review plans and obtain concurrence. The district bridge maintenance engineer may attend these meetings.
3. The bureaus videotape bridge sites so the designer can see the site.
4. The designer prepares a Type, Size, and Location report (TSL) that is sent to the district for review.
5. A field Plan-In-Hand review is held at the 70-percent-complete stage. It involves an office meeting and an on-site review. The review is attended by representatives of all bureaus.
6. Pre-final plans (95-percent complete) are sent to the districts for review. Often there is little time for review. No major changes can be made at this stage. Maintenance does not sign bridge plans. Any meetings connected with this review are held in the district office, but bridge design does not attend. Written comments are sent to the bridge office.

The procedure for road design projects is:

1. District planning prepares and distributes a four-page description of planned projects. This is a relatively new procedure initiated in mid-1990. All district bureaus, including maintenance, receive a copy for review and comment. Each bureau can make an on-site visit. A group visit is not made. A meeting is then held in the district. All comments are addressed but not necessarily approved. A final scope report is prepared and submitted to central office for review. Bureaus can go through the chain of command to pursue comments not approved if they feel strongly enough about them.
2. The final project report is circulated to all central office bureaus for review. Each bureau writes its comments. A meeting is held to review the comments.
3. A drainage field check is held on some projects. At this point, drainage design is essentially complete and plans are at the 35-percent-complete stage. Maintenance is invited if their input is thought to be needed.
4. Maintenance is always involved at the 70-percent review. A 70-percent review is held on larger projects, but not for smaller projects. A memo of invitation is sent to maintenance, construction, traffic, materials and sometimes planning. Plans are not circulated before the office review but may be available for review in design. Plans are reviewed page by page in the office review. Comments are collected as minutes of the meeting. The office review is followed by a field review. Review comments are used to finish the design plans.
5. A final review is held when plans are 90-percent complete. Plans are circulated for signature. Maintenance must sign title sheet before plans can be considered complete. Reviewers can mark up plans or write comments. Time for this review may be short.
6. Maintenance may be asked informally for answers to specific questions any time during the design stage.

This section describes the procedures for the Pavement Management System.

1. A condition rating survey is conducted every 2 years (since 1976) by a survey team. It is a planning and programming tool for districts. Each construction section of road is rated using a 1 to 9 scale. The rating used is the average of the individual team member ratings. The averaging helps eliminate bias. For interstate roads, the team consists of two persons from central office and two from the district. One of the district representatives may be from maintenance. The team for primary roads includes two representatives from district maintenance, one from design, and one from planning. These ratings directly affect priorities for improvements.
2. A Pavement Review Team drives and inspects the interstate system every 2 years (alternating with the year of the condition rating survey). The team assigns each construction section to one of four categories. The categories represent the year in which work is thought to be needed. The categories are 1 to 2 years, 3 to 5, 6 to 10, and more than 10. The team members represent central office bureaus of planning, design, maintenance, construction, and materials.
3. A pavement feedback system was started in 1985 to provide factual data to help determine priorities among districts. It is not used as much yet as the first two systems. With this system, the first 500 ft of each mile of interstate is rated. The rating is conducted every 2 years to coincide with the Pavement Review. While the rating considers maintenance, maintenance personnel are not involved. Ratings are conducted entirely by the central office bureau of materials. Actual measurements are taken to provide a more technical analysis.
4. The Mechanistic Pavement Design (*5*) is used for new pavements and reconstruction. Procedures are being developed for resurfacing alternatives. A Maintenance Management Information System (MMIS) was developed to provide cost data for the Mechanistic Pavement Design procedure. MMIS was implemented 2 years ago. User costs are not considered in evaluating the alternatives.
5. Most design personnel (80 to 90 percent) have received value engineering training. It is used more in the design process

than for specific VE studies. Several VE studies are undertaken each year for training purposes. Value engineering is performed on selected projects before letting them to contract. In addition, a VE clause is included in most contracts for contractor VE proposals. The district VE team is under the direction of an assistant design engineer. Members are selected on an ad-hoc basis. Road-user costs are used in determining incentive and disincentive amounts where these are included in contracts.

Communications are achieved through the following meetings.

1. The Specifications Committee meets monthly or bimonthly. Members include representatives from maintenance, construction, FHWA, materials, road design, bridge design, and local roads. Suggestions for changes can come from anyone. The Committee authorizes changes unless the change is thought to be controversial. In that case, it may be submitted to the joint co-op committee for review before approval.
2. The Bridge Manual Committee meets annually. Maintenance is represented on this committee. All standard details are on CAD. Suggestions are tested on experimental projects before the manual is changed.
3. The Road Design Committee meets as needed. Suggestions for change are circulated for review.
4. An annual design engineers' meeting is held. In addition, a second design engineers' meeting is held, where personnel from other bureaus are invited.
5. All bureaus hold two meetings per year to discuss problems. Representatives from other bureaus are invited to attend. All bureaus can submit questions or topics for consideration at any bureau meeting.
6. Most input to bridge design is at the annual bridge maintenance engineers' meeting, where bridge design is invited to attend.

A bridge management system is being developed. It will incorporate life-cycle costing. Eighty-five percent of the data is available now. An ad-hoc committee has been appointed to direct development of the system. Representatives of maintenance, bridge, programming and planning, and local roads are on the committee.

Texas

Organization. The Texas State Department of Highway Transportation and Public Transportation is decentralized for road design, construction, and maintenance. Bridge design is partially decentralized.

Each of the 24 districts has responsibility for maintenance, highway design, and construction. These responsibilities are further decentralized to the residencies. Each resident engineer is responsible for highway design, construction, and maintenance. There are 254 counties in the state, 288 maintenance sections, and 128 residencies. Decentralization to the residencies has been in progress for about 15 years. There are still a few residencies that are not yet fully decentralized in all three areas. The residency designers, maintenance foremen, project engineers, and laboratory personnel all report directly to the resident engineer. Preliminary surveys are also under the supervision of the resident engineer.

All districts have a district design unit to supplement the residencies. Central office also has a design unit to assist the districts. In addition, design consultants may also be used. Resident engineers must approve all designs for their areas, no matter where the design is performed. Districts are responsible for acquisition of right-of-way.

Five districts have some bridge design capability. Most bridges are designed in Central Office, although design consultants may also be used. Central Bridge includes: (1) hydraulics for statewide use; (2) bridge plans review — a 100-percent review of all central office and district designs, and spot checks of consultant designs for compatibility with Department standards; (3) inspections by the bridge safety inspection section, by underwater inspectors, and by contracting with consultants to perform other inspections; (4) bridge construction liaison, including welding inspectors for all structural steel details; and (5) shop plan review. Resident engineers are responsible for bridge construction and maintenance. Districts and residencies may design projects for other districts or residencies to balance work loads.

Procedures. Texas does not have a formal process for ensuring that maintenance is considered in the design process. Rather it has been achieved by requiring the resident engineer to maintain the roads that he or she designs and constructs. The resident engineer must use the design standards (or obtain a design exception) and must develop the optimum design for the allocated funds.

Communications. Decentralizing design, construction, and maintenance to the residencies requires effective training and communication to ensure uniformity of design and adherence to policies and standards. In Texas, this is achieved through the methods discussed here.

1. The Department has an extensive training program in highway design, construction, and maintenance. The design training includes use of their CADD system. Courses have been developed for three levels of expertise. About 500 employees attend the design training courses each year.
2. There is an annual 3-day short course that all attend. This meeting provides an opportunity for sharing solutions.
3. Communications at all levels are attained through design manuals, specifications, memos, distribution of research, and so forth.
4. The State Maintenance Engineer is a member of the State Specifications Committee and has input into standard specifications and special provisions.
5. Any change that involves another division is reviewed with that division.
6. Environmental agreements and commitments must be followed through design, construction, and maintenance.
7. The districts hold monthly or bimonthly foremens' meetings. Resident engineers may attend. The districts also hold periodic resident engineers' meetings.
8. Some districts hold predesign conferences, which resident engineers and maintenance foremen attend.
9. An annual bridge design conference is held to discuss problems. Bridge safety inspectors identify problems.
10. Residency construction and design personnel work on construction and design for cross-training purposes and to balance workloads.
11. Personnel are rotated between central office and the Austin district for training purposes and to avoid moving personnel.

12. Many districts use a design review committee, especially for predesign conferences and P.S. & E. reviews. The district maintenance engineer, resident engineer, and maintenance foreman participate in these reviews.

13. Maintenance division field engineers meet regularly with the district maintenance engineers to discuss problems and successful solutions between central office and the districts.

CHAPTER 3

PROCESS FOR INCLUDING MAINTENANCE CONSIDERATIONS IN DESIGN

A formal process is needed that will promote recognition of the maintenance implications of each design and will allow and encourage continuous interaction of highway and bridge designers with maintenance personnel.

PROCESS DEVELOPMENT

After the first interviews in Caltrans (the California Department of Transportation), an initial process was developed for use in discussions during the remaining interviews. The initial process was based on the literature reviews, the questionnaire responses, and supplemental material attached to the completed questionnaires. At each interview, this process was discussed to identify problems and to suggest needed improvements. These suggestions were incorporated into the process described in this report.

The two most common responses to Question No. 12 "*What improvements in the design process are needed to minimize maintenance problems?*" were:

(1) improve or increase the input from maintenance; and
(2) improve communications between design and maintenance.

Increased input from maintenance was listed on 14 questionnaire responses and improved communications on 12. Maintainability was third, with 4 responses. A process was designed to achieve those objectives.

A sample checklist was developed based on the lists of problems and solutions from the questionnaires and on information collected in the interviews.

PILOT TEST

The work plan for the project provided for pilot testing the proposed process in a state highway or transportation agency. The purpose of the pilot test was to ensure practicality of the process and to identify any improvements needed in the process.

The Utah Department of Transportation was selected for the test. A description of the pilot test in Utah, the results of the test, and subsequent recommendations for improvements are presented in Appendix B.

Approval of the proposed process took longer than anticipated. Consequently, the length of time for conducting the pilot test had to be shortened to keep the project on schedule. However, it is felt that the test was sufficiently long to meet the needs of the project. The Utah DOT has incorporated the process into its project development procedure and will continue its use.

Following the pilot test, the process was revised to incorporate the findings and recommendations from the pilot test. The process described in this chapter reflects those improvements.

USE OF VALUE ENGINEERING

As noted in Chapter Two, over 60 percent of those responding to the questionnaires use value engineering methods for some evaluations of designs. Ninety percent reported using life-cycle costs for evaluating alternatives. From this response, it was concluded that a majority have value engineering procedures in place and most agencies have life-cycle cost analysis procedures. Consequently, there is little need for extensive procedures and explanations of value engineering and life-cycle costs in this document. Most agencies will be inclined to use their current procedures.

TYPICAL ORGANIZATIONS

The process must be applicable to the types of organizations typically found in highway agencies. The organization charts (*2*) for all of the state highway and transportation agencies were reviewed to determine the management level in each organization where maintenance and design personnel in central office and the districts have a common supervisor. That is the management level where the appeal process should end.

About half of the state highway agencies have decentralized all or part of the roadway design workload to the districts. In the other half, all roadway design is performed in the central office. Where roadway design is decentralized, nearly all agencies retain some roadway design capability in the central office to assist the districts. Bridge design is centralized in all but a very few agencies.

An increasing portion of the design workload for both roadways and bridges is performed by design consultants. Administration and coordination of consultant contracts may be assigned to either the district or central office, depending on the agency.

RECOMMENDED PROCESSES

Because of these variations in organizations, separate processes are needed for decentralized and centralized design functions. In addition there are two types of problems relating to maintenance considerations in design: (1) problems that are specific to a particular project and (2) general problems that affect all similar projects in the agency. Thus, the procedures were developed considering the different organization and problem types.

Two basic procedures were developed: one for *specific* problems and one for *general* problems. Both procedures were designed to be applicable for either central design or district design.

Each of these procedures is described in this chapter. The procedures are quite similar because the same basic analyses must be made, whether at the district or central office, for both specific and general problems. The level of effort for each analysis should be relative to the type of problem. For example, minor problems usually can be evaluated without conducting full-blown value engineering evaluations or life-cycle cost analyses.

Each agency will have to adapt these procedures to fit its particular organization. The titles used in the flowcharts are those most commonly found in state highway agencies. However, some states use regions instead of districts; branch, office or division instead of bureau; and so forth. The appeal process should end at the management level with responsibility for roadway design, bridge design, and maintenance. In the proposed process, that individual is the chief engineer. It should be noted that the titles will require revisions to reflect those used in each agency.

The procedures recommend the establishment of a central office Design Improvement Committee in all agencies and District Design Improvement Committees where design is decentralized to the districts. The function of the Design Improvement Committee may be assigned to the specifications or standards review committee in the central office. (In some states, there are several committees, each responsible for a specialized portion of the specifications or standards.) If that additional work is too burdensome for the standards review committee(s), a separate Design Improvement Committee is recommended.

Agencies that have district design capabilities should appoint District Design Improvement Committees to address maintenance problems related to designs within each district. As previously noted for the central office Design Improvement Committee, this function may be assigned to existing committees. Because districts are not organized uniformly in all states, some further modifications may be required to accommodate the various organizations.

Maintenance should be represented on each committee. Other logical committee members include representatives from road design, bridge design, traffic, materials, and construction. Selection of members would, of course, depend on the agency's organization and the number of design improvement committees. Where possible, specific agenda items should be enumerated before each meeting.

MANAGEMENT SYSTEMS

Preconstruction management systems provide systematic procedures for managing the activities in the design process from project conception to contract letting. The systems should provide for completion of the plans at each stage, with sufficient time for reviews. The review activity definitions should be revised, as necessary, to include reviews by maintenance personnel.

Road and bridge design manuals should be revised, to incorporate maintenance considerations into the design process as maintenance problems and solutions are identified.

Pavement management systems, bridge management systems, and roadside management systems are used to set priorities for improvements to the highway network in their respective areas. All changes in the design standards resulting from the incorporation of maintenance considerations into designs must be communicated to the managers of the appropriate system so the system can be updated for future projections.

Maintenance management systems typically provide cost data for all maintenance activities that may be used to evaluate the significance of problems, as input to value engineering evaluations and life-cycle cost analyses. The use of these systems varies widely among agencies.

PROCESS FOR SPECIFIC PROBLEMS

Project-specific problems are those that apply to only one project. Often, improvements in these designs will not be applicable to other projects. The process for identifying specific problems and addressing maintenance considerations in design is outlined in the following steps. This process is used for either roadway or bridge design. There are a few differences in the process for central design and district design. These differences are noted in the description of the process.

1. Identify Specific Maintenance Problems Related to Designs

Potential methods of identifying problems include:

Scoping

A team approach in defining the scope of work for projects is recommended. Maintenance should be represented on the scoping team. The maintenance management level (foreman, area supervisor, or district maintenance engineer) most familiar with the project location and its related problems should be selected for the team. The maintenance supervisor who will participate in the scoping meeting should prepare a Maintenance Scoping Recommendation form and submit it to the designer at the meeting. The purpose of this form is to encourage consideration of problems before the scoping meeting. The designer can then attach a copy of the form to the scoping report. The designer should address all listed maintenance concerns in the scoping report. A sample form for maintenance scoping recommendations is shown in Figure 3. It is suggested that the project design engineer meet with the maintenance station supervisors to learn of maintenance problems first hand. Designers should review projects on site with the maintenance supervisor. The maintenance supervisors should bring their maintenance management reports to this meeting. For bridge rehabilitation projects, the bridge safety inspection reports should be reviewed as a part of the scoping process.

A "worst-case" scenario should be used in scoping projects—especially for reconstruction and rehabilitation work—because the rate of deterioration is difficult to predict and because the project may be delayed due to unavailability of funds, environmental issues, or other reasons. Underestimating the scope can

Project Number:________________________		**Date:**____________
Designer:________________________		
Maintenance Reviewer:__________________		

Specific Problem	Suggested Solution

Figure 3. Sample maintenance scoping recommendations.

result in insufficient funding to meet the actual needs 2 or 3 years in the future when the project is actually let to contract.

A realistic project scope will help prevent unnecessary design changes in the later stages of the process. A firm scope is needed, no matter who is responsible for the design. Where design consultants are assigned, changes in project scope may also result in increased consultant level of effort, necessitating revisions to the design contract.

Review of Project Plans

Preliminary design plans should be made for review early enough in the design process that maintenance representatives can request changes without causing major delays in the completion of the plans. This early design review should take place at about the 35-percent-complete stage. Preliminary plan-in-hand field reviews made when plans are about 70-percent complete should also include representatives from maintenance.

Final Plans

Final plan reviews are held when plans are nearly finished, about 95-percent complete. Although this stage is too late to make any significant changes, maintenance should also review these plans. Often, the time available for this review is quite short. Critical path schedules for the design process should provide sufficient time for the review. Each bureau, including maintenance, should sign off on the plans signifying approval of the final plans.

2. Communicate the Problem to the Designer

Personal contact between the maintenance supervisors and the designers is the best method of communication. This method is most successful when the designer and maintenance supervisor are both members of a field review team. District designers can meet with maintenance supervisors fairly easily, either at the project site or in the district office.

Where personal contact is not possible, the problems should be put in writing and submitted to the designer. (Communications should be through the agency project coordinator for consultant design projects.) Written communications should include: a statement of the maintenance problem related to design, a description of why it is a problem for maintenance and any factors that have a bearing on the problem, and suggested changes in design to resolve the problem.

3. Develop a Checklist of Maintenance Problems

To enhance the designer's awareness of maintenance problems, it is also suggested that the maintenance section prepare a checklist of the most commonly overlooked maintenance considerations. Maintenance personnel at all levels should be encouraged to submit problems for the checklist. Many design-related maintenance problems can be resolved at little or no additional cost if designers are aware of them. One example is the setting of the skew angle on bridges. If the angle is the same as the angle of the snow plows, plows are likely to hang up in the joints. A minor change in the skew angle can prevent this. The maintenance section should consolidate all of the suggestions into one checklist for statewide use. This list will help designers to be constantly aware of these problems and to automatically include the necessary features in the designs to alleviate them. The checklist should also be incorporated into the appropriate design manuals.

A sample checklist is shown in Figure 4. Each agency should develop its own checklist to address its own unique problems. The list need not include problems that the agency has already resolved because those solutions will have been incorporated into the standards, design procedures, and manuals.

Developing and conducting training sessions for designers is another recommended method for heightening awareness of maintenance problems. Maintenance should develop training materials, such as slides, transparencies, and videotapes, which document specific problems and solutions. Training sessions should be conducted periodically until all designers have been trained. Additional sessions should be held as updated training materials are developed.

4. Identify Alternative Designs

The sources of design alternatives will vary for each problem identified. These sources include designer knowledge, suggestions from maintenance and construction, research applications from published results, and research conducted specifically for the problem.

Surfacing

1. Is the pavement designed to carry the projected loads?
2. How will surface repairs be made considering the traffic?
3. How will the pavement be rehabilitated in the future?
4. Will widening be required in the near future? If yes, how will it accomplished?

Shoulders

1. Does traffic warrant paving the shoulders?
2. Will the shoulders be needed as traffic lanes in the near future? If yes, are they designed to carry the load?
3. Can concrete shoulders be constructed integrally with concrete paving to eliminate joint failures and strengthen the roadway pavement?
4. If aggregate shoulders, can they be bladed safely under traffic?

Drainage

1. Are drains adjacent to or under concrete barriers accessible for cleaning?
2. Do ditch designs provide for controlling erosion?
3. Are pipe ends designed to control erosion?
4. Are clean-outs provided in closed drainage systems?
5. Are all pipe culverts large enough to permit cleaning?
6. Is rodent protection provided for underdrain outlets?
7. Will channel alignments cause erosion problems? Is there adequate right of way to make repairs?
8. Are pipe coatings resistant to chemical conditions of effluent and soil?
9. Are nonstandard grates specified?

Roadsides

1. Can drought-resistant plantings be used?
2. Can native grasses be used to reduce or eliminate mowing?
3. Are slopes too steep to mow?
4. Are slopes flat enough to resist erosion and slides?
5. Can sound walls be placed on the right-of-way line to eliminate maintenance behind the walls? If not, is access provided?
6. Are gates provided in wing fences to permit access to inspect and maintain bridges and drainage facilities?
7. Is access provided to mow behind all guardrails?

Traffic

1. Is it economical to flatten slopes in the clear zone to eliminate guardrail?
2. Does the guardrail design use standard materials so maintenance can minimize the stocking of repair parts?
3. How will vegetation under guardrail be controlled? Would paving be justified?
4. Can maintenance repair guardrail without closing a traffic lane? If no, should a concrete barrier be substituted?
5. Should thermoplastic be specified instead of paint to reduce maintenance and interference with traffic?
6. Are attenuators standard so maintenance can minimize the stocking of repair parts?
7. Are signal controllers protected from traffic?
8. Are signs coated to reduce the effects of vandalism?
9. Will the fastener design for signs prevent theft?

Figure 4. (Figure continues on the opposite page.)

Bridges

1. Are bridges designed to permit jacking to facilitate servicing, repair or replacement of bridge bearings?
2. Are provisions included for waterproofing decks?
3. Are maintenance and operating manuals provided for movable bridges and other complex structures?
4. Is the shoulder wide enough to accommodate the snooper without impeding traffic?
5. For skewed bridges, is the angle of snowplow blades considered in setting the bridge skew? Where the bridge skew and snowplow angle are the same, plows are more likely to catch on the joint, damaging the joint or the plow.
6. Are critical inspection items listed on the plans to advise bridge safety inspectors?
7. Are bridge components accessible for inspection and maintenance?
8. Are joints adequately sealed to prevent water getting to the bearings and supports below the joints?
9. Are the interiors of box beams accessible for inspection? Are outlets provided for lighting?
10. Do deck drains carry the water below the beams to prevent water damage from splash-back?
11. Do deck drainage systems have clean-outs? Does the system have any sharp bends that may cause clogging?
12. Is the channel protected to prevent erosion?
13. Is drainage at abutments provided to prevent erosion?
14. Are vertical and horizontal clearances adequate to prevent damage?
15. Are there any unusual joint details?

Winter Maintenance

1. Is adequate room provided to store snow?
2. How will snow be removed from bridge decks?
3. Are median cross-overs provided on divided roadways for ease of routing snow and ice control vehicles?

Miscellaneous

1. Are there any non-documented agreements with landowners?
2. Are school bus turning areas provided?

Figure 4. Sample checklist of maintenance concerns.

5. Evaluate Problems and Alternative Designs

The complexity of the problem and the number of alternatives will determine the extent of the evaluation. Evaluation of minor design changes typically will be fairly simple, whereas major design changes will require more extensive studies to select the optimum alternative. The future performance of each alternative must be predicted, either through existing records or by estimation, for both major and minor design changes.

Minor Design Changes. Evaluation of the alternatives for minor design changes can be achieved by considering the advantages and disadvantages of each alternative, such as (1) maintenance or construction problems associated with each alternative, (2) safety factors, (3) traffic-handling problems during construction, (4) environmental concerns, and (5) requirements of external agencies—federal, state, or local. Many minor design changes involve little or no cost differences between alternatives.

Major Design Changes. Proposed alternatives for major design changes usually require more extensive analyses. In addition to the items listed for consideration for minor changes, evaluations such as value engineering (VE) and life-cycle cost analyses (LCCA) may be required. (A complete VE analysis includes analyses of life-cycle costs; however, LCCA may be undertaken without completing all of the VE steps.) Because of the effort required to complete VE and LCC analyses, they should be used primarily for evaluation of significant changes, major or controversial items, and new products or methods. Value engineering is discussed in more detail in Appendix C, and life-cycle cost analysis is explained in Appendix D.

6. Evaluate Alternatives

The final step in evaluation involves a comparison of the alternatives and a selection of the optimum alternative. The decision concerning acceptance of the optimum alternative rests first with the project designer. The designer must evaluate the alternatives and decide which alternative should be incorporated into the plans. If this constitutes a change, the designer is respon-

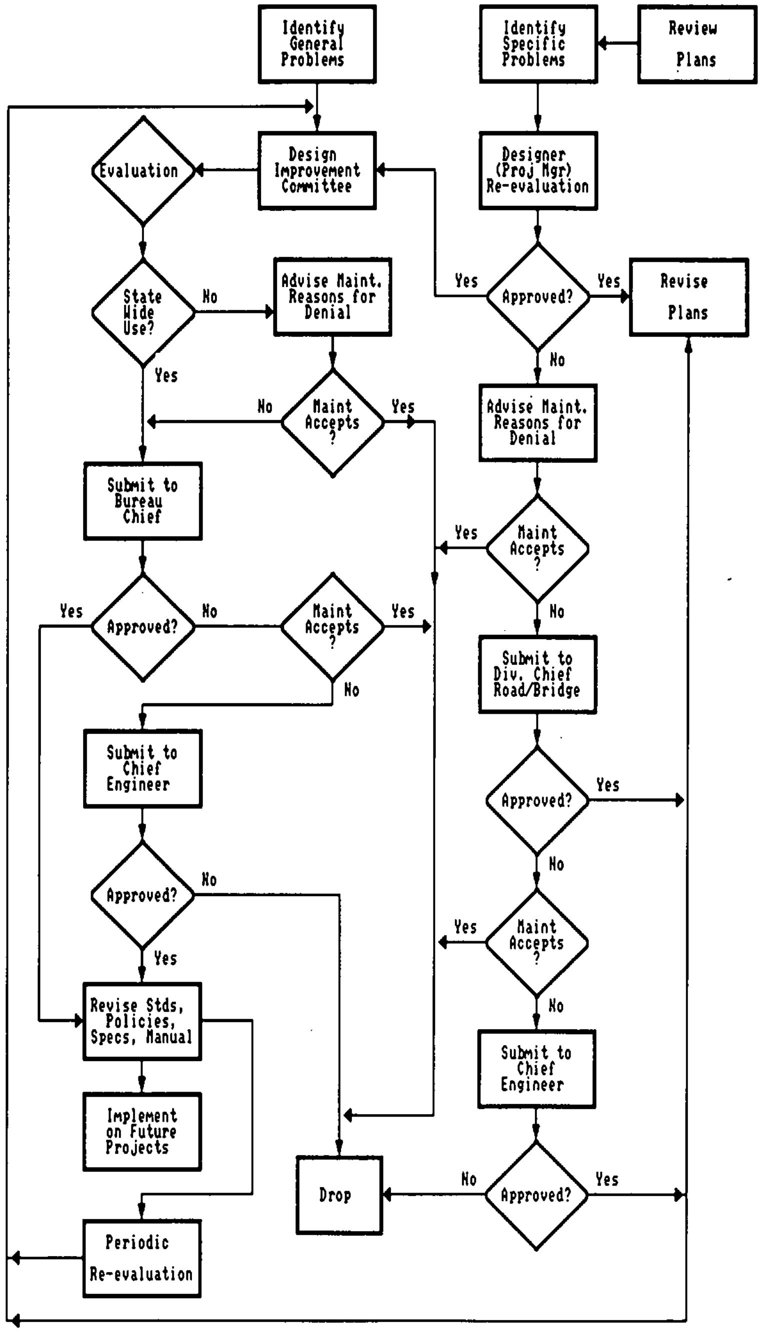

Figure 5. Design decision tree—central design.

sible for revising the plans, specifications, and other contract documents.

7. Communicate Decisions

All problems submitted by maintenance deserve a response. If a suggestion cannot be implemented, the designer should explain why. The process is designed so the initiator can appeal the decision if the problem is causing significant maintenance problems. Refer to the Central Design Decision Tree in Figure 5 and the District Design Decision Tree in Figure 6 for the appeal processes.

8. District Design Improvement Committee

District designers should submit copies of the problems and suggestions for improvements and the approved alternatives to the District Design Improvement Committee for consideration on other similar design projects. This Committee should also

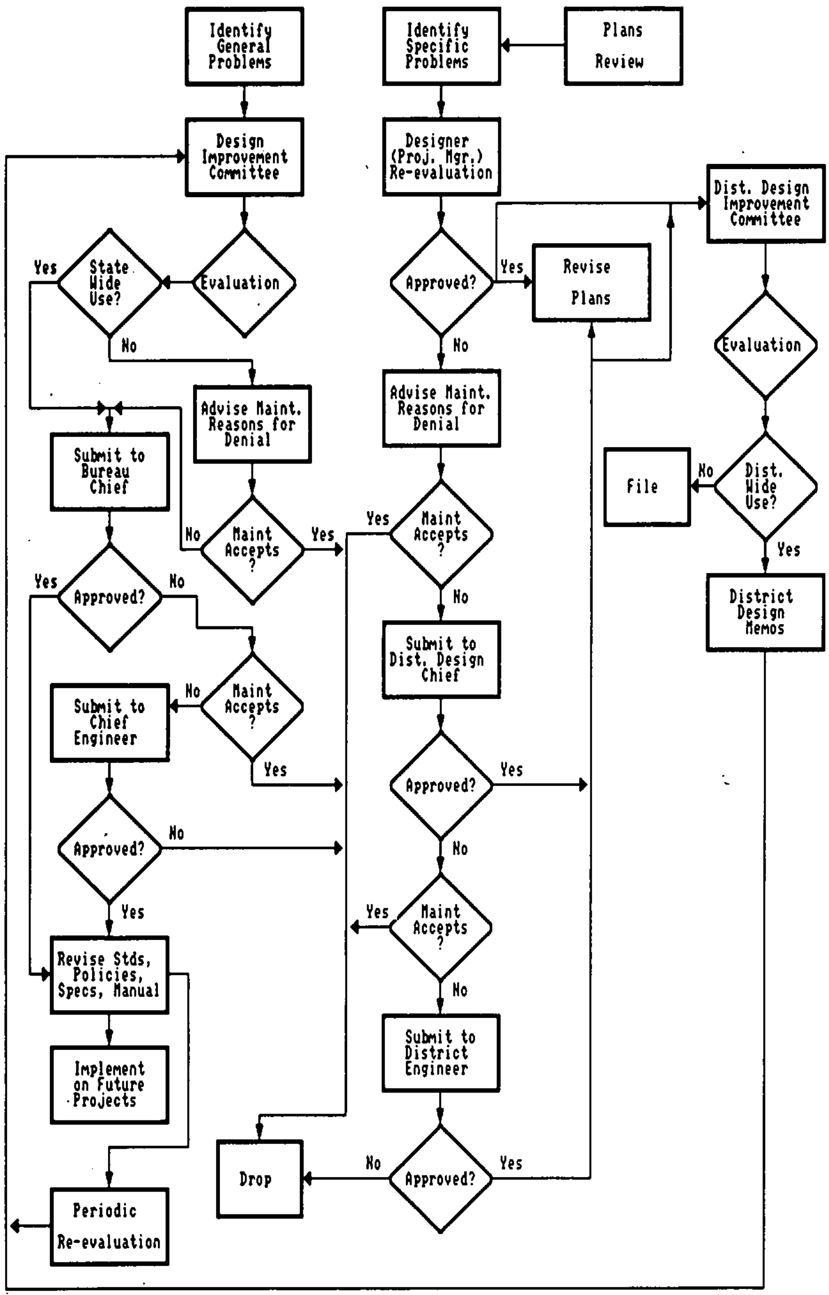

Figure 6. Design decision tree—district design.

advise other designers of any changes in district design policies and standards that can affect future designs.

9. Statewide Design Improvement Committee

The District Design Improvement Committees should send copies of their approved solutions to the Statewide Design Improvement Committee for consideration. Central designers should submit copies of the problems and suggestions for improvements and the approved alternatives directly to the Statewide Design Improvement Committee for consideration for use on other similar design projects. Again, this Committee should advise other designers of any changes in Statewide design policies and standards.

PROCESS FOR GENERAL PROBLEMS

General problems are those that would affect all similar designs agencywide. In most cases, improvements in designs will require changes in the policies and standards.

The process for identifying general problems and including maintenance considerations in design is outlined in the following steps. The process is essentially the same whether design is decentralized to the districts or centralized in the head office. One difference is that, with district design, the District Design Improvement Committee will identify many of the general problems and solutions.

1. Identify Specific Maintenance Problems Related to Designs

Potential methods of identifying problems include: (1) maintenance experience with specific designs; (2) review of policies, standards, and specifications by having maintenance personnel serve on a Design Standards Committee; (3) reviews of project plans, including concept plans, preliminary plans, and final plans; (4) post-construction reviews; (5) employee suggestions; (6) attendance of designers at maintenance supervisor meetings; (7) attendance of maintenance representatives at designer meetings; and (8) review of recent research publications.

2. Define the Problem

General problems will have to be presented in writing. Written communications should include a statement of the problem, a description of why it is a problem for maintenance and any factors that have a bearing on the problem, and suggested solutions to the problem. A sample problem statement format is shown in Figure 7.

3. Submit to the Statewide Design Improvement Committee

The Statewide Design Improvement committee is responsible for evaluating problems to determine if design improvements can and should be made; identifying and evaluating design alternatives; and recommending changes in designs, policies, and standards or advising the originators of rejected submissions.

4. Identify Alternative Designs

The sources of design alternatives will vary for each problem identified. These sources include: suggestions from problem statements or committee members, research applications from published results, and research conducted specifically for the problem.

5. Evaluate Problems and Alternative Designs

The complexity of the problem and the number of alternatives will determine the extent of the evaluation. Evaluation of a major design change will require consideration of essentially all of the items listed in this section. Minor changes would more likely require consideration of only a few of these items. The future performance of each alternative must be predicted, either through existing records or by estimation, for both major and minor design changes.

Minor Design Changes. Evaluation of the alternatives for minor design changes can be achieved by considering the advantages and disadvantages of each alternative, including: (1) maintenance and construction problems associated with each alternative, (2) safety factors, (3) traffic-handling problems during construction, (4) environmental concerns, and (5) requirements of external agencies—federal, state, or local.

Many minor design changes involve little or no cost differences between alternatives.

Major Design Changes. Proposed alternatives for major design changes usually require more extensive analyses. In addition to the items listed for consideration for minor changes, evaluations such as value engineering (VE) and life-cycle cost analyses (LCCA) may be required. (A complete VE analysis includes analyses of life-cycle costs; however, LCCA may be undertaken without completing all of the VE steps.) Because of the effort required to complete VE and LCC analyses, they should be used primarily for evaluation of significant changes, major or controversial items, and new products or methods. These analyses may result in revisions to design standards, standard drawings, and specifications. Value engineering is discussed in more detail in Appendix C, and life-cycle cost analysis is explained in Appendix D.

6. Committee Decision

The decision to implement design improvements recommended by the Design Improvement Committee will depend on the nature of the change and the positions and authority of the members of the Committee. If Committee members are in charge of specific functions such as road design, bridge design, and the like, changes in their area of responsibility may be made without approvals of higher authority. Where this is not the case, the Committee's recommendations should be routed to the appropriate manager.

7. Communicate Decisions

All problems submitted deserve a response. If a suggestion is not recommended for implementation, an explanation should be provided. The process is designed so the initiator can appeal the decision if the problem is causing significant problems to maintenance. (See the design decision trees in Figures 5 and 6.)

In addition to responding to the initiator of the problem statements, all approved design improvements should be communicated to design, maintenance, and construction personnel through (a) distribution of updated policies, procedures, specifications, design manuals, standard drawings, and so forth; (b) memoranda to designers; and (c) discussions at annual design, construction, and maintenance meetings.

Administrators of management systems for pavements, bridges, and roadsides should receive copies of the updated policies, procedures, specifications, manuals, and standards for use in updating the criteria in their systems. For future reference, a special file should be set up for documenting problems, evaluations, and decisions.

Maintenance Projects

Projects originating in maintenance should also be reviewed. Contract documents should be sent to construction and materials for review and comment prior to advertising.

Statement of Problem

Describe the problem and how it affects maintenance. (Use sketches where appropriate to describe the problem.)

Urgency

How serious is the problem? (Person-hours to correct annually, number of times maintenance is required each year, frequency of flooding, etc.)

Recommendation:

Recommended solution to the problem and the reasons for its selection. (Use sketches if appropriate.)

Submitted By:________________________**Phone:**______________**Date:**___________

Design Improvement Committee Action:

Figure 7. Sample maintenance problem statement.

IMPLEMENTATION OF THE PROCESS

In these times of tight budgets and aging facilities, it is essential that agencies look at the long-term effects of design policies. Developing designs that reduce future maintenance costs can be the more prudent policy even though initial construction costs may be somewhat higher.

It is suggested that the process be implemented through the following steps.

1. Commitment

As with any other goal, top management in each agency must be committed to the consideration of maintenance in the design procedures if maintenance and design personnel are to take it seriously. There should be no doubt that top management supports the concept if implementation is to be successful.

2. Organize

Appoint a design/maintenance coordinator. Appoint design improvement committee(s) for the central office. One committee will likely be sufficient for smaller agencies. Separate committees for each major specialty may be necessary in larger agencies. This function may be assigned to existing standards committees if it can be added to their duties without overburdening them. Maintenance, design, construction, and materials should be represented on all committees.

Where design is decentralized to the districts, a district design improvement committee should be appointed for each district. Again, maintenance, design, construction, and materials should be represented on all committees.

3. Adapt the Process

Adapt the process to fit the organization, conditions, and policies under which the agency must operate. Revise the sample processes, checklists, and forms for problem statements and maintenance scoping recommendations.

Incorporate the process, policies, checklists, and responsibilities into project development procedures, design manuals, maintenance manuals, and position descriptions as appropriate. The process for considering maintenance in design should become a part of the normal functions of design and maintenance — not a separate function — to ensure continuity of the process.

4. Develop a Measurement System

Develop a measurement system to evaluate the effectiveness of the process. The purpose of this system is to document the results (benefits) of the process to encourage continuation of the effort. For example, when the process is implemented, maintenance should conduct in-depth reviews of several projects to identify improvements needed to incorporate maintenance concerns. This same process should be conducted periodically, perhaps every year, to determine whether the concerns are being addressed and if the number of needed improvements actually decrease.

5. Initiation

Initiate implementation of the process through direct contact with the design and maintenance supervisors. This step can be accomplished through meetings with these supervisors to explain the process and their role in ensuring that maintenance is considered. Joint meetings attended by both design and maintenance are preferred. Where several meetings are necessary, a team that includes representatives from design, maintenance, and management should be formed to conduct the meetings. This same team should conduct all of the meetings to reduce misunderstandings.

Hand out the implementation schedule, written procedures, checklists, sample problem statements, the form for maintenance scoping recommendations, and the measurement criteria at the meeting(s). Design and maintenance personnel should receive the same handouts and instructions.

6. Follow-Up

The design/maintenance coordinator should be available by telephone and through meetings to respond to questions concerning the process and make adjustments in the process to ensure that it is working.

7. Monitoring

The coordinator should monitor maintenance consideration in design through the measurement system explained in Step 4; summarize results on a regular periodic basis, say, monthly; and report those results to top management. The coordinator should make recommendations for corrections of any problems found through the measurement system. Corrections should be made through the normal supervisors.

8. Updating

As problems are identified and solutions are developed, design procedures and manuals should be updated to incorporate the improved designs. When a problem is resolved in this manner, that particular problem should be removed form the checklist.

CHAPTER 4

DESIGN FEATURES INCORPORATING MAINTENANCE CONSIDERATIONS

The highway and bridge design features described in this section have been compiled from current literature, from interviews with selected state transportation agency personnel, from research being conducted by various private and public organizations, from questionnaire responses, and from the experience of the project investigators. Both of the investigators and all of the other team members who reviewed the report have attempted to see that none of these suggested design features violate or conflict with any current safety guidelines known to them. However, it is recommended that, when incorporating any of these features into their designs, agencies first consider the safety laws, regulations and guidelines, and other design requirements in effect at that time.

The features and suggestions presented here can be listed under three basic categories described as follows:

1. Well-established and proven concepts practiced by most of the transportation agencies. These concepts have been included here to provide a complete list. They also serve to remind design engineers of the importance of these features.
2. Successful techniques and suggestions used by some agencies. These techniques have been included for the benefit of the others who could try to verify their usefulness.
3. New ideas and research concepts. More experience and testing are required with these features. This aspect has been clearly emphasized to prevent misguiding readers.

This chapter is divided into two main sections. The first section includes highway design features such as policies, roadways, drainage systems, appurtenances, and roadside elements. The second section covers bridge design features including deck, deck joints, deck drainage, railings, bearings, girders, abutment and piers, and approaches.

HIGHWAY DESIGN FEATURES INCORPORATING MAINTENANCE CONSIDERATIONS

This discussion is divided into five sections: (1) Policies, (2) Roadways, (3) Drainage Systems, (4) Appurtenances, and (5) Roadsides.

Policies

Consideration of maintenance should begin early, during the location studies, and continue throughout the design process. In many cases, highway geometrics have substantial impact on maintenance requirements. Erosion control, which generally consumes a large part of maintenance expenditures, can be minimized by proper location and geometric design, which also contributes to a more aesthetically pleasing facility. Access and right-of-way availability are other important features contributing to ease of maintenance.

Policy Design Considerations

1. Investigate geology and geotechnical features to avoid or minimize potential problems such as rock and landslides, poor foundation conditions, highly erosive soils, and unsuitable materials.
2. Locate those highways in mountainous and hilly areas in a southern exposure as much as possible to minimize pavement icing and snow accumulation. Upper hillside locations can reduce, even eliminate, the potential for snow slides. Consider space requirements for dumping or storing plowed snow, with proper drainage as the snow melts.
3. Investigate hydrology and hydraulic features to minimize erosion, debris accumulation, disruption of natural channels, flood damage, and scour potential. The maintenance cost of drainage elements is a major cost item. Careful attention to requirements for adequate drainage and protection of the highway from floods is important to reduce maintenance costs.
4. Consider access requirements for maintenance purposes and future rehabilitation in all aspects of highway location and design. For example, maintenance turnarounds must be accommodated at median crossovers, through U-turns under grade separation structures, or by special ramps to overpass (or underpass) structures. Interchanges have high maintenance requirements due to the extensive paved and landscaped areas and to the many signs and light poles.
5. Avoid horizontal curvature and sag vertical curves on bridge structures. Superelevated bridge decks need more maintenance attention due to runoff from melting snow and icing conditions. Sag vertical curves may cause water ponding on the deck if the drainage system gets clogged.
6. Consider maintenance needs in establishing right-of-way limits and fence locations. It may be possible to eliminate maintenance requirements outside the fence if the fencing location is coordinated with the right-of-way acquisition. If this is not possible, then gates or easements should be considered. Adequate space (minimum 10 ft) should be provided between the toe or top of slope and fencing to accommodate maintenance vehicles and equipment. Consider the purchase of additional right of way to flatten short sections of high embankments so they can be maintained more easily.
7. Conduct a value engineering analysis to compare embankment sections having flat slopes and wider right of way with sections having steeper slopes or retaining walls, or both. Include maintenance costs in the analysis.

8. Consider the maintenance facility requirements such as yards, stockpile sites, borrow and pit sites, snow storage, and waste areas in acquisition of right of way.

Roadways

The roadway features covered here include mainline and ramp pavements, shoulders, medians, islands, and embankments. Pavement maintenance and rehabilitation consume a large part of maintenance expenditures. Thickness, durability, joints, reinforcements, and other structural aspects of the pavements have been the subject of numerous tests and research projects. Therefore, they are not included here. Maintaining the bearing capacity of the subgrade by proper drainage is one of the critical items in preserving the design life of a pavement.

Roadway Design Considerations

1. Provide adequate subgrade drainage using various techniques such as designing the proposed roadway grade above the water table, providing deep side ditches, using free draining base material and french drains or underdrain pipes. Minimize loss of fine material and clogging of the subdrainage by wrapping filter fabrics around french drains and perforated pipes. To reduce any damage due to erosion and clogging, underdrain pipes should outlet into paved ditches or culverts. Outlets should be marked so maintenance can keep them open.

2. Provide skid-resistant surfacing in wet climates. This can be achieved by grooves in concrete pavements and placing an open-graded surface course over asphaltic concrete.

3. Consider future pavement resurfacing requirements when establishing vertical clearances and designing elements such as inlet grates and manhole covers.

4. Consider the use of longer pavement life (50 years) and PCC pavement in congested urban areas. Maintaining the traffic flow during rehabilitation or resurfacing operations is so difficult and delays are so substantial that a properly conducted life-cycle analysis, including user costs, can easily substantiate the need for more durable pavement in highways with high traffic volumes.

5. Consider the use of full pavement design from shoulder to shoulder in urban areas. This eliminates the troublesome joint between the pavement and shoulder, provides adequate strength for future use of shoulders as travel lanes, and provides better lateral support to the mainline pavement.

Full pavement design is an expensive solution that can only be justified in heavily traveled urban highways. For others, consider extending the pavement structure into the shoulder at least 2 to 3 ft. Studies show that truck encroachments are confined to this area. Similarly, on highways with unpaved shoulders, consider paving the areas subject to rutting due to encroachment by vehicles (*6*). These encroachments usually occur at the inside edge of horizontal curves, lane transitions, T intersections, and turnouts. Consider the use of durable pavements with longer design lives at ramp terminals where the ramps meet the cross street.

6. Where guardrail is used, consider paving the area under the guardrail to minimize vegetation control problems. These areas are difficult to mow and alternative maintenance solutions such as manual control or the use of herbicide may not be attractive because of cost and environmental considerations.

7. Provide a shoulder sloping away from the pavement on the high side of superelevated sections. This will prevent icing conditions on the pavement due to melting snow deposited on the shoulder. However, it should be remembered that minimum shoulder slope should be 1 percent, and the algebraic difference between the shoulder and roadway slopes should not exceed 7 percent.

8. Create a contrast between asphalt pavement and asphalt shoulder by applying stone chips to the shoulder surface. However, on medians with concrete barrier and drainage inlets, these chips, if loosened because of inadequate adhesion, can cause clogging of the inlets and drainage system. A solution may be to use a slotted pipe along the concrete barrier for drainage purposes.

9. Avoid the use of unpaved narrow medians or small traffic islands. Maintaining any grass surface in these areas is difficult, costly, and dangerous. Provide mountable curbs, pave the surface, and specify appropriate sterilant chemicals to be applied under the paved surface in order to minimize weed growth. Painted islands can be used, but they require constant repainting. Raised markers solve this problem and provide better night visibility. However, unless they are recessed, they can be damaged by snowplows.

10. If the median is 22 ft or less in width, consider offsetting the concrete median barrier rather than placing it in the middle. This helps to increase the shoulder on one side to 12 ft (and reduce the other to 8 ft) to allow safer parking of maintenance equipment while providing the maintenance crew with more adequate space for conducting routine maintenance or servicing signs, light standards, or glare-screens (Figure 8).

11. Provide flat slopes and rounding to minimize erosion potential and to make maintenance operations easier. Desirable embankment slopes within the vehicle recovery area (30 ft from the edge of pavement) should be 6:1, and beyond, 4:1. Maintenance equipment cannot operate on slopes steeper than 3:1. Cut slopes should preferably be no steeper than 3:1, but never steeper than 2:1 except in rock.

12. Consider providing benches in higher cut slopes to collect debris, slow runoff, and to collect water from slope drains. The width and height of these benches should be designed to allow access for maintenance equipment. As an alternative to benching, a wider area can be provided at the base, which can be used by maintenance equipment and for debris and snow collection. If a concrete barrier or fence is used, adequate room behind the barrier or fence for operation of maintenance vehicles should be provided as well as access through a removable section of the barrier (Figure 9).

Drainage Systems

Highway drainage systems include culverts, storm water systems in urban areas (inlets, catch basins, manholes, and pipes), curbs, ditches, detention and retention ponds, pumping stations, environmental protection devices, and flood control systems. Maintenance problems related to drainage are substantial and result in some of the most costly items in the maintenance budget. These items include erosion control for ditches, cleaning of culverts and stormwater systems, repair of eroded and scoured outlet areas, corrosion control, and repair of damage due to frost and clogging.

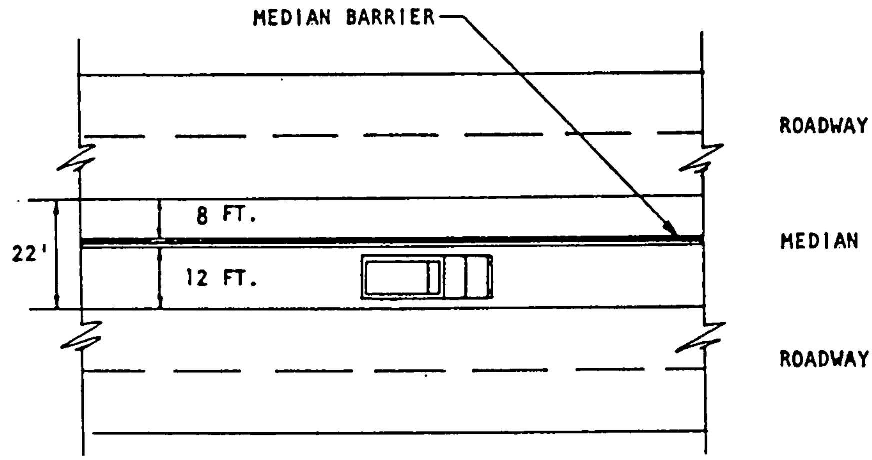

Figure 8. Median barrier offset.

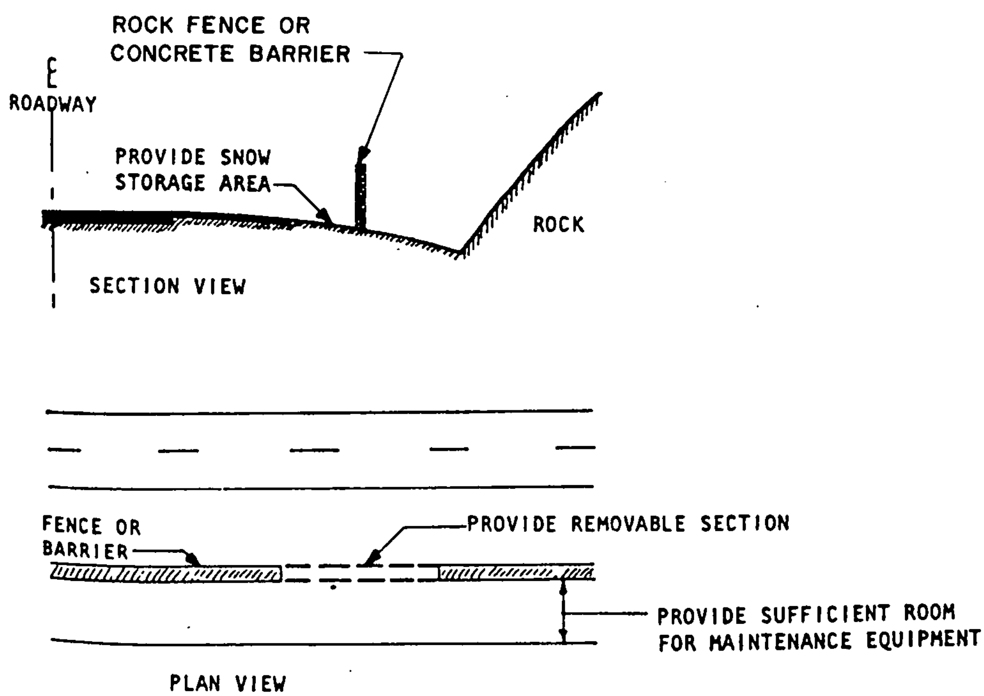

Figure 9. Space for maintenance in rockfall areas.

Drainage Design Considerations

1. Select vertical and horizontal alignments of culverts so that inlets and outlets are close to the existing channels. Sedimentation or erosion may occur if the new alignment is much different from the existing channel. Under high fills, culverts may have greater settlement in the middle, resulting in ponding and sedimentation. Consider cambering culverts to avoid ponding in pipes.

2. Base selection of pipe and culvert materials on evaluations of acidity, resistivity, chloride, and sulfate levels in the soil and water. Galvanizing, bituminous coatings, and heavier gage pipes will help increase metal pipes' resistance to corrosion. For concrete pipe or culverts, special cement type, increased cover of reinforcing bars, and use of high-density concrete should be considered when these conditions are encountered.

Abrasion of culvert inverts depends on the flow characteristics and materials carried by the stream. At locations where high abrasion is anticipated, paving the invert with bituminous material or concrete or lining the invert with metal planks should be considered. Increasing the thickness of the metal or concrete is another alternative. But the best results can be obtained by reducing the velocity of flow through the culvert.

3. Size culverts to allow passage of debris. Design headwalls and wingwalls flush with the culvert end to minimize debris accumulation. In some cases, a debris collection structure in

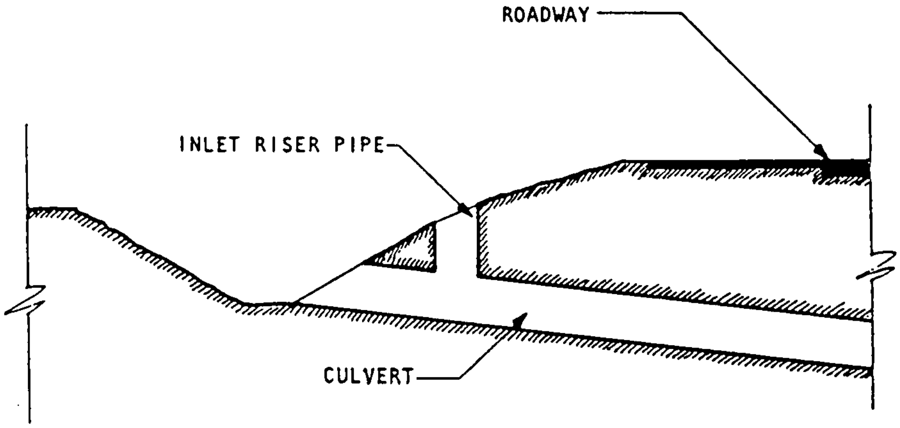

Figure 10. Inlet riser pipe.

front of the culvert inlet may be required. Access for maintenance equipment should be provided for periodic cleaning. Consider including an inlet riser to provide access in case the inlet becomes clogged (Figure 10).

4. Provide a full or partial headwall to anchor pipe subject to uplift due to scouring and buoyancy. This can occur to metal pipes that are located under relatively flat fill slopes. Provide energy dissipators at the outlets where scouring and erosion are possible. Dry riprap, grouted riprap, splash blocks, stilling basins, drop structures, and concrete baffles can be used for this purpose. In selection of the dissipator type, sedimentation and debris accumulation potential should be taken into consideration. Access for maintenance at the outlet area is also needed.

5. Provide access to ditches along the highway. Proper functioning of ditches is essential to convey surface water out of the highway right of way. Debris, nuisance vegetation, erosion, sedimentation, and undermining of ditch paving interfere with this function. Ditch slopes should be designed to allow maintenance vehicles to cross easily, and ditch paving should be strong enough to carry the equipment loads. To reduce the costs, the structural section of ditch paving can be increased to provide crossings only at designated locations.

6. Provide the appropriate ditch grade to minimize the possibility of erosion or sedimentation. An unlined ditch grade should be greater than 0.3 percent to avoid ponding. Also, in the design of unlined ditches, sharp bends in vertical and horizontal alignments should be avoided to reduce erosion potential. If rigid ditch liners are used because of high velocity, limited right of way, or other factors, cutoff walls and filter layers or underdrains should be considered to prevent undermining or frost heave problems. Consider the use of energy dissipators in transition areas from paved to unpaved sections if flow velocities warrant them. At the top of cut slopes, create a ditch with a berm (preferably lined) if the slope is subject to sliding, rather than cutting a ditch in the original ground.

7. In grassed medians, provide flush-mounted inlets with concrete aprons around them. In curbed sections where clogging with debris is a possibility, provide an additional inlet on each side of the planned inlet at the low point to eliminate ponding. All inlets should be combined with curb openings if debris accumulation is a problem. Locate inlets and manholes such that access by maintenance equipment is not obstructed by guardrail, concrete barriers, piers, sign structures, fences and poles; and in turn, such that maintenance equipment does not obstruct traffic or create unsafe conditions. Design inlets to minimize vandalism and dislodgment by traffic.

8. Avoid the use of curbs to reduce danger to traffic and damage to snow removal equipment. If this is not possible, use mountable curbs and always taper the end of curb sections. Do not use bituminous curbs as they are not durable and require excessive maintenance. Extend the expansion joints in the pavement through curb or curb-and-gutter sections.

Appurtenances

Together with pavement and drainage, appurtenances demand a large share of the maintenance budget. Traffic, vandalism, animals, and atmospheric conditions cause most of the damage to these elements. Their maintenance and repair are labor-intensive activities; therefore, substantial cost savings can be achieved if they are designed and built to be safe, durable, and easy to maintain.

Appurtenances can be classified under two main categories: Roadway Appurtenances and Roadside Appurtenances. Roadway appurtenances include: (1) barriers and guardrails, (2) glarescreens, (3) pavement markings and markers, (4) rumblestrips, and (5) attenuators.

Roadside appurtenances include: (1) signs, (2) lighting, (3) delineators, (4) sound walls, and (5) fences.

Roadway Appurtenances

Barriers and Guardrails are provided for the purpose of protecting run-off-the-road vehicles from (1) crashing into the opposing traffic and other hazardous objects such as piers, abutments, signs, light poles, and falling rocks and (2) penetrating areas with steep slopes and other hazardous conditions. Although they are designed to reduce the severity of accidents, by their very nature they may increase the frequency of accidents. Therefore, it is always better to design a highway with minimal need for barriers and guardrails. Consider the following solutions for this purpose:

1. Provide flatter embankment slopes within the recovery area (within 30 ft of the edge of pavement).
2. Relocate or eliminate roadside obstacles (such as lengthening bridge spans to move the abutment away from the edge of the pavement, providing fill cones in front of abutments, and constructing an earth mound around the median pier).
3. Provide breakaway posts for signs and light standards.
4. Mount signs on structures, and mount signs and light standards on concrete median barriers wherever possible.
5. Design ditches with flat slopes.
6. Consider the use of attenuators in place of guardrails where attenuators would be less hazardous than a length of guardrail.

Use concrete median barrier in narrow medians. The curved face of the barrier is designed such that vehicles hitting it at a narrow angle are redirected parallel to the travelway. Barriers cause less damage to these vehicles and, in turn, require minimum maintenance. Sterilize the areas under the barrier to reduce weed growth between the barrier and pavement.

Consider the use of a concrete barrier as a combination of barrier and glarescreen by extending its height. Although this solution will reduce the cost of glarescreen maintenance, the possibility of surveillance through glarescreens is lost because it blocks visibility from a patrol car.

Consider designing a water-conveying median barrier to eliminate the need for slotted inlets in shoulders and installing a steel plate shaped to match the barrier face, hinging it in place, to facilitate cleaning the catch basins under the barrier.

Consider the use of open guardrail design in areas subject to snow or sand accumulation. Standardization of guardrail sections helps to reduce costs associated with procurement and storage of replacement parts. Shorter rail sections are easier to transport and handle. This could also help to reduce the repair time, thus increasing safety for both the public and maintenance crew. Select materials to increase the "salvage values" of rail and posts. Consider possible adjustment of the rail section due to future overlay by providing an extra hole in the posts. Provide details to facilitate weed and debris control operations around guardrails. Extending shoulder paving through the guardrail and specifying soil sterilant together with road oil are two possibilities. Provide access to areas enclosed by guardrail or provide low-maintenance cover. Impervious material, such as asphalt, placed around the guardrail post directs the water away from the base of the post, thus reducing the possibility of water entering the embankment and causing a potential slide.

Glarescreens are provided to reduce nighttime glare problems for motorists driving roadways with narrow and unlighted medians or where a two-way service road is located immediately adjacent to the mainline. Maintenance impacts are generally due to accident damage, debris accumulation, deterioration due to atmospheric factors, vandalism, and damage from snowplows.

Provide wide medians (30 ft or wider) or lighting to eliminate the need for glarescreen to reduce construction and maintenance costs. Wherever possible, provide appropriate plantings and earth mounds. However, plants need extensive maintenance until they are well established, followed by routine maintenance. Earth mounds require erosion and weed control.

Use materials that are less prone to vandalism. Consider the use of plastic paddle-type screens that can be mounted on concrete median barriers. They return to their original shape after an impact, provide access in case of emergency, and minimize the accumulation of debris and snow. Provide mounting details so repairs can be made easily. By careful standardization, procurement cost and spare parts storage can be minimized. Specify corrosion-resistant elements (galvanized or stainless steel) for anchoring hardware.

Pavement Markings and Markers. Wear from traffic, snowplows, sanding operations, and atmospheric conditions are the main factors in the maintenance of markings and markers. Replacing worn markings and lost markers is a costly operation. It also creates conditions that can be unsafe for both maintenance personnel and the general public.

Consider the use of epoxy, thermoplastic material, or pre-cut tape in place of paint. The standard paint, although cheaper, does not last long under heavy traffic and harsh atmospheric conditions. In non-snow areas, consider the use of raised pavement markers instead of striping. They last longer, provide good visibility, and encourage the motorist to stay within the lane. Raised pavement markers are difficult to remove in preparation for overlaying the pavement, but their use together with long-life pavements can be very cost-effective in urban areas. A grooved system with recessed pavement markers can be used to overcome snowplow damage. Select striping patterns and application levels such that the material requirements are minimized.

Rumblestrips are used in shoulders, gores, and medians to define the edges of the traveled way and in the mainline to warn motorists of approaches to toll collection facilities, stop signs, and other similar situations. Maintenance impacts result from damage by traffic, by snow removal equipment, and by debris removal operations.

Consider the use of depressed rumblestrips rather than raised markers. Depressions can be provided either by imprinting fresh concrete surface or sawing grooves. Surface drainage and debris removal need to be considered in the design.

Attenuators are used in places where hazardous fixed objects, such as bridge abutments or piers, bridge rails, sign posts, and bridge ramp gore areas cannot be avoided. A wide variety of attenuators is available and still others are under development. The major maintenance requirement is quick repair or replacement after a collision. An ideal attenuator is durable and can be easily and quickly brought back to its original condition and position with inexpensive and available replacement parts. Select a system where corrosion of metal parts and deterioration of other elements are minimized. Make sure that the system does not create a hazardous condition on the adjacent lanes immediately following a collision. Consider the needs of snow removal and storage in locating the attenuator.

The Texas State Department of Highways and Public Transportation has developed a low-maintenance attenuator. It has the desirable features of the ideal attenuator previously described. It is mainly made of rubber and, following a collision, can be pulled back out and re-anchored to its original position. A drawing of the device is shown in Figure 11.

The Connecticut DOT also developed a special system called the Connecticut Impact Attenuator System (CIAS) (see Figure 12). It has been used experimentally for 5 years and regularly for 2 to 3 years. Cylinders damaged by a collision are removed and new ones bolted into place. This system reduces the exposure of maintenance workers while it quickly restores protection for the motorist. Connecticut has also developed a truck-mounted version of the attenuator to protect maintenance workers.

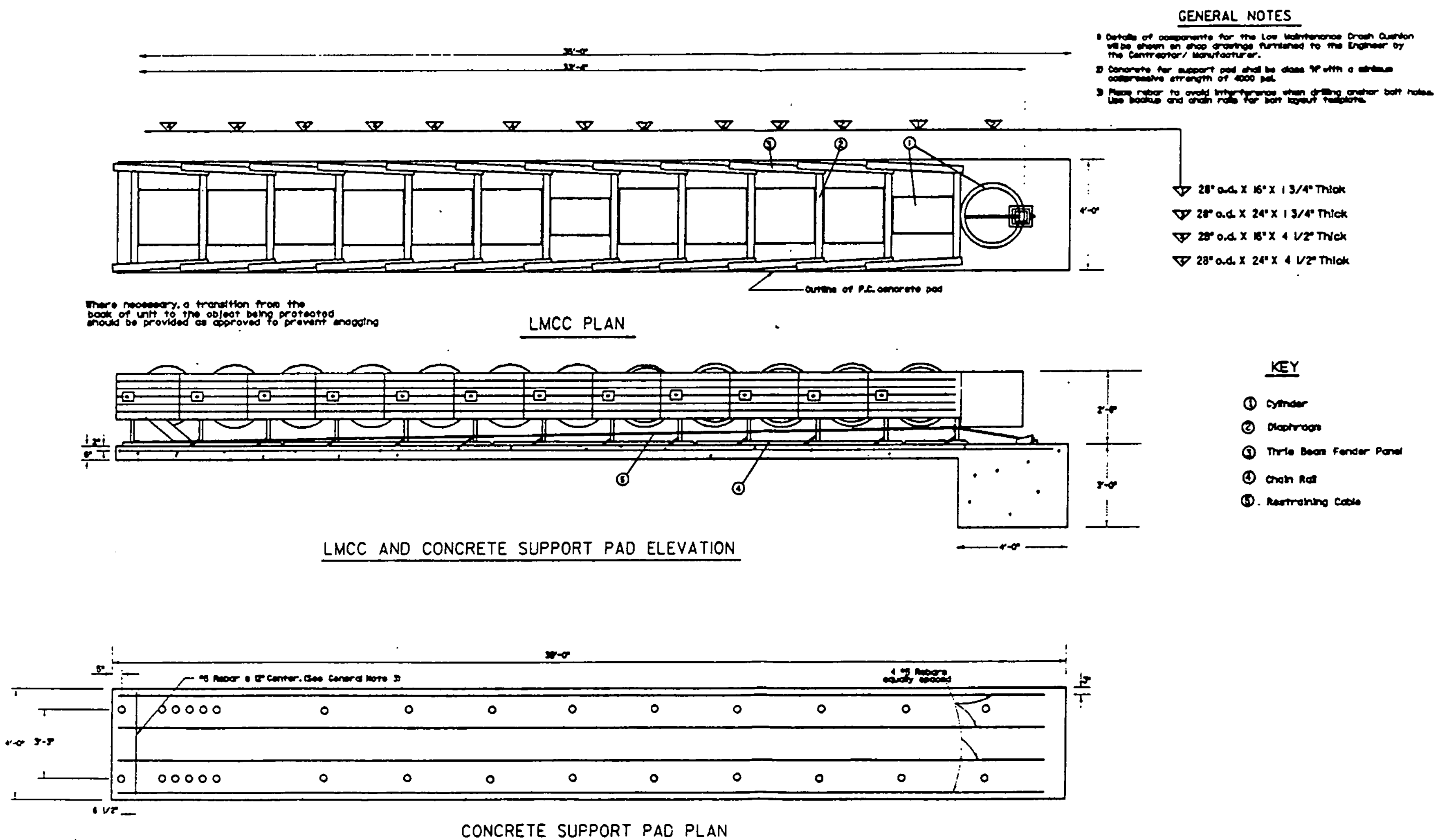

Figure 11. Texas low-maintenance crash cushion.

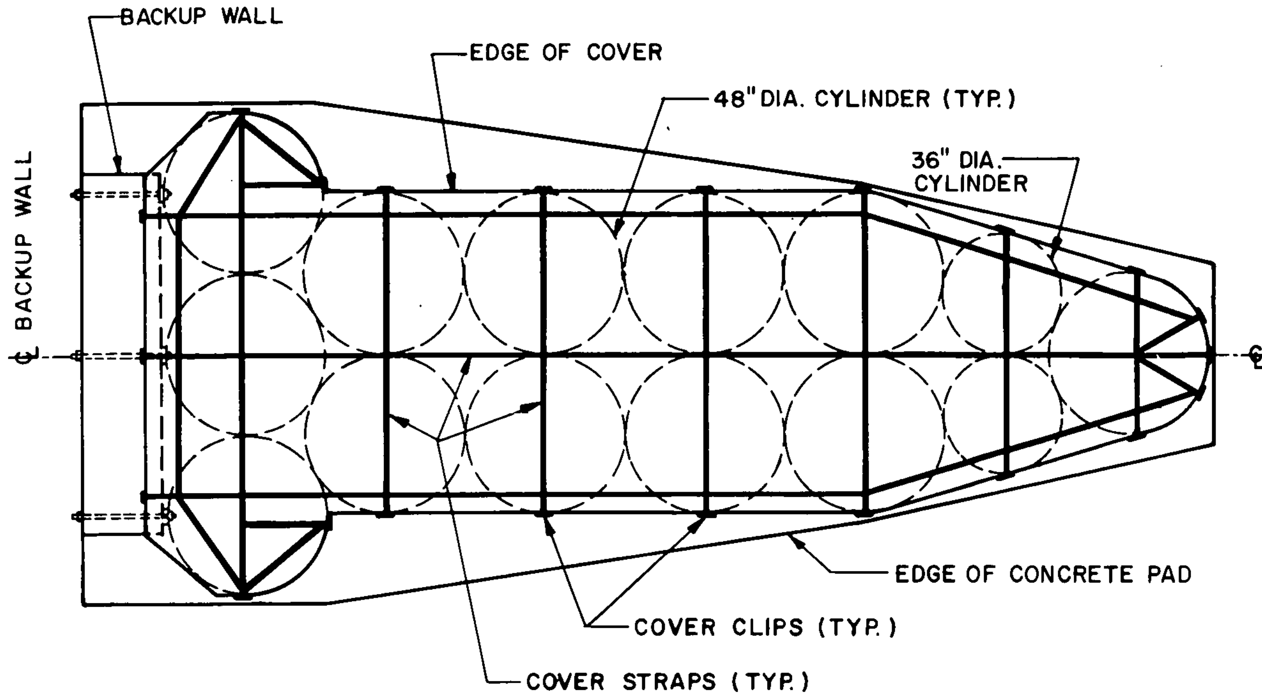

Figure 12. Connecticut crash cushion.

Roadside Appurtenances

Signs are generally mounted on single or double posts or on large overhead structures. Major maintenance requirements include painting, cleaning, replacing, and servicing fixtures of lighted signs, and repairing or replacing support posts damaged by accidents or deterioration. Vandalism, especially graffiti in urban areas and bullet holes in rural areas, is a serious problem and demands a significant maintenance effort.

Locate signs such that guardrail requirements are minimized, access is easily and safely available, visibility is not inhibited, conflict with landscaping and other highway elements is carefully avoided, and vegetation control operations are not hampered. If possible, place signs outside the run-off-the-road vehicle recovery area. This placement minimizes maintenance requirements and allows space for maintenance activities and snow removal operations.

Consider mounting signs on overhead bridge structures, thus eliminating the need for overhead sign supports. For the overhead sign structure, provide access and space for maintenance equipment at the sign base and a catwalk on the structure. If a sign is placed on a steep embankment behind a guardrail, consider providing a berm around it for maintenance work. It is difficult to place a ladder safely on a slope. Pave or use soil sterilant around the sign base to avoid manual control of vegetation. Avoid locating sign supports in ditches, where they will be subject to erosion or may interfere with ditch maintenance. Provide breakaway post designs that can be easily repaired or replaced. Use corrosion-resistant material such as galvanized steel or aluminum for metal posts to eliminate the need for painting. Use reflectorized sheeting, especially for overhead signs, to eliminate the need for lighting and to reduce maintenance work. Standardization helps to reduce procurement and stockpiling costs. Use sign material and other hardware that is resistant to vandalism and can be cleaned easily.

Lighting provides improved visibility at night and thus greatly contributes to traffic safety. Lighting also reduces the effect of headlight glare and provides better visibility during nighttime maintenance and rehabilitation activities, both of which improve safety. Maintenance requirements include cleaning, relamping, repairs, and replacement. Light poles create hazardous conditions for run-off-the-road vehicles, and therefore require guardrails or barriers for protection of motorists. They also create obstructions to vegetation control operations. Consider locating light standards on top of concrete median barriers or between split barriers to reduce the number of poles. However, servicing poles located in the median requires sufficient shoulder width for maintenance equipment. In narrow medians, as described previously, this can be achieved by offsetting the median barrier to one side. Other alternatives for reducing the number of poles include combining luminaires between ramps and mainline, mounting luminaires on overhead structures or retaining walls, and providing highmast lighting. Although highmast lighting reduces costs associated with accident or vandalism replacement and cleaning, maintenance problems can be experienced due to mechanical difficulties in the operation of luminaire-lowering devices. Specifications should require performance guarantees from the manufacturers against these mechanical problems.

Standardize lighting components to reduce procurement and stockpiling costs. Specify corrosion-resistant poles to eliminate painting requirements. Luminaires should be the cut-off type to reduce the glare, therefore directly contributing to accident reduction. Use long-life and high-output lamps to minimize relamping activities and to reduce the number of poles.

Delineators are reflective markers mounted on posts and located at the outside edges of shoulders. Maintenance requirements include cleaning, repair, and replacement due to damage by vehicles, snowplows, vandalism, and atmospheric conditions.

Do not use delineators in lighted areas as they are ineffective. Mount the reflective markers and median barriers or guardrail posts wherever possible. However, because of the height requirements, these may have to be considered supplemental to the post delineators. Consider moving the posts away from the edge of the shoulder to reduce the potential for damage by vehicles and snowplows. Investigate the possibility of combining delineators with snowpoles, where needed, to reduce initial and maintenance costs. Extend the shoulder paving or treat the area around the delineators with soil sterilant and prime to reduce vegetation control work. Consider the use of flexible posts to reduce repair and replacement costs.

Sound Walls. In response to the demand of the public living adjacent to highways, the use of sound walls has increased significantly in recent years. There is a great variety of materials used for the construction of sound walls. The maintenance requirements include repairs and replacement due to damage by vehicles, atmospheric action, and vandalism. In some areas, graffiti is the single most important problem. Snow and vegetation control operations and access to the areas behind the sound walls for maintenance work on fencing, landscaping, and drainage elements need to be considered in the design.

Locate sound walls beyond the vehicle recovery area wherever possible. Otherwise provide a separate barrier in front of the sound wall or combine a concrete barrier with the sound wall to protect motorists and to improve maintainability. If possible, place the sound wall at the right-of-way (R.O.W.) boundary so there is no area behind the sound wall that needs maintenance. In this case, an earth berm together with a low sound wall can be used instead of R.O.W. fence. If the wall cannot be placed on the R.O.W. line, provide access for maintenance through overlapping sections of the wall or by special easement. Vegetation control requirements can be minimized or eliminated by providing low-maintenance ground cover or surface treatments. Another possibility is to work out an agreement with the adjacent property owners for them to maintain the area behind the wall or to transfer ownership of the excess right of way to them.

Because painting is an expensive maintenance item, select sound wall materials and coatings that are more resistant to graffiti and easy to clean. Procurement and stockpiling costs can be minimized by standardizing components.

Fences are provided to keep people and animals out of the highway right of way. Maintenance requirements include repairs or replacement because of damage by vehicular accidents, deterioration, vandalism, livestock, erosion, rockslides, and heavy snow loads. Because of access requirements, fencing affects other maintenance activities such as vegetation control, inspection and cleaning of drainage channels and structures, snow and ice control, roadside maintenance, and material storage.

Select a galvanized chain-link fence in urban areas. In rural areas, attach farm fence fabric or barbed wire on the outside of posts to avoid damage by livestock leaning or rubbing against the fence. A 2-ft-wide paved area under the fence in urban areas can help to reduce the cost of expensive manual or herbicide vegetation control. In high-accident locations, provide a barrier or use less expensive fencing systems to reduce replacement costs. In wet or erosion-prone areas, design the fence to ensure its stability or revise its location. Across shallow drainage channels, use an open design with barbed wire or a hinged lower section to limit obstruction by debris. Consider the use of urban-type chain-link fence in sections close to urban areas to eliminate future replacement needs. Several alternatives to minimize damage due to the accumulation of snow include providing a separate snow fence behind the access fence, using open barbed-wire fence, locating the fence at the top of cut slope, or providing flatter slopes. Another option is the acquisition of a wider right of way. Access through the fence for other maintenance activities should be reviewed with maintenance personnel, and locked access gates should be provided wherever needed. Consider eliminating the fence in areas such as rugged land, dense vegetation, and along rivers where a natural barrier exists. Fences can be installed later if necessary.

Roadsides

Landscaping, erosion, sedimentation control, and maintenance of rest areas are included in this section. Landscaping combines the erosion control of highway rights of way with other functions such as glare control and also helps to beautify the facility. Erosion control should not be an afterthought but should be built into the design. A highway located and designed to fit the terrain with minimum disturbance to the existing features will reduce erosion-related maintenance costs. Rest areas are provided to improve highway safety by enabling the motorist to stop at periodic intervals on long trips.

Maintenance problems related to roadsides are control of vegetation growth by mowing or chemical application, debris and litter collection, adverse effects of deicing chemicals on turf and trees, erosion control, and vandalism.

Roadside Design Considerations

1. Conduct a site analysis to determine what parts of the roadside need regular plant management, occasional management, or very limited management to maintain the aesthetic and operational features. Select appropriate plant material for each area to attain a vegetation cover that would provide both adequate erosion control and a pleasant appearance at a low maintenance cost (*7*).

2. The turf adjacent to the pavement generally requires regular maintenance and is normally mowed several times a year to improve safety, sight distance, litter control, and drainage. In snow areas, this part of the roadside also gets salt-laden spray. Therefore, a turf mixture that will withstand salt spray, infrequent mowing, and traffic damage needs to be selected.

In areas beyond the normal mowing limits, select plant material that will reduce maintenance substantially but still provide an acceptable appearance. Mixtures of native herbs and wildflowers can be used for this purpose. Most native plants and wildflowers require no topsoil or fertilizer to establish and are acclimated to the area's weather conditions. Native grasses may take several years to establish. Annual wildflowers provide adequate appearance and erosion control during the first few seasons while the native grasses are being established. Use native grasses only in areas not visible to the public. They provide weed-free and nearly maintenance-free ground cover, and excellent erosion control. Mowing and chemical applications are reduced or eliminated. Both construction and maintenance costs are minimized. As part of overall landscaping strategy, consider enhancement of the existing native plants through periodic prescribed burns, which help to stop brush encroachment and decrease the abundance of cool-season, non-native grasses (*8*). Burns should be performed when cool-season grasses are actively growing and native warm-season grasses are still dormant.

2. Select the most appropriate technique for slope erosion control consistent with soils, hydraulics, and maintenance requirements. Possible alternative methods include:
   (a) Construct serrated or stepped slopes to reduce the velocity of runoff, to help accumulate loose material on the steps, and to enhance vegetation growth.
   (b) Construct slope drains with pipes, half-pipes, or paved and sodded flumes. Conflict with mowing, undermining, erosion at outlets, and clogging at inlets are some of the maintenance problems.
   (c) Construct a berm at the top of cut slope to divert water from the slope face. Access is needed for maintenance. The berm should be placed far enough from the slope to avoid sloughing. Avoid the use of ditches in place of berms, because paved ditches are subject to undermining and unpaved ditches may result in serious erosion and sloughing.
   (d) Note that paving and sodding are expensive techniques. Sodding needs to be compatible with the existing soils, and it is subject to washout if not installed properly. Paving is subject to undermining and may require weed control.
   (e) Provide access and working space for maintenance equipment if a siltation pond is needed to control sedimentation.

3. Consider the following elements in selection and design of rest areas:
   (a) Study soil, hydrology, and topography of each alternative site to minimize maintenance costs for slopes, landscaping, drainage, and vegetation control. Consider snowplowing and sweeping operations in preparation of the rest area layout.
   (b) Standardize hardware to reduce repair parts inventory costs. Consider the storage needs of maintenance personnel in the design of buildings. Locate litter receptacles close to picnic tables and parking areas.
   (c) Minimize opportunity for vandalism by designing and specifying elements that are more resistant to breakage and damage, such as wire-reinforced windows, bigger bolts for connections, and mar-resistant materials. Locate these facilities in the most public parts of the rest area to discourage vandals.

BRIDGE DESIGN FEATURES INCORPORATING MAINTENANCE CONSIDERATIONS

The bridge elements reviewed in this section take into consideration the following features: accessibility for inspection, maintenance, and repairs; corrosion protection; material selection; ease of rehabilitation, and maintenance of traffic during retrofitting. Bridge components such as railings, decks, joints, bearings, foundations, and drainage systems are particularly vulnerable to deterioration caused by direct impact loads, corrosive action, working loads and forces, and atmospheric and hydraulic actions.

The specific bridge elements reviewed in this section are: (1) Decks, (2) Deck joints, (3) Deck drainage, (4) Railings, (5) Bearings, (6) Concrete and Steel Girders, (7) Substructures, and (8) Approaches.

Decks

Bridge deck deterioration is one of the most costly highway maintenance problems. Experience indicates that many bridge decks require repair or replacement during the useful life of the bridge. Concrete deck problems are primarily due to penetration of chlorides, which results in corrosion of reinforcing steel and subsequent spalling of the concrete.

Deck Design Considerations

1. Specify epoxy-coated bars in decks subject to salt application to prevent corrosion cells from forming between the top and bottom mats. All reinforcing steel in the deck should be coated.

2. Emphasize the importance of concrete quality control and placement of reinforcing steel on plans and in the specifications. The water-cement ratio should be no greater than 0.4 and air entrainment should be specified. Consider the use of Type "K" cement to reduce deck cracking (*9,10*). Desirably, the clear cover to the top mat of steel should be 2½ in. (63 mm), but never less than 2 in. (50 mm).

3. Specify high-density (not less than 98 percent), low-slump concrete or latex-modified concrete (LMC) with low permeability for overlays.

4. In particularly vulnerable structures, such as segmental bridges, install post-tensioned prestressing in inert duct material. Also, consider the use of epoxy-coated prestressing strands (*11*).

5. Consider the use of cathodic protection (*12*). The bridge engineer should work closely with a corrosion control engineer when considering the use of a cathodic protection system. Cathodic protection consists of applying to steel a direct current of such polarity and intensity as to raise the electrical potential of the cathodic areas to the potential of the anodes. When this is successfully done, corrosion currents can no longer flow and corrosion can not proceed. The required currents are normally quite small and the applied voltages are seldom higher than 1 or 2 volts. A cathodic system needs to be maintained properly to prevent galvanic action. Periodic monitoring of the applied voltage is required to ensure adequate protection without the danger of overprotection. The anodes, being sacrificial, must be replaced periodically.

6. Consider the use of zinc metalizing on steel-reinforced concrete located in marine environments to provide galvanic cathodic protection. Research conducted by the Florida DOT indicates that using sprayed molten zinc as a concrete surface anode for sacrificial cathodic protection of imbedded reinforcing steel offers a possible low-cost alternative to conventional rehabilitation and cathodic protection. The arc-sprayed zinc shows excellent bonding to concrete and steel. The use of this technique was pioneered by Caltrans.

7. Consider the use of high molecular weight methacrylate resin to seal deck cracks. Caltrans and the Florida DOT report satisfactory results from the use of this resin, which is applied to cleaned and dry concrete deck and then covered by sand after at least 20 min. Any excess sand is removed from the deck surface by vacuuming or sweeping before opening it to traffic. A public safety program associated with the use of methacrylate resin must be prepared by a certified industrial hygienist before the application, and emissions must be monitored during construction.

8. Design the deck and supporting system so that any future repair work can be accomplished while maintaining traffic. The number and spacing of girders, stringers, or beams should be designed to provide the required traffic lanes and work areas.

9. On occasion, bridges require widening to accommodate higher traffic volumes or to provide safer structures. The longitudinal expansion joints between the widened portion and the existing bridge are a great source of bridge maintenance problems. Widenings should be attached to the existing structure without joints (*13*). Bridge widening is most effective when the new deck is attached by lapping deck reinforcement rather than using dowels. Steel and precast concrete girder bridges can be widened more easily under traffic than other types of structures. Initially, the widening must be built above the grade of the existing structure to allow for dead-load deflection, and the deflected widening must meet the grade of the existing structure. If proper provisions are not made to accommodate the dead-load deflection, construction and maintenance problems will ensue.

Deck Joints

Bridge expansion joints must accommodate all superstructure movements and carry high impact loads; they should also provide a watertight seal. Maintenance impacts of deck joint failure include the deterioration of the superstructure elements as a result of water and deicing chemicals leaking through the joints. A nonfunctioning or jammed joint, and the resulting pressure, cause undesired movement of abutments, or piers, and cracking and spalling of the deck, concrete beams, and abutment or pier caps.

Deck Joint Design Considerations

1. Design the joint assembly to carry wheel loads with no appreciable deflection and provide steel armoring for the ends of the concrete deck sections. One of the more common defects in expansion joints is the failure of the anchorage system. The anchors should be located no higher than 3 in. (75 mm) below the top of the deck surface and should be incorporated in the main reinforcement of the structure. The durability of drilled expansion bolts under vibration or impact conditions is low. Furthermore, drilled holes allow the entrance of water and deicing chemicals, which causes the corrosion of bolts.

2. Reduce the number of expansion joints to an acceptable minimum. Elimination of joints may be accomplished by designing for continuity and taking advantage of the flexibility of the structural system. Precast, prestressed girder bridges should be designed continuous for live load to reduce joints. Prestressed girders should be made continuous for the maximum practical length. The prestressed girders should be designed as simple span girders without regard to live-load continuity. The girders are made continuous by anchorage of reinforcing steel into a continuity diaphragm which is poured in-place with the deck slab. Additional reinforcing steel is positioned in the cast-in-place deck slab to resist the continuous live-load moments developed as a result of the continuity. Consider elimination of joints during bridge redecking (*14*).

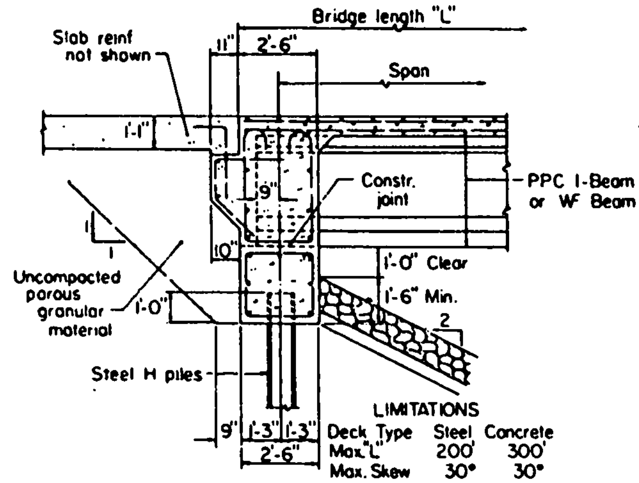

Figure 13. Integral abutment.

3. Design the abutment integrally with the end of the superstructure (Figure 13). In this concept, the abutment and piles are designed to move together in reaction to expansion and contraction of the superstructure. This technique eliminates the need for expansion joints and bearings at the abutment (*15*). For proper functioning of an integral abutment structure, the approach system must provide for temperature movements of the bridge and must have adequate provisions for drainage.

4. Use oversize expansion joints to allow for fabrication and installation tolerances and unanticipated movement. A design for 25-percent additional movement is recommended. These joints compensate for movements that are caused by factors such as loss of prestress, creep, and shrinkage, which are difficult to calculate accurately. Details and dimensions covering the possible temperature range during construction should be furnished so they are installed correctly.

5. Avoid the use of open joints. They allow debris to pass through the joint and accumulate on beams, pier caps, and bearings. The debris retains moisture and deicing chemicals that cause deterioration of these elements. The open joints are also easily clogged with incompressible material, which negates the purpose of the joints; that is, to allow for expansion and contraction. Clogged joints transfer the expansion, thus causing movement of abutments and spalling of concrete decks, beams, and abutments or pier caps. When open joints are used, deflector plates should be installed to protect the bearings. Also, the ends of girders and pier caps should be protected from corrosion. Epoxy coatings may be used for this purpose. However, they do not last long and must be renewed by routine maintenance.

6. Use a performance specification. This specification could result in a more effective albeit more expensive joint. However, a life-cycle cost study could indicate its feasibility.

7. Strive to achieve waterproof expansion joints. Commercially available reinforced elastomeric joint assemblies have eliminated the problem of debris passing through the joint. However, these joint assemblies usually do not maintain a waterproof seal if proper compression is not maintained. New details, materials, and installation techniques are continuously being developed by the suppliers to overcome this deficiency. They need proper testing and inspection.

Some feel that obtaining a watertight bridge joint is an elusive goal and details must be developed to control the water that passes through the joint. One such detail has a deflector plate on one side and a collector plate on the other side, under the strip seal or elastomeric joint material, for diverting and collecting the moisture that leaks through the seals (*16*). More research and testing are required to verify the validity of this approach.

8. Another proprietary system used by the Connecticut DOT with good results is a patented asphaltic plug-type joint which accommodates movements up to 2 in. (50 mm). This joint is flexible and watertight. It is a combination of rubberized bitumen and selected single-size aggregate. The joint system is about 20 in. (500 mm) wide, with a steel plate over the joint. It is constructed on-site in a hot process. More use is needed to confirm its success.

Deck Drainage

Maintenance impacts associated with deck drainage can be summarized as follows: obstruction of deck drains with debris, which can burst downspouts when trapped water freezes; damage to drain inlets by snow removal equipment; corrosion of the drainage system elements due to retention of deicing chemicals; deterioration of the superstructure and substructure elements when water is not directed away from these elements; retention of water and deicing salts due to inadequate deck drainage, which accelerates deterioration of the deck; and erosion of bridge end slopes and undermining of slope paving, which occurs when the drainage outlets are not properly directed.

Deck Drainage Design Considerations

1. Design the minimum number of drains with adequate grades and cross slopes. Generally, catch basins should be provided at both ends of bridges located in urban areas where the approach pavements are curbed. These catch basins should be attached to the abutment wingwalls or approach slabs to prevent the joint from opening.

2. Avoid placing bridges on sag vertical curves, especially when concrete barriers are used. When the drain becomes clogged, the barrier causes water to accumulate on the deck. If this cannot be avoided, drainage outlets through the barrier should be provided to prevent ponding.

3. Locate inlet grates in front of curbs or barriers in such a way that they can be cleaned as a part of routine snowplowing and sweeping operations. Provide a flat inlet grate to avoid damage to the inlet and plow. Design inlet grates in such a way that they can be lifted by one person and bolted in place to prevent being dislodged by traffic. Avoid the use of aluminum inlets. They may cause accelerated corrosion due to electrolytic-cell action if they inadvertently touch the steel reinforcing or structural members. Use inert materials for drainage systems where possible, and standardize components to reduce inventory requirements and to facilitate replacement.

4. Provide oversized pipes and fittings, inlet openings, and catch basins to eliminate clogging even though not required for capacity purposes. It is recommended that an 8-in. (200-mm) diameter downspout pipe be used to minimize clogging. Consider the use of plastic pipe to reduce the corrosion problem.

5. Provide accessible cleanouts. Incorporate inspection catwalks or maintenance platforms that can be reached by ladders if access can not be achieved from below with lifting equipment. In severe clogging conditions, provide mechanical joints so the downspout system can be disassembled if necessary. Do not design downspouts embedded in concrete piers. If water is trapped in a clogged system, freezing can damage the pier.

Extend downspouts at least 2 in. (50 mm) to clear all superstructure members, and install deflector and splash plates to prevent water from contacting other portions of the structure as it is discharged. The design should prevent wind from blowing discharged water back onto structure elements. Provide splash blocks or rip-rap at the outlet to prevent erosion. Also, design outlets at an angle to terminate at a height sufficient to avoid a buildup of debris.

Railings

Bridge railings must be designed for quick repair and for the ability to remain intact following collision. Other maintenance aspects require that they should be relatively easy to clean, paint, or carry out repair work as needed due to corrosion or deterioration, and they should allow for easy snow, ice, and debris control operations.

Railing Design Considerations

1. Design concrete barrier rail, which will generally remain intact after a collision and require minimum maintenance.

2. Eliminate the use of metal railing on top of concrete barriers for purely aesthetic purposes.

3. Use epoxy-coated reinforcing, increased cover over reinforcing, and a sealant application for barrier subject to saltwater environment or contact with deicing chemicals.

4. Provide openings in concrete barriers, where site conditions permit, so snow, debris, or drainage can be discharged under or through the railings. However, this application should be avoided where it would result in debris, snow, or drainage runoff being thrown onto piers, abutments, superstructure elements, or other roadways.

Bearings

Bearings are provided to support the superstructure and to carry loads and forces into the substructure. Expansion bearings must allow both translation and rotation. Maintenance impacts result from the failures that occur when bearings seize or are restrained from providing the required movements. Dirt, salt, and water are principal factors in bearing failures.

Bearing Design Considerations

1. Eliminate or reduce the number of bearings by designing a continuous superstructure with integral interior piers. This obviously helps to reduce maintenance and future rehabilitation requirements. However, the continuous superstructure unfortunately causes an increase in the magnitude of movements at the expansion bearings. Designers should conduct trade-off studies on the span arrangements to select the option that will have the fewest future maintenance problems.

2. Design abutments to allow for possible future jacking operations necessary for replacing bearings or for other purposes, such as to compensate for possible settlement. The location for jacking and the size of loads should be determined and the details should be included in the plans. Anticipating future problems such as required clearances for removal of components, and stiffener and reinforcement requirements, can facilitate rehabilitation efforts. A minimum of 6 in. (150 mm) between support and structure soffit is required for jacking, inspection, and cleaning.

3. Provide elastomeric bearing pads for movements of up to 3 in. (75 mm). Elastomeric pads, in combination with tetrafluoroethylene (TFE) and stainless steel, can accommodate larger movements. They do not seize or corrode, and they require a minimal amount of maintenance. Defective material has been the main cause of failure of these bearings. Proper specifications and testing are required to avoid this problem. AASHTO design specifications should be considered minimum requirements.

4. Protect all bearings from dirt, deicing salt, and water by proper design details. For example, pier caps should be sloped away from bearings to eliminate possible water accumulation, and details should be provided to prevent birds from nesting in bearing areas.

5. Provide setting details so the bearings can be aligned properly. It should be specified that as-built locations and positions of bearings be permanently recorded.

6. Design the locations of plate edges and anchor bolts with adequate cover to avoid spalling of concrete.

7. Prepare a formal maintenance directive for routine maintenance work such as lubrication.

Concrete Girders

Concrete girder bridges, if properly constructed, seldom cause maintenance problems. However, it is advisable to pay attention to design details to avoid any problems.

Concrete Girder Design Considerations

1. Size and locate steel reinforcement to allow proper placement of the concrete. It is important to remember that the fabrication tolerances, especially on large-diameter bars, may preclude extremely close tolerances on bar locations. Some leeway on bar placement should be allowed while still providing adequate cover.

2. Pay special attention to areas of high stress concentrations. For example, in box girder bridges, fillets are required at the intersection of webs with the top flange because of stress concentrations. Thickness changes should be accomplished by an adequate transition.

3. Concrete may burst or spall due to out-of-plane pressures, curvature, and inclinations. Excessive cracking may occur in anchorage areas because of eccentricity of the prestressing steel. Provide additional reinforcement and use spiral reinforcement to counteract these pressures.

4. Provide access holes for inspection and repair of concrete box girder bridges. Consider the need for lighting and ventilation. Consider the provision of ducts through diaphragms and the installation of anchorages for future tendons in order to be able to rehabilitate box girder bridges.

5. Consider the use of arch tunnels or reinforced concrete box culverts where possible in lieu of a bridge to eliminate maintenance problems.

Steel Girders

In the design of steel bridges, steel toughness, fatigue strength, and weldability are important factors. For example, repeated live loads combined with stress concentrations can lead to fatigue failure. Steel with low toughness characteristics is subject to brittle fracture, especially at low temperatures. By far the most important maintenance impact is corrosion protection of the steel structure.

Steel Girder Design Considerations

1. Pay special attention to the design details. Many cracks initiate at or near connections, at points of stress concentrations, and as a result of secondary stresses. Redundancy should be introduced to reduce or eliminate fracture of critical members. Bolted splices should be used for field connections and for connecting diaphragms or wind bracing.

2. Define the areas that are fatigue-stress critical. Many cracks result from welding flaws, discontinuities, and weld repairs. Shop drawings for all weldments and attachments should be carefully reviewed.

3. Show on the plans or include in the bridge maintenance manual the location and the category of critical steel design details and other critical inspection items for the information of the bridge maintenance engineers. This process, if done during the design, will also help the designer to determine the required inspection facilities and possibly to avoid some maintenance-critical designs.

4. Determine criteria for painting and other corrosion prevention systems considering the local environment and site conditions. The wind, spray, condensation, use of deicing chemicals, and proximity of industrial facilities are some of the factors affecting site conditions.

5. Consider maintenance painting costs in the comparison of structural systems. Life-cycle cost analyses should be conducted to make decisions not only between concrete and steel, but also between alternative steel configurations. For example, painting costs for a steel box girder are much less than those for a truss or girder-and-beam system.

6. Provide details to avoid the entrance of moisture between adjacent plates or shapes. Drainage for all components should be provided, and crevices that can make the painting difficult or impossible should be avoided. Sharp edges on steel components can result in inadequate paint cover. Using rolled members

whenever possible or grinding off sharp edges can help to solve this problem.

7. Provide access for inspection, cleaning, and painting. Catwalks, rail systems, portable scaffolding, movable platforms, elevators, and connection devices for temporary cables and lines may be required. Work space and ventilation requirements should be considered for painting interior cells. Light color paints improve the visibility in these areas. Consider a 12-ft-wide shoulder on the bridge to accommodate the new snoopers, which can reach 65 ft under spans.

8. Select weathering steel for use only in proper environments to reduce maintenance costs. The following conditions may prevent formation of the desired oxide coating that protects the steel: marine environment subject to saltwater spray or fog, areas that do not dry easily, industrial areas with corrosive fumes, and areas that are subject to splash of deicing chemicals.

Wherever weathering steel is used, the following techniques should be considered to minimize staining the facilities below the bridge: (a) add drip plates to the bottom flanges of girders; (b) install cantilevered drip pans below bearing areas, and (c) apply surface sealants to substructure units.

9. Another promising corrosion protection system under development by the Connecticut DOT uses the metalizing technique. An alloy consisting of 85 percent zinc and 15 percent aluminum is sprayed onto the structural steel after the surface is cleaned to a white metal with no rust or paint. The alloy is sealed with a polyamide epoxy and then coated with aliphatic urethane, which can incorporate any color desired. It is reported that a railroad bridge in Philadelphia was partially coated with this technique in 1938 and is still in good shape. More study and life-cycle cost analyses are required (*17*).

10. Design cable-stayed bridges such that future replacement of cables can be accomplished easily (*18*).

Substructure

Maintenance problems associated with substructure elements include vertical and lateral movements, scour, debris buildup, corrosion-induced delamination, concrete scaling and spalling, and erosion control on slopes in front of bridge abutments.

Substructure Design Considerations

1. Establish highway alignment and determine structure configuration to minimize scour conditions and any buildup of debris. Footing elevations and size and pier shapes should be designed such that scour depth estimated for the selected design flood does not cause any undermining of the footing. Use solid-type piers or base pedestals at least 2 ft (600 mm) above the high-water mark, as multiple-leg piers can trap debris more easily.

2. Use pile foundations in expansive and compressible soils. Due to very deep compressible soil condition, sometimes excessive long-term settlements cannot be avoided. In these cases, a viable jacking system should be included in the design. Negative skin friction forces should be considered in compressible soils.

3. Do not use unprotected weathering steel in immersed and splash zones. It will not perform better than regular steel. Cathodic protection will protect immersed steel better than coatings.

4. Specify low water-cement ratio for underwater concrete. It should also be specified that concrete should not be placed in running water or be allowed to fall through water. The operation should be continuous, and no steel should be left protruding from the finished concrete. Epoxy-coated strands should be used in prestressed precast piles in salt environment.

5. Design abutment and pier cap seats such that they provide adequate drainage and are self-cleaning. Incorporate screens in abutment and pier caps where birds are likely to nest. Backfill behind the abutments should be of free-draining material, and permeable material should be placed directly behind abutments with frequent weepholes. Avoid the use of cantilevered wingwalls because of the difficulty in compacting backfill material.

6. Specify a minimum of 3 in. (75 mm) of cover over reinforcing steel and epoxy-coated rebars, and cover the top and sides of pier caps with sealer to minimize concrete spalling.

7. Provide deck drains at the ends of the bridge and inlets in the approach area as needed to control surface runoff. Also, provide curbs, flumes, and catch basins as needed. Provide cutoff walls, toewalls, sheet piling, or concrete braces against pier columns to prevent shifting of slope paving under bridges.

8. Consider closing the areas under viaducts in urban areas to eliminate unauthorized use and collection of waste material.

Approaches

In addition to being a constant problem for maintenance engineers, the bridge approaches may create an unpleasant and unsafe bump for the traveling public because of differential settlement. Backfill material, drainage, and construction methods are the critical items in building approaches that reduce maintenance requirements.

Approach Design Considerations

1. Design continuous approach slabs from wingwall to wingwall to eliminate differential settlements within approach slabs.

2. Consider widening approach shoulders to allow more space for temporary storage of snow.

3. Provide proper drainage for approach slabs to avoid erosion and undermining. Provide subgrade drainage, and consider special drainage troughs under the expansion joint between the approach slab and pavement.

4. Specify select granular material in approach fills and consider a compacted surcharge to reduce future settlement.

5. Consider approach slabs supported by timber or composite piles of varying lengths to accommodate differential settlement between approach roadways and bridge abutments.

Additional suggestions for improved design features to resolve maintenance problems may be found in references 23–25.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations of the research are organized under three main headings — Findings, Process, and Design Features — in consort with the objectives of the study.

FINDINGS

The majority of the agencies responding to the questionnaires reported significant maintenance problems resulting from insufficient consideration of maintenance in the design process. Yet, almost all agencies claim that maintenance is considered in the design of highway facilities. Only a few agencies have formal processes, however. It is obvious that a more formal, procedural approach is needed to overcome the problems.

As the highway network ages and budgets continue to tighten, effective designs that reduce maintenance efforts will become increasingly important. Even now, in some urban areas, it is not possible to close a lane for maintenance at any hour of the day without severely affecting traffic. Designers must consider, during the design process, how each facility can be maintained. Because very few designers have maintenance experience or training, the design procedure must include methods for maintenance input into designs.

All agencies should consider the impact that designs will have on maintenance. Lighting and signal projects increase utility bills—forever. Surface maintenance and snow removal will increase when roadways are widened. And rest areas must be serviced and the utilities paid.

"Maintainability" of highway facilities should have one of the highest priorities among the concerns of the designer. The goal is not only to reduce the costs of maintenance or construction, but more specifically to obtain the maximum benefit from the highway expenditures over the expected life of the project at the minimum total cost. An important part of maintainability is the impact on the highway user. The designer must also address the question of accommodating traffic during maintenance operations.

PROCESS

A brief description of the process for considering maintenance impacts in design is presented in this section. It is followed by recommendations for implementing the process.

The process that was developed through this research provides for involvement of maintenance personnel at all key checkpoints in the design process, from scoping through review of all design plans. Early involvement by maintenance personnel in project designs can prevent major changes when designs are nearly complete. The procedure provides for maintenance involvement whether designs are prepared in the central office, the districts, or by consultants. Project-specific problems and general problems that apply to all designs must be identified and resolved. Because highway and transportation organizations are each organized uniquely, the process was designed to be adaptable. Adapting the recommended process and making it work will require attention to the considerations that follow.

Commitment

Top management's commitment to the incorporation of maintenance considerations in the design process must be apparent to both designers and maintenance personnel. If the process is to be achieved, it must have the solid support of the agency's leaders.

To encourage maintenance supervisors to contribute to the process, it is recommended that attendance and participation at scoping and design reviews be included in their job descriptions and be considered in their performance evaluations.

Designers should also be evaluated on their performance in incorporating maintenance considerations in design.

Communications

Communication between designers and maintenance personnel needs substantial improvement. Informal contacts, although successful in some instances, should not be considered sufficient. Such informal communications depend primarily on personalities and are rarely documented for the benefit of others. It is recommended that all agencies develop formal procedures following the guidelines described in this report and require all personnel to adhere to these procedures. Strong commitment to good communications by top management is a prerequisite for success.

As one means of communication, the maintenance division should develop a "checklist" of the most common maintenance concerns for consideration by designers. This list should be updated regularly to include new problems that develop. A sample checklist is presented in Chapter Three. The checklist will enable the designers to consider maintenance issues as they begin their designs. Early knowledge of the problems will result in problem resolution during the design process instead of at the end. Doing things right the first time contributes directly to productivity improvement.

Training

Few designers have maintenance experience. Representatives from maintenance should attend the annual agency designers' conference to discuss maintenance problems related to designs. Similarly, design representatives should attend annual maintenance conferences to learn of problems first hand.

The maintenance division should produce a training program for designers showing design-related maintenance problems. Suitable visual aids — photographs, slides, videotapes, drawings, etc. — should be developed for use in conducting the training. These training sessions can lead to better understanding of the problems and formulation of designs to overcome them. As part of the training program, trips should be organized for designers to observe construction and maintenance problems in the field.

Many maintenance supervisors, especially station foremen and area supervisors, may not be able to read and interpret the project plans. In some cases, lack of plan comprehension precludes any meaningful input from these experienced maintenance personnel in the design stage. Agencies that have this problem should prepare and conduct training sessions in plan reading for these employees so they can understand how designs directly affect their operations.

Value Engineering

Very often value engineering (VE) studies neglect user costs in the analyses resulting in erroneous conclusions. It is important to remember that the users pay for the highway facilities through taxes. Therefore, the costs to the user for delays encountered for maintenance and construction need to be included in the comparative studies to properly evaluate the alternatives and to minimize the total cost to the users (*20,21*).

VE studies should be assigned to trained VE teams made up of experienced personnel with representatives from appropriate specialties, including maintenance. Maintenance management systems should be reviewed periodically to ensure that the data requirements for the value engineering process are met. Meaningful life-cycle cost analyses require accurate data on maintenance costs as well as for other costs. Close coordination with research and development is also required.

Implementation

The process for considering maintenance requirements in design should be incorporated into the agency's normal design procedures rather than operated as a separate process. In this way, consideration of maintenance by designers will become the normal procedure.

DESIGN FEATURES

Examples of design features that successfully reduce maintenance problems are described in Chapter Four. These can be grouped into two basic categories: (1) standard details and specifications and (2) site-specific features.

Standard Details and Specifications

Standards, specifications, and special provisions should be regularly reviewed by special committees. Maintenance should be represented on all of these committees. Proper value engineering techniques should be applied in the evaluation of alternative standards and specifications. Those selected to make the evaluations must be trained in value engineering principles and procedures.

Cost is not always a factor in evaluating design alternatives. In many cases, a change in design can alleviate a maintenance problem with little or no change in the construction cost.

Maintenance problems of a general nature should be considered in establishing priorities for research and development programs. Materials, elements, methods of construction, and maintenance should be included in the list of candidate items for research.

Site-Specific Features

Features such as location of access gates or snow fences require very close interaction with the maintenance personnel familiar with the site. Identification of these requirements early in the design process can expedite the project and permit designers to incorporate them into the design without last-minute changes, which cost time and money.

Operation and maintenance procedure manuals should be prepared for all unusual facilities, i.e., those where normal routine maintenance is not sufficient. Several examples of unusual maintenance operations include servicing movable bridges, bridge bearings, tunnel ventilation facilities, and rest area heating and air conditioning units. Designers should consider, during the design process, how such facilities will be repaired and maintained, and develop appropriate designs.

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APPENDIX A

Questionnaire Summaries

Three questionnaires were prepared -- one each for maintenance, road design and bridge design. The responses from those questionnaires are summarized in this appendix.

Maintenance

1. Do you have a formal process for evaluating maintenance problems related to designs and communicating needed changes to designers?

Of the forty-nine agencies responding to this question, eighteen reported having a formal process.

If yes, describe the evaluation technique used and the communication process:

- ***Arkansas.*** The project review team (construction and maintenance) evaluates completed projects and conveys the evaluations to design.
- ***California.*** Each district has a plan and specifications review process prior to advertising. Formal joint meetings are held at various stages on large or complex projects.
- ***Connecticut.*** The district maintenance planner reviews all plans for maintenance problems.
- ***Florida.*** Maintenance participates in the 60% and 90% design reviews and the final construction reviews.
- ***Illinois.*** Maintenance is represented on the specification committee.
- ***Kansas.*** Design, construction, and maintenance review 2 completed projects each year for new ideas and the results are considered by design.
- ***Maine.*** Maintenance deals directly with the highway and bridge design engineer and the assistant via the division engineer.
- ***Maryland.*** The maintenance staff has input at the preliminary and final design review stages. In addition, a quality project review process is used to evaluate specific projects. The goals of the process are to reduce design time and effort, reduce the need for extra work, improve the quality of construction, reduce maintenance costs and improve safety and operational characteristics.
- ***New Jersey.*** Reviews during plan development and at meetings and discussions.
- ***New York.*** Project initiation packages for projects are sent to maintenance groups in the regions. Maintenance reviews and comments on the advance detail plans.

- ***Oklahoma.*** A yearly design review is held (local and regional) with FHWA, roadway and bridge design, traffic engineering and maintenance personnel where they tour and review the previous years' projects throughout the state.
- ***Oregon.*** Consultations with the district manager during scoping and preliminary engineering (PE), post-construction reviews, the location project manager contacts the maintenance section foreman, and project-specific and functional problems are fed to roadway design.
- ***Pennsylvania.*** Experienced maintenance personnel participate in project reviews in the field.
- ***Rhode Island.*** Plans are reviewed by maintenance, comments are transmitted by memo to design.
- ***Texas.*** Local maintenance personnel report directly to the resident engineer who is responsible for design, construction, and maintenance of roadway facilities in his resident area. The district maintenance engineer continually reviews maintenance practices and communicates with the resident engineers.
- ***Virginia.*** While there is no formal process, the field inspection teams have members who have maintenance responsibility and can communicate problems relating to design.
- ***Ontario.*** Designs are reviewed by local maintenance staff. Typically, a maintenance supervisor attends local meeting and communicates concerns to the designer. The district maintenance staff also attend technical review meetings.
- ***Saskatchewan.*** The maintenance field staff reviews each geometric design to provide comments and explain maintenance problems. Typical maintenance problems are discussed at inter-district meetings and transmitted directly or through the maintenance branch to the design and traffic safety branch.
- ***Hennepin County, MN.*** The operations division (maintenance operations) formally comments on traffic signal and roadway design plans which design considers prior to final plans going out for bids. A committee to evaluate roadway problems should be created to review successes and failures.
- ***Maricopa County, AZ.*** The process is informal.

2. Is maintainability considered in the design of highway facilities?

Thirty-six of the 49 responding agencies reported that maintainability is considered; seven were uncertain if it is considered.

If yes, is the process formal or informal?

Nine agencies reported having formal processes -- seven states and two provinces. They are California, Connecticut, Florida, Kansas, Maryland, Pennsylvania, Texas, Alberta and Saskatchewan.

Are maintenance personnel involved in the process?

Maintenance personnel are involved in 36 agencies.

If yes, describe their role and the level of maintenance personnel involved:

- ***Arkansas.*** District maintenance through the district engineer.
- ***California.*** Explain maintenance to design in meetings.
- ***Colorado.*** Field maintenance meets with design engineers on field investigations.

- ***Connecticut.*** The district maintenance planner reviews all plans and comments through the office of maintenance.
- ***Florida.*** Maintenance engineers participate in design and construction field reviews.
- ***Idaho.*** The district maintenance engineer or local foreman review plans for maintenance problems informally.
- ***Illinois.*** The district maintenance engineer signs off on all roadway plans, often in the 11th hour.
- ***Kansas.*** The construction and maintenance functions are combined at headquarters and review construction plans for maintenance problems; at the field level, the area engineer is involved in the design field check.
- ***Kentucky.*** District and central office maintenance personnel routinely provide feedback and frequently attend plans-in-hand inspections.
- ***Maine.*** The division engineer or design engineer accompanies the design team on field and final inspections.
- ***Maryland.*** Formal: The assistant district maintenance engineer and resident maintenance engineer may address maintenance concerns during preliminary and final review stages. General: maintenance concerns on design policies and practices are presented to the chief engineer through the deputy chief engineer -- maintenance.
- ***Michigan.*** The district maintenance engineer (operations engineer) is invited to review plans at the time of the grade inspection.
- ***Minnesota.*** Routinely project by project at district level.
- ***Missouri.*** Maintenance personnel act in an advisory capacity at design field checks.
- ***Montana.*** Field maintenance chiefs are asked to participate in project design reviews. Plans are sent to maintenance personnel for review prior to finalizing.
- ***New Hampshire.*** The district or assistant district engineer attends municipal officials meeting at approximately 25% stage of design. Until recently maintenance involvement thereafter has been too late.
- ***New Jersey.*** Phase review and meetings with field maintenance engineers and supervisors.
- ***New Mexico.*** Patrol foremen review preliminary plans for changes to resolve potential maintenance problems and take part in final inspections.
- ***New York.*** The resident engineer reviews plans.
- ***North Carolina.*** The division maintenance engineers have opportunities to review construction plans, participate in field inspections and provide comments to design personnel.
- ***North Dakota.*** The state maintenance engineer and his staff make suggestions at preliminary stages.
- ***Ohio.*** The central office of the bureau of maintenance has representatives on committees and task forces pertaining to construction, specifications, traffic control, and pavement management. The central office maintenance field engineers are on field review teams and are in weekly contact with district maintenance personnel.

- ***Oklahoma.*** The branch manager, assistant division engineer and division manager participate in design reviews and formal prioritization of projects and furnish life-cycle maintenance costs and roadside landscaping and beautification input.
- ***Oregon.*** Post-construction and design reviews, usually at the district manager level but may include maintenance or specialty (electrical, landscaping) crew supervisors.
- ***Pennsylvania.*** Formal reviews are conducted by the maintenance program engineer and/or assistant maintenance engineers. Problems are discussed with construction and design at joint meetings.
- ***Texas.*** Districts each have a plan, specification, and estimate review committee which includes a maintenance representative. Usually the district maintenance engineer is appointed to the committee.
- ***Vermont.*** The district transportation administrators review design plans and provide comments.
- ***Virginia.*** The district engineer, the assistant district engineer for maintenance, the resident engineers and assistant resident engineers all have maintenance responsibilities and are involved in project development including project field inspections.
- ***Wyoming.*** The maintenance foremen provide information on maintainability to the district maintenance engineer, who relays it to the district engineer and the district construction engineer at staff meetings. Information is also received at the state maintenance engineer's meetings, and resident engineers also receive input.
- ***Alberta.*** Most roadway designs are now done at the district level where the maintenance of these roads is the responsibility of the district staff. It is intended that maintainability is considered during the design stage.
- ***British Columbia.*** Entails design specialists initiating contact with maintenance engineers for input on specific projects prior to design completion.
- ***Manitoba.*** The province is broken down into 13 engineering districts, each responsible for design, construction, and maintenance.
- ***Ontario.*** Maintenance staff members are involved in standards reviews and sit on various task forces and committees dealing with design issues.
- ***Saskatchewan.*** District maintenance engineers and area maintenance supervisors review designs and explain maintenance problems.
- ***Bureau of Indian Affairs.*** One of the 12 areas has a management level engineer involved in the review process.
- ***Hennepin County, MN.*** The road and bridge and traffic operations sections are given the opportunity to comment on design plans and also in preliminary design of roadways.

At what stage of design are they involved?

- ***Arkansas.*** At project initiation and the PIH inspection.
- ***California.*** Varies, depending on the project.
- ***Colorado.*** Early in the process.
- ***Connecticut.*** At the preliminary design plan stage.

- ***Florida.*** At the 60% and 90% completions of design.
- ***Idaho.*** Usually at the final design.
- ***Illinois.*** From programming to final design. It is up to the district maintenance engineer.
- ***Iowa.*** When a problem or failure occurs.
- ***Kansas.*** Headquarters: at the end of design; area engineer: at the field check.
- ***Kentucky.*** At all stages.
- ***Maine.*** At the planning, pre-design and final stages.
- ***Maryland.*** In the formal process, at the preliminary and final review stages. General problems may be at any time.
- ***Michigan.*** At the final review.
- ***Minnesota.*** Varies, depending on the maintenance impact on the project.
- ***Missouri.*** Throughout the preliminary and detail stages.
- ***Nevada.*** After the fact, construction complete, maintenance problems noted.
- ***New Hampshire.*** Maintenance personnel will now review designs at the 60% and 95% stages in addition to the 25% stage.
- ***New Jersey.*** When the plans are approximately 50% to 75% complete.
- ***New Mexico.*** At the plan-in-hand review.
- ***New York.*** At the initial scoping and advanced detail plan stage.
- ***North Carolina.*** Preliminary (right-of-way) plans and final (construction) plan preparation.
- ***North Dakota.*** Preliminary design.
- ***Ohio.*** Initial field review of preliminary engineering on major rehabilitation; prepare and process plans for minor rehabilitation.
- ***Oklahoma.*** Prior, during, and after review.
- ***Oregon.*** Location phase, preliminary design, and plan-in-hand.
- ***Pennsylvania.*** Preliminary and final design.
- ***Texas.*** All stages.
- ***Vermont.*** All stages.
- ***Virginia.*** All stages.
- ***Wyoming.*** Usually not involved directly in design, may be involved in design during the final plan inspections.
- ***Alberta.*** Presumably at beginning.
- ***British Columbia.*** Usually in the late stages of design and often not with consideration of fundamentally changing any aspect.
- ***Manitoba.*** Survey and design stage.

- ***Ontario.*** Pre-design and final design review, could be involved during design for specific issues.
- ***Saskatchewan.*** Beginning of design (i.e., historic runoffs) and at design reviews (i.e., group field inspections) prior to finalization.
- ***Bureau of Indian Affairs.*** After plans are substantially complete.
- ***Hennepin County, MN.*** At the preliminary design, plus a review of plans and specifications when municipal and state approvals are requested (when plans are nearly finalized).

3. Do you have any significant maintenance problems resulting from insufficient considerations during design, including problems with materials and construction specifications?

Thirty-five agencies reported having problems; fourteen do not.

4. If the answer to Question 3 is yes, list the design details that are causing the most maintenance problems.

Problems	No. of Responses
AC pavement failure	7
Shoulder -- inadequate design	7
Drainage erosion	6
AC pavement rutting	5
Bridge joints	5
Premature pavement failure	5
Snow storage	5
Base failures	4
Bridge drainage	4
Slope erosion/slides	4
Bridge end settlements	3
Bridge expansion devices	3
Guardrail material variation	3
Inadequate drainage design	3
Open-graded AC pavement -- ravelling	3
Pavement crack and joint failure	3
Snow drifting	3
Unramped median or island curbs	3
Bridge deck cracking	2
Bridge skew vs. snow plow angle	2
Concrete bridge slope protection failure	2
Crash cushion parts storage	2
Deterioration of bridge bearings	2
Landscaping	2
Raised pavement markers	2
Reflective cracking - AC overlays	2

Each of the following problems was cited by one agency:

AC pavement -- slick	Bridge beams collect debris
Bridges not equipped for maintenance safety	Bridges -- no provision for inspection and maint.
Bridge deck delamination	CMP corrosion
Cattle guard placement	Centerline tie steel placement
Closed drainage systems clog	Concrete girder end failure
Design unable to design spot improvement	Deteriorating drainage structures
Deterioration of bridge concrete	Deterioration of weathering steel
Full-depth PCC pavement patch failure	Geometrics confuse users
Guardrail mowing	Guardrail terminal rotation
Icing of bridges on curves	Location of traffic controllers
Materials problems	Median barrier impedes drainage
PCC pavement deteriorated under overlay	Placement of signs, guardrail, etc.
Roadway lighting maintenance	Rotation or shoving of pile bent abutment
Shoulder damage at rest areas/weigh stations	Sign support design
Slopes too steep to mow	Sound barrier -- litter/landscaping
Special landowner agreements	Special maintenance of designs
Traffic capacity problem	Utilities on structures
Washed out median inlets	Width of overlay

5. Which factors are included in evaluating alternative designs?

Factor	No. of Responses	Factor	No. of Responses
Construction costs	40	Environmental concerns	1
Operation & maintenance costs	31	Future construction costs	1
Traffic disruptions-maintenance	27	Life cycle costs	1
Design costs	21	Maintenance costs	1
User costs	21	Navigational requirements	1
Snow drifting	2	Right of way costs	1
Snow storage	2	Worker and public safety	1
Aesthetics	1		

Who makes the evaluation?

Evaluator	No. of Responses	Evaluator	No. of Responses
Design division	11	Construction	1
Designer	8	Design project manager	1
Chief engineer	2	Design, construction and maint.	1
Chief of design	2	Director	1
District engineer	2	District design engineer	1
District support staff	2	Management committee	1
District personnel	2	Operations staff	1
Engineering divisions	2	Resident engineer	1
Maintenance	2	Team	1
Planning division	2	Traffic engineer	1

Appropriate level	1	VE team when used	1
Construction/road design	1	VE unit	1

6. Is the life expectancy of materials and components considered?

Of the 41 agencies that responded to this question, 36 answered yes.

If yes, provide examples:

- ***Arizona.*** Pavement structures, drainage features.
- ***Arkansas.*** Surface types.
- ***California.*** Sign materials, galvanized steel, base materials, pavement types -- local conditions.
- ***Colorado.*** Sprinkler systems, pavements
- ***Connecticut.*** Pavements, noise barriers, barrier rails, catch basin tops and grates, traffic controllers and conduits. A 1-year test period is used for experimental materials.
- ***Florida.*** Sign materials, alternative culvert materials, paints, thermoplastics, joint sealants, raised pavement markers.
- ***Idaho.*** Surfacing type.
- ***Illinois.*** Pavement designs.
- ***Iowa.*** Improved course aggregate durability for PCC pavements, AC concrete mixes to stop rutting, and selection of materials to provide best benefit/cost ratio or minimal annual costs.
- ***Kansas.*** Expect materials to last life of project. If materials fail, recommend discontinue their use.
- ***Kentucky.*** Thickness of paint and galvanic materials, bituminous coating of metal pipes; various quality controls of all materials, thickness of pavements and bridge decks.
- ***Maryland.*** Painting of concrete Jersey barrier. Much of our Jersey barrier was painted for aesthetic and protective purposes. Discontinued painting when it was found that paint was not cost effective for prevention of chloride intrusion.
- ***Minnesota.*** Especially in pavement determination process, also with respect to appurtenances and traffic services (striping, signing, etc.).
- ***Missouri.*** On an interstate shoulder rehabilitation project it made no sense to completely rebuild shoulders as PCC pavement would need resurfacing within 10 years so a lesser design used instead.
- ***Montana.*** Have moratorium on use of open-graded-friction-course due to maintenance difficulties caused by rapid aging and premature ravelling.
- ***Nevada.*** Design review process.
- ***New Hampshire.*** The bureau of materials and research and the bureau of highway design aim at long life materials and components but available funding considered in final determinations.
- ***New Jersey.*** Aggregate selection, epoxy cements, epoxy coated rebar, and construction methodology.
- ***New York.*** Considered but not formal process such as life-cycle costs.

- ***North Carolina.*** Prestressed concrete versus steel girders for bridges, concrete pavement versus asphalt pavement.
- ***North Dakota.*** Mostly pavement sections and structures, especially drainage items.
- ***Ohio.*** Determined by the bureau of location and design.
- ***Oregon.*** Pavement type selection, culverts (material selection matrix), construction type for coastal bridges in salt air environment.
- ***Pennsylvania.*** Bituminous pavement versus concrete pavement, cold mix recycling versus use of virgin material, VE analysis.
- ***Rhode Island.*** Pavement designed for anticipated traffic load over extended time, now considering expected life of sign sheeting when specifying sign material.
- ***Texas.*** Life expectancy of all components is extremely important. Initial and final costs and travelling public's needs have to be considered.
- ***Virginia.*** Difference in life expectancy of bituminous versus portland cement concrete pavements.
- ***Wyoming.*** Concrete versus asphalt pavement, concrete joint materials, drainage systems.
- ***British Columbia.*** Formal life-cycle costing analysis not done routinely, however, durability is considered in choosing alternatives (e.g., sign and delineator materials).
- ***Manitoba.*** Concrete cross-culverts on major highway, concrete pavements on major highways located on high plastic soils.
- ***Saskatchewan.*** Subgrades and geometrics are generally expected to last 20 to 50 years, surfacing structures expected to last 5 to 20 years depending on traffic and classification.
- ***Bureau of Indian Affairs.*** Estimate pavement life 5 years, drainage 10 years.
- ***Hennepin County, MN.*** Reconstruction of roadway shoulders provides 20-year life. Overlays and seal coats add additional life expectancy. Try to stay with standard product in which "spares" are available.
- ***Maricopa County, AZ.*** Minimal paving installed by county forces for most initial surfaces. As required, designed and reconstructed by bidding.

7. Does your agency have a value engineering review process?

Of the 46 agencies that responded to this question, 29 (or 63%) have value engineering review processes,

If, yes, are maintenance personnel involved in the process?

Maintenance personnel are involved in the process in 24 agencies -- 83 percent of the agencies with VE review processes.

If yes, describe role:

- ***Arizona.*** Members of design evaluation task group.
- ***Arkansas.*** Staff maintenance engineers on review team.
- ***California.*** Team members or leaders.

- ***Colorado.*** If selected as team member.
- ***Florida.*** Team leaders or members.
- ***Hawaii.*** Field maintenance evaluates contractor VE proposals.
- ***Illinois.*** Team member. Routinely included if maintenance is an issue.
- ***Iowa.*** Team members.
- ***Kansas.*** Not formally used in design detail, used when presented by contractors. VE review team includes construction and maintenance personnel.
- ***Kentucky.*** Meetings and plan reviews with design, maintenance, traffic, and construction are held on major project
- ***Massachusetts.*** Maintenance has input but safety considerations override maintenance provisions.
- ***Michigan.*** Department has VE committee made up of members of several divisions including maintenance. Design chairs and dominates committee.
- ***Minnesota.*** Committees go through the VE process. Maintenance representatives are members.
- ***Missouri.*** Team members and advisors.
- ***Montana.*** Maintenance person on VE panel or involved in review of VE proposals.
- ***Nebraska.*** Participate in annual inspection with construction, design, and FHWA of projects under construction. Design errors are usually obvious.
- ***Nevada.*** Provide input to committee from maintenance standpoint.
- ***New Jersey.*** When and if contacted.
- ***North Carolina.*** Review items at request of VE group.
- ***Oklahoma.*** The state maintenance engineer serves on the department's VE committee. All field maintenance engineers have participated in VE schools and have or will serve on VE teams.
- ***Oregon.*** A few maintenance personnel are trained in VE concepts.
- ***Pennsylvania.*** Maintenance is periodically involved as team members to perform studies on design projects.
- ***Texas.*** Districts have PS and E review committees which include a maintenance representative.
- ***Virginia.*** Maintenance personnel may be on VE team.
- ***Wyoming.*** Maintenance personnel are members of VE teams. Maintenance problems in the design and ease of maintenance in the finished product are considered.
- ***British Columbia.*** Investigation of pavement management systems is under way. If adopted, it may incorporate value (life-cycle) cost considerations including maintenance costs in rehabilitation program determinations.

8. How do designers communicate special maintenance needs of their designs (such as operation of traffic controllers, location of underdrain outlets and care of bridge bearings) to maintenance personnel?

- ***Alabama.*** Not done
- ***Arizona.*** Communication methods between designers and maintenance personnel vary widely by type of facility. For the most complex facilities (large drainage or vehicular tunnels, major bridges, freeway control systems), operating and maintenance manuals are being developed. For specialty items such as bridges and traffic controllers, maintenance inspection is handled by operations units that are a part of the same sections that develop the design. These units either provide maintenance directly or in conjunction with district maintenance personnel. For more common needs, there is no normal contact between designers and maintenance.
- ***Arkansas.*** Field inspections with district personnel.
- ***California.*** Operating manuals, "as-built plans", and personal contact.
- ***Colorado.*** Maintenance foremen attend most final reviews.
- ***Connecticut.*** Maintenance receives final plans and specifications.
- ***Florida.*** Suppliers must provide maintenance training when special equipment maintenance is needed.
- ***Hawaii.*** By memorandum.
- ***Idaho.*** No formal process. Done in districts if at all.
- ***Illinois.*** Improve communications between maintenance and bridge design.
- ***Iowa.*** Notes on plans or written correspondence.
- ***Kansas.*** Through plans, overall review of maintenance manuals, specific needs communicated directly to maintenance supervisor.
- ***Kentucky.*** By word of mouth, or memo to central office.
- ***Louisiana.*** Written procedures, sketches and schematic diagrams, often not communicated properly.
- ***Maryland.*** Availability of as-built plans to maintenance forces may address some of this (i.e., underdrains); bridge inspection reports are communicated to maintenance personnel with work requests.
- ***Massachusetts.*** They do not.
- ***Michigan.*** Little input sought from maintenance except in design of movable bridges.
- ***Minnesota.*** To maintenance engineers or maintenance superintendents as needed.
- ***Missouri.*** No formal process.
- ***Montana.*** No formal process exists.
- ***Nebraska.*** Usually on plans. Maintenance personnel not usually aware of these unless construction advises them.
- ***Nevada.*** Written notification to district and maintenance offices, phone, periodic bridge inspections with summary reports to entities.

- ***New Hampshire.*** Internal discussion, memos, plans (design and record) and as-built plans.
- ***New Jersey.*** Phase review, instructional memos and operations bulletins.
- ***New Mexico.*** Plan-in-hand reviews.
- ***New York.*** Notes on the plans for very unusual situations.
- ***North Carolina.*** Communication if maintenance is involved at the design phase, or informal meeting between design and maintenance.
- ***North Dakota.*** Problem: flow of information is from maintenance and operations to design and project development and not the reverse.
- ***Ohio.*** Personal contact, memos, guidelines, special provisions and committees.
- ***Oklahoma.*** Designers consult with maintenance personnel as needed.
- ***Oregon.*** Operators' manuals, as-built contract plans, markers (i.e., special guidepost paddles), walk-throughs with manufacturer representatives, warranty information, occasional special instruction.
- ***Pennsylvania.*** Memos, directives, joint meetings, cross-train engineers, encourage meetings between maintenance and construction during project construction
- ***Rhode Island.*** No formal process to address this need.
- ***Texas.*** Design/construction engineer of a roadway facility is responsible for maintenance. He is aware of any special maintenance needs and advises appropriate personnel.
- ***Vermont.*** Incorporated into design plans.
- ***Virginia.*** Special letters to the district administrator and the state maintenance engineer.
- ***Wyoming.*** Sometimes there is a lack of communication in this area. Designers communicate to district personnel (construction engineers or district staff) who may contact maintenance personnel.
- ***Alberta.*** Through informal discussions between project managers and maintenance personnel.
- ***British Columbia.*** Often these needs are not provided to maintenance unless requested. Where a manufacturer has provided specifications, they are usually provided to maintenance engineers.
- ***Manitoba.*** Generally, the district staff is responsible for both design and construction of road works except bridges so they are aware of most maintenance needs. The same district engineer responsible for maintenance function.
- ***Nova Scotia.*** Designers supply plans, letters, description of maintenance required, etc.
- ***Ontario.*** If it is a head office design need, through head office maintenance who will transmit to the district through memo, standards, etc. If a regional need, directly to district since it is usually a local design issue.
- ***Saskatchewan.*** Very poorly. There is no formal turnover outlining these types of considerations. However, due to ongoing interaction between design, construction, and maintenance, much of this known.
- ***Bureau of Indian Affairs.*** Do not.

- ***Hennepin County, MN.*** Design and operations discuss the parameters involved at preliminary design stage. Try to purchase and use same controller type for ease of design maintenance, proven reliability, good maintenance record. Road and bridge personnel generally are not consulted by designers.
- ***Maricopa County, AZ.*** Through formal and informal communication; chain of communication is short and direct and not a frequent problem.

9. Does your agency have a pavement management system in use?

Thirty-seven agencies -- 80 percent of those reporting -- have pavement management systems (PMS). Six other agencies are in the developmental stage.

If yes, what input does maintenance have to the system?

- ***Alabama.*** Work accomplished for asphalt pavement.
- ***Arizona.*** Maintenance costs by location.
- ***Arkansas.*** Maintenance costs.
- ***California.*** All PMS input.
- ***Colorado.*** MMS provides some data.
- ***Connecticut.*** Annual pavement evaluation by maintenance personnel.
- ***Florida.*** Under development.
- ***Hawaii.*** Reports road condition to materials lab. Lab inputs data.
- ***Idaho.*** Annual maintenance feature inventory.
- ***Illinois.*** Survey teams with maintenance members survey pavements and prepare a condition rating survey for planning and programming; a pavement review team, which includes both district and central office maintenance personnel, evaluates interstate pavements; and maintenance had input in the development of the pavement feedback system.
- ***Iowa.*** Maintenance costs, member of PMS Steering Committee.
- ***Kansas.*** Maintenance costs and major actions are fed into PMS.
- ***Kentucky.*** Meet with pavement management frequently and discuss mutual issues.
- ***Maryland.*** Resident maintenance engineer participates in annual pavement rating survey which results in yearly pavement condition report.
- ***Massachusetts.*** Condition reports.
- ***Michigan.*** In the process of implementing PMS.
- ***Minnesota.*** The maintenance management system was set up to provide roadway surface information to PMS. So far data has not been transferred, programming not complete.
- ***Missouri.*** We are developing system now.
- ***Montana.*** Maintenance representative on PMS steering committee.
- ***Nebraska.*** Maintenance cost records on required maintenance for pavements over 5-year period considered in overall pavement ratings.
- ***Nevada.*** Maintenance conducts annual survey.

- ***New Hampshire.*** PMS not yet implemented to full potential.
- ***New Jersey.*** PMS operated within maintenance unit.
- ***New Mexico.*** None at this time.
- ***New York.*** PMS being developed.
- ***North Carolina.*** Suggest repair strategies for various distresses, recommend priorities for rehabilitation, participate in pavement type and design selection.
- ***North Dakota.*** PMS a function of the planning division.
- ***Ohio.*** Representatives on the task force, district maintenance provides engineering judgment of rehabilitation and maintenance on district level, the bureau of maintenance has direct contact with the districts through its field engineers.
- ***Oregon.*** Pavement maintenance expenditure data, condition ratings and local (district) input into overlay prioritization and treatment selection.
- ***Pennsylvania.*** Maintenance corrects deficiencies identified by PMS and updates system accordingly.
- ***South Carolina.*** Unit maintenance costs and repair severity.
- ***South Dakota.*** None.
- ***Texas.*** PMS is a major responsibility of the maintenance and operations division.
- ***Vermont.*** None.
- ***Virginia.*** System maintained by the maintenance division.
- ***Wyoming.*** The planning division is working on developing a system.
- ***Alberta.*** Little or none.
- ***British Columbia.*** Investigation of pavement management systems under way, if adopted may incorporate value (life-cycle) cost considerations including maintenance costs in rehabilitation program determinations.
- ***Manitoba.*** Issues addressed in informal process.
- ***Ontario.*** Informal discussions with district maintenance staff.
- ***Saskatchewan.*** Relatively new system, a major component of PMS is maintenance costs and history which come from the maintenance management information system, the maintenance branch is involved in the design and use of PMIS.
- ***Bureau of Indian Affairs.*** Rate the pavement visually, express priorities to managers.
- ***Hennepin County, MN.*** Not yet. Will have new PMS in operation in late 1990. Have contracted with PMS, Inc. to provide "Series 30" system.
- ***Maricopa County, AZ.*** Part of team that reviews existing pavement.

10. Does your agency have a bridge management system?

Forty-seven agencies responded to this question. Of those, 15 have bridge management systems (BMS) in use. Seven agencies are developing systems.

If yes, what input does maintenance have to the system?

- ***Alabama.*** Being developed.
- ***Florida.*** State maintenance operates BMS.
- ***Idaho.*** All input is by maintenance.
- ***Louisiana.*** Productivity and expenditure summary of bridge maintenance activities, quantity and quality standards for bridge maintenance activities.
- ***Maryland.*** Minimal to none.
- ***Michigan.*** In process of designing a bridge management system.
- ***Minnesota.*** Have identified tools we will use but no system has been implemented as yet.
- ***New Jersey.*** BMS operated within maintenance organization.
- ***New York.*** A BMS is being developed.
- ***North Carolina.*** Bridge maintenance provides most input with data from inspections.
- ***North Dakota.*** Development stage.
- ***Oklahoma.*** Presently using the AASHTO Bridge Manual for maintenance inspection of bridges, making condition ratings and appraisals; routine bridge maintenance activities are part of the maintenance management system.
- ***Oregon.*** System currently under development (spring 1990).
- ***Pennsylvania.*** The bureau of maintenance corrects deficiencies identified by BMS and updates system accordingly.
- ***Texas.*** BMS presently under development.
- ***Vermont.*** Review inspectors' reports and recommendations and implement repairs as needed.
- ***Virginia.*** The maintenance division maintains part of the system.
- ***Alberta.*** Major maintenance of bridges is handled by group separate from road maintenance personnel.
- ***Ontario.*** Various maintenance repair/design items identified by district maintenance staff.
- ***Saskatchewan.*** To be answered by the bridge branch.
- ***Maricopa County, AZ.*** Bridge section inspects. Discussions occur with maintenance section for corrective actions and for any problems.

11. Does your agency have a roadside management system?

Thirteen of the 48 agencies that responded to this question have roadside management systems (RMS). One agency has developed a system but had not yet implemented it. Another is in the developmental stage and two are considering developing systems.

If yes, what input does maintenance have to the system?

- ***Alabama.*** Developed but not implemented.
- ***Arizona.*** Roadside vegetation program in MMS.

- ***Florida.*** State maintenance reviews roadside development procedures.
- ***Hawaii.*** District maintenance manages roadside.
- ***Idaho.*** Included in the MMS.
- ***Illinois.*** Maintenance manages the system.
- ***Louisiana.*** For roadside maintenance activities, productivity standards and expenditure summary and inspection reports.
- ***Michigan.*** Looking into roadside management system for study.
- ***Minnesota.*** Roadside management is conceptual at this time.
- ***Missouri.*** Maintenance responsible for the system.
- ***Nebraska.*** Regular/routine maintenance is roadside management program.
- ***New Jersey.*** RMS operated within the maintenance organization.
- ***New Mexico.*** Maintenance is in control of system.
- ***North Carolina.*** Assist in setting mowing limits, mowing heights, use of turf growth retardants.
- ***Oklahoma.*** Roadside is part of our MMS.
- ***Oregon.*** None except inventory of certain features in MMS.
- ***Pennsylvania.*** Annual working plan prepared by 11 district office roadside specialists (maintenance "team"), plan reviewed and approved by district engineer in charge of maintenance.
- ***Texas.*** Current vegetation management standards govern roadside management of vegetation, the landscape section of the maintenance/operations division establishes policy, district maintenance engineers direct vegetation management within the districts.
- ***Virginia.*** System under development.
- ***Manitoba.*** The maintenance management system is involved in all maintenance of right of way including depressed median plantings, shelter belts to reduce winter visibility problems and chemical and mechanical control of vegetation.
- ***Saskatchewan.*** Standards for control of development adjacent to highways are in the Roadside Development Manual. Standards for roadside right-of-way maintenance are developed by the maintenance branch in consultation with the design branch. The standards are enforced and utilized by district maintenance.
- ***Maricopa County, AZ.*** Not only input but control.

12. What improvements in the design process are needed to minimize maintenance problems?

- ***Alabama.*** Input and consultation from maintenance personnel.
- ***Arizona.*** Formal field reviews 1-2 years after construction complete.
- ***Arkansas.*** More involvement of maintenance staff in preliminary designs.

- ***California.*** More interaction between maintenance field personnel and design engineers, especially for young engineers.
- ***Colorado.*** Designers spend more time with maintenance crews. Look at total costs, not just first costs.
- ***Connecticut.*** Allowance of additional time to perform project reviews.
- ***Florida.*** Communications can be improved.
- ***Hawaii.*** Compare low maintenance or no maintenance with higher first cost. Design should consider how facility will be maintained.
- ***Idaho.*** More formal, structured process for input from maintenance during design.
- ***Illinois.*** Maintenance should have opportunity to review and comment on new or revised policies and standards.
- ***Iowa.*** Involve maintenance more in review processes, field reviews and standards. Improve communications.
- ***Kansas.*** Use simplest design possible.
- ***Kentucky.*** Closer coordination between designers (in-house and consultants and the division of maintenance).
- ***Louisiana.*** Input from maintenance to design or at least open communication between them, consider maintainability in design of highway facilities.
- ***Maryland.*** Involvement of maintenance quality assurance in VE process, review of proposed revision to design standards and specifications.
- ***Michigan.*** We feel maintenance input given very little credibility when dealing with design and budget items.
- ***Montana.*** Existing informal process is working well.
- ***Nebraska.*** More input during design process, someone knowledgeable to review plans.
- ***Nevada.*** Communicate with the maintenance division, field review prior to design.
- ***New Hampshire.*** Desirable for all designers to spend part of training program in maintenance to become aware of maintenance problems. Familiarity with Report No. FHWA-TS-78-216, *Integration of Maintenance Needs Into Preconstruction Procedures*, is encouraged in this department.
- ***New Jersey.*** Greater level of involvement between designers and field maintenance supervisors.
- ***New Mexico.*** More communication and more money.
- ***New York.*** Consideration of life-cycle costs, communication and whether maintenance has the resources to maintain the facility as intended.
- ***North Dakota.*** A reorientation of design and project development staff and division heads towards maintenance operations and the consequences designs can have on maintenance operations and costs.
- ***Ohio.*** Established a physical research group to keep designers advised on advances in highway technology and to evaluate new products and ideas.

- ***Oklahoma.*** Design process must include active and constant communication and correlation with the operational process prior, during and after completion of all projects.
- ***Oregon.*** Recently implemented: location design review at 30-50% complete and final design review at 30% and 80% complete.
- ***Pennsylvania.*** Design procedures are OK, problems occur only when they are not followed or short cuts are taken. Consultants are not familiar with problems and designs are not as good as those by in-house.
- ***South Carolina.*** A formal feedback system of maintenance problems caused by design decisions.
- ***Texas.*** Present design process is working reasonably well.
- ***Vermont.*** Keeping lines of communication open.
- ***Virginia.*** More concerned about traffic problems caused by closing lanes on heavily traveled roads for maintenance.
- ***Wyoming.*** More communication between construction and maintenance divisions, involve maintenance engineers in the preliminary plan review process.
- ***Alberta.*** More quality communication between designers and maintenance during preliminary stage of design and construction, better understanding of the impact of design on maintenance required by designers and maintenance staff.
- ***British Columbia.*** Formalization of the process of considering maintenance problems/costs at a preliminary stage of planning and throughout design and construction.
- ***Manitoba.*** Identified problem areas dealt with during design process.
- ***Ontario.*** Better cross-section to address winter maintenance concerns, longer pavement life or designs minimizing maintenance, better quality control.
- ***Saskatchewan.*** Increased communication and meetings between design and maintenance field staff and relevant head office branch who develop all policies and standards for both.
- ***Bureau of Indian Affairs.*** Require maintenance to be involved in planning stage.
- ***Hennepin County, MN.*** Should be open communication between design and maintenance at all times. Design personnel should discuss their thoughts on the structure of the roadway with maintenance at the preliminary and final stages of design. Operations must be given chance to review plans and design must be willing to adapt to changes.
- ***Maricopa County, AZ.*** No major recurring problems. A periodic field trip guided by the operations engineer and attended by designers would further minimize problems. Standards for roadside right-of-way maintenance are developed by the maintenance branch in consultation with the design branch. Video presentations of problem areas would be effective alternative.

Road Design

1. Is maintenance considered in the design of highway facilities?

All fifty agencies that responded to this question do consider maintenance in design.

If yes, is the process formal or informal?

Nine agencies have formal processes.

Are maintenance personnel involved in the process?

Maintenance personnel are involved in the process in 45 agencies.

If yes, describe their role and the management level involved.

- ***Alabama.*** The division maintenance engineers (in the field) have the opportunity to review plans and attend scope-of-work and plan reviews for 4R project.
- ***Arkansas.*** Design personnel meet with the district engineer during the design of project.
- ***California.*** The maintenance section manager is consulted about problems during preparation of the Project Scope Summary Report (PSSR).
- ***Colorado.*** Maintenance personnel are consulted informally about roads in their area.
- ***Connecticut.*** The district maintenance planning section reviews project designs and submits comments through the director of maintenance to engineering.
- ***Florida.*** Local maintenance engineers review roadway plans for potential maintenance problems. Their comments are incorporated into plans.
- ***Idaho.*** The district maintenance supervisor and the maintenance foreman conduct joint field reviews with design personnel.
- ***Illinois.*** District maintenance identifies sections for the 5-year program and attends field checks at the 70% design stage.
- ***Iowa.*** The district maintenance engineer, resident maintenance engineer or the maintenance office assistant (depending on the complexity and type of project) attends field exam.
- ***Kansas.*** The area engineer has responsibility for both construction and maintenance and is contacted about potential problems and attends the field check.
- ***Kentucky.*** Maintenance is invited to attend all project inspections.
- ***Louisiana.*** The district maintenance engineer is involved in plan development reviews.
- ***Maine.*** The supervisor and foreman advise design and construction of potential problems.
- ***Massachusetts.*** The maintenance engineer is on the design committee which sets design and construction standards and details.
- ***Michigan.*** The maintenance engineer sits on the engineering committee that approves pavement designs. The district maintenance engineer attends major design reviews and reviews final plans.
- ***Minnesota.*** The operations engineer, area superintendents and supervisors are invited to meetings and one-on-one conversations.
- ***Missouri.*** The maintenance and traffic engineer is a member of the design committee. District maintenance participates in field checks.
- ***Montana.*** Maintenance is invited to pre-program field reviews. The district maintenance chief of sectionman attends plan-in-hand reviews.

- ***Nebraska.*** The district engineer attends inspections. The district maintenance superintendent may participate.
- ***Nevada.*** The maintenance foreman/district representative is involved in pavement management at several levels throughout design: pavement management for minimum maintenance projects, 3R projects, and preliminary design field study.
- ***New Hampshire.*** The district maintenance engineer advises design of needs and expectations. The district maintenance foreman identifies and resolves field problems specific to the project.
- ***New Jersey.*** Initial scope input requested from maintenance. The maintenance division is included in the review process.
- ***New Mexico.*** Any input from maintenance is considered.
- ***New York.*** Each region has developed its own review process but generally gives maintenance several opportunities to review proposed designs. In most regions, the regional maintenance engineer helps select projects to be programmed, reviews the project initiation request, design reports and preliminary plans and signs the final plans as acceptable.
- ***North Carolina.*** The maintenance engineer or district engineer is usually involved on field reviews.
- ***North Dakota.*** The maintenance engineer and the district engineer are involved in project concept development and give input.
- ***Oklahoma.*** The maintenance engineer is occasionally involved.
- ***Oregon.*** The district manager, assistant district manager or the section foreman is consulted during the field survey. The district manager reviews preliminary plans and may attend the final design review.
- ***Rhode Island.*** The maintenance division reviews all design plan submissions.
- ***South Carolina.*** Known problems are discussed with district.
- ***South Dakota.*** The area engineer provides input to design.
- ***Texas.*** The resident engineer is in charge of design, construction and maintenance for the residency.
- ***Utah.*** Through district construction personnel.
- ***Vermont.*** The district transportation administrator reviews design plans.
- ***Virginia.*** The resident engineer is responsible for construction and maintenance.
- ***Wyoming.*** Usually through the district staff.
- ***Alberta.*** The district transportation engineer reviews grading and geometric designs.
- ***British Columbia.*** The district highways manager is interviewed by the designer to obtain maintenance concerns within the design project area.
- ***Nova Scotia.*** The regional manager reviews plans with the division engineer who is in charge of maintenance.
- ***Ontario.*** Field maintenance supervisors at all levels identify needs to planning and design for consideration in preconstruction.
- ***Quebec.*** Involved in writing standards. Consulted through regions and districts during design.

- ***Saskatchewan.*** Design dialogue with maintenance staff. The bridge maintenance manager reviews contract documents.
- ***Port Authority of New York and New Jersey.*** Provide information and review contract documents.
- ***Hennepin County, MN.*** The design engineer requests reviews by the maintenance engineer.
- ***Maricopa County, AZ.*** Maintenance recommends projects for improvements and participates in a drive-through.

At what stages of design are they involved?

- ***Alabama.*** PIH and PS and E on new construction. Selection and work items on 4R projects.
- ***Arkansas.*** When plans are approximately 50% complete.
- ***California.*** Planning, Project Scope Summary Report, and PS and E.
- ***Colorado.*** Scoping and survey stages plus field inspections.
- ***Connecticut.*** Preliminary design plan.
- ***Florida.*** 60% and 90% design phases.
- ***Idaho.*** Preliminary concept stage.
- ***Illinois.*** Location phase and 70% complete.
- ***Iowa.*** Field exam, concept, and plan review.
- ***Kansas.*** Project authorization stage and at the 50% plan completion.
- ***Kentucky.*** Preliminary line and grade and at final inspection.
- ***Louisiana.*** Pre-design conference, PIH field inspection and advance check prints at final plan stage.
- ***Maine.*** Final field inspection.
- ***Maryland.*** From project initiation to award.
- ***Massachusetts.*** Policy and standard level, not project specific.
- ***Michigan.*** All stages from project initiation to post-construction meetings.
- ***Minnesota.*** First in pre-design process, then at any stage where input might be useful.
- ***Missouri.*** Preliminary and detail.
- ***Montana.*** Early stages and PIHs. The maintenance engineer receives copies of all pre-program field reports.
- ***Nebraska.*** Throughout the process, but mainly at the preliminary stage.
- ***Nevada.*** Headquarters maintenance is not directly involved. The district is every day.
- ***New Hampshire.*** The district maintenance engineer is involved at the 20%, 60% and 90% design stages; the maintenance district foreman only at the 60% complete stage.
- ***New Jersey.*** At scoping and four phase reviews.
- ***New Mexico.*** Whenever input is offered.

- ***New York.*** All stages.
- ***North Carolina.*** Preliminary R/W plan design and preliminary construction plan design.
- ***North Dakota.*** The maintenance engineer and district engineer at the project concept stage. The district engineer is also involved in the preliminary design phase and the final plan review phase.
- ***Oklahoma.*** Preliminary and final design.
- ***Oregon.*** Preliminary design, initial field survey and final design.
- ***Rhode Island.*** 10% through 90% plans.
- ***South Carolina.*** First field inspection.
- ***South Dakota.*** All stages.
- ***Texas.*** The district reviews all plans prior to going to contract. The reviews include maintenance.
- ***Utah.*** Project assessment through final design and construction.
- ***Vermont.*** Throughout the design process.
- ***Virginia.*** Preliminary field review (20%) and field inspection (55%).
- ***Alberta.*** Initial and final review stages.
- ***British Columbia.*** Mid-way through the functional design and at the beginning of the detailed design plus at the penultimate drawing stage for detailed design.
- ***Nova Scotia.*** At any stage.
- ***Ontario.*** Planning, preliminary design, design and review and construction stages.
- ***Quebec.*** Prior to going to construction.
- ***Saskatchewan.*** During design and pre-tender stages.
- ***Port Authority of New York and New Jersey.*** Initial design through contract documents.
- ***Hennepin County, MN.*** When plans near completion.
- ***Maricopa County, AZ.*** Prior to actual design.

2. Which factors are included in evaluating alternative designs?

Factor	No. of Responses	Factor	No. of Responses
Construction costs	46	Existing conditions	2
Operation & maintenance costs	41	Public input	2
Traffic disruptions -- maintenance	35	Potential flooding of private property	2
User costs	28	Worker and public safety	2
Design costs	25	Constructability	1
Environmental concerns	8	Continuity	1
Traffic handling during construction	6	Design standards	1
Life-cycle costs	5	Drainage	1
Right of way costs	4	Impact on businesses	1
Safety	4	Lead time	1
Future construction costs	3	Levels of service	1

Maintenance costs	1	Transportation issues	1
Material availability	1	Utilities	1
Preview history of success	1		

Who makes the evaluation?

Evaluator	No. of Responses	Evaluator	No. of Responses
Designer	20	Planning division	2
Design division	9	Value engineering unit	2
District design engineer	6	Assistant division chief	1
Team	6	Chief engineer	1
Chief of design	5	Consultant	1
Road design engineer	5	District planning engineer	1
Construction	3	District personnel	1
District engineer	3	Pavement design committee	1
Engineering divisions	3	Programs and contracts	1
Maintenance	3	Regional design group	1
Traffic engineer	3	Section chief	1
Materials section	2		

3. Is the life expectancy of materials considered?

Forty-nine of the fifty responses were yes, life expectancy is considered.

Examples:

Examples of materials and components where life expectancy is considered are tabulated below.

Examples	No. of Responses	Examples	No. of Responses
Pavement selection	36	Traffic signals and controllers	2
Culvert selection	18	Asphalt cement	1
Pavement markings	6	Catch basins	1
Guardrail/barrier selection	6	Conduits	1
Shoulder type selection	4	Curbs	1
Sign materials	4	Delineators	1
Bridge type selection	3	Guardrail posts	1
Aggregate durability	2	Latex modified for bridge decks	1
New product evaluation	2	Rebar coatings	1
Pavement joint materials	2	Roadway lighting	1
Sound barriers	2	Slope treatments	1
Steel castings	2		

4. Does your agency have a value engineering review process?

Thirty-two of the fifty-one agencies (63%) responding to this question have value engineering review processes.

If yes, are maintenance personnel involved in the process?

Maintenance personnel are involved in thirty of the thirty-two agencies with VE processes.

If yes, describe role:

- ***Alabama.*** Plans 30 percent complete.
- ***Arkansas.*** As VE team member and review proposals for implementation.
- ***California.*** Team member or leader.
- ***Florida.*** Review team members.
- ***Illinois.*** Districts have VE teams including maintenance representative.
- ***Iowa.*** Member of the VE team.
- ***Kentucky.*** Inspections to determine best and least expensive alternatives to design.
- ***Louisiana.*** Informal reviews involving design, construction, and maintenance personnel at Baton Rouge headquarters level but based on predominant opinion, not exhaustive study.
- ***Maryland.*** Input before value engineering review.
- ***Massachusetts.*** Engineers from the maintenance division are part of the VE team.
- ***Michigan.*** Maintenance division member on VE task force reviews recommendations suggested by VE teams.
- ***Missouri.*** Participate as team members on VE reviews that affect the maintenance division.
- ***Montana.*** VE teams submit recommendations for upper management approval.
- ***Nebraska.*** Member of VE team or as resource for maintenance information.
- ***Nevada.*** Maintenance foreman or crew supervisor is a member of the multi-discipline VE team.
- ***New Mexico.*** VE process performed only on selected projects.
- ***New York.*** Part of VE team.
- ***North Carolina.*** Not part of the study team, but division maintenance or district engineer is consulted by study team as needed.
- ***North Dakota.*** District engineer reviews VE proposal and makes recommendations.
- ***Oklahoma.*** Maintenance personnel on some VE review teams, just getting started with training.
- ***Oregon.*** VE used on selected projects, normally in preliminary design. A few maintenance supervisors are trained in VE techniques and may be selected for a project specific VE team.
- ***Pennsylvania.*** Maintenance is periodically involved.
- ***South Dakota.*** Input on maintenance procedures, problems solicited on various designs (informal).
- ***Texas.*** District reviews all plans prior to going to contract. Review includes maintenance.
- ***Utah.*** Input sought on projects which would have a great deal of impact on maintenance later on.
- ***Virginia.*** Serve as member of VE team.
- ***Wyoming.*** Member of VE team.

- ***Alberta.*** The district transportation engineer may chair a sub-committee studying a particular geometric design standard warrant guideline or be involved in reviews of recommendations proposed by a committee.
- ***Quebec.*** High authorities at regional and district levels often give advice. Maintenance personnel always at standards writing level.
- ***Port Authority of New York and New Jersey.*** Depends on type of facility and project. When included, they are full team members.

What management level?

- ***Alabama.*** Statewide and division.
- ***Arkansas.*** Area maintenance engineer serves on VE team. The assistant chief engineer for construction and maintenance reviews VE proposals for implementation.
- ***Colorado.*** Appropriate level.
- ***Florida.*** Local level.
- ***Iowa.*** Staff.
- ***Kentucky.*** Mid-level.
- ***Massachusetts.*** Project level.
- ***Michigan.*** Section head of division or district maintenance engineer.
- ***Missouri.*** Division and district personnel
- ***Montana.*** All levels.
- ***Nevada.*** Maintenance foreman
- ***New Mexico.*** District maintenance engineer.
- ***New York.*** Civil engineers II and III
- ***North Dakota.*** District engineer.
- ***Oklahoma.*** Field divisions and above.
- ***Oregon.*** Varies.
- ***Pennsylvania.*** Team members.
- ***South Dakota.*** Foreman.
- ***Utah.*** District maintenance engineer and central maintenance division engineer.
- ***Vermont.*** Considering process for future.
- ***Virginia.*** Middle.
- ***Wyoming.*** District maintenance engineer and staff maintenance engineer.
- ***Alberta.*** District transportation engineers are senior managers and members of the committee.
- ***Port Authority of New York and New Jersey.*** Varies.

5. Does your agency have a pavement management system?

Forty-three agencies have pavement management systems -- 84 percent of those responding. Four agencies are developing systems.

If yes, how is it used in the design process?

- ***Alabama.*** Evaluate existing pavements on 4R projects.
- ***Arkansas.*** Prioritize projects.
- ***California.*** Evaluate existing pavements.
- ***Connecticut.*** To determine pavement structure design.
- ***Florida.*** Condition survey used to set priorities for pavement rehabilitation.
- ***Hawaii.*** Materials determines pavement design.
- ***Idaho.*** Not used for design.
- ***Illinois.*** Monitor life expectancy of pavement designs and rehabilitation techniques.
- ***Iowa.*** 3R/4R design concepts, pavement determination, life-cycle costs, and pavement life studies.
- ***Kansas.*** To determine pavement action-surface rehabilitation versus reconstruction.
- ***Kentucky.*** The pavement management branch provides pavement design staff with results of condition surveys, rutting data for bit pavement, skid-resistance and deflection data for in-service pavements. This information is used in the development of pavement rehabilitation designs and for refinement of pavement design procedures.
- ***Louisiana.*** Newly established, not yet fully functional.
- ***Maine.*** Treatment recommendations.
- ***Maryland.*** Presently being initiated.
- ***Massachusetts.*** Feeds into project prioritization process.
- ***Michigan.*** Testing PMS along with conventional methods of project selection; has capability to select pavement rehabilitation alternatives by cost/benefit factors for initial cost, total traffic lane miles and how condition is improved for cost.
- ***Minnesota.*** To identify roadways needing overlays and determine overlay thickness.
- ***Missouri.*** Presently under development.
- ***Montana.*** To help prioritize sections of roads for programming purposes.
- ***Nebraska.*** Helps set priority of projects.
- ***Nevada.*** Not formal at present, system used to locate and prioritize minimum maintenance and 3R projects.
- ***New Hampshire.*** The NH PMS is in the infancy stage, the main focus is on data gathering. So far the data has been used to prioritize interstate pavement overlays.
- ***New Jersey.*** The prioritization system maintenance staff periodically prepares the pavement management skid resistance inventory and the pavement management priority list report. Also

the bureau of geotechnical engineering uses it in developing designs for pavement rehabilitation projects and historical performance of various pavement types.

- ***New Mexico.*** To establish priority of project in annual program which determines order of project design.
- ***New York.*** System under development.
- ***North Carolina.*** Pavement design and PMS are staffed to the pavement management branch. Design uses PMS products to optimize least cost, longer listing pavements for rehabilitation and new construction.
- ***North Dakota.*** Used as guide to prioritize projects.
- ***Ohio.*** The life-cycle costs of various pavement designs are evaluated over a 20-year period. The most cost effective meeting design criterion is selected.
- ***Oklahoma.*** PMS is being developed.
- ***Oregon.*** In the future, it is to be used to provide feedback on design performance, cost information, inventory data at specific sites to develop preliminary designs and pavement condition information.
- ***Rhode Island.*** Currently being developed.
- ***South Dakota.*** Minimal use currently. It is used for yes or no decisions to reconstruct. Plan to use it for design in future.
- ***Texas.*** To prioritize and design pavement needs within the state.
- ***Utah.*** Recommendations developed through the PMS process as part of the planning study report are the initial basis for design of any project.
- ***Vermont.*** In determining when highway sections will be paved and the thickness of overlays.
- ***Virginia.*** Overlays, joint repair, deck rehabilitation or replacement are scheduled with road improvements when applicable.
- ***Wyoming.*** To schedule projects for maintenance or reconstruction.
- ***Alberta.*** PMS data are used to provide prototypes for all new pavement and rehabilitation designs.
- ***British Columbia.*** Data are analyzed for compliance with maximum permissible limits. Remedial work is undertaken on failing sections of roadway as funds permit.
- ***Ontario.*** Provides information on pavement deterioration/condition and looks at pavement stresses, i.e., cracks, rutting, stripping, ride, strength, etc.
- ***Quebec.*** Determines type of paving to be used in project.
- ***Saskatchewan.*** New system, limited use, primarily for system strategic planning versus project specific data.
- ***Port Authority of New York and New Jersey.*** To establish design schedule.
- ***Hennepin County, MN.*** To help identify roadways needing overlays and to determine overlay thickness.

- ***Maricopa County, AZ.*** Determining priority list, roadway classification, clear distance, and type of roadway to construct.

What input does maintenance have to the system?

- ***Alabama.*** Very little now. Expect to input maintenance costs in future.
- ***Arkansas.*** Monitor projects and recommend priorities.
- ***Colorado.*** Member of the PMS steering committee.
- ***Connecticut.*** Annual evaluation of pavement condition.
- ***Florida.*** Condition survey work.
- ***Hawaii.*** None.
- ***Idaho.*** Maintenance costs.
- ***Illinois.*** Member of committee for pavement management.
- ***Iowa.*** The maintenance director is a member of the PMS committee.
- ***Kansas.*** Costs of maintenance actions are identified and pavement condition data for use in PMS.
- ***Kentucky.*** The pavement committee reviews information from maintenance, materials, and design, The maintenance division is responsible for recommending resurfacing and rehabilitation projects.
- ***Maine.*** None.
- ***Maryland.*** Too early to ascertain.
- ***Massachusetts.*** Only indicate most useful reports (type and format), principally ride quality and distress.
- ***Michigan.*** None yet. Trying to develop system to evaluate cost/benefit of maintenance.
- ***Minnesota.*** PMS resides in the operations department. Maintenance is a part of operations.
- ***Montana.*** Provide information to the project analysis bureau data base.
- ***Nebraska.*** Maintenance cost per mile.
- ***Nevada.*** PMS evaluates maintenance expenditures, gives added priority for 3R work if excessive maintenance costs have not resulted in improved pavement serviceability.
- ***New Hampshire.*** Does not supply data, has advised PMS on what data and formats needed.
- ***New Jersey.*** Maintenance forces prepare PMS.
- ***New York.*** Maintenance is on the pavement management committee developing the system.
- ***North Carolina.*** Give feedback, i.e., actual repair costs for more efficient products and strategies.
- ***North Dakota.*** District personnel gather distress data, maintenance personnel contacted for input.
- ***Ohio.*** Bureau of maintenance has members on pavement management team.

- ***Oregon.*** In the past: identified and prioritized surface preservation treatments and provided pavement condition ratings. In the future: will provide cost and treatment data, help prioritize projects and provide input into PMS development.
- ***South Dakota.*** Area engineers and supervisors provide input on construction and maintenance decisions.
- ***Texas.*** The districts review all plans prior to going to contract. The review includes maintenance.
- ***Utah.*** The district maintenance engineer with the PM engineer during the field review identifies (1) concerns and problems related with pavement of a specific section of highway and (2) the needs for improvement, i.e., rehabilitation, rejuvenate or reconstruction.
- ***Vermont.*** None.
- ***Virginia.*** Maintain the program.
- ***Alberta.*** Nil so far.
- ***British Columbia.*** Not much. Routine maintenance effected to ensure safe passage of traffic and is independent of the rehabilitation process.
- ***Ontario.*** The maintenance supervisor or engineer contributes informally to decisions made based on pavement management data and other visual and costing data.
- ***Quebec.*** Maintenance personnel give the designer and others in the pavement management system the characteristics they want in future projects.
- ***Saskatchewan.*** Provide annual maintenance costs on a highway segment basis which may trigger alternative upgrading or rehabilitation strategies.
- ***Port Authority of New York and New Jersey.*** Facility staff is part of the evaluation team.
- ***Hennepin County, MN.*** PMS resides in the operations department, maintenance is a part of operations.
- ***Maricopa County, AZ.*** Reviews construction plans.

6. Does your agency have a roadside management system in use?

Twenty-two agencies (44 percent) have roadside management systems. Of these, two are a part of the maintenance management system. One agency is developing a system.

If yes, how is it used in the design process?

- ***Colorado.*** Evaluate roadside safety costs.
- ***Idaho.*** Input from the roadside program coordinator. The roadside management system is a part of MMS.
- ***Illinois.*** Coordinated with the district landscape architect.
- ***Louisiana.*** Not used
- ***Maine.*** To provide recommendations for loaming, special seeding, tree replacement on rehabilitation and reconstruction projects.
- ***Maryland.*** Integral part of design.
- ***Missouri.*** Coordinated between design and maintenance personnel.

- ***Nebraska.*** The agronomist reviews plans to ensure conformity with maintenance, the agronomist recommends grass and flower types, the landscape architect suggests tree planting locations for maintenance and safety.
- ***Nevada.*** Part of the maintenance management system.
- ***New Mexico.*** Make recommendations for erosion control, seeding and special problems with sediments and runoff.
- ***North Carolina.*** Roadside design policy is based on the AASHTO Roadside Design Guide.
- ***Pennsylvania.*** To enhance safety, establish erosion control and enhance or preserve existing vegetation.
- ***Rhode Island.*** The landscaping unit, as a part of the design section, reviews projects and develops roadside improvements where feasible
- ***South Dakota.*** Used to decide species of vegetation to plant based on soil type to assure adequate cover.
- ***Texas.*** The vegetation management and landscape management sections provide assistance to the districts and residencies.
- ***Virginia.*** Now under development.
- ***British Columbia.*** No formal process. The regional offices send problems to the highway engineer branch; if applicable, standards are changed at the highway engineer branch.
- ***Ontario.*** Information is available to programmers in developing the 5-year capital program as well as to designers.
- ***Quebec.*** Impact studies consider roadside improvements that should be done during road reconstruction.
- ***Saskatchewan.*** The Roadside Development Manual outlines the minimum standards controlling development adjacent to roadways, the maintenance manuals address maintenance activities with right of way
- ***Maricopa County, AZ.*** Determining roadway classification, clear distance and design life.

What input does maintenance have to the system?

- ***Colorado.*** Basic data.
- ***Idaho.*** From roadside program coordinator.
- ***Illinois.*** Through MMIS.
- ***Louisiana.*** Directed by maintenance.
- ***Maryland.*** Crash cushions and median barrier.
- ***Michigan.*** The roadside committee member from maintenance provides direction and input into the development of the roadside management system.
- ***Missouri.*** Coordinated between design and maintenance personnel.
- ***Montana.*** Maintenance people handle roadside maintenance after projects are constructed.
- ***Nebraska.*** Continuous communication with roadway design division's agronomist.

- ***New Mexico.*** Constant contact to solve problems and relay information to design.
- ***North Carolina.*** Workshops held to acquaint maintenance personnel with proper roadside safety and clear zone concepts.
- ***Pennsylvania.*** Consultation occurs, maintenance has the primary responsibility.
- ***Rhode Island.*** The landscaping unit works maintenance concerns into designs.
- ***South Dakota.*** Foreman input at maintenance management meetings.
- ***Texas.*** These management sections work directly with district maintenance personnel.
- ***Virginia.*** Through field employees with maintenance responsibilities and discussions.
- ***British Columbia.*** Maintenance contractors respond to services within the requirements of the maintenance contracts; standards are checked by quality assurance program.
- ***Ontario.*** Maintenance manages the roadside management system.
- ***Quebec.*** Data and advice.
- ***Saskatchewan.*** Minimal input to the Roadside Development Manual, maintenance is the custodian of the manual addressing standards for right-of-way maintenance activities.

7. How does the designer obtain special maintenance needs for design from maintenance personnel during the design process?

- ***Arkansas.*** Field inspections with district personnel during design.
- ***California.*** Personal contacts and reports from maintenance personnel.
- ***Colorado.*** Hit-or-miss depending on communications between maintenance and the designer.
- ***Connecticut.*** The director of maintenance reviews plans or sends representative to preliminary design meeting.
- ***Florida.*** From reviews (60% and 90% complete) of plans.
- ***Hawaii.*** By contacting district maintenance or construction.
- ***Idaho.*** Direct contact with maintenance personnel when needed.
- ***Illinois.*** Maintenance personnel participate in field evaluations and reviews prior to and during preparation.
- ***Iowa.*** Input through 3R/4R review team, field exams, project review process, and maintenance review of standards.
- ***Kansas.*** By request to district personnel.
- ***Kentucky.*** Maintenance personnel advise district personnel of common problems and some discussion.
- ***Louisiana.*** Only obtained for projects designed in district by district personnel and during various review stages.
- ***Maine.*** Through comments at preliminary and final inspections.
- ***Maryland.*** Field reviews.
- ***Massachusetts.*** Maintenance reports on projects that originate in the maintenance section.

- ***Michigan.*** Maintenance needs requested at project initiation and at formal reviews. Maintenance is involved in formal post construction reviews to find improvements.
- ***Minnesota.*** Consult with maintenance engineer.
- ***Missouri.*** Coordination between district maintenance and design personnel.
- ***Montana.*** Through pre-program reviews and design plan-in-hand inspections.
- ***Nebraska.*** Preliminary field checks and communication during the design process.
- ***Nevada.*** PDFS and continuous contact with the districts during the design process.
- ***New Hampshire.*** The district maintenance engineer advises design of needs and expectations. The district maintenance foreman identifies and resolves field problems specific to the project.
- ***New Jersey.*** During the pre-design and scoping process and at field meetings with the designer and maintenance during the preliminary design stage.
- ***New Mexico.*** Through project development team and inspections.
- ***New York.*** During the preliminary design phase field reviews are conducted with maintenance personnel and by regional maintenance group review and comment on preliminary design reports and plans.
- ***North Carolina.*** Primarily during field reviews of design plans.
- ***North Dakota.*** From district personnel at field reviews during design.
- ***Ohio.*** The design review team reviews newly constructed projects with the intent of improving constructability and maintenance of future projects.
- ***Oklahoma.*** Presented by field division personnel when we go to plan-in-hand inspections, and designers worked with maintenance prior to plan-in-hand on landscape projects.
- ***Oregon.*** Plans-in-hand reviews prior to advertising project and the district manager reviews plans and specifications.
- ***Pennsylvania.*** Field reviews with maintenance at project inception, and designers consult with maintenance staff as project develops as needed to verify solutions to existing or anticipated maintenance problems.
- ***Rhode Island.*** The maintenance division reviews all design submissions.
- ***South Carolina.*** From district maintenance personnel.
- ***South Dakota.*** Designers solicit information from the area engineer who is responsible for construction and maintenance.
- ***Texas.*** The resident engineer organization (described in Question #1) provides direct maintenance input into the design process.
- ***Utah.*** Maintenance engineers provide input at the preliminary field review, the plan-in-hand review and the pre-advertising review. In addition, the designer can call on maintenance personnel as needed for consultation, reports or documentations supporting maintenance problems and justifying mitigations to alleviate maintenance problems.
- ***Vermont.*** Through review comments by the district transportation administrator.
- ***Virginia.*** Via the resident engineer.

- ***Wyoming.*** From the district maintenance engineer.
- ***Alberta.*** From the district transportation engineer on each design.
- ***British Columbia.*** Informal communication between maintenance and designers.
- ***Nova Scotia.*** The regional manager forwards problems to the director of engineering.
- ***Ontario.*** Information is provided through personnel contact with the district supervisor or engineer, maintenance management records (costs/activities), and personnel knowledge about the road.
- ***Quebec.*** Consult district and regional authorities.
- ***Saskatchewan.*** Head office or district operational staff review designs at preliminary stages, maintenance has opportunity for input at that time.
- ***Bureau of Indian Affairs.*** The designer makes assumptions on information informally.
- ***Port Authority of New York and New Jersey.*** Direct discussion with staff as necessary during design and at the contract document review phase.
- ***Hennepin County, MN.*** Consult with the maintenance engineer.
- ***Maricopa County, AZ.*** During various review stages.

8. How are designers made aware of maintenance problems caused by specific designs so future designs can be improved?

- ***Alabama.*** Requests during design reviews for new construction projects; selection and plan preparation on 4R projects.
- ***Arkansas.*** Quarterly deficiency review with construction, FHWA and roadway design.
- ***California.*** Personal contact and reports from maintenance personnel.
- ***Colorado.*** The staff design engineer attends maintenance superintendent meetings and district staff meetings.
- ***Connecticut.*** The director of maintenance notifies preconstruction.
- ***Florida.*** Through VE team discussions.
- ***Hawaii.*** By district offices.
- ***Idaho.*** Post-construction reviews include maintenance.
- ***Illinois.*** Design policies and standards revised based on MMIS.
- ***Iowa.*** Communication from central maintenance and districts.
- ***Kentucky.*** Maintenance personnel advise district personnel of common problems. Some discussion also occurs.
- ***Louisiana.*** Input from district construction, district traffic and district maintenance in the predesign and final reviews.
- ***Maine.*** Through comments at final field inspection and development of design process.
- ***Maryland.*** Field reviews.
- ***Massachusetts.*** Through maintenance interaction with design committees.

- ***Michigan.*** Maintenance needs are requested at project initiation and at formal reviews. Maintenance is involved in the formal post-construction reviews to find improvements.
- ***Minnesota.*** The maintenance engineer consults with the design engineer.
- ***Missouri.*** Coordination between district maintenance and design personnel.
- ***Montana.*** Feedback from districts through design and program review meetings and correspondence through the Helena headquarters maintenance bureau.
- ***Nebraska.*** Through district engineers, information from yearly reviews of selected projects.
- ***Nevada.*** It is difficult. Information may not get to the designer that needs it.
- ***New Hampshire.*** Communication between road design and maintenance. Maintenance participation with road design, traffic and construction in developing standards.
- ***New Jersey.*** Through the normal plan review process at each stage of the phase review process.
- ***New Mexico.*** Construction reports to project development via project review reports.
- ***New York.*** No formal procedure. Depends on degree of cooperation and communication between design and maintenance in each region.
- ***North Carolina.*** Field reviews. A design-maintenance conference was held in 1981.
- ***North Dakota.*** Transmitted from maintenance engineer to design engineer.
- ***Ohio.*** Maintenance and design engineers talk informally on projects.
- ***Oklahoma.*** Normally communicate openly with field divisions.
- ***Oregon.*** Post-construction narrative, memos, phone calls from region construction and maintenance personnel, and the district maintenance supervisor reviews plans and specifications prior to advertising.
- ***Pennsylvania.*** Intra-office memos and staff meetings periodically or for specific problem projects.
- ***Rhode Island.*** The maintenance division comments directly on features that may present (or have caused) problems.
- ***South Carolina.*** By memos or conversations with district maintenance personnel.
- ***South Dakota.*** Through discussions with project engineers and feedback at annual engineer and maintenance meetings.
- ***Texas.*** The resident engineer organization (described in Question #1) provides direct maintenance input into the design process.
- ***Utah.*** Maintenance notifies the design engineer directly. The standards committee of the department can modify or change standards drawings or specifications if it will mitigate maintenance problems on highways in the future.
- ***Vermont.*** Memos, pictures and word of mouth from maintenance personnel.
- ***Virginia.*** The resident engineer, post-construction reviews, and the quality assurance program.
- ***Wyoming.*** Directly from maintenance people involved.

- ***Alberta.*** From the district transportation engineer and the operations branch on surfacing and materials designs.
- ***British Columbia.*** No formal system, just by general communication.
- ***Nova Scotia.*** The regional manager forwards problems to the director of engineering.
- ***Ontario.*** Direct feedback during construction, following construction through pavement reports on failures and district and regional personnel bring information to the design organization.
- ***Quebec.*** Maintenance personnel contact designer with problems.
- ***Saskatchewan.*** System-wide concerns: review, update or development of design standards. Project-specific concerns: project upgrade reviews.
- ***Bureau of Indian Affairs.*** Public and maintenance operations foreman.
- ***Port Authority of New York and New Jersey.*** The facility staff notifies the design staff.
- ***Hennepin County, MN.*** The maintenance engineer consults with the design engineer.
- ***Maricopa County, AZ.*** Maintenance personnel communicate with design personnel.

9. Please describe examples of maintenance problems submitted by maintenance, traffic operations or construction personnel.

The following problems were listed by more than one agency.

Problems	No. of Responses	Problems	No. of Responses
Drainage problems/design	12	Erosion at bridge ends	3
Slope stability	9	Flatten slopes	3
Pavement deterioration	8	Guardrail design changes	3
Ditch erosion	7	Location of controller cabinets	3
Culvert design	5	Paved shoulder treatment	3
Bridge joints	4	Pavement designs	3
Drain pipe deterioration	4	Roadway settlements	3
Improve intersection design	4	Delineator spacing/other problems	3
Raised islands and medians	4	Ditch design for snow storage	3
Snow conditions	4	Concrete barrier deterioration	2
Traffic control plans	4	Crossovers	2
Vegetation control under guardrail	4	Culvert end erosion	2
Curb and gutter designs	2	Rutting of asphalt pavements	2
Fence deterioration	2	Shoulder maintenance	2
Joint maintenance	2	Shoulder paved 2-feet wide	2
Lane deficiencies	2	Sign support designs	2
Open-graded friction course raveled	2	Thermoplastic pavement markings	2
Pave islands	2	Underdrain outlet improvements	2
Paved ditches	2	Vegetation to reduce mowing	2

One agency listed each of the following problems:

Barriers in way of snow removal equipment
Bridge approach slabs/relief joints
Bridge deck problems
Cable GR on outside of curve -- excessive hits
Cable guardrail -- snow drifting
Portable lighting maintenance
Pump house design
Pavement joints guide traffic
Raised pavement markers
Relamping difficulties
Concrete barrier instead of guardrail
Construction safety
Culvert inlet and outlet access
Fencing water gaps
Frost heaves
Glare screen design
High accident locations
Landscape maintenance cost
Latex additive in bituminous layers
Living snow fence
Location of electrical junction boxes
Median designs
Monolithic paved islands
Maintenance during construction
Maintenance operations under high traffic volumes
PCC pavement -- anchor lugs
Patching procedures
Pavement marking deterioration
Pavement surface drainage
Plugged catch basin grates
Repair frequency of BCT guardrail ends
Rest area designs
Rock/obstruction removal for mowing
Rodent screens on drain outlets
Shoulder rumble strip addition
Shoulder strengthening for traffic
Shoulders -- aggregate in lieu of dirt
Signal timing
Signal wiring designs
Standardized materials components
Storage of construction equipment
Temporary pavement markings
Temporary roadways
Traffic loop problems
Traffic signal mounting corrosion
Trash guards on culverts plug up
Traversable culvert end sections
Underdrain installation
Wall failures
Waste material usage

10. How do designers communicate special maintenance needs of their designs (such as operation of traffic controllers or location of underdrain outlets) to maintenance personnel?

- ***Alabama.*** Review designs where maintenance problems could exist with maintenance personnel.
- ***Arkansas.*** Field inspection with district construction personnel.
- ***California.*** Personal contact, telephone and written reports.
- ***Colorado.*** Direct communication with foremen and/or district maintenance superintendent.
- ***Connecticut.*** Maintenance responds to review plans and identify special needs.
- ***Florida.*** Special notes on the plans.
- ***Hawaii.*** Review of plans prior to advertising.
- ***Idaho.*** Plans and information are provided to maintenance.
- ***Illinois.*** District maintenance reviews final plans. Central maintenance reviews design policies and standards.
- ***Iowa.*** Workshops, seminars, discussions in field, field reviews and good communications.
- ***Kansas.*** Direct contact from the designer to the area engineer.
- ***Kentucky.*** Inspections, direct correspondence and conversation.
- ***Louisiana.*** Field inspection at sites, written and verbal communication or from standard details in plans.
- ***Maine.*** Verbal communication with maintenance personnel.
- ***Maryland.*** Construction notes on the plans and in special provisions.
- ***Massachusetts.*** Through design and record plans.

- ***Michigan.*** Receive a set of plans. Maintenance should be informed during design through attendance at field inspections.
- ***Minnesota.*** Formally and informally consult with each other.
- ***Missouri.*** Coordination and complete design plans.
- ***Montana.*** Memos, field reviews, plans distribution and plan reviews.
- ***Nebraska.*** Telephone contact.
- ***Nevada.*** This can be a problem: i.e., truck escape ramp arrester beds need to be raked at regular intervals to keep rolling resistance of beds high so that runaway trucks don't run full length of arrester bed, especially at speeds lower than design speed.
- ***New Hampshire.*** Contract plans are distributed to the maintenance district engineers to alert them to common and special design features. Steel witness markers are placed at sides of road to locate culverts and underdrains.
- ***New Jersey.*** Meetings, phone, memos, and maintenance comments solicited on special items prior to incorporation into design.
- ***New Mexico.*** Through project plans and inspections.
- ***New York.*** Traffic signal maintenance crews work for regional traffic which is involved in signal design. Maintenance receives as-built plans which note drainage.
- ***North Carolina.*** Written instruction and transmittal of construction plans.
- ***North Dakota.*** Through district personnel during the design process.
- ***Ohio.*** Informal communication between maintenance personnel and designers.
- ***Oklahoma.*** Discussed at plan-in-hand and joint meetings with field division engineers.
- ***Oregon.*** Occasionally, write operations and maintenance instructions. Request markers be installed at underdrain outlets.
- ***Pennsylvania.*** Field reviews with maintenance at project inception, designers consult with maintenance staff as project develops as needed to verify solutions to existing or anticipated maintenance problems, intra-office memos, and hold staff meetings periodically or for specific problem projects.
- ***Rhode Island.*** Correspondence during design phase and maintenance reviews all design submissions.
- ***South Carolina.*** Plans, standard drawings and specifications.
- ***South Dakota.*** Currently insufficient. More communication is desirable.
- ***Texas.*** The resident engineer organization (described in Question #1) provides direct maintenance input into the design process.
- ***Utah.*** Designer furnishes project plans to maintenance for review from start to finish.
- ***Vermont.*** Through finance and maintenance agreements, stormwater discharge permits, special provisions and project plans.
- ***Virginia.*** Annual meeting, post-construction inspections and sign delineation.
- ***Wyoming.*** Construction plans.

- ***Alberta.*** Notes to file forwarded to district personnel (details are located on the design plans) or identified in the as-built final information and details if significant changes made.
- ***British Columbia.*** Send drawings and specifications to maintenance with maintenance manuals for special features: i.e., pumps, bridges, dikes, etc.
- ***Ontario.*** During pre-construction engineering process, provision of special maintenance contracts by others working for the district after construction and acceptance, by putting on technology courses and seminars, and through maintenance organization and functional head office organizations.
- ***Quebec.*** Meetings, letters, technical reports, product specifications, standardization, etc.
- ***Saskatchewan.*** Contract drawings and documents, formal transfer of project from design to construction to maintenance provides opportunity to identify special project factors, and informal communication between district design, construction and maintenance engineers.
- ***Bureau of Indian Affairs.*** Network of communication is non-existent.
- ***Port Authority of New York and New Jersey.*** Meetings with facility staff.
- ***Hennepin County, MN.*** Formal and informal consultation.
- ***Maricopa County, AZ.*** Let maintenance review plans before construction.

11. List specific designs used to alleviate maintenance problems and reduce maintenance costs.

Designs	No. of Responses	Designs	No. of Responses
Flatten slopes	13	Install underdrains	4
Pavement design	10	Vegetation to reduce mowing	4
Paving under guardrail	9	Culvert end erosion control	3
Concrete barriers instead of guardrail	8	Drainage structure clean outs	3
Erosion control design	8	Eliminate raised channelization	3
Pave shoulders	8	Pave approaches/driveways	3
Lined drainage ditches	7	Bridge end drain system	2
Plastic pavement markings	6	Bridge joint design improvement	2
Catch basin design	5	Concrete shoulders	2
Culvert design	4	Curb design	2
Energy dissipators on drainage struct.	2	Improvements for snow removal	2
Galvanize bridge rail	2	Outlet protectors for underdrains	2
Improve drainage design	2	Stage construction to allow settlement	2
Improved intersection design	2	Subgrade height to reduce snow drift	2

The following designs were each implemented by one agency:

Design	Design
3-lane bridge design	Longer guardrail posts
Alternative guardrail parts	Maintenance engr. on standard plan review
Anchor lugs on PCC pavement	Mark striping prior to seal coating
Approach graded to drain away from road	Median barrier location
Barrel mounted guard fence design	Median opening locations
Barrier wall design	Minimum culvert size = 24" diameter
Beam guardrail in lieu of cable	Monolithic paved islands
Beefed-up shoulder design	Move hazards to reduce guardrail

Breakaway sign bolts
Breakaway supports
Bridge approach slabs
Bridge drain size increased
Bridge steel paint -- easier inspection
Cable guardrail -- snow drifting
Cattleguard improvements
Clean-outs on bridge drainage `system
Concrete cross pipes
Controlled blasting
Culvert materials
Drainage problem corrections
Earth ditch checks
Elastomeric bearing pads
Elim. OH sign lights on lighted roadways
Extend box culvert beyond clear zone
Extend bridge spans to eliminate GR
Flat bottom ditches
Guardrail -- 12.5' sections instead of 25'
Guardrail end treatment
HFX foam impact attenuators
Impact attenuator selection
Improved erosion control materials
Improved pavement joint design
Improved pavement joint materials
Improved pavement surface drainage
Improved sign support to ease sign replacement
Install wires in conduits
Landscaping design
Larger field entrance culverts
Latex additive in bituminous layers
Latex concrete bridge deck wearing surface
Living snow fence
Mowing pads by retaining walls
Noise wall materials
Oversized culverts to prevent plugging
Paved medians and islands
Paved median design
Photo record of hydraulic structures
Pipe instead of open ditches
Post-construction QC meetings
Provided snow storage area
Pump house design
Raised pavement markers
Recessed pavement markers
Replaced fencing
Replaced bridges with box culverts
Replaced small bridges with pipe culverts
Retain construction median cross-overs
Seeding all disturbed areas
Selection of safety devises
Shoulder curb installation
Shoulder design in snow areas
Sign mounting height -- mower clearance
Sign panel materials
Slope pavement edge -- minimize shoulder blading
Sloped ends of drain outlets
Special freeway management systems
Stabilize gravel shoulders
Standardize components
Standardize traffic controllers
Subbase design
Thicker shoulders at ramps
Traffic signal controller location
Underdrain outlet improvement
Water gap gates

Bridge Design

1. Is maintenance considered in design?

Fifty-two do consider maintenance in bridge design; one does not.

If yes, is the process formal or informal?

Six agencies have formal processes for consideration of maintenance in bridge design: California, Connecticut, Maine, Minnesota, Oregon, and Ontario.

If yes, is maintenance considered on all bridges or only on special-design bridges?

Forty-eight of the 52 agencies consider all bridges.

Are maintenance personnel involved in the process?

Maintenance is involved in 38 of the agencies -- 73 percent of the agencies.

Role of Maintenance?

- ***Alabama.*** Advise on designs and details causing maintenance problems and suggest solutions.
- ***Arizona.*** Provide input directly from the bridge maintenance branch. Coordinated through a review process by bridge operations services.
- ***Arkansas.*** The district engineer is involved in the preliminary design stage and is responsible for maintenance in his district, design gets input from his maintenance experience.
- ***California.*** A structure maintenance engineer participates in the type selection review meeting.
- ***Connecticut.*** Design plan review with recommendations and/or comments referred to the design division through the bridge maintenance manager, reviews are conducted by the district bridge superintendents and senior engineers, the manager of bridge maintenance reviews with respect to statewide continuing maintenance considerations.
- ***District of Columbia.*** They are consulted by project managers and engineers.
- ***Florida.*** Review of design plans at about 90% completion, also involved in preparing design requirements included in our design guidelines book.
- ***Hawaii.*** The field consultant unit in the bridge design section deals with maintenance of structures and is in contact with maintenance engineers of the various districts. Input is primarily for in-house designed bridges.
- ***Idaho.*** Process informal and therefore lacks consistency which results in limited maintenance input; the level of management is generally the bridge design group leader and the district project development supervisor.
- ***Illinois.*** District bridge maintenance engineers review preliminary plans.
- ***Iowa.*** Middle and upper management discuss maintenance considerations to be incorporated into a project.
- ***Kansas.*** Through a project field check.
- ***Kentucky.*** They informally provide us with feedback about suggested changes in design and/or details to eliminate or reduce problems.
- ***Louisiana.*** Bridge inspections, reports, sketches, pictures verbal descriptions, field review, bridge rating and postings, bridge overlays. Design advised by maintenance of problems on regular basis.
- ***Maine.*** Preliminary and construction plans are sent to the bridge maintenance engineer for review.
- ***Maryland.*** Bridge inspectors provide feedback on elements which present maintenance concerns; we modify design details to reduce concerns.
- ***Massachusetts.*** Not officially. Maintenance concerns are forwarded to the bridge section for consideration. No formal vehicle by which maintenance reviews bridge designs.
- ***Michigan.*** Design is cognizant of bridge features that contribute to sound maintenance and features detrimental to good maintenance. Maintenance engineers review all preliminary bridge plans in central and district offices.

- ***Minnesota.*** Regional construction and maintenance liaison engineers review plans when they are completed and provide input based on their experience.
- ***Missouri.*** A continued dialogue with maintenance personnel.
- ***Montana.*** District maintenance comment on bridge layout at time of plan-in-hand inspections.
- ***Nebraska.*** Field trips with the district engineer to evaluate bridge sites and note maintenance problems.
- ***Nevada.*** The assistant district engineer for maintenance plus the district maintenance superintendent or foreman join in FHWA post construction reviews on selected projects and may also be involved in preconstruction field reviews.
- ***New Hampshire.*** The administrator of the bureau of bridge maintenance and/or his assistant are sent preliminary bridge plans to review for new designs. They are consulted for suggestions on bridge rehabilitation projects.
- ***New Jersey.*** They review bridge plans based on nature of project.
- ***New Mexico.*** Fairly close day-to-day working relationship between maintenance personnel and bridge design personnel.
- ***North Carolina.*** When a bridge is designed, the structure design project engineer may check with maintenance personnel (usually assistant unit head) for maintenance recommendations. The Structure Design Manual has maintenance considerations outlined for some bridges.
- ***Ohio.*** Informal process where design solicits feedback from maintenance on various features of design.
- ***Oregon.*** Review of contract plans-input on details to be included in office practice standards by the district maintenance engineer, region bridge maintenance engineer, and state bridge maintenance engineer.
- ***South Dakota.*** Part of plan review process, asked for input on structure, TS and L participation by field, preliminary layout materials reviewed by field.
- ***Washington.*** Normally on bridge rehabilitation projects there is active involvement by the bridge condition inspection unit supervisor and the district bridge maintenance supervisor. In design of new bridges their input is limited to needed provisions for bridge inspection and maintenance access.
- ***Wyoming.*** Comments and maintenance problems reported informally to the bridge office by the district maintenance engineers.
- ***Alberta.*** An organizational unit represented at middle and lower management levels has as its major role the maintenance of structures. They review new designs for maintenance considerations. An engineer is also specifically concerned with developing quantitative tests for durability of sealers, deck surfaces, concrete, etc.
- ***British Columbia.*** Standard design details and standard bridge components are established by the standards committee. The bridge construction manager and the plant inspection engineer are included to identify and minimize maintenance problems.
- ***Manitoba.*** Maintenance personnel regularly apprise our designers regarding maintenance problems.

- ***Ontario.*** The regional structural section heads are responsible for the design, inspection, maintenance and rehabilitation of bridges, head office structural section heads for design and policy setting, and the structural durability committee for policy setting.
- ***Saskatchewan.*** Designers have dialogue with maintenance staff. The bridge maintenance manager reviews contract documents.
- ***Port Authority of New York and New Jersey.*** The operating department for the facility solicits input from facility maintenance staff and facility manager. Information is forwarded to the engineering department.
- ***Hennepin County, MN.*** The design engineer requests review by maintenance engineer before advertising for bids.
- ***Maricopa County, AZ.*** Recommended projects for improvement; discussion of maintenance problems.

At what stage of design is maintenance involved?

- ***Alabama.*** Preliminary and rehabilitation.
- ***Arizona.*** All stages.
- ***Arkansas.*** Preliminary design.
- ***California.*** At the type selection review meeting.
- ***Connecticut.*** After the type of structure, span lengths, and materials of construction have been established by design at approximately 20% complete and generally at the semi-final stage (90% complete). For special structures, progress plans or special intermediate submissions may also be reviewed.
- ***District of Columbia.*** At any stage deemed necessary.
- ***Florida.*** Generally at the 90% stage and at an earlier stage on major structures where they may have significant impact.
- ***Hawaii.*** All phases of in-house projects.
- ***Idaho.*** Major structures: concept stage. Other structures: during preliminary design review.
- ***Illinois.*** Preliminary plans.
- ***Iowa.*** At the beginning stage.
- ***Kansas.*** At the field check.
- ***Kentucky.*** They are not involved on specific projects but they provide us with feedback intermittently as problems arise so that policies or practices can be revised.
- ***Louisiana.*** Preliminary plans: at plan-in-hand, and continuously as problems develop. Maintenance personnel are given a chance to review final plans.
- ***Maine.*** At the preliminary and final design stages.
- ***Michigan.*** Preliminary plan stage, final plan stage, and post-construction.
- ***Minnesota.*** When plans are complete.
- ***Missouri.*** None defined.

- ***Montana.*** Preliminary plan-in-hand.
- ***Nebraska.*** Prior to preliminary design recommendations.
- ***Nevada.*** Field reviews and post-construction critiques.
- ***New Hampshire.*** Detailed plan review occurs at the 30% stage. Maintenance is also involved in final project issues meetings, however this is a more general overview.
- ***New Jersey.*** Maintenance is involved in earliest decisions about executing needed repairs and whether or not work should be done by consultant.
- ***New Mexico.*** Not directly involved in design. Discuss solutions of observed problems with bridge design.
- ***North Carolina.*** Throughout entire design cycle for different bridge components.
- ***Ohio.*** All stages.
- ***Oregon.*** Prior to design: input into office standards. Preliminary design: input into project location narrative. Final design: review of contract plans.
- ***South Dakota.*** Limited involvement in all stages.
- ***Utah.*** The structures division has responsibility to perform bridge inspections on all bridges in the state, so the division is aware of problem areas and takes measures to eliminate them in future projects.
- ***Washington.*** Preliminary and final design stages.
- ***Wyoming.*** Resident engineers submit project recommendations. The small size of Wyoming's staff allows close liaison between resident engineers and maintenance personnel.
- ***Alberta.*** Preliminary engineering stage, at point where the structure type is chosen and then at final acceptance of design.
- ***British Columbia.*** Preliminary/conceptual stage.
- ***Manitoba.*** Ongoing day-to-day basis.
- ***Ontario.*** Regional and head office structural section heads: throughout the design stages. The durability committee reviews details as needed.
- ***Saskatchewan.*** During the design and at the pre-tender stages.
- ***Port Authority of New York and New Jersey.*** Preliminary and final design phases.
- ***Hennepin County, MN.*** When plans are 80% to 100% complete.
- ***Maricopa County, AZ.*** Prior to actual design and review of all detail plans.

2. Which factors are included in evaluating alternative designs?

Factor	No. of Responses	Factor	No. of Responses
Construction costs	46	Aesthetics	3
Operation & maintenance costs	36	Engineering evaluation	2
Traffic disruptions for maintenance	28	Environmental concerns	2
Design costs	20	Traffic handling during construction	2
User costs	15	Scour susceptibility	2
Constructability	3	Construction inspection costs	1

Cost of shop drawing reviews	1	Life-cycle costs	1
Ease of inspection	1	Maintainability	1
Fatigue considerations	1	Navigational requirements	1
Fracture criticality	1	Prefabrication	1
FHWA advisories	1	Rehabilitation feasibility	1
Improvements in state-of-the-art	1	Utilities	1

Most agencies listed more than one factor.

Who makes the evaluation?

Evaluator	No. of Responses	Evaluator	No. of Responses
Bridge designer	14	Assist. director -- design	1
Bridge engineer (div. head)	10	Area road engineer	1
Bridge division	10	Bridge planner	1
Design squad leader	4	Construction	1
Design team	4	Design division	1
Preliminary bridge design	3	Estimating office	1
Assistant bridge engineer	2	Traffic engineer	1
Maintenance	2		

3. Is life expectancy of materials and components considered?

Forty-three agencies answered yes; ten no.

If yes, provide examples:

- ***Alabama.*** Long-life bearings, heavy joint armor, dense, high-strength concrete decks, corrosion resistant piling or protection, and high-quality paint system.
- ***Arizona.*** Epoxy coated rebar, preference for major structures with greater mass or dead-load to live-load ratios.
- ***Arkansas.*** Additional cover of top deck reinforcing, epoxy coated bars in decks and rail, use of A588 structural steel, use of continuous spans, and prohibit asphalt overlays on decks.
- ***Connecticut.*** Membrane waterproofing/latex concrete wearing surface to extend life of reinforced concrete bridge decks, use of epoxy coated rebar in bridge decks, parapets, pier caps and columns; apply protective compounds to concrete surfaces subject to adverse environment; limit use of cathodic protection to bridge decks and isolated pile foundations; various materials are used on experimental basis for observation and evaluation for purpose of acceptance/rejection; and restrictions on the use of weathering steel.
- ***Florida.*** Effects of chloride intrusion in our bridges dictates minimum height of concrete or steel beams over salt water, extremely aggressive environmental dictates type of cement, use of additives and/or sealants, and piles in footers kept below mean low water level at all times to avoid splash zone wherever possible.
- ***Hawaii.*** Steel and concrete structures designed for 50 years; timber for 35 years.
- ***Idaho.*** We design all bridges in conformance with AASHTO Design Specifications. These specifications contain requirements for fatigue in the design of steel members and crack control for concrete members. Material specifications for various components have special requirements to insure each component functions properly and serves the intended life (i.e., TFE bearing surfaces).

- ***Illinois.*** Concrete system is used instead of steel in many situations where first costs would indicate steel as the appropriate material and concrete overlays instead of Class I in many situations.
- ***Iowa.*** Class of aggregate in concrete mixes.
- ***Kansas.*** Cast-in-place vs. structural steel, deck overlays versus extra top bar clearance.
- ***Louisiana.*** Concrete is material of choice over steel because of initial costs and future maintenance.
- ***Maine.*** Timber decks are considered to last 25 years, steel grid floors 30 years, concrete decks 40 years; structural plate structures (culverts > 10-foot span) are considered to last 50 years and buried concrete structures 75 years.
- ***Maryland.*** We have included cathodic protection for deck repairs where the deck is an integral part of the superstructure (box girders). We use coatings on concrete where it's susceptible to chloride damage.
- ***Michigan.*** Epoxy coated bars versus bare steel, 4.5 ksi steel versus 3.5 ksi concrete for decks, modern paint system of zinc rich primary epoxy and urethane top coat, concrete deck on box beams versus bituminous, and PVC deck drains versus galvanized steel.
- ***Minnesota.*** From experience, materials that have not performed well in the past are not used.
- ***Missouri.*** From lab tests or other research data available from other sources.
- ***Montana.*** Bulb tee prestressed versus steel with cast-in-place deck -- grouted joints between tees have more maintenance but less initial cost.
- ***Nebraska.*** Widening or rehabilitation of superstructure with timber substructure with limited life span.
- ***New Hampshire.*** High quality paint systems used to decrease life cycle costs, higher quality concrete sealers used to increase time before reapplication is required, epoxy coated rebar to increase life of concrete bridge decks, and timber bridge members are pressure treated to maximize life expectancy.
- ***New Jersey.*** Materials are selected based on ability to serve the intended bridge design life.
- ***New Mexico.*** Gathering data from observation of bridges on the interstate system in regard to deck life, evolution of performance of bridge deck overlays, fatigue life of steel bridges, performance of details (i.e., expansion joints, bearings, etc.)
- ***New York.*** Comparison between concrete and steel and the limitations of each material as a bridge component.
- ***North Carolina.*** Bearing types, joint types, and prestressed concrete bridges versus steel bridges.
- ***North Dakota.*** Expansion joints.
- ***Ohio.*** Policy on A588 steel and prestressed boxes chosen over reinforced concrete slabs.
- ***Oregon.*** All materials incorporated in structures have life expectancy of 50 years or better, exception: deck overlays.
- ***Pennsylvania.*** Our design guidelines require specific life expectancy (100 years on most new designs).

- ***South Dakota.*** Epoxy-coated reinforcing steel versus black, paint systems, concrete strengths, fatigue life, corrosion considerations.
- ***Texas.*** Various types of expansion joints, asphalt versus concrete overlay, and bridge bearings.
- ***Utah.*** Economics is the essence of engineering. Life expectancy determines the suitability of any material.
- ***Virginia.*** All materials designed into permanent structure expected to last approximately 50 years.
- ***Washington.*** Use epoxy coated rebar in marine environments and in top of reinforced concrete slabs. Elsewhere is standard non-coated. Quest for "best" bearing assemblies available and for more durable expansion joints is evidenced by establishment of senior engineering specialist to oversee this area. Tried corrosion inhibitors, epoxy coated PT strands, and higher strength lower water/cement concrete. Working towards shop and/or field applications of 3-part urethane paint systems.
- ***Wyoming.*** In Wyoming's dry climate, both concrete and steel perform well. Freeze-thaw damage can be severe so adequate protection from salt water due to de-icing action is considered.
- ***Alberta.*** Plant-cast concrete is used instead of CIP concrete whenever geometry and structure type allow, large steel culverts may now influence greater use of CIP concrete arch culverts, steel girders always made from weathering steel, extensive use of epoxy coated rebar made in addition to deck waterproofing systems on structures receiving de-icing salt, galvanizing extensively used for steel inserts, bearings, etc.
- ***British Columbia.*** Timber versus steel or concrete, painted steel versus unpainted, various painting systems, and waterproofing membranes.
- ***Ontario.*** The procedure is explained the Ministry's "Structural Financial Analysis Manual."
- ***Quebec.*** Wood piles in saturated soils considered permanent, wood cribs for piers, abutments and wall have service life of 20 to 30 years, steel and concrete structures minimum life expectancy of 50 years, concrete decks on high density bridges have a life expectancy of 20 years -- or more when done with special concrete or on decks protected by waterproof membrane.
- ***Port Authority of New York and New Jersey.*** When economically competitive, longer life product is specified, i.e., coatings such as paint systems, galvanizing and epoxy coatings for steel, longer life wearing courses, denser, higher quality concrete mixes.
- ***Hennepin County, MN.*** Estimate based on annual inspections.
- ***Maricopa County, AZ.*** Simplified designs to eliminate potential problems.

4. Does your agency have a value engineering review process?

Thirty-four of the 52 agencies (65 percent) who reported have value engineering procedures in place.

If yes, are maintenance personnel involved in the process?

Maintenance personnel participate in value engineering in 24 of the 34 agencies.

If yes, describe their role in VE:

- ***Alabama.*** One of five team members.
- ***Arizona.*** Indirectly, see the answers to Questions 1 and 6.
- ***Arkansas.*** As a member of a value engineering team.
- ***California.*** Maintenance is asked to estimate remaining service life.
- ***Florida.*** As a member of the team reviewing plans.
- ***Illinois.*** If a value engineering proposal affects the future maintenance of the bridge we consult the bureau of maintenance for advice and comments.
- ***Iowa.*** VE reviews are completed by VE teams. Maintenance has members on many of the teams.
- ***Louisiana.*** We consider that we do continuous VE from conception to completion of plans on each project; all sections and areas of the department and the public are continuously involved.
- ***Maryland.*** VE teams include representatives from a broad range of disciplines including maintenance.
- ***Michigan.*** As a part of a VE team with primary responsibility to provide maintenance input.
- ***Minnesota.*** Sometimes VE studies are performed on selected projects. Maintenance personnel may be part of the team.
- ***Nevada.*** Field maintenance supervision is included on VE teams.
- ***New Jersey.*** Depends on project. Maintenance people may be on a VE team.
- ***North Carolina.*** Maintenance does not have a representative on the VE committee but is involved on special structures.
- ***Oklahoma.*** Participate with personnel from all other areas of the department in a VE process at the preliminary plan stage.
- ***Oregon.*** Participate on VE teams and provide information on specific VE projects as requested.
- ***Pennsylvania.*** Depending on type of project, our districts establish the VE teams. Where appropriate a maintenance person is a member of the VE team.
- ***Texas.*** Maintenance personnel involved in appropriate projects. They have input on matters in which they have working knowledge.
- ***Utah.*** Serve on review committee.
- ***Virginia.*** Maintenance personnel may be on VE team.
- ***Washington.*** Indirectly, as a resource to VE team members.
- ***Wyoming.*** VE teams are established for temporary study of problems.
- ***Alberta.*** VE exists only informally, not in current sense of VE. At times it takes form of hindsight.
- ***British Columbia.*** Though no formal VE provisions are in contracts, sometimes contractors' suggestions are adopted (used churn drilled pipe instead of building a coffer dam) for foundation construction to save cost (approximately 30%), and precast concrete deck form instead of conventional timber forms to save construction time only.

- ***Quebec.*** Feedback from maintenance and inspection personnel is communicated to chiefs of design teams during meetings and then transferred to designer through written design directives.
- ***Bureau of Indian Affairs.*** VE is done on informal basis and is considered on a project-by-project basis.
- ***Port Authority of New York and New Jersey.*** They are represented through the operating department staff who sits on the VE team.

5. Does your agency have a bridge management system in use?

Of the 48 agencies that answered this question, 12 have bridge management systems (BMS) in use, four have systems nearly completed and 7 are in the developmental stage.

If yes, how is it used in the design process?

- ***Alabama.*** System under development. Expect to get life-cycle costs, including those for construction, maintenance and replacement.
- ***Hawaii.*** Setting priority listing of structures to be replaced and/or rehabilitated.
- ***Kansas.*** Prioritized projects for replacement, rehabilitation, and maintenance.
- ***Michigan.*** In process of developing -- currently have portion that establishes priorities for bridge rehabilitation using bridge inspection data to identify deficiencies.
- ***New Jersey.*** The NJ DOT bridge management system is not fully developed. It identifies structural needs, prepares preliminary work scopes and associated costs, prioritizes groups of structures, and models future bridge needs.
- ***New Mexico.*** In process of development. The system is used to select bridges for replacement based on load capacity, adequacy of geometrics and remaining life; on interstate system bridges are selected for rehabilitation and replacement based on field inspections of all bridges by district inspectors and bridge design personnel.
- ***Oregon.*** Being developed; consideration of life cycle costs involving maintenance costs.
- ***Pennsylvania.*** In prioritizing maintenance, rehabilitation, and replacement work, and is also used in determining parametric studies, when required, to support decisions on type of detail, material and/or bridge.
- ***South Dakota.*** In preliminary stages of developing computerized BMS. Now setting up data base. Existing bridge maintenance file and NBIS inspections were reviewed to gain site-specific information.
- ***Utah.*** In the process of developing a BMS.
- ***Washington.*** Have a bridge deck management system and a 20-year bridge preservation plan, but are 4 to 5 years away from having maintenance input to new designs in complete BMS. Our BMS allows minimal broad range of maintenance, rehabilitation, protection, and replacement (and "do nothing") strategies and encompasses use of many materials (including new and developing materials) . Have no BDMS process currently that has impact on design process.

- ***Alberta.*** Actually, present system consists of reacting, through repair, renovation or maintenance action when bridge inspections indicate problems or incipient problems. Elaborate bridge inspection management system (referred to in Question #9) provides current and useful information but it is not yet a management system per se.
- ***Ontario.*** To check life cycle costs of alternatives and to set priorities at network level.
- ***Quebec.*** The bridge management system is mainly used for scheduling inspection and planning maintenance; it is not considered in planning process.
- ***Saskatchewan.*** Where appropriate, repair, rehabilitation, strengthening, or replacement options are developed in response to needs identified by BMS.
- ***Bureau of Indian Affairs.*** Is not formally used.
- ***Port Authority of New York and New Jersey.*** The Port Authority conducts periodic biennial and hands-on inspections of its bridges. The detailed reports form a basis for prioritizing maintenance programs at all tunnel and bridge facilities.
- ***Hennepin County, MN.*** Annual bridge inspections and inventories are made and reviewed by the design engineer. Data are sent to MN DOT bridge office for filing and preparation of various conditions and priority reports.
- ***Maricopa County, AZ.*** Determining priority list.

What input does maintenance have to the bridge management system?

- ***Alabama.*** Maintenance, rehabilitation/repair and operating costs.
- ***Hawaii.*** Management system developed with input from maintenance personnel from all districts.
- ***Idaho.*** Bridge maintenance system being developed by the bridge maintenance section.
- ***Kansas.*** Maintenance requests bridge repair projects and is also involved through bridge inspection with establishing the bridge paint and repair program; maintenance personnel give input to bridge inspectors who are under the design section. District personnel accompany bridge inspectors on bridge inspections.
- ***Louisiana.*** Bridge inspection reports, pictures, verbal and written communications.
- ***Michigan.*** Bridge inspections conducted by maintenance engineers. Written report on each bridge is recorded in data base to be used in the bridge management system. Maintenance personnel also serve on bridge management system team.
- ***New Jersey.*** Type of work associated with maintenance costs and date of maintenance action are the primary data input by maintenance.
- ***New Mexico.*** Maintenance is primary division involved in the system being developed by the New Mexico State University.
- ***North Carolina.*** Maintenance uses system most of time.
- ***Oregon.*** Bridge inspection is a big part of the bridge management system. Bridge maintenance records provide part of inspection data.

- ***Pennsylvania.*** All bridge maintenance inspection done by bridge staff. Based on condition rating, maintenance is prioritized. Liaison between bridge units and maintenance staff is continuously maintained to ensure deficiencies are taken care of in a technically sound manner.
- ***South Dakota.*** Much of data base is provided by maintenance.
- ***Utah.*** Have good communication with and receive input from maintenance division; have bridge maintenance coordinator in structures division working with maintenance division
- ***Washington.*** Considerable input in some areas such as rehabilitation and major repair.
- ***Manitoba.*** Making every effort to put a BMS in place, any recommendations for proven system?
- ***Ontario.*** Maintenance and rehabilitation costs, priorities, and budget.
- ***Quebec.*** Inspection reports and maintenance repairs fed into management system.
- ***Saskatchewan.*** Provides inspection reports, identifies needs, participates in development, and provides feed-back for bridge repair or rehabilitation options.
- ***Bureau of Indian Affairs.*** Road and bridge maintenance are handled on priority need based on ADT and extent of repairs needed.
- ***Hennepin County, MN.*** Design engineer requests review and maintenance on conditions that require improvement.
- ***Maricopa County, AZ.*** Discussion of problems.

6. How does the designer obtain special maintenance needs for design from maintenance personnel during the design process?

- ***Alabama.*** Expect it to be through BMS data base.
- ***Arizona.*** Designers have direct contact with bridge maintenance staff, review files on bridge replacement projects and contact maintenance regarding bridge details.
- ***Arkansas.*** Study of inspection forms and by request to districts on rehabilitation projects.
- ***California.*** When working on rehabilitation or widening project, the designer is required to review previous bridge inspection reports containing needed work recommendations. Designers frequently discuss project with bridge maintenance engineering staff.
- ***Connecticut.*** Many details, policies and procedures in the department's Bridge Design Manual are based on historical maintenance concerns. The plan review process often serves to initiate valid commentary with respect to current department practices known to be deficient based on statewide maintenance observation and requirements.
- ***District of Columbia.*** The designer consults with maintenance personnel.
- ***Florida.*** It is part of reviews, for example, identify the need for special under-bridge platforms, access, etc.
- ***Hawaii.*** Verbally, for in-house projects.
- ***Idaho.*** The district design staff coordinates district needs including maintenance with centralized bridge design.

- ***Illinois.*** Maintenance is not typically consulted; however, in scour or ice jam prone locations maintenance is consulted.
- ***Iowa.*** The designer discusses projects with maintenance personnel when he determines there is a need to do so.
- ***Kansas.*** The designer asks specifically or at the field check.
- ***Kentucky.*** By direct contact with maintenance personnel.
- ***Louisiana.*** Personal interviews, field reviews, bridge inspection reports -- verbal and written.
- ***Maine.*** Designers frequently discuss specific design issues with bridge maintenance engineers and field managers.
- ***Michigan.*** All bridge plans, both preliminary and final, are subject to review by district and central office maintenance engineers. Standard details and standard procedures are under the constant scrutiny of field personnel, both maintenance and construction.
- ***Minnesota.*** Designers can discuss concerns with bridge construction and maintenance liaison engineer. For repair and reconstruction projects, maintenance sometimes requests special items.
- ***Missouri.*** By contacting maintenance personnel.
- ***Montana.*** District maintenance comments on plan-in-hand.
- ***Nebraska.*** Not routinely, occasionally a request may come from a district office.
- ***Nevada.*** Normally maintenance needs will be brought to the designers by district personnel during field or plan reviews.
- ***New Hampshire.*** Personal contact between the design chief and the bridge maintenance management. This works very well for the NH DOT as we are relatively small with centralized headquarters for bridge design and bridge maintenance.
- ***New Jersey.*** By sending a set of plans for their comments.
- ***New Mexico.*** Information of bridge failures and deterioration is relayed to designers from bridge inspectors and the construction unit of the bridge design section.
- ***New York.*** Maintenance is not directly considered in design process. There is no formalized information between bridge maintenance and bridge design.
- ***North Carolina.*** Very good coordination between the structure design unit and the bridge maintenance unit. When project engineers from structure design needs information they call or meet with appropriate maintenance personnel.
- ***North Dakota.*** Communication with districts.
- ***Ohio.*** Not during design process on a per job basis, except in certain instances.
- ***Oklahoma.*** Usually he does not receive such information.
- ***Oregon.*** From project location narrative, review of preliminary plans, and review of final plans by maintenance units.
- ***Pennsylvania.*** Through internal memos, BMS data base, and verbally.

- ***South Carolina.*** Designers work closely with bridge maintenance engineer for widening and rehabilitation projects including field inspection of structure and recommendation of repairs.
- ***South Dakota.*** Through plan review process and from inspection reports and previous maintenance history of the site.
- ***Utah.*** Normally does not. Information received from bridge inspectors and bridge maintenance coordinator.
- ***Vermont.*** Informal comments or communication.
- ***Virginia.*** Through district engineer and district bridge engineer.
- ***Washington.*** There is normally no interaction between bridge designers and maintenance personnel. Access issues relating to inspection are addressed through the management section of the bridge office.
- ***Wyoming.*** Through resident engineers' written recommendations.
- ***Alberta.*** When designers anticipate that certain details may be maintenance prone, they will individually review with maintenance personnel for improvement. However, separation by geography and authority structure does not foster this type of communication.
- ***British Columbia.*** Designers obtain special maintenance needs through direct contact with construction and maintenance personnel.
- ***Manitoba.*** Through ongoing discussions.
- ***Nova Scotia.*** Such problems are forwarded through the field staff to design staff, usually by memo.
- ***Ontario.*** Through reviews and discussions.
- ***Quebec.*** No special needs, except for contract plans and specifications.
- ***Saskatchewan.*** By talking to the maintenance personnel; all bridge related activities under management of one department unit.
- ***Bureau of Indian Affairs.*** May not be done at this time.
- ***Port Authority of New York and New Jersey.*** The operating department for the facility solicits input from facility maintenance staff and facility manager; information is forwarded to the engineering department.
- ***Hennepin County, MN.*** Discussions with maintenance engineer and annual visual inspections.
- ***Maricopa County, AZ.*** Review of plans.

7. How are designers made aware of maintenance problems caused by specific designs so future designs can be improved?

- ***Alabama.*** Bridge maintenance and construction personnel advise bridge designers verbally or in writing of construction and maintenance problems.
- ***Arizona.*** Copies of bridge inspection reports detailing special problems are sent to bridge design services.

- ***Arkansas.*** Inspection forms, informal conversations with the maintenance division, statewide construction and maintenance conferences, and discussions with district personnel at joint site inspections.
- ***California.*** Maintenance writes a memo to the technical committee chairman responsible for the specific area (i.e., joint seals, structural steel, etc.). The chairman issues a memo to designers with instructions. Each designer receives a copy and maintains a binder with these memos.
- ***Colorado.*** Maintenance problems are discovered by bridge inspectors. Inspectors relay problems to the bridge engineer who corrects future designs.
- ***Connecticut.*** Issues of administrative or departmental significance are channeled from the director of maintenance up through chain of command to the chief engineer and then to the assistant chief engineer of preconstruction for disposition by the division of designs. Issues of routine nature are handled directly between the director of maintenance and the director of engineering (designs) or sub-elements within the division of designs.
- ***District of Columbia.*** Maintenance personnel inform designers of specific design problems.
- ***Florida.*** Through design guidelines, i.e., prefer continuous structures thus eliminating expansion joints, maximizing beam spacing thus reducing cost and number of bearings, and require all bridges have provisions to allow removal and replacement of bearing pads.
- ***Hawaii.*** Verbally -- in-house, memos on occasion and/or field inspections.
- ***Idaho.*** In written and verbal reports from bridge inspections and district maintenance staff, and hold a pre-final bridge construction inspection with construction staff, bridge maintenance staff and bridge designer.
- ***Illinois.*** No formal system. Informal contacts between maintenance and bridge people provide the most information as well as participation in annual maintenance engineers' meetings.
- ***Iowa.*** Feedback received from maintenance as problems arise and review of existing bridges.
- ***Kansas.*** Bridge inspection managed by design.
- ***Kentucky.*** Maintenance personnel inform us verbally and by memo and by reading various technical publications.
- ***Louisiana.*** The design section is advised by the maintenance section of problems encountered on regular basis.
- ***Maine.*** Designers attend semi-final inspection to receive feedback from resident engineers and contractors. Bridge maintenance forwards a bridge completion report for every project with appropriate notes of concerns.
- ***Maryland.*** Bridge inspectors provide feedback on elements which present maintenance concerns; we modify design details to reduce concerns.
- ***Massachusetts.*** Informally by word of mouth and/or experience of engineers.
- ***Michigan.*** Maintenance uses phone, memos, or visits office.
- ***Minnesota.*** Bridge construction and maintenance liaison engineers inform designers of problems.
- ***Missouri.*** Maintenance personnel contact bridge personnel.

- ***Montana.*** Maintenance engineer communicates problem to bridge engineer. Bridge engineer tasks resolution of problem and disseminates information to design staff.
- ***Nebraska.*** Through policy changes in design, weekly staff meetings, field trips, input from construction personnel.
- ***Nevada.*** Post-construction conferences on selected projects and during the design field review process.
- ***New Hampshire.*** Direct contact from bridge maintenance management, usually with photos of specific problems that recently occurred at newly completed bridge projects.
- ***New Jersey.*** Feedback from maintenance and formal construction design reviews.
- ***New Mexico.*** By ongoing communications between field maintenance personnel and bridge design.
- ***New York.*** Through informal conversations or correspondence at the discretion of the maintenance person.
- ***North Carolina.*** There are several joint meetings between design and maintenance including workshops, seminars, and extensive field investigations.
- ***North Dakota.*** Data from the district offices.
- ***Ohio.*** Staff meetings between design and maintenance. District bridge engineers meet annually.
- ***Oklahoma.*** An engineer in bridge design is assigned the duty of obtaining information from bridge maintenance personnel about problem areas so that those problems can be corrected in future designs.
- ***Oregon.*** Office practice standards are continuously updated and include details and directives regarding maintenance features including suggestions and identified problems from field maintenance personnel and others.
- ***Pennsylvania.*** Through internal memos, BMS data base, and verbally.
- ***South Carolina.*** No formal process is in place. The bridge maintenance engineer advises design office as problems occur.
- ***South Dakota.*** Aware of construction problems through the bridge construction engineer, problems seen by the region bridge maintenance supervisor at final inspection are relayed to the design office, and review inspection reports and repeated repair conditions.
- ***Texas.*** The bridge division construction engineer advises the design section of design problems. In some cases, the district construction engineer may advise the bridge division of maintenance problems resulting from designs.
- ***Utah.*** Normally does not. Information referred from bridge inspectors and bridge maintenance coordinator.
- ***Vermont.*** Informal or written comments from bridge inspectors.
- ***Virginia.*** Through periodic meetings with field personnel.
- ***Washington.*** Through memos and Bridge Design Manual updates and sometimes through technical specialists within the bridge design office.
- ***Wyoming.*** Usually through verbal feedback from the district maintenance engineers.

- ***Alberta.*** Through management review of maintenance problems when filtered back and then formally through joint decisions, leading to approved standards and details; informally designers try to revise details if they are aware of problems.
- ***British Columbia.*** Through suggestions from the construction or maintenance personnel; through designers' own observations.
- ***Manitoba.*** Through ongoing discussions.
- ***Nova Scotia.*** Notified by field engineers.
- ***Ontario.*** Through inspection reports.
- ***Quebec.*** By the head of the design team who is in relation with maintenance officers of the regions and the special maintenance engineers who prepare plans and specifications.
- ***Saskatchewan.*** Through feedback from construction and maintenance reports.
- ***Bureau of Indian Affairs.*** By word of mouth followed by requests through contract or correspondence.
- ***Port Authority of New York and New Jersey.*** Through detailed condition surveys that are part of the preliminary design process and through detailed inspection reports on all Port Authority facilities.
- ***Hennepin County, MN.*** Discussions with maintenance engineer and visual inspections.
- ***Maricopa County, AZ.*** Discussion of problems.

8. Please describe examples of maintenance problems submitted by maintenance, traffic operations or construction personnel.

Maintenance Problem	No. of Responses	Maintenance Problem	No. of Responses
Bridge joints, expansion devices	26	Coating system performance	4
Bridge bearings	13	Scour -- footings	4
Deck drainage	12	Cracking/spalling -- substructure	3
Approach or approach slab settlement	6	End damage of pier caps/girders at expansion joints	3
Bridge drain system	5	Deck delamination	3
Concrete deterioration	5	Access for inspection/maintenance	2
Cracking of concrete decks	5	Damage from overheight loads	2
Erosion at abutments and wing walls	5	Steel connections	2
Fatigue cracking in steel girders	5		

The following problems were each cited by one agency:

Abutment joint inside backwall	Abutment moving
Approach slab cracking	Bearing seats sloped to drain
Bridge rail problems	Camber in high-skew prestressed box beam
Clearances -- vertical and horizontal	Concrete repair materials performance
Concrete sealer performance	Construction traffic control not working
Corrosion locations	Deck overlays de-bonding
End fills -- riprap not slope paving	Erosion control improvements
Excessive chloride on structures	Excessive pile deterioration
Hydraulic systems -- movable bridges	Lighting, power and ventilation in closed areas
Pile encasements sloped to drain	Prestressed box beam warped
Rebar placement and clearances	Reduce number of deck joints
Rusting of pins	Rusting of unpainted weathering steel
Shear key failure, precast concrete box beam	Simplified details
Skew angle same as snow plow	

9. How do designers communicate special maintenance needs of their designs (such as deck drains or care of bridge bearings) to maintenance personnel?

- ***Alabama.*** Verbal and written requirements to alert inspectors about certain signs of distress. Maintenance and inspection manuals for some designs.
- ***Arizona.*** A bridge maintenance manual is prepared for unique bridges. Usually, it involves feedback and discussion of problems with the bridge maintenance branch.
- ***Arkansas.*** No formal way but good communication between divisions.
- ***California.*** Memos to the area bridge maintenance engineer, who transmits needs via bridge inspection reports specifying work to be done.
- ***Colorado.*** Do not do well in this area. Have discussed presenting special program to assist maintenance in securing funds and to do the work to maintain bridges.
- ***Connecticut.*** By soliciting comments through plan review process. On moveable structures, inspection platforms, and fire protection system, operation, training and maintenance manuals are prepared and furnished by the designer.
- ***District of Columbia.*** Needs are communicated verbally or by memo.
- ***Florida.*** Unique situations requiring other than expected maintenance problems require development of inspection and maintenance manuals.
- ***Hawaii.*** No set procedure.
- ***Idaho.*** On major bridges: a bridge inspection manual is developed (it needs to be expanded to cover maintenance). Currently the bridge design section provides information on special maintenance requirements upon request.
- ***Illinois.*** Usually accomplished through informal means or by participation in annual maintenance engineers' meetings.
- ***Iowa.*** The general philosophy of designers is to eliminate items that require special maintenance.
- ***Kansas.*** General comments to construction and maintenance are in the Maintenance Manual. Specific concerns are on plans or in letters.
- ***Kentucky.*** Informally by verbal and/or written request.
- ***Louisiana.*** By written notice, usually preceded by phone call, and through bridge inspection reports, pictures, accident reports, and sketches.
- ***Maine.*** Provide maintenance and inspection manuals on major and unusual bridges.
- ***Maryland.*** Winter training sessions through the district offices.
- ***Massachusetts.*** It is not done. Rather, these details are avoided.

- ***Michigan.*** For complex or unusual bridges a bridge maintenance manual is prepared. Other special needs are brought to the attention of maintenance by letter during design.
- ***Minnesota.*** We produce a bridge maintenance manual that describes maintenance procedures necessary to care for various items.
- ***Montana.*** We do not design features that require special maintenance. We try to design more maintenance free details.
- ***Nebraska.*** They do not.
- ***Nevada.*** Our maintenance inspection section submits these types of items to districts on maintenance inspection reports as needed work.
- ***New Hampshire.*** The only special maintenance needs communicated to maintenance involve moveable bridges. On these bridges, lubrication schedules and other specialty procedures are directed via a maintenance manual which is usually developed by a specialty consultant.
- ***New Jersey.*** Ask for their comments.
- ***New Mexico.*** Bridge design sends memos with photographs, etc. urging maintenance personnel to clean joint seals, tops of decks and bridge seats and also to repair faulty joints.
- ***New York.*** They do not currently communicate with maintenance.
- ***North Carolina:*** Because of such close coordination, our maintenance personnel are very well qualified and knowledgeable about all components being used in bridge design.
- ***North Dakota.*** Written request by the bridge engineer to the district office.
- ***Ohio.*** Through the bridge maintenance engineer.
- ***Oklahoma.*** We try to avoid details that will require special maintenance needs.
- ***Oregon.*** Through the state bridge maintenance engineer, the Maintenance Guide Manual, and annual maintenance seminar.
- ***Pennsylvania.*** Bridge maintenance items are already a part of the BMS through which bridge inspections report maintenance needs. In addition to regular liaison for critical maintenance needs, a yearly maintenance program is developed jointly by each district bridge unit and maintenance staff.
- ***South Carolina.*** No procedure exists.
- ***South Dakota.*** Direct correspondence to appropriate maintenance personnel.
- ***Texas.*** Communications between bridge designers and maintenance personnel are channeled through various district headquarters to the bridge division construction engineer or the engineer of bridge design.
- ***Utah.*** By contact with bridge maintenance coordinator and by written reports generated from bridge inspections, the area maintenance supervisor is requested to accompany inspectors on bridges for which he has responsibility.
- ***Vermont.*** None experienced.
- ***Virginia.*** Through the district bridge engineers.
- ***Washington.*** No formal process. There are PM manuals for movable bridges and some major bridges.

- ***Wyoming.*** Communication between the bridge office and the headquarters maintenance office.
- ***Alberta.*** Done (infrequently) when a particular design is clearly recognized as being problematic, in which case the bridge inspection management system is flagged for special and/or more frequent inspections.
- ***British Columbia.*** Through maintenance standards and, for special design bridges, through the operations manuals provided bridge maintenance personnel.
- ***Nova Scotia.*** Discussions between personnel.
- ***Ontario.*** The Ministry's maintenance quality standards.
- ***Quebec.*** Only on some big bridges where non-removal of would clog drainage gutter and outlets.
- ***Saskatchewan.*** By memo.
- ***Bureau of Indian Affairs.*** Probably not done.
- ***Port Authority of New York and New Jersey.*** The operating department is made aware of such problems through detailed engineering inspection reports and is responsible for directing maintenance staff to correct conditions.
- ***Hennepin County, MN.*** Discussions with maintenance personnel. A maintenance manual was prepared for the Hennepin Avenue suspension bridge.
- ***Maricopa County, AZ.*** Recommends maintenance work.

10. List specific designs used to alleviate maintenance problems and reduce maintenance costs.

Specific Designs	No. of Responses
Epoxy coated rebar	22
Continuous spans (to eliminate expansion joints)	19
Deck drain improvements	16
A588 steel to eliminate painting and paint removal	14
Expansion joint improvements	11
Elastomeric bearings	10
Integral abutments (eliminate bearings and expansion joints)	10
Abutment drainage and water proofing	8
Proper paints for steel components	6
Concrete instead of steel	4
Deck protective systems	4
Riprap slope protection at stream crossings	4
Sealed expansion joints	4
Higher quality concrete decks	3
Improved scour and hydraulic design	3
Precast/prestressed concrete girders (no paint)	3
Approach slab improvements	2
Concrete pile encasements (corrosion protection)	2
Concrete instead of timber	2
Expansion bearings	2
Galvanizing of steel components	2
Improved access for inspection and maintenance	2
Pier protection upstream	2

Provisions for jacking -- bearing maintenance 2
Special designs for coastal bridges 2
Steel connection design improvements 2

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Precast/prestressed concrete girders (no paint)	3
Approach slab improvements	2
Concrete pile encasements (corrosion protection)	2
Concrete instead of timber	2
Expansion bearings	2
Galvanizing steel components	2
Improved access for inspection and maintenance	2
Pier protection upstream	2
Provisions for jacking -- bearing maintenance	2
Special designs for coastal bridges	2
Steel connection design improvements	2

Each of the following designs was listed by one agency:

Aluminum bridge rail
Cast-in-place and prestressed bridges
Chain link fence for bridge railings
Concrete coatings
Concrete safety barrier rail
Continuous bridge parapet
Edge bearings -- precast box beams
Eliminate details that collect water or dirt
Embed girders to eliminate expansion joints
Flushing system installations
Geotech cloth under riprap
Incorporation of research findings
Large culvert design for 9/10 full @ Q50
Maximum beam spacing (fewer bearings)
Minimum profile grade for drainage
Proper use of concrete additives and sealants
Bolted connections instead of welding
Cathodic protection of underwater anchor cable
Concrete culvert instead of short bridges
Concrete curing procedure improvements
Conservative approach to foundations
Details for repair of spalled bent caps
Electrical outlets in dark areas
Eliminate drainage outlets inside of box girder
Evaluation procedure ensures quality material
Galvanized diaphragms
Improved parapet design
Laminated timber for stringers and decks
Low slump overlays
Micro-wave movable bridge control system
Prestressed box beam bridges
Reinforced concrete deck on box beams

Restricted use of weathering steel
Revised guardrail to lessen snow problem
Rubber energy absorbing devices
Tie-backs for sill-type abutments
Retrofit railing details
Rigid frames instead of simple spans
Slotted rails for snow removal
Curb-less decks instead of scuppers

APPENDIX B

Utah Pilot Test

The project work plan provided for a test of the process under actual conditions to ensure its practicality and to identify any needed improvements in the process prior to completion of the study.

Pilot Test State

The Utah Department of Transportation was selected to be the pilot state for these reasons:

- Responsibility for road design in the Department is decentralized to the districts. A central road design group supplements the districts' efforts. All bridge design is centralized. This is the most common design organization used by the state highway and transportation departments. Selection of Utah permitted the testing of the processes for both district and central office design.
- The Department expressed a willingness to be the test state.
- Mr. Dale Peterson, Engineer of Standards and Review for the Utah Department of Transportation, is a member of the Project Panel for this research. Mr. Peterson completed NCHRP Program Synthesis of Highway Practice 122, *Life-cycle Cost Analysis of Pavements*, (19) in 1985, so he is familiar with current practices in analyzing life-cycle costs.

Pilot Test Plan

The test was conducted in the following steps:

1. Initiation of the pilot test was delayed until late June, 1991, pending approval of the proposed process for testing. To keep the project on schedule, only information collected through October, 1991, was included in the findings.
2. The Department appointed the Value Analysis Engineer as the coordinator for the test. The Central Design Improvement Committee included representatives from roadway design, structures design, maintenance, construction and materials. District Two, with headquarters in Salt Lake City, was selected as the test district. Members of the District Design Improvement Committee represented design, construction, maintenance and materials.
3. The Principal Investigator and Co-Principal Investigator met with both committees and other Department personnel to explain the process, the test plan and the expected results.

   At these meetings, the consultants assisted the committees in adapting the processes to the needs of the agency. The basic processes were adapted for use by the Department. Minor changes were made to match procedures, personnel titles and the like.

   Central maintenance had developed a check list for its use in reviewing construction plans. That check list was updated to eliminate items no longer needed and to incorporate additional items identified by the Department and selected items from the sample check list developed

in the study. The check list was provided to designers for the first time. A copy of the Utah check list is shown in Figure B-1, on Page B-6.

   The sample problem statement was revised to better fit the needs of the Department. See Figure B-2, Page B-10.

   Copies of the tailored processes, check lists and problem statements were developed for use by the Department.

4. As a part of the initiation meeting, an implementation plan was developed. This plan included:
   - Implementing plan reviews for contractual maintenance projects. Currently, the district maintenance engineer submits a memo to the central maintenance office to prepare a "no plan" contract. A copy of the request will now be sent to the district materials and construction engineers so they may review it before it is advertised. Previously, they did not see plans for these projects until the contracts were advertised.
   - Providing copies of the Department's Plan Reading Course Workbooks to station supervisors so they can learn to read plans to better prepare themselves to make comments during scoping and plan reviews. It is estimated that only 15 percent of the station supervisors can now adequately read plans.
   - Developing an additional form, *Maintenance Scoping Concerns*, for use by maintenance at the scoping phase to request items to be included in the project design. A copy of the form is shown in Figure B-3, Page B-11.
   - Implementing the process statewide. Because of the short time frame and the summer work load, implementation was handled through memoranda. Maintenance supervisors in each district received a memorandum from the Engineer for Maintenance advising them of their responsibilities in the process. Similarly, the Engineer for Preconstruction sent a memorandum to district and central office design supervisors. Copies of these are presented in Figures B-4 and B-5, beginning on Page B-12.

Test Results and Findings

Problem Statements

Thirty-two problems were identified through the submission of problem statements by the end of October. The Central Design Improvement Committee reviewed the problems, grouped them, and developed an action plan. The action plan provided for resolution of the problems. (Copies of all problem statements were furnished to the consultants.)

The problems, related to standards, requiring approval from the Standards Committee were:

- snow fence standards and policies update;
- drains located under concrete barriers which makes cleaning very difficult;
- proper connection of slope drains to end sections;
- cattleguards set too low;
- shoulder drains not extended past the toe of fill; and
- consideration of installing slot drains along barriers.

Preconstruction was assigned:

- disposal of rotomilled tailings; and
- improved communications between maintenance and design personnel.

Structures will address:

- undermining of slope pavement by water from structure drainage;
- rough approaches to structures; and
- the need for curbs and drains at the end of parapets to keep water from damaging slope pavements.

The Maintenance Standards Committee will evaluate extending the spacing of temporary tab pavement markers from 40 feet to 50 feet.

Construction will review the problem with shoulder drains that are too low after final surfacing.

Some of the problems identified through the problem statements have been added to the maintenance check list.

It was suggested that maintenance can identify areas where projects should be initiated — areas such as frequently hit guardrail locations where only a new design can resolve the problem or where snow fence is needed. The Problem Statement form can be used to identify needed projects.

Problem Statement Form

The Central Design Improvement Committee suggested these changes in the Problem Statement format:

- revise the title to emphasize that the form is for maintenance problems related to designs;
- eliminate the cost implications and replace with a quantitative measure (person-hours required per year, frequency of flooding, number of times maintenance has been required each year, etc.);
- omit the alternatives section on the form and request a recommended solution with the reasons for the recommendation; and
- encourage the use of sketches on the form to clarify the problem.

A copy of the revised form is shown in Figure B-6 on Page B-14. The sample problem statement form, presented as Figure 7 on Page 38, reflects these recommendations.

Some of the problem statements were not clearly written. It was recommended that in the future, the statements be submitted through the area supervisor or district maintenance engineer where they could be reviewed and clarified prior to submission to central maintenance. The purpose of this review is to ensure that the statements are clearly stated — not to screen the suggestions.

Check List

Maintenance is using the check list as a guide in reviewing plans. They believe design will be motivated to use the check list during the design process to avoid being questioned on every project.

Reviews

Maintenance personnel need 2 to 3 weeks notice to schedule attendance at scoping meetings and plan reviews.

Participation at scoping and review meetings should be added to the position description for station and area maintenance supervisors.

As noted above, approximately 15 percent of the station supervisors can satisfactorily read plans. Training in plan reading is needed if they are to contribute the maximum amount at the reviews. Distribution of the Plan Reading Workbooks was not accomplished during the pilot test period, but it is expected that they will be available soon. A summary description of the work included in each set of plans will assist the supervisors in the interim. This description should list the major items of work planned.

The Appeal Process

Only one decision was appealed during the pilot test: the planting of Russian olive trees for landscaping causes maintenance problems. These trees grow too well and spread into areas in the right of way where they must be cut. Through an appeal, another more desirable tree was substituted.

VE and Life-Cycle Cost Analyses

Neither value engineering nor life-cycle cost analyses are used to any great extent by the Department. Neither was used to evaluate alternatives generated by the problem statements to date.

Department Conclusions

The Process

The Department is satisfied that implementing the process has proved beneficial and that continuation will provide continuing benefits. The maintenance division is enthusiastic about the process, and design is receptive. Designers want to satisfy maintenance needs but have not always been aware of maintenance problems. Few, if any, designers have maintenance experience. The process is being incorporated into the Department's Procedure for Project Development to define the role of maintenance at scoping and plans review meetings.

Design has always tried to involve maintenance in the reviews. It is expected that implementation of this process will improve that participation. The pilot test period was too short to prove conclusively that improvement has occurred.

Members of the Central Design Improvement Committee emphasized keeping the process as easy to use as possible. Their suggestion: *Keep it simple. Don't use full-blown life-cycle cost analyses unless they are really necessary — where the best alternative is not obvious or for major items where the potential payoff is worth the extra effort.*

Communications

The project coordinator was invited to speak at the annual maintenance supervisors' conference that was held in November 1991. He explained the objectives, how the process works and the input expected from field maintenance supervisors. They expect increased participation from the field following that meeting. A copy of the paper he presented is attached, beginning on Page B-15. If timing had permitted, a meeting such as this should have been held to initiate the pilot test.

The maintenance representative on the Central Design Improvement Committee will be invited to attend the next annual preconstruction conference to explain the process.

The District Two Design Improvement Committee had a limited role in the pilot test. Because Utah has a relatively small organization, it is easy to communicate directly with central office.

Consequently, the Central Design Improvement Committee handled all of the problem statements. The problem statements from all districts were submitted to central maintenance. All design reviews are centralized so it was easier to coordinate at that level.

Figure B-1

Utah Check List

Surfacing

1. How will surface repairs be made considering the traffic?
2. How will the pavement be rehabilitated in the future?
3. Will widening be required in the near future? If yes, how will it accomplished?
4. Have provisions been made for sealing longitudinal construction joints with rubberized joint sealant between passes with the laydown machine on bituminous overlays?
5. Is crack sealing prior to placement of plant mix seal provided?
6. Is profiling provided to ensure smooth transitions in pavements?

   Along curb and gutter?

   At on and off ramps where paving changes from concrete to bituminous?

   At structure ends for overlay projects?

   At railroad crossings?

   At the beginning and end of the project?
6. Do the specifications provide for a transverse saw cut and a tapered removal of the existing mat at project ends of overlay projects to avoid feathering the end of the overlay? (The feathered material is frequently peeled off by snowplows.)
7. Is a bid item provided for a rejuvenating agent to be used as a surface flush coat if it is needed?
8. Are Type "C" chips specified for bituminous seal coats?

Shoulders

1. Does traffic warrant paving the shoulders?
2. Will the shoulders be needed as traffic lanes in the near future?

   If yes, are they designed to carry the load?
3. If aggregate shoulders, can they be bladed safely under traffic?
4. Have provisions been made to build shoulders up to match the new pavement on overlay projects?

Drainage

1. Are drains adjacent to or under Jersey barriers accessible for cleaning?
2. Do ditch designs provide for controlling erosion?
3. Are pipe ends designed to control erosion?
4. Are clean outs provided in closed drainage systems?
5. Are all pipe culverts large enough to permit cleaning?

Figure B-1 (Continued)

Utah Check List

6. Is rodent protection provided for underdrain outlets?
7. Will channel alignments cause erosion problems?

   Is there adequate right of way to make repairs?
8. Are non-standard grates specified? If so, can they be avoided?
9. Are catch basin grates bicycle-safe?
10. Do catch basin elevations match the pavement grade?
11. Are there provisions for raising catch basins and manholes to match pavement grades for overlays?

Roadsides

1. Is seeding provided for all areas which will be disturbed by construction?

   Is seeding method "A" specified? (It is the preferred method.)

   Is seeding provided to the edge of the pavement?
2. Can native grasses be specified to reduce or eliminate mowing? (Prefer intermediate crested wheat or Indian rice grass.)

   Are noxious plants included in specified seed mixes?
3. Are slopes too steep to mow?
4. Are slopes flat enough to resist erosion and slides?
5. Can sound walls be placed on the right-of-way line to eliminate maintenance behind the walls?

   If not, is access provided?
6. Are gates provided in wing fences to permit access to inspect and maintain bridges and drainage facilities?
7. Is access provided to mow behind all guardrail?
8. Are tree and shrubbery plantings located at least 40 feet from the shoulder so they will not be in the area which will be sprayed?
9. Can drought-resistant plantings be used?

   Are desirable trees specified for plantings? (Do not specify Russian olive trees because they spread like weeds.)

Traffic

1. Is it economical to flatten slopes in the clear zone to eliminate guardrail?
2. Does the guardrail design use standard materials so maintenance can minimize the stocking of repair parts?

Figure B-1 (Continued)

Utah Check List

3. How will vegetation under guardrail be controlled?

   Would paving be justified?
4. Can maintenance repair guardrail without closing a traffic lane?

   If no, should concrete barrier be substituted?
5. Can concrete barrier be specified instead of upgrading guardrail?
6. Is guardrail attached to the structures?
7. Is traffic re-striping provided on projects where it will be obliterated?
8. Is traffic tape or epoxy specified instead of paint for traffic striping on interstate and urban PMSC projects?

   Is the proper tape specified for the use? (Edge lines, etc.)

   Can tape be specified for pavement messages to reduce labor and equipment costs?
9. Are standard attenuators used so maintenance can minimize the stocking of repair parts?
10. Is the placement of barrels for impact attenuators in accordance with the standard drawings?
11. Is a provision for removing and resetting delineators included?
12. Is delineation provided for barriers?
13. Do the drawings eliminate the use of aluminum delineators?
14. Can mileposts be placed outside the line of the delineators?
15. Can the raised islands be removed or eliminated? (Islands create hazards for snowplows and require painting.)
16. Are there provisions for removing old signal detection pads?
17. Are there provisions for sign rehabilitation or replacement?
18. Are object markers specified for attenuators, guardrail, concrete barriers, drainage, paint lines, etc.?

Bridges

1. Are bridges designed to permit jacking to facilitate servicing, repair or replacement of bridge bearings?
2. Are provisions included for waterproofing decks?
3. Are maintenance manuals provided for complex structures? (Indicate on the plans or in the contract documents that manuals will be provided.)
4. Is the shoulder wide enough to accommodate the snooper without impeding traffic?
5. For skewed bridges, is the angle of snow plow blades considered in setting the bridge skew to avoid catching plows on joints?
6. Are critical inspection items listed on the plans to advise bridge safety inspectors?

Figure B-1 (Continued)

Utah Check List

7. Are bridge components accessible for inspection and maintenance?
8. Are joints adequately sealed to prevent water getting to the bearings and supports below the joints?
9. Are the interiors of box beams accessible for inspection?
10. Do deck drains carry the water below the beams to prevent water damage from splash back?
11. Will deck drains cause erosion or dump water on roadways?
12. Can deck drains be extended to fit deck overlay grades?
13. Is the channel protected to prevent erosion?
14. Is drainage at abutments provided to prevent erosion?
15. Are vertical and horizontal clearances adequate to prevent damage?
16. Is there adequate allowance for future overlays beneath overpass structures?
17. Are there any unusual joint details?
18. Is a 25-foot approach slab provided on each end of the structure?
19. Are there provisions for matching grades on overlays?

    Raising approach slabs?

    Removing transitions to structures?

Winter Maintenance

1. Where is adequate room provided to store snow?
2. How will snow be removed from bridge decks?
3. Are median cross-overs provided on divided roadways for ease of routing snow and ice control vehicles?
4. Is marking of median crossovers provided?

Miscellaneous

1. Are there any non-documented agreements with landowners?
2. Are school bus turning areas provided?
3. Can cattleguards be moved further up the ramps away from the turning radii?
4. Have provisions been made to adjust the elevations of cattleguards where pavements are overlaid?

Figure B-2

Maintenance Problem Statement

Statement of Problem

Describe the problem.

Impact on Maintenance

How serious is the problem? What are the cost implications?

Alternatives

List the design alternatives that would solve the problem and the advantages and disadvantages of each. One alternative is the existing design.

Recommendation:

Describe the recommended alternative and the reasons for its selection.

Submitted By: ____________________ ***Phone:*** ______________

Date: ________________

Design Improvement Committee Action:

Figure B-3

Maintenance Scoping Concerns

Project Number: ______________________ *Date:* ______________

Designer: ____

Maintenance Reviewer: ____________________________________

Specific Problem	*Suggested Solution*

cc: Dale E. Peterson, Engineer of Standards and Review
Jim McMinimee, Maintenance Operations Engineer

Figure B-4 — Maintenance Memorandum

Memorandum **UTAH DEPARTMENT OF TRANSPORTATION**

DATE: July 8, 1991

TO : All District Maintenance Engineers

FROM : Gerald Barrett, P.E.
Engineer for Maintenance

SUBJECT: Maintenance Concerns in Design

The Department has decided to make an increased commitment in considering maintenance concerns into the design of projects. The following will be done in order to get our concerns addressed prior to construction:

1. When requesting an orange book contract or putting it together yourself, a copy of the request will be sent to the District Construction and Materials Engineer of your District. This will make sure these individuals have a chance to review it and are made aware of the project before it is let out for bids. Give these individuals a date to respond by and inform them the project will not be delayed if a response isn't received.

2. The responsible Station Supervisor or an Area Supervisor will be required to attend all project scoping meetings. The most recent semiannual inspection report, of the project area, should be brought to the scoping meeting. The attached "Maintenance Scoping Concerns" form will be filled out after the review by the person attending and sent to the designer. A copy will also be forwarded to Jim McMinimee and Dale Peterson, Engineer of Standards & Review. The designer will be required to address each concern in writing to the person who completed the form. If all concerns are not addressed satisfactorily by the designer, Jim McMinimee is to be notified. Please distribute this form to all supervisors who will be attending scoping meetings.

3. The responsible Station Supervisor or an Area Supervisor will be required to attend all project review meetings.

4. Many times maintenance problems are designed into projects over and over again. The designers are unaware that these problems exist. A form has been devised to reveal these types of problems to the designers. The attached "Maintenance Problem Statement" form will be used to inform the designers of these problems and correct them on future projects. Please distribute this form to all supervisors so any of these types of problems currently showing up in your District can be addressed. Return the completed "Maintenance Problem Statements" to Jim McMinimee by July 22, 1991.

This is an excellent opportunity to eliminate many of the design problems causing added maintenance expenses; so let's take advantage of it.

Figure B-5 — Design Memorandum

T-307

Memorandum

UTAH DEPARTMENT OF TRANSPORTATION

DATE: July 10, 1991

TO : Assistant District Directors and Assistant Chief Roadway Design

FROM : L. R. Jester, P.E.
Engineer for Preconstruction

SUBJECT: Incorporating Maintenance Concerns In Design

We (UDOT) have been selected as the pilot state for a NCHRP Study entitled "Incorporation of Maintenance Considerations in Highway Design". It is expected that by implementing a few additional features, none of which will delay the design process, we may improve the communication between maintenance and preconstruction personnel. If future maintenance problems are avoided by addressing them in the design process we can save significant amounts of funds over the life cycle of the highway.

By performing the following, it is felt that maintenance concerns may be better addressed in design:

1. Review the attached checklist of maintenance concerns while designing a project. These are general problems that often are designed into projects that become maintenance headaches, often without the designer's knowledge, after construction.

2. Meet with local maintenance personnel, either the Station Supervisor or an Area Supervisor, preferably at the scoping meeting. Discuss project specific problems that currently exist or new ones that may be considered in the design. The Station Supervisor will complete a "Maintenance Scoping Concerns" form after this meeting. It will include a list of specific problems they would like addressed in the design, along with possible solutions to these problems. A written response to maintenance addressing each of these specific issues is necessary from the designer. Reasons must be provided as to why any of these suggestions will not be incorporated into the design. These responses should be sent to: Jim McMinimee in Central Maintenance, the Maintenance Supervisor who attended the scoping meeting, and Dale Peterson in Standards & Review.

Please distribute this memo and attached checklist to all designers you supervise. Thank you.

Figure B-6

Revised Maintenance Problem Statement

Statement of Problem

Describe the problem.

Recommendation:

Describe the recommended alternative and the reasons for its selection.

Sketch:

Show or attach any drawings necessary to illustrate the problem or recommendation.

Submitted By:____________________ ***Phone:***____________

Date:______________

Design Improvement Committee Action:

State of Utah
UTAH DEPARTMENT OF TRANSPORTATION

Norman H. Bangerter
Governor
Eugene H. Findlay, C.P.A.
Executive Director
H.H. Richardson, P.E.
Assistant Director

4501 South 2700 West
Salt Lake City Utah 84119-5998
(801) 965-4000

Dear Bob,

As you know, I made a presentation at the annual maintenance conference on November 13, 1991. In attendance were all maintenance personnel from area supervisors on up, including the District Directors. The response was very favorable. Only one important issue was raised after the presentation. It voiced the concern that often comments made by maintenance people at scoping meetings are not included in the plans. I told them that if they use the procedure outlined, designers will be required to formally address all their concerns. This includes providing the reasons for all concerns not included in the plans.

I also handed out the new "Maintenance Problem Statement" forms and a copy of the "Maintenance Scoping Concerns" form to all in attendance.

I have attached a copy of my presentation for your information.

Sincerely,

Tracy Conti

Tracy Conti

Attachment

UDOT Maintenance Conference
Tracy Conti, P.E.
November 13, 1991

MAINTENANCE CONSIDERATIONS IN DESIGN

Background

Maintenance has been neglected and ignored by design for years. This was realized at the national level, so the Transportation Research Board hired a consultant to prepare a paper addressing "Maintenance Considerations In Design". The consultants developed a process to include these concerns into design. The main objectives of the consultant's process is to get maintenance involved early in the design process and to provide an avenue to bring problems to the designer's attention. Utah was selected as the pilot state to test this process. The consultants came and met with us for a couple of days and we agreed to attempt to implement their ideas into UDOT for a test period from July to the first of November. We agreed to try it not only to help the consultant evaluate their ideas, but because it could be of some benefit to us. After this short test time, maintenance feels that much of this process will be implemented permanently.

The process called for the establishment of committees at the central complex and in the Districts. For the pilot study, the central committee was formed, along with one in District 2 because of its proximity to the complex. The Central Committee is represented by people from Materials, Roadway Design, Structures, Construction, Jim McMinimee from Maintenance, and myself from Standards & Review. The District Committee had representatives from District Design, Materials, Construction, Lamar Richins from Maintenance, and myself. Because the consultants developed this general process to implement into any highway organization, we had to customize many of their ideas to best work in UDOT. Because it is primarily to benefit maintenance, it was tailored so that the driving force is maintenance. If you want to make it work and follow the procedures I'll talk about later, the designers will be required to follow your advice.

A buzz word going around many agencies and corporations, including UDOT, these days is "Total Quality Management". The definition of this is preventing mistakes from occurring, instead of correcting them later. Arizona's Highway Department estimates that 40% of the designers' time is spent doing corrections or rework. UDOT is certainly in this area as well. Total quality calls for doing things right the first time, every time. In design this requires that all necessary information must be made available as early as possible to prevent rework. If this process is used and used correctly, it will definitely lead UDOT towards better quality.

The specific steps which UDOT has implemented or is implementing are:

Maintenance Problem Statements

Many times maintenance problems are designed into projects over and over again. The designers are unaware that these problems exist. These problems could also be caused by defects in Standard Drawings or policy. A tool has been devised to try and remedy these problems. The "Maintenance Problem Statement" is this tool. These statements can be submitted by anyone in the field, not just supervisors, aware of an existing problem. I know we sent these out to test it earlier; without much guidance. About 30 of them were submitted. We received varied responses from around the state. Some areas, such as Lamar Richin's (probably because of his involvement with this project), responded very well, while very few were received from other areas. The problems submitted are being reviewed to decide what action needs to taken. Several statements cited common problem areas, among these were:

> The placement of snow fences. As a former designer, I know the placement of these are often ignored. Obviously the policy regarding them has to be reviewed; and if necessary, modified and distributed to designers.
>
> The placement of catch basins next to concrete barriers. Obviously, the closer the basin is to the barrier the better it will drain, but provisions must be made to be able to remove the grate for cleaning without having to move the barrier. The Standard Drawing will need to be looked at.
>
> The elevation of cattleguards at the completion of construction projects. After an overlay, the cattleguard can't be a few inches lower than the pavement. Provisions must be made in the plans to raise the cattleguard or rotomill the pavement to eliminate the bump. Again the Standard Drawing will need to be looked at.
>
> Water getting under the slope protection of structures.

This form has been modified to make it easier to use. It is to be an ongoing thing. Anytime you observe a general problem of this nature, you should complete and submit the "Maintenance Problem Statement Form" to central maintenance so the problem can be addressed by the Central Committee. The alternative to an existing

problem may have a higher initial cost, but lower annual or maintenance costs. These alternatives should be considered because the overall life cycle costs may be lower. A formal procedure for this may be prepared by Maintenance to better outline this procedure.

Maintenance Scoping Concerns

A key element of the process is involving maintenance at the initial scoping meeting where the project concept is established. The designers have been informed that it is mandatory for either the station supervisor or an area supervisor to be at the scoping meeting. This will be incorporated into the new 08-1 Procedure (the project development procedure used by all designers) currently being prepared. No one knows more or is more familiar with a section of highway than those who have to deal with it daily. This makes you and the station supervisor the best source of information concerning site specific problems. Because you are the best source, it is important that you are properly prepared for this meeting. Before the scoping meeting, the semiannual inspection report should be reviewed so no problems are overlooked. A form, the "Maintenance Scoping Concerns", has been prepared to list your concerns. These concerns are given to the designer, and all of them must be considered for implementation. A copy of the form will also be forwarded to Dale Peterson in Standards and Review, so the design reviewer will be aware of these concerns. Any disputes will be resolved by the central committee. It is important to remember that these are for "site specific" problems on the project limits; such as:

> The culvert at Milepost 100 overflows every storm despite being clean. A larger size must be needed.

The problem statements are for more general problems relating to common design practices, standards, or policy. Using these will again promote Total Quality Management principles by preventing problems, instead of correcting them after the fact.

Checklist

Whenever a review, whether it is a PIH, PS & E, or final, is scheduled a set of plans are sent to central maintenance, where it is reviewed for possible future maintenance problems. To look for these a checklist containing potential problems is used. The checklist being used was out of date and incomplete. Part of the process proposed by the consultant contained a checklist similar to the one used by maintenance. It was modified to better fit

UDOT; as a result our checklist is more complete and current. This checklist was also distributed to all designers so they can consider these concerns and incorporate them while they are designing the project. This again prevents mistakes and limits rework.

Maintenance Attendance at Project Reviews

In the near future, FHWA will be reducing its involvement in the design review process. A tremendous amount of knowledge will be lost because of this. This comes at a time when cost over runs in construction are a major problem. The majority of the burden for the review will be handled by UDOT's Design Review section. With this increased load the reviews will have to be limited to insuring the plans conform to standards, such as:

> Does the length of this curve provide the required sight distance for the specified design speed?
>
> Have all utility agreements been received?

Time will not be spent on checking the quantities and accuracy. The quality will have to come from the designer. It will be crucial that maintenance people be present at the reviews to help provide this quality control. A quick survey of the reviewers indicate maintenance personnel only attend about half of the reviews. This number must increase. Not only is attendance important, but they must be prepared to contribute at the meetings. This is sometimes difficult because of the lack of training in reading plans for maintenance personnel. It's estimated that as few as 15% of maintenance personnel are competent plan readers. There is an old self instruction plan reading course floating around UDOT. Although it is old and out of date it still should teach the essentials sufficiently. We would like to distribute a copy of it to at least the area supervisors, so as their time permits they can go through this workbook to increase their plan reading skills. After they finish, the study guides can be routed to station supervisors and anyone else that may be attending plan reviews. This way when they attend plan reviews they'll understand what's shown in the plans and be better prepared to comment on the contents.

Post Construction Reviews

Post construction reviews are currently held on selected completed projects. The emphasis on these has been to encourage good design and construction practices and to eliminate poor aspects.

Maintenance has always been invited to these meetings and is encouraged to attend any future ones. As this process becomes a more integral continuous practice, separate post construction reviews specifically for maintenance may be likely. However, if you identify a problem during construction, don't hesitate to contact the project engineer and work through them to correct the it. A post construction review is too late to correct problems on this project, but hopefully prevents similar mistakes from occurring in the future.

Maintenance at Preconstruction Conference

It would be beneficial to design people to have a presentation explaining maintenance concerns from a different perspective than their own. An excellent opportunity would be at the annual preconstruction conference. I know this topic hasn't been discussed in the last few years at least. It might open the eyes of some designers.

Orange Book Contracts

The current practice for preparing the orange book contracts consists of either preparing the minimum plan sets at the District or requesting Jerry Wardell to prepare them. Most of the time the responsible project engineer and the district materials engineer don't see or even hear about the project until it is advertised. To make sure these people are made aware of the future project and have a chance to review it, a copy of the request for the project is to be forwarded to the District Materials and Construction Engineers. Give these people a date to respond by and inform them the project will not be delayed if a response isn't received.

Conclusion

Because of the size and the operating procedures of UDOT, it won't be necessary to have committees in each District. District personnel will be asked for input on the Central Committee whenever needed. When we adapted the consultant's process to fit UDOT it was intentionally designed to be "driven" by maintenance. This makes sense because this is where the knowledge base is and it also receives the greatest benefit from the program. If the effort is made by maintenance personnel on their end; the designer will be required to respond and address any concerns expressed.

The primary goal of this program is simple: Improve communication between preconstruction and maintenance. Do things right the first time, every time.

APPENDIX C

Value Engineering

Value engineering evaluations of a project or its components are used to determine the potential for reducing the life-cycle costs while improving its performance, reliability, quality and maintainability. Value engineering can be undertaken at any phase of the design process, but maximum benefit can be obtained if it is performed during the initial or preliminary design phase when major elements of the design have been identified but prior to the preliminary design review.

> Value Engineering is defined by the Society of American Value Engineering as: *The systematic application of recognized techniques which identify the function of a product or service, establish a value for that function, and provide the necessary function reliably at the lowest overall cost. In all instances the required function should be achieved at the lowest life-cycle cost consistent with requirements for performance, maintainability, safety and esthetics.* (21)

Value engineering principles can be applied to policies, standards and design criteria. Since materials, equipment and construction techniques go through a constant evolution, periodic evaluation of standards by value engineering is desirable.

Although the purpose of these procedures is to establish a process for incorporation of maintenance considerations in design, a brief description of value engineering methodology is included here for information purposes.

Value engineering studies are usually completed in these phases:

1. selection of the project or item to study;
2. investigation and information collection to determine the problem, costs, what is now accomplished and what must be accomplished;
3. speculation to answer questions such as what else will perform the function to identify alternatives;
4. evaluation of alternatives, including how each would work, what the cost would be, and whether each would perform the function;
5. development includes selecting the most promising alternatives, determining total and life-cycle costs, and completing the evaluations;
6. in the presentation phase, the advantages and shortcomings of the recommended alternative are presented for approval;
7. the approved alternative is incorporated into the plans, policies and standards in the implementation phase; and
8. the results are monitored in the audit phase. (20)

Agencies that have value engineering procedures in place should use their own procedures. Those that do not should refer to the most current volume of Value Engineering for Highways published by the Federal Highway Administration.

APPENDIX D

Life-Cycle Cost Analysis

Life-cycle cost analyses are conducted to compare the total cost of each alternative over the expected life of the improvement. Costs that should be considered in the LCC analysis include:

- design costs,
- construction costs,
- right of way costs,
- routine maintenance costs,
- periodic maintenance and rehabilitation costs,
- operating costs,
- accident costs, and
- users' costs.

The present worth of any salvage value for the facility at the end of its expected life is subtracted from the total present worth of all costs to arrive at the net total life-cycle cost.

Any costs that are estimated to be the same for all alternatives can be ignored in the calculations. Where cost data are not available, estimates of those costs must be made.

Discount rates are used in the life-cycle cost analyses to convert the various costs anticipated to accrue over the expected life of a facility to a common point in time considering inflation and interest costs. There is general agreement that the discount rate should be the difference between the market interest rate and inflation using constant dollars. (19, Page 7)

Selection of the discount rate is important because unrealistic discount rates may distort the results. Higher discount rates tend to favor alternatives with lower initial costs and higher maintenance costs — the present worth of future maintenance costs is low when discounted. Conversely, low discount rates favor higher first costs because the present worth of future maintenance is high when discounted.

Because the discount rate varies with the cost of capital and the general economic conditions, a fixed discount rate for all agencies is not feasible. We recommend that the discount rate be the interest rate for AA 20-year bonds for the state minus the inflation rate.

The factors used in life-cycle cost analyses must be carefully selected to avoid bias. The life expectancies of materials and components must be realistic and achievable. Otherwise, alternative evaluations will give erroneous results.

User costs should be included in the analysis if construction, rehabilitation or maintenance activities will have a significant impact on traffic. The difficulty of closing lanes, especially in urban areas, mandates that user costs be included in making comparisons of alternatives where traffic will be affected. (22)

NCHRP Synthesis 122 defines three methods of discounted cash flow analysis: the present worth method, the annualized method, and the rate of return method. The present worth method is recommended for use in comparing alternative designs in this process. The description from the synthesis is quoted here for convenience. Additional information can be obtained by reviewing the complete synthesis. Refer to Appendix D of that publication for the economic tables.

The ***present-worth method*** is an economic method that involves the conversion of all of the present and future expenses to a base of today's costs. The present worth of some planned future expenditure is equivalent to the amount of money that would need to be invested now at a given compound interest rate for the original investment plus interest to equal the expected cost at the time it is needed. For example, an investment of 30 cents at 5 percent compound interest will equal one dollar in 25 years. All costs are predicted, and they are then reduced to one single cost in the present. The totals of these present-worth costs are then compared one with another and the lowest-cost alternative is chosen, providing all other things are equal.

Equation (2) is for the single present worth of a future sum of money for a given number of years with a given discount rate. This equation is for non-recurring costs.

$$P.W. = F \frac{1}{(1 + i)n} \qquad (2)$$

where

P.W. = Present Worth.

F = The future sum of money at the end of n years from now that is equal to P.W. with a discount rate of i.

n = Number of years.

i = Discount rate per time period.

The present worth of a single future value F can be determined by multiplying it by the single-payment present-worth factor (SPW). Values for SPW can be found in the economic tables in Appendix D (of the Synthesis).

Equation (3) is used to determine the present worth of a series of end-of-the-year payments for a given number of years with a given discount rate. This equation is for recurring costs.

$$P.W. = A \frac{(1 + i)^n - 1}{i(1 + i)^n} \qquad (3)$$

where

A = End-of-year payments in a uniform series for n years that is equivalent to P.W. at discount rate i.

The present worth of a series of annual payments "A" can be determined by multiplying "A" by the uniform present-worth factor (UPW) for given values of n and i. Values for UPW can be found in the economic tables in Appendix D of the Synthesis. Several key items of information are needed to determine the percent worth of rehabilitation and maintenance. These factors include a cost definition, a discount rate, an analysis period or life, a methodology for determining salvage value, and the expected life for the various potential rehabilitation alternatives.

An example of using the present-worth method including a cash-flow diagram is shown in Figure C-1.

Figure C-1 — Example of the Present Worth Method and Corresponding Cash Flow Diagram

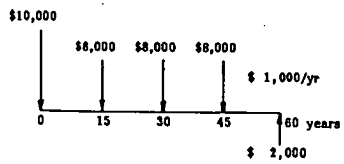
Plan A has a first cost of $10,000, an estimated life of 15 years, an annual operating cost of $1,000, and a salvage value of $2,000.

Plan B has a first cost of $15,000, an estimated life of 20 years, annual operating costs of $900, and a salvage value of $4,000.

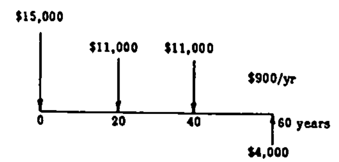
The appropriate interest rate for comparing alternatives in this cost center is 12%.

ANALYSIS:

Plan A



Plan B



PLAN A:

P.W. First cost =	$ 10,000
P.W. 1st renewal = (1st cost - salvage)(SPW;15;12%)	
= ($10,000 - $2,000)(0.1827) =	1,462
P.W. 2nd renewal = (1st cost - salvage)(SPW;30;12%)	
= ($10,000 - $2,000)(0.0334) =	267
P.W. 3rd renewal = (1st cost - salvage)(SPW;45;12%)	
= ($10,000 - $2,000)(0.0061) =	49
P.W. of 60 yr operating costs = ($1,000)(UPW;60;12%)	
= ($1,000)(8.324) =	8,324
P.W. of salvage value = (-$2,000)(SPW;60;12%)	
= (-$2,000)(0.0011) =	-2
Total present worth of Plan A =	$ 20,100

PLAN B:

P.W. First cost =	$ 15,000
P.W. 1st renewal = (1st cost - salvage)(SPW;20;12%)	
= ($15,000 - $4,000)(0.1037) =	1,141
P.W. 2nd renewal = (1st cost - salvage)(SPW;40;12%)	
= ($15,000 - $4,000)(0.0107) =	118
P.W. of 60 yr operating costs = ($900)(UPW;60;12%)	
= ($900)(8.324) =	7,492
P.W. of salvage value = (-$4,000)(SPW;60;12%)	
= (-$4,000)(0.0011) =	-4
Total present worth of Plan B =	$ 23,747

Additional References

The following publications will provide additional information on economic and life-cycle cost analysis techniques:

- Campbell, Bruce, and Humphrey, Thomas F., NCHRP Synthesis 142, *Methods of Cost-Effectiveness Analysis for Highway Projects*, Transportation Research Board, National Academy of Sciences, Washington, D.C. (December 1988) 22 pages
- Technical Manual TM 5-802-1, *Economic Studies for Military Construction Design — Applications*, Headquarters, Department of the Army, Washington, D.C. (December 31, 1986) 113 pages

THE TRANSPORTATION RESEARCH BOARD is a unit of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. It evolved in 1974 from the Highway Research Board which was established in 1920. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society. The Board's purpose is to stimulate research concerning the nature and performance of transportation systems, to disseminate information that the research produces, and to encourage the application of appropriate research findings. The Board's program is carried out by more than 270 committees, task forces, and panels composed of more than 3,300 administrators, engineers, social scientists, attorneys, educators, and others concerned with transportation; they serve without compensation. The program is supported by state transportation and highway departments, the modal administrations of the U.S. Department of Transportation, the Association of American Railroads, the National Highway Traffic Safety Administration, and other organizations and individuals interested in the development of transportation.

The National Academy of Sciences is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Frank Press is president of the National Academy of Sciences.

The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research and recognizes the superior achievements of engineers. Dr. Robert M. White is president of the National Academy of Engineering.

The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Kenneth I. Shine is president of the Institute of Medicine.

The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purpose of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Frank Press and Dr. Robert M. White are chairman and vice chairman, respectively, of the National Research Council.

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