



AASHTO

Maintenance Manual for Roadways and Bridges

2007



American Association
of State Highway and
Transportation Officials



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Preface

This 2007 revision of the AASHTO Maintenance Manual is based on information gleaned from recent highway transportation literature on maintenance, and field visits and interviews conducted by Kenneth A. Brewer as the principal author under National Cooperative Highway Research Program (NCHRP) Project SP20-07, Task 170. This document was prepared under the guidance of the NCHRP SP20-07, Task 170.

Intended for persons early in their career in roadway and bridge maintenance, the *Maintenance Manual for Roadways and Bridges* will assist them in understanding the various processes, methods, and materials that are applied to maintain the bridge and highway system effectively. Also intended to be a dynamic document, the manual will need to be updated as research and applications change the relevant content sections. Historically, highway maintenance has encompassed personnel management, materials selection, equipment use, and application of methods to react to problems in bridges and roadways, budgeting, and planning. The field is now evolving into a new engineering science of its own, resulting from a synergistic combination of traditional civil engineering, industrial engineering, business management, materials science, industrial psychology, and environmental science. This manual is envisioned as the first step in documenting that transition; this first-generation text will lead and guide the professional development of the engineering managers of roadway and bridge maintenance in the beginning of the 21st century.

This manual, however, will need to be used in conjunction with your own agency's maintenance operation policy manual, maintenance standards publication, and organizational operation guides. The effective engineering manager of maintenance in the 21st century will have to supplement the education and experience brought to the maintenance position with self-study, continuing professional education, and on-the-job training in management principles and concepts.

Some illustrations and examples in this manual show a particular product, brand, trademark, agency, or company. AASHTO does not endorse any manufactured product, licensed process, or other proprietary item shown in this manual. All such illustrations are provided to make the accompanying text more understandable, and no reference to such items in this manual should be construed as an endorsement.

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1.0 Maintenance Management

1.1 INTRODUCTION

When highway departments were first formed in the early 20th century, they were seen as construction organizations. Design was a minor responsibility of the organizations. Agency leadership quickly realized, however, that constructing a road properly required a technically adequate and implementable design. As a fledgling road network developed, network maintenance became a recognized activity important to the long-term success and stability of the highway system. During World War II, very little investment was made in the highway system, enabling the United States to devote its resources to the war effort. After World War II, the deteriorated highway system was rapidly expanded and rehabilitated. This increased level of investment to expand and rebuild the highway network created an awareness of the need to begin a rational management process of highway maintenance.

1.1.1 Evolution of Maintenance Management Concepts and Systems

One of the first thorough, systematic studies of highway maintenance attempting to identify the degree to which the engineering management of maintenance was an important component of successfully maintaining a highway network was the Iowa State Highway Maintenance Study (16). The 12-month study (August 1959 to August 1960) focused on three areas of activity:

- Maintenance of the structural or physical highway itself
- Provision of services, such as snow removal and detour upkeep
- Management of the above activities

A detailed supplement to the report documented each type of activity conducted by the Iowa State Highway Commission within the study areas during the study periods (17). Taken together, these two documents were the factual database showing the need for the systematic management of maintenance and the need for research specifically addressed to improving maintenance for the next 15 years.

A significant milestone that focused attention on maintenance management concepts and systems was the 1968 Maintenance Management Workshop (18). This workshop included an overview of what the various states had accomplished in terms of managing maintenance up to 1968 and what were seen as the next decade's challenges. Building on this workshop, maintenance engineers began to apply statistical quality control to highway maintenance as early as 1971 (19).

As statistical quality control entered the field of maintenance management, so did business management principles. This evolutionary step has been quite advantageous, as many states have increased their use of contracts to provide an acceptable level of service. Many departments began to adopt a "management by objectives" approach. Target goals for efficiency and productivity were established with a "bottom-line" analysis for fiscal control and budgetary review of programs. Positive effects of this approach were examination for areas of unnecessary duplication, identification of contract maintenance opportunities, and regular managerial review of programs. This approach also led to research on the development of maintenance levels of service and guidelines for moving to a "level of service" approach to managing maintenance (48). The downside of this approach included some agencies suffering from micromanagement, lower levels of management in some agencies developing low morale from loss of decision-making authority, and severe cost-reduction measures in some agencies generating employment fluctuations. Application of business management principles to maintenance has evolved to the use of strategic planning as a model for maintenance management.



One state, for example, has developed a maintenance performance plan with three separate areas of strategic emphasis (41):

- Developing an effective work force
- Optimizing resources
- Practicing sound stewardship of the environment

This state's adoption of a strategic planning model of management resulted in reorganization of the maintenance management function, decentralizing much of the decision making to engineering managers of major areas of the state. Four functional areas of activity now group personnel and resources:

- Bridge maintenance and operations
- Maintenance (roadway) operations
- Maintenance (roadway) programs
- Maintenance (roadway) services

Management of highway maintenance typically uses information from several different data-base areas (41):

- The maintenance management system (MMS).
- Payroll reports.
- Equipment records.
- Accounting reports.
- The transportation inventory database (a record of the infrastructure).
- Bridge inspection processes and reports.
- The pavement management system (PMS).
- Typically, the bridge management system (BMS) is also included.

Maintenance managers typically have an MMS available that is intended to control and manage the flow of this information so that each level of maintenance manager can make decisions supported by a rational database. The flow and information management process in a typical MMS (41) is objectively oriented to provide specific numeric values to everything that happens with an associated cost. In this sense, the process is a classical engineering economy systems analysis. Many MMSs that operate in this fashion have their original organizational roots in the principles and processes published in National Cooperative Highway Research Program (NCHRP) Report 131 on performance budgeting (39). While the process is not typically integrated across all elements of a transportation department's activities that have a bearing on the need for or conduct of highway maintenance, it does incorporate the critical information elements needed to manage the maintenance function internally.

1.1.2 Development of Integrated Management Systems

Efforts have begun to develop integrated management systems for maintenance. It is not currently known if an integrated management system for maintenance should be a variation of the typical MMS shown above or a central processing host to all of the various functional information bases within a department (of which the MMS is just one). The information above reveals how input databases from an expansion of functional activities continue to broaden the sensitivity of the maintenance manager's decisions. Most departments of transportation (DOTs) have traditionally been top-down in their management control. Pressures developed later to adopt bottom-up planning and the principles of "total quality management" (TQM) as applied to a public sector activity, along with "quality assurance/quality control" (QA/QC) techniques. Computer hardware and software capable of processing and organizing information in large quantities, in multiple levels of inquiry, at high speeds, and in input/output forms that were unthinkable when MMSs were initiated in the early 1970s have become available.

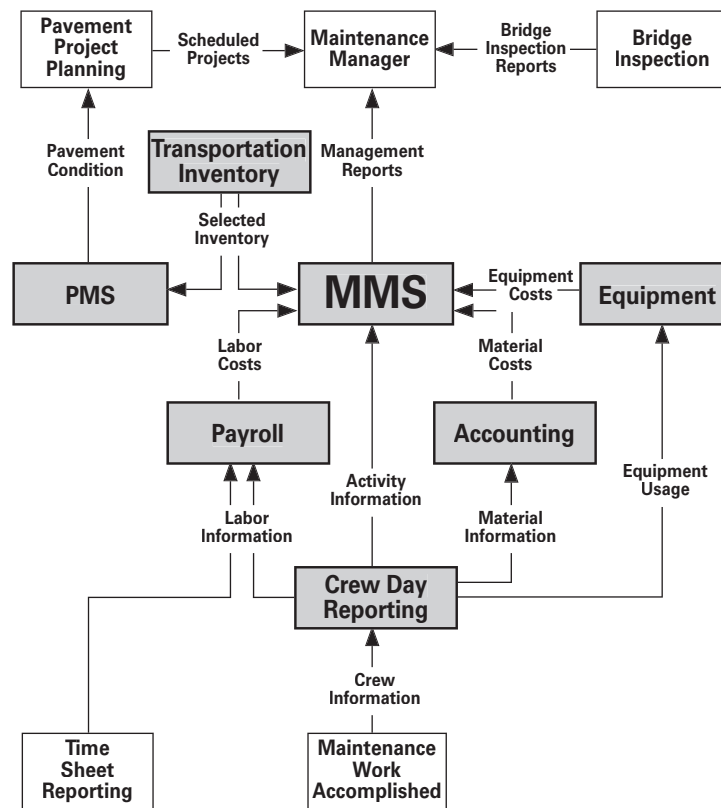


FIGURE 1-1. Maintenance Management System Information Flow

Source: Maintenance Management System Study for the Iowa DOT by Wilbur Smith Associates, June 1993

A comprehensive attempt to determine what an integrated management system that encompasses maintenance should be has been reported in NCHRP Report 363 (27). That effort identified three areas of characteristics or developments needed to produce integrated management systems for maintenance. The study suggested that a very important change would be to ensure that all data collection and maintenance activity reports take place at the level where the information can actually be used to improve or change the way business is done.

A concept scheme was developed that can guide an agency attempting to create an integrated management system. It was recognized that whatever degree of integration an agency chooses to pursue, the next-generation of MMSs will be more integrated across maintenance and other functional

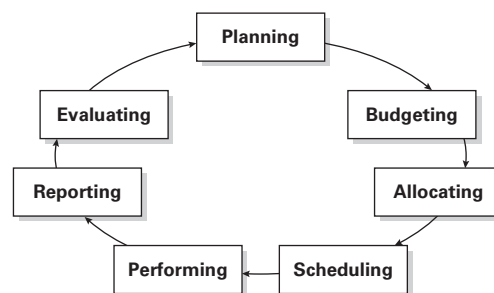


FIGURE 1-2. Maintenance Management Activity Flow

Source: Maintenance Management System Study for the Iowa DOT by Wilbur Smith Associates, June 1993

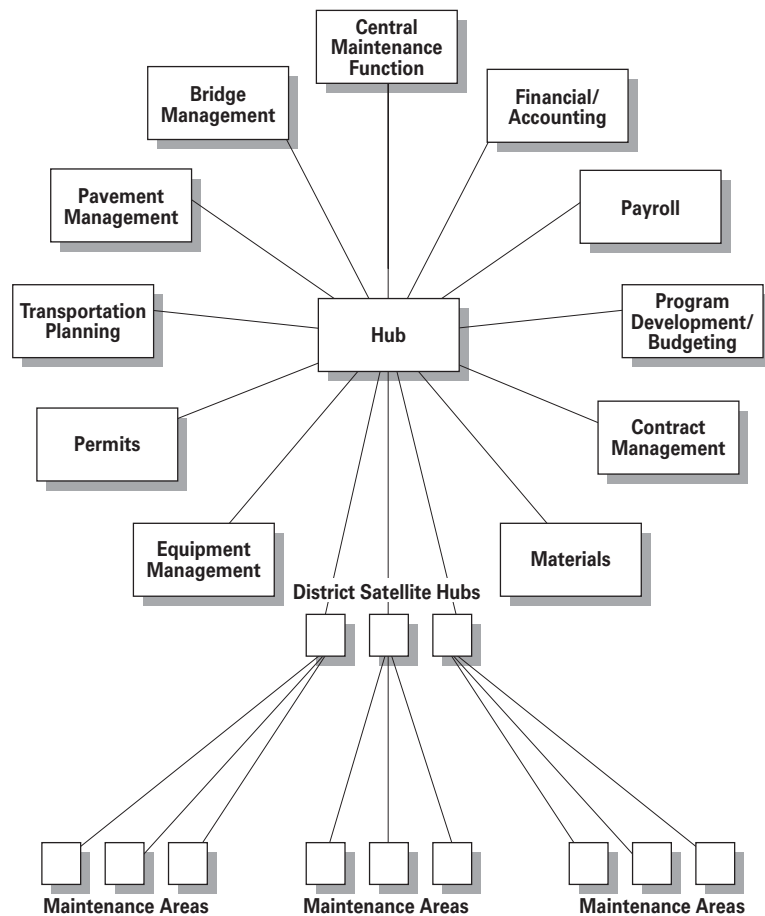


FIGURE 1-3. Hub-and-Spoke Maintenance Management Structure

databases within a department and among the various activities within maintenance. Because business management is a much larger market for management technology (both hardware and software) than are the U.S. DOTs, transportation agencies can “borrow” or transfer technology from business advances in information processing, telecommunication, interactive display, and the study of information’s role on the decision-making process without ever moving to an integrated management system. However, for those agencies wishing to move to an integrated management system, a “hub-and-spoke” concept was proposed to organize the information flow (see Figure 1-3) (27).

1.1.3 Asset Management

The current challenge in Integrated Maintenance Management is the development of effective asset management. The June 1999 adoption of the Governmental Accounting Standards Board Statement 34 (GASB 34) required that major infrastructure assets either acquired or having major additions or improvements in fiscal years after June 15, 1980 be capitalized in financial statements. In addition, the cost of using the assets must be reflected (10).

Since GASB 34 is an accounting standard intended to set guidelines for how an agency considers costs, investments, and the preservation or decline of assets, there is some flexibility in how the numbers are analyzed. A conventional accounting approach establishes the original cost of the asset (e.g., a bridge or section of roadway) and reduces its value by the accumulated depreciation while the asset has been used to determine its current value. An alternate approach (the “modified method”) assumes that the agency will preserve the asset through time by consistently performing its tasks (i.e., maintenance and rehabilitation) at the same level of performance or condition. Because the *condition* of the

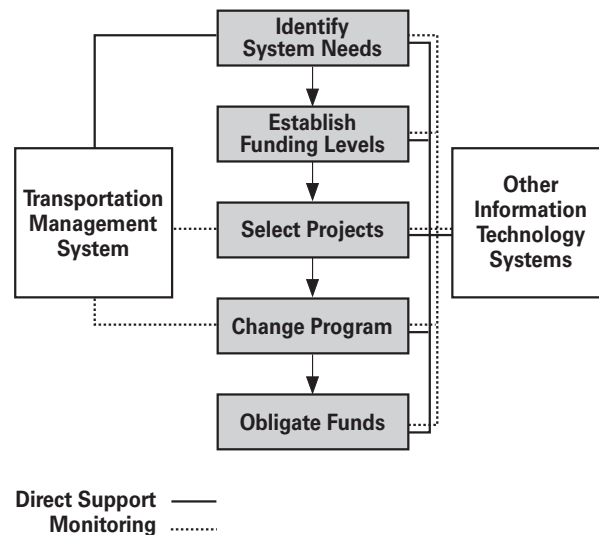


FIGURE 1-4. Michigan's Process for Developing Transportation Programs Using Six Existing Databases

asset remains relatively constant, the *value* of the asset remains relatively constant through time. If an agency decides to use the modified approach to comply with GASB 34, then the agency needs to adopt a management system to ensure that the asset's condition is preserved. One study indicated that most agencies, including state departments of transportation, used the modified method to produce fiscal reports complying with GASB 34 (28). This management development has produced an urgent need for top-level managers to be able to understand and evaluate the impact of shifting resources from one major activity area to another. Thus, the need to be able to extract data from any management database and compare it to another database element is critical.

The Michigan DOT, for example, has reported that they have developed a process that allows them to interface across the following database management systems:

- Pavement
- Bridge
- Congestion
- Safety
- Public Transit
- Intermodal Facilities

As a result, the Michigan DOT has used a "business plan approach" on a public agency to create a unified Transportation Management System (TMS) (11).

The Michigan DOT has provided some "lessons learned" from this process, including the following:

1. Establish cooperation between information technology staff and business process owners.
2. Maintain buy-in using a business plan that supports technical efforts.
3. Commit to a statewide referencing system.
4. Decide whether to build or buy.
5. Ensure effective project management.
6. It is much easier and cheaper to stay current than to catch up.
7. Satisfy system users.

The *NCHRP Transportation Asset Guide* provides practical instructions to agencies continuing to develop and improve their compliance with GASB 34 (36). The guide sets forth some defining principles. One of these principles is that "asset management" has many possible approaches, including the following:

1. a next-generation infrastructure management system;
2. a way to bring private-sector thinking into public-sector decisions;
3. an economics-based approach to investment planning and decision making;
4. a comprehensive program of facility maintenance or maintenance contracting;
5. a management philosophy to secure the future life of transportation infrastructure; and
6. a way of combining pavement, bridge, safety, and other maintenance management systems to yield more effective information.

All of the above approaches are part of sound asset management, but no single approach defines asset management comprehensively. For instance, the Florida DOT reported in 2003 that their emphasis has largely been to pursue a fence-to-fence contract maintenance approach as an implementation of asset management (21). A wider understanding of asset management builds on the following principles:

1. Asset management is policy driven. Decisions about managing infrastructure reflect the policy goals and objectives that define the condition of assets, the levels of performance, and the quality of services to meet customer needs and achieve economic, community, and environmental goals. The Federal Highway Administration (FHWA) has emphasized this aspect of asset management in a *FOCUS* article outlining how asset management and customer satisfaction are related (12).
2. Asset management is performance-based. Goals and objectives must have clear performance measures. Targets established for performance measures must be technically and financially realistic, moreover, as they will guide decision makers in analyzing options, setting priorities, establishing budgets, and implementing programs.
3. Asset management examines options and tradeoffs at each level of decision making. Resources are limited. Investment decisions in other areas and in regard to other assets are interrelated and have an effect on transportation assets. Therefore, decision-makers should consider all options and evaluate the tradeoffs among alternatives.
4. Asset management takes the long-term view. Analyses of program options should incorporate a long-term view of facility conditions, performance, and cost. Analysis procedures rooted in engineering and economics are most effective in assessing the tradeoffs among different actions at different times in an asset's life cycle.
5. Asset management bases decisions on merit. Choices among options during program development, project selection, and program and service delivery should be based on comparisons of costs and the consequences of meeting performance targets. Objective, high-quality information must be applied at each step, using analytical methods and decision-making criteria consistent with policy goals and objectives, and with the agency's business processes.
6. Asset management maintains clear accountability. Performance measures are monitored and reported. This provides feedback on the effectiveness of transportation investments and services, as well as accountability to management for work accomplished and for the effectiveness of program and service delivery.

Most agencies already employ aspects of good asset management practices. The principles in the NCHRP guide suggest ways for agencies to leverage strengths and improve the integration of data, information, and decision making. To be most effective, asset management principles must be applied comprehensively to all of the agency's infrastructure expenditures, including preservation, operation, and system expansion, and in capital construction as well as maintenance and operations programs. The NCHRP *Transportation Asset Management Guide* covers asset management in these investment areas and in resource allocation and utilization. Nonetheless, an agency does not need to mount an all-

encompassing effort to make headway in asset management, but instead can apply the concepts and principles quickly with current personnel and information technology, taking advantage of good asset management practices already in place.

As an example, in the recent past an emphasis existed on balancing “reactive” bridge and roadway maintenance with “preventive” maintenance. Any management work done to move to a more prevention-oriented philosophy of maintenance can be folded easily into an asset management approach to the maintenance, operation, and expansion of transportation infrastructure. The budgeting process is only one activity in which the tradeoffs outlined above will have to be adjusted to the reality of the short-term cost of pursuing long-term preventive maintenance, but adopting as many as possible of the tools available to assist decision-makers will enhance the degree to which transportation assets are properly preserved (43).

1.1.4 Roadway Management

1.1.4.1 Introduction

Chapter 2 is intended to provide the new maintenance engineer or new maintenance manager with an overview of the aspects and issues considered to be most urgent with respect to managing the roadway. As discussed in Chapter 1, the movement toward managing the entire transportation infrastructure under the principles of asset management will permeate the maintenance organization. Since maintenance activity has historically been involved in preserving the roadway asset, asset management should make the maintenance organization’s work more important but will likely require adjustment and change in focus within the organization’s leadership and management.

The program content of the 10th American Association of State Highway and Transportation Officials (AASHTO)–TRB Maintenance Management Conference (46) provides insight into the concerns and interests of state maintenance engineers and managers. The program was divided into eight emphasis areas:

- Contract maintenance
- Customer satisfaction
- Equipment
- Maintenance management
- Pavement
- Roadside and environment
- Snow and ice control
- Workforce development

Each of these areas will be examined as an urgent focus within the context of asset management of the roadway.

1.1.4.2 Contract Maintenance

The fundamental guide for contract maintenance is the AASHTO document, *A Guide for Methods and Procedures in Contract Maintenance* (2). This document offers a thorough introduction to the benefits and issues of contract maintenance for a state DOT, explains the various approaches to maintenance contracting, and discusses suggested procedures. A number of brief case studies are included. Among these, contract maintenance activities of the Virginia DOT and Florida DOT are particularly significant, as both are beginning to undertake “asset management” contracts.

Asset management as a process for roadway management first began to surface in the United States when maintenance engineers and maintenance managers from Europe, Canada, and several Pacific Rim nations made presentations at the Annual Meeting of the Transportation Research Board in the early 1990s. Those nations have, basically, already moved to total privatization of the maintenance function, in which the public agency manages the asset through the administration of various contracts. Such a process, undertaken by the Ontario Ministry of Transportation, was described by Shael Gwartz at the 10th AASHTO–TRB Maintenance Management Conference (5). Maintenance “asset management” contracts entered into by the Virginia DOT and Florida DOT are hybrid approaches in which some maintenance activities and responsibilities are retained by the state DOT.



Moving toward asset management by contract—or at least conducting more maintenance by contracting—has ramifications in other areas, including equipment fleet size, fleet composition, equipment unit acquisition and disposal, workforce retention, workforce training and development, inspection of work, quality assurance methods, and performance standards. Engineers and managers new to the maintenance organization should make every effort to participate in the discussion held by the AASHTO Subcommittee on Maintenance in order to become knowledgeable about these issues.

1.1.4.3 Maintenance Management

Maintenance management is actually being altered most dramatically by the growth of the computer modeling of information flow. Previously, the flow of information was vertical, insofar as raw data flowed up and information (whether analyzed or interpreted data) flowed down, giving control to those at the top of the information pyramid. In the past 10 years, however, the development and widespread acquisition of powerful desktop and laptop computers has changed the flow of information within organizations, both vertically and laterally. As a result, private businesses have developed a more fluid and “horizontal” management style, a philosophy that has gradually been adopted by public agencies. Consequently, issues regarding the further automation of management activities have arisen, with information technology applied directly to the collection and analysis of data to facilitate quality assurance, work scheduling, and activity performance (26, 47). At the same time, the movement toward “asset management” has spurred what previously was a somewhat lackluster interest in implementing integrated data information systems, linking management systems in maintenance, bridges, safety, and pavement, among others (24). It is appropriate that pressure for the total integration of information for managing the transportation infrastructure has occurred simultaneously with the increasing speed and capacity of computer hardware and software.

1.1.4.4 Workforce Development

The great quandary of maintenance management is to define and decide upon the kind of workforce needed to complete a given assignment. These are questions that each state DOT has to answer for itself, in consultation with its external policy makers. Once a measure of direction is established toward knowing what the maintenance organization is expected to do (not necessarily a comprehensive solution for a given problem), the organization can then begin to develop a workforce suitable to the task. Fortunately, the U.S. workforce is rapidly becoming computer literate and comfortable with computer-based training. Smithson and Edson discuss innovative computer-based simulations (“gaming” exercises) that produce short training-to-learning time ratios, with high levels of knowledge and skill retention (9, 42). Thus, while some time and self-examination is needed to determine the workforce makeup of any state DOT maintenance organization, the means to develop needed workforce skills rapidly are increasingly available.

1.1.4.5 Customer Satisfaction

Maintenance management will continue to be greatly influenced by the needs of road users determined through various “customer” inputs. Much as a politician who “lives by the polls” also “dies by the polls,” maintenance engineers and managers must learn enough about private sector market research to be able to determine when studies of customer needs and preferences provide useful information. Maintenance activities should not alienate road users to the extent that the state DOT loses all political support for its programs and budget. At the same time, however, maintenance engineers and managers have a professional responsibility to determine what is actually needed to maintain and preserve roadways. Moving toward an asset management model means that significantly more emphasis may have to be given to roadway preservation than customer satisfaction surveys suggest. Customer satisfaction surveys tend to reflect very short-range perceptions, similar to political issue tracking surveys. The presentations by Dull and Lebwohl (8), Bilotto (5), and Adams and Martinelli (3) all shared insights into the need to exercise good judgment when using customer satisfaction data.

1.1.4.6 Equipment

Because the structure of the fleet needed by a maintenance organization depends largely upon how maintenance is managed (in-house forces, total contract, selected area contracts, etc.), the principal focus will be on financing the acquisition of needed equipment and the cost-effective disposal of equipment that is unnecessary or obsolete. Swenson formulates the financial aspects of this issue nicely (44).

1.1.4.7 Pavements

Even when highway infrastructure is separated into roadway and bridge components, pavement still remains the largest single cost category in the entire financial inventory. Moving to an asset management philosophy is therefore likely to place even greater emphasis on the problems and possible solutions for pavement preservation than existed previously. Pavement preservation assumes greater significance when focusing on activities such as drainage under the pavement; inspection to provide early detection of voids under the pavement; quality control for aggregates, asphalt binders, and cement products; methods of relating materials and processes to rutting and tire path wear; and methods and materials to produce more durable patches, etc. This is not to suggest these issues have not received attention in the past; to the contrary, the research literature amply attests to the examination of practices in all these important areas. However, management pressure now ensures that research is directed more narrowly toward the successful implementation of these practices.

1.1.4.8 Roadside and Environment

Environmental concerns and issues continue to grow. Thornton et al. outline how the Penn DOT has attempted to incorporate general environmental concerns and issues into a management program that addresses roadway and roadside maintenance (45). Nelson et al. reported on the New York State DOT's broader focus in attempting to generate an "environmental stewardship" approach to maintenance and operations (37). Asset management often tends to focus an agency's thinking more toward the preservation of physical capital (indeed, that was the intent of the investment banking industry in its push for the adoption of GASB 34). However, not to pursue proper management of the roadside and environment may place that agency's political capital at risk. Thus, roadway management must continue to optimize use of the roadside environment.

1.1.4.9 Snow and Ice Control

Management of a snow and ice control program for winter maintenance in the "snow belt" should take its lead from the AASHTO *Guide for Snow and Ice Control* (1). While snow and ice control is not an issue for states or regions of states with climates that rarely (if ever) experience snow and ice, the process of snow and ice control requires the consideration of issues affecting all state DOTs. To deal with snow and ice properly, the maintenance agency must examine equipment needs and seek equipment innovations (4). The agency must also consider the environmental impact of the methods and materials used, as well as the fiscal and safety impacts of policies and procedures (6). Since winter weather is beyond the control of the agency, snow and ice storms can assume the characteristics of natural disasters requiring as much advance planning as possible, taking into account alternate scenarios with contingency plans to address them. In an era of asset management, then, the manner in which state DOTs manage snow and ice control as maintenance activities can help new maintenance engineers and managers in states where snow and ice control are not an issue, instructing them in the management of situations requiring large and sudden surges in the consumption of resources.

1.2 MANAGEMENT AND ADMINISTRATION

1.2.1 Functional Aspects

Within any given state, maintaining the highway network to preserve the capital investment in the network and to provide the services needed by highway users is a very complex management and administrative responsibility. Maintenance engineers and managers are expected to understand a wide variety of functional aspects of managing complex organizations and to assemble a staff capable of applying sufficient detailed knowledge in each functional area.

Highway maintenance encompasses a program to preserve and repair a system of roadways with its elements to its designed or accepted configuration and to an accepted quality of roadway performance. Elements of the highway network to be maintained include travel way surfaces, shoulders, roadsides, drainage facilities, bridges, tunnels, signs, markings, lighting fixtures, and truck weighing and inspection facilities. The program includes such traffic services as lighting and signal operation, snow and ice removal, operation of roadside rest areas, operation of movable span bridges, and roadside beautification.

Highway maintenance programs are developed to reduce the negative effects (real or perceived) of weather, vegetation growth, deterioration of roadway elements, traffic wear on surfaces, vandalism, and other types of damage. Deterioration includes the effects of aging, material failures, obsolete designs, and construction imperfections. The maintenance organization conducting this program is judged by performance criteria internal to the organization; by the confidence of those providing the funds for maintenance that resources are being wisely allocated and used as evidenced by adequate funding; by the perception of the traveling public as to how well the program efforts are addressing maintenance issues important to the public; and finally, by peer review and judgment (when peer review is conducted).

The maintenance program may be conducted completely in-house; conducted through agreements with local public agencies (e.g., counties and cities); conducted with private contracts for selected activities; or conducted completely through contracts with outside vendors. Most states operate by contracting selected activities to private vendors while retaining all activities deemed to be best provided by in-house personnel, ensuring proper quality control and quality assurance. Thus, the maintenance program will necessarily include maintenance and repair of certain buildings, stockpiles, and equipment essential to performing all of the functional aspects of the maintenance program retained in-house. Maintenance of these buildings, stockpiles, and equipment is not directly related to maintaining the highway, but is a part of the highway maintenance program.

While the boundary between “maintenance” and “construction” varies according to local policies, local contract administration, and the legal guidelines for administering funds available for maintenance and construction, maintenance is generally limited to activities that do not increase the capability, strength, or capacity of an element of a facility. At times a maintenance and repair activity improves a roadway element, but those times are usually limited to replacing a destroyed element with an improved version developed since the original installation. For example, an old design guardrail end section may be hit and destroyed; in the repair process, a newer design unit is installed that upgrades and improves the safety capability of the guardrail end section as a maintenance activity. However, a contract to replace all of the old guardrail end sections across an entire region would be a “construction and rehabilitation” contract excluded from the functional maintenance program. The AASHTO-adopted guidelines for the distinction between maintenance and construction are included here, along with the AASHTO-adopted definition of highway construction, to further clarify the functional aspect of the highway maintenance program. (See Table 1-1 and Section 1.2.1.3, Highway Construction Definitions.)

1.2.1.1 Organization for Maintenance

While there are similarities in how the various states are organized to manage and conduct maintenance, each state has unique functions and organizational characteristics. When the organizational chart is developed outlining the maintenance manager’s responsibilities and authority, the scope and depth of activity covered will be defined partly by the overall organizational philosophy of the parent DOT (or department of highways). A decentralized DOT with the central office having only a coordination role in the planning and programming of a maintenance district may outline a much broader range of responsibilities and authority than a centralized one. The degree to which a DOT is organized with functional activities grouped for program planning and implementation or is organized with functions grouped by the mode of transportation with which each activity is associated profoundly impacts the range and scope of a maintenance manager’s responsibilities and authority. Generally, most DOTs are organized by mode, with highway maintenance being the sole responsibility of the manager of roadway maintenance. However, the New York DOT, for example, has a history of emphasizing organization by function (see Figure 1-6).

In most cases, anything that is not construction or traffic operations on existing highways is a maintenance responsibility. The maintenance organization may be responsible for other activities, such as operating ferries, operating toll collection systems, issuing and monitoring permits, operating and maintaining a departmental motor pool, and maintaining public service facilities. In some DOTs, traffic operations is an integral part of the maintenance responsibility.

In some states, maintenance and construction are part of the same organization. Many states are divided into districts with some districts under the supervision of operations or maintenance engineers. In some districts within a state, the operations or maintenance engineer is a subordinate in a more general organization structure that sometimes includes design engineering and facility construction.

TABLE 1-1. Summary Table—Distinction Between Construction and Maintenance

	Construction		Maintenance	
	Construction and Reconstruction	Betterment	Physical Maintenance	Traffic Services
Traveled Way	All operations on new location involving considerable reconstruction to modern standards for 500 ft or more. Widening sufficient to change geometric type, as from a two-lane to a three- or four-, from a three- to a four-, or from a four- to a six-lane highway, with all lanes not less than 11 ft. Addition of 500 ft or more of frontage road in any 1 mile.	Placing new loose material on road surfaces to substantially increase thickness of surfacing beyond that originally built for 500 or more continuous feet. Improvement of surface to higher type for 500 ft or more. Resurfacing of hard surfaces with bituminous material $\frac{1}{4}$ in. thick or more for a length of 500 continuous feet or more. Replacement of existing pavement with higher standard for 500 ft or more. Widening with no change in number or lanes. Addition of less than 500 ft of frontage road in any 1 mile.	Scarifying, reshaping, applying dust palliatives, and restoring material losses; patching, mudjacking, joint filing, crack sealing, surface treating, etc. Resurfacing of hard surfaces with bituminous material less than $\frac{3}{4}$ in. thick. Replacement of traveled way in kind for less than 500 continuous feet. Replacement of unsuitable base materials in patching operations.	Removal of snow and ice, and related operations such as sanding, chemical applications, etc. Restoring pavement stripes and markings, and replacing raised pavement markers.
Shoulders and Side Road	All work incidental to above. Original surfacing for 500 or more continuous feet.	All work incidental to above. Resurfacing, stabilizing, or widening of shoulders and side road approaches for a length of 500 continuous feet or more.	All work incidental to above. Restoring material losses. Replacement of shoulder in kind. Reseeding and resodding.	Same as above.
Roadsides	All work incidental to above.	Widening the roadbed. Substantial slope flattening or landscape treatment.	Restoration of erosion controls. Removing slides, reshaping drainage channels and side slopes, mowing and tree trimming. Replacing topsoil, sod, shrubs, etc. Chemical spraying.	Erection of snow fences. Opening of inlets clogged with snow and ice. Removal of litter.
Intersections	All work incidental to above. Complete reconstruction of intersections, including changes in type of intersection as from plain to a grade separation and ramps.	Nominal channelization of intersections. Addition of auxiliary lanes.	As covered by other items in this column.	As covered by other items in this column.

(Continued on next page)

TABLE 1-1. Summary Table (continued)

	Construction		Maintenance	
	Construction and Reconstruction	Betterment	Physical Maintenance	Traffic Services
Alignment Changes	New location. Appreciable alignment changes for 500 ft or more with or without change in highway type.	Minor changes in alignment with profile, such as easing horizontal curves or eliminating irregularities in profile. Regrading or resurfacing to introduce or increase superelevation on curves, or to improve sight distance where such work does not exceed 1,000 ft per mile.	None.	None.
Right-of-Way Additions	None, some, or all.	None or some.	None.	None.
Stage Construction	Where above operations are performed by stages, widely separated in time, each may be classed as construction, betterment, or maintenance, depending on its characteristics.	Where above operations are performed by stages, widely separated in time, each may be classed as betterment or maintenance, depending on its characteristics.	None.	None.
Incidental Items	Where overall improvement is classed as construction or reconstruction, incidental operations of the maintenance or betterment class should be considered part of the construction or reconstruction.	Where overall improvement is classed as betterment, incidental operations of the maintenance class should be considered part of the betterment.	None.	None.
Unusual or Disaster Operations	Extensive repair or replacement due to damage as a result of storm, flood, or military operations, may be charged to extraordinary maintenance, betterment, or construction, depending upon scope of work.	None.	None.	None.

TABLE 1-1. Summary Table (continued)

	Construction		Maintenance	
	Construction and Reconstruction	Betterment	Physical Maintenance	Traffic Services
Drainage	All work incidental to above. Building flood control, flood prevention, and earthwork protective structures. Installations or extensions of curb, gutter, or under-drain for a length of 500 ft or more in any 1 mile.	Extending old culverts and replacing inlets and headwalls. Replacing culverts with those of greater capacity. Installation of additional pipe culverts or additional structures with spans not greater than 10 ft. Installation or extension of curb, gutter, or underdrain of less than 500 ft in any 1 mile.	Replacement (using approximately same design) of curb, gutter, riprap, underdrain, and culverts. Cleaning and repairing culverts, inlets, etc.	None.
Structures	All work incidental to above. On structures having a span of 20 ft or less, complete re-construction to a higher standard. Complete reconstruction or additions to bridges of more than 10 ft span. Widening of bridges over 100 ft long. Extensions or new installations of walls involving over 80 cubic yards of structural material.	Replacement of bridge rails and floors to higher standard. Widening of bridges 100 ft or less between abutments. Extensions or new installation of walls involving 80 cubic yards or less of structural material. Replacement of walls to higher standard.	Cleaning, painting, and repairing. Replacements (using approximately same design) of rails, floors, stringers, or beams. Replacement of walls in kind. Repair of drawbridges and ferries.	Operation of ferries, including cost of power, operators, and periodic replacements. That part of operation of drawbridges charged to highway traffic.
Traffic Control and Service Facilities	All work incidental to above. First erection of traffic signs and direction and route markers.	Replacement of all major signs with superior set, or individual installations of specially erected signs. Installation of traffic signals, railroad protection devices, lighting systems or extension of same. Extension or new installation of guardrail for 500 continuous feet or more. Nominal channelization. Installation or complete replacement with superior design of facilities for roadside rest areas.	None.	Painting, repairing, and replacing in kind of signs, guardrails, guide markers, signals, lighting standards, etc. Addition of small numbers of traffic control devices. Maintenance and replacement in kind of rest areas. Servicing of and furnishing power and light bulbs for lighting and traffic control devices. Policing, roadside cleaning operations, operation of roadside areas, towing service, information booths, etc.

The following figures (Figures 1-5 through 1-7) provide illustrations of several varying administrative organization formats in which particular states have attempted to respond to their respective unique needs. While each state has distinctive characteristics, some general formats are common (i.e., decentralized vs. centralized decisions, modal vs. functional units).

1.2.1.2 Planning and Budgeting for Maintenance

Planning and budgeting for maintenance are interconnected activities. However, planning should focus more on assessing the functional activities necessary as a result of the highway network configuration and the distribution of the highway features with respect to the distribution of resources (personnel, equipment, and materials). Planning for maintenance should provide an estimate of the amount of maintenance needed to sustain the highway network at various levels of service (repair and replace for safety needs only, sustain the value of present investment in the network, upgrade the value and functional utility of the network, for example). Then the budgetary requirements for the various levels of service can be set after maintenance performance and quality standards have been applied to yield estimates for the personnel, equipment, and materials needed to accomplish a certain level of maintenance service. A wide variety of tools and methods are available to do this type of planning to various degrees. Each state has somewhat different information management needs and capabilities. Thus, each state should carefully consider what seems to be useful and helpful in any method or technique to make their maintenance planning compatible with program planning across the DOT.

A variety of management systems to develop budgets are in use in various states. Selection of a budgeting (and planning) system by each state should largely be done on the basis of what works best and which system encourages the best lines of communication within the organization.

Highway maintenance budgets can be formulated from past performance data or needs based on established levels of service. Because budgets based solely on past performance can perpetuate both good and bad practices, they should be prepared with caution. There is growing interest in doing both planning and budgeting from a perspective of preserving the public investment in the highway network, similar to the capital investment analysis that a private corporation would perform. Adoption of such a budgeting philosophy will likely require some adjustment to the current budget development process in place in most DOTs to incorporate more of a “present net worth” analysis.

Maintenance management should work closely with those responsible for development of the total highway budget to accomplish the following:

- Recommend which highways and bridges need reconstruction in consideration of projected maintenance requirements. Use of pavement and bridge management systems is a systematic way to define needs and establish priorities.
- Adjust maintenance requirements in view of approved construction projects and schedules.
- Determine future construction schedules in order to adjust maintenance requirements on roadways that may be reconstructed or constructed beyond the next budgetary period.

Budgeting should also include the monitoring of expenditures, ensuring that the intended level of service and allocation of funds is not exceeded. Agencies seeking to improve their budgeting process as part of an overall effort to improve the quality of completed maintenance activities should consult NCHRP Project 14-12, *Highway Maintenance Quality Assurance Final Report (40)*. It contains recommendations for linking the budget process, resource monitoring allocation, and evaluating maintenance quality; it also has a model application to implement the process. This project report can be reviewed on the Internet at www.trb.org under the link to on-line publications, then NCHRP web documents, then Document #8 (1997).

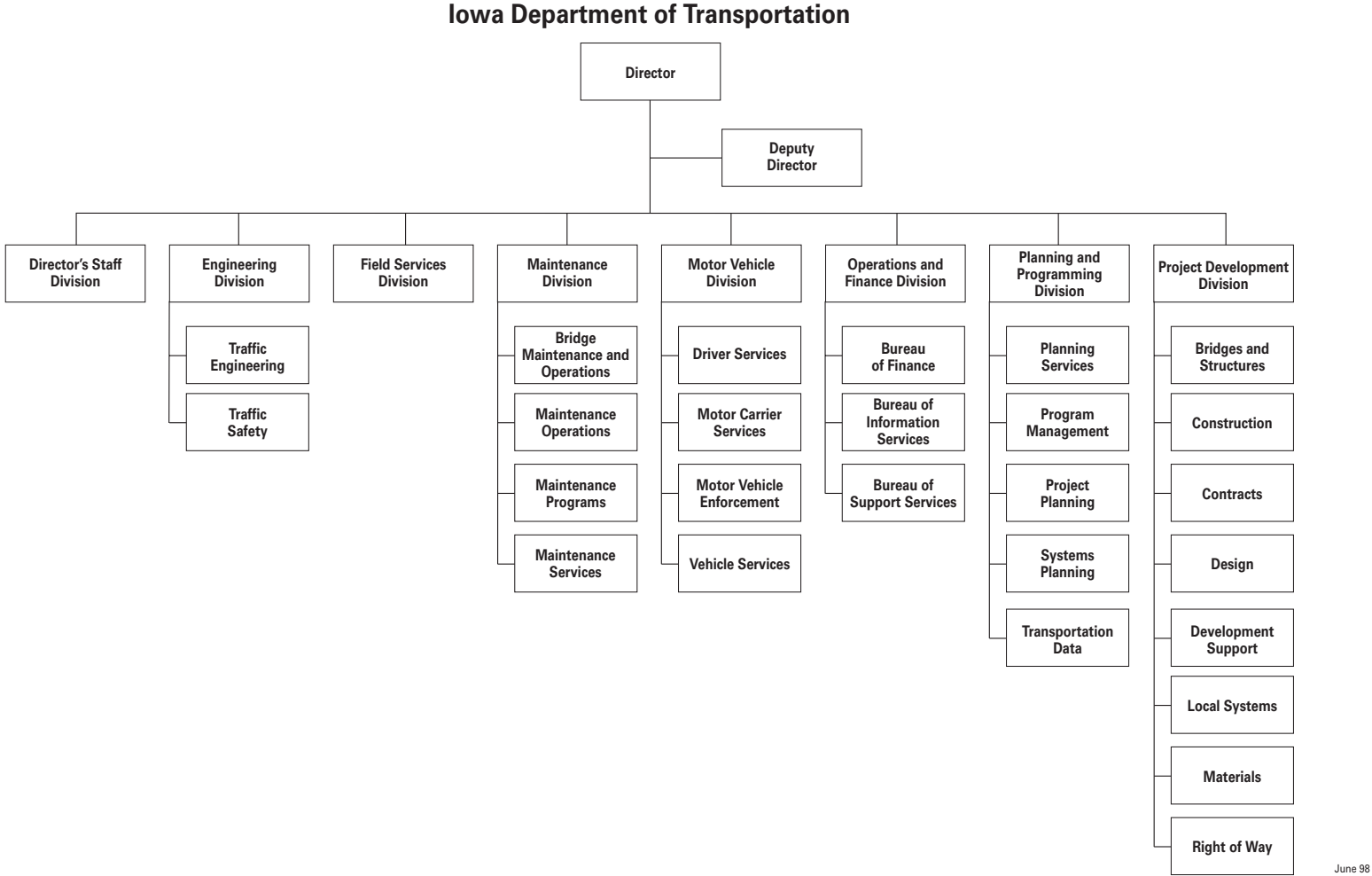


FIGURE 1-5. DOT Organization Typical of Centralized Administration
Note: The organization structure includes six transportation centers (formerly district offices) that are distributed throughout the state. The maintenance, field services, planning and programming, and project development divisions have division representatives on each transportation center staff.

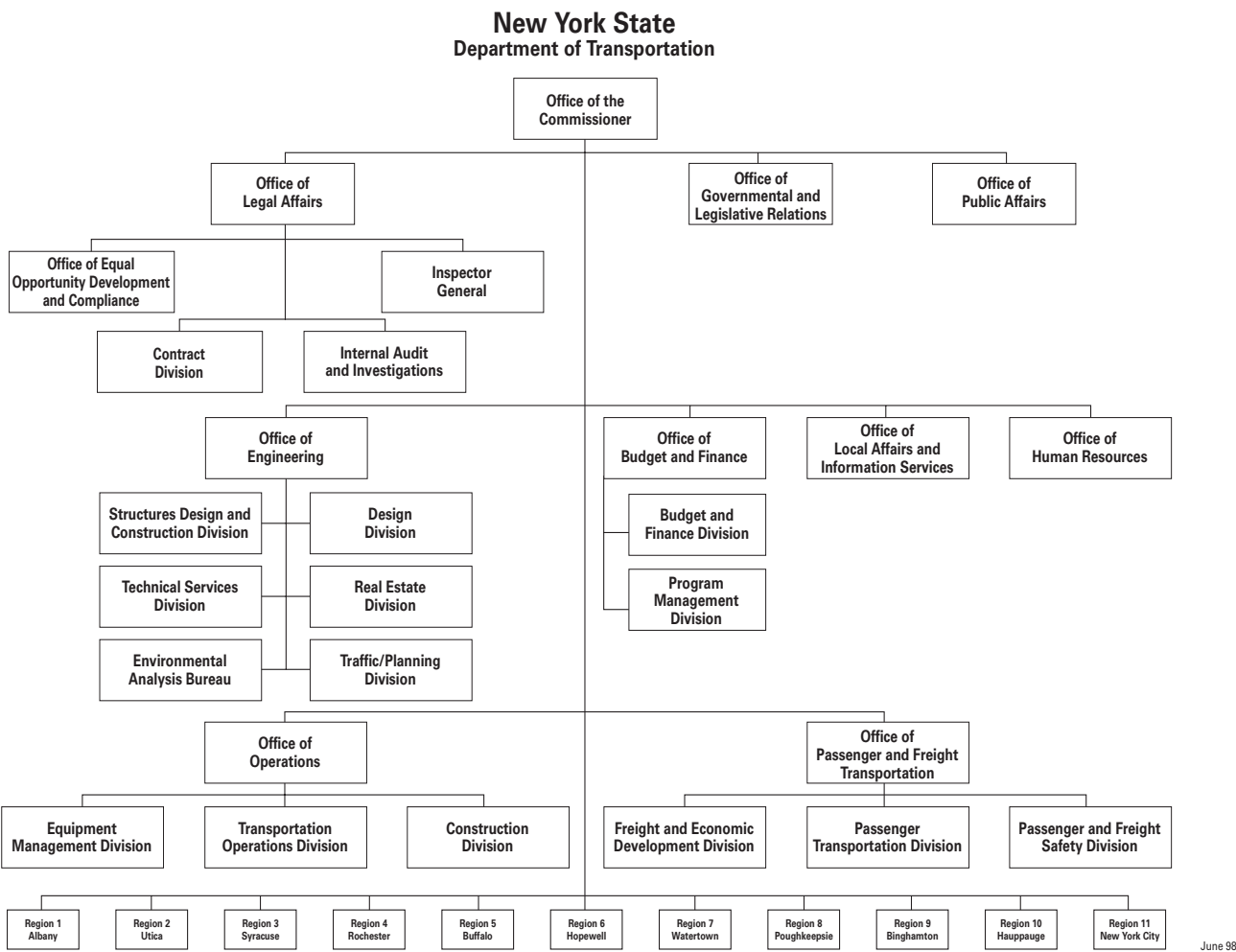
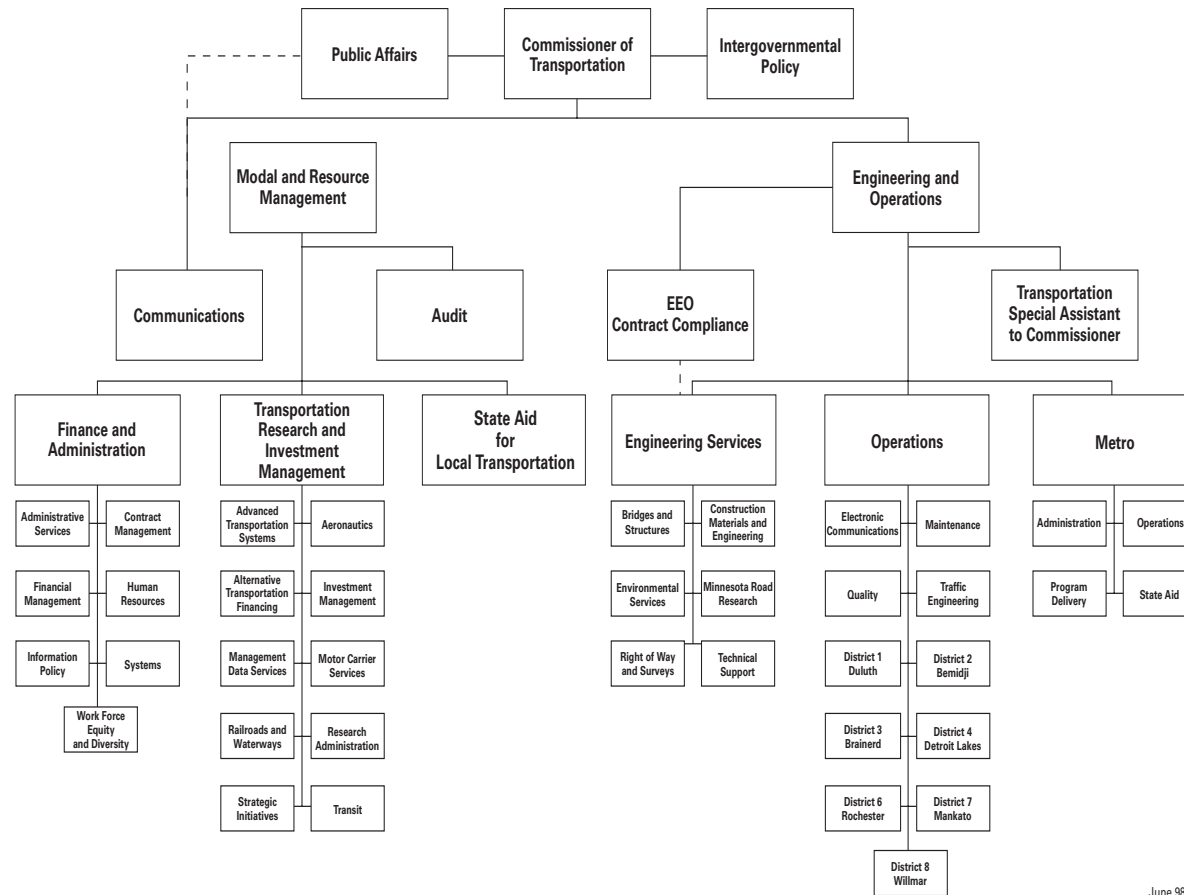


FIGURE 1-6. DOT Organization by Function

State of Minnesota Department of Transportation Organization



June 98

FIGURE 1-7. DOT Organization Typical of Centralized Administration Attempting to Balance Rural and Urban Metropolitan Needs

1.2.1.3 Highway Construction Definitions (Adopted June 30, 1986)

General Criteria

Work must be substantial in scope, and substantially extend the service life of the facility or component thereof, and/or enhance safety, and/or replace or renovate a failed component of the highway facility that has served its useful life.

Pavement and Shoulders

All pavement or shoulder work on new or existing alignment that is significant in scope or that is incidental to roadsides, structures and drainage, or traffic services work; that would provide improved traffic capacity; that would provide improved traffic safety; that would improve or restore adequate skid resistance; that would improve or restore the profile or cross slope of a pavement; that would increase the structural capacity; that would seal pavement surfaces to prevent water intrusion; that would substantially extend the service life of a pavement; that would replace all or part of a failed pavement or shoulders with an equal or higher standard material; that would stabilize, restore, or replace failed pavement base material; and/or, that would replace or restore a failed highway component that has served its useful service life.

Roadsides

All roadsides work on new or existing alignment that is significant in scope or that is incidental to pavement as shoulders, structures and drainage, or traffic services work; that would provide for the stabilization or restoration of significant roadway section landslides; that would provide for the installation of landscape materials; and/or, that would provide for improved roadside safety.

Structures and Drainage

All structural and drainage work on new or existing alignment that is significant in scope or that is incidental to pavement and shoulders, roadsides or traffic control, and traffic services work; that would provide for improved traffic capacity; that would provide for improved traffic safety; that would restore or increase carrying capacity or hydraulic capacity; that would restore the structural integrity of bridge components; that would protect bridge reinforcing steel against corrosion; that would provide for the replacement of a failed protective coating system with an equal or higher standard material; that would provide for the installation of pavement and/or shoulder drainage systems; that would provide for the replacement of a failed structural or drainage component with a higher type of material; and/or, that would replace or restore a failed component that has served its useful service life.

Traffic Control and Service Facilities

All traffic control or service facilities work on new or existing alignment that is significant in scope or that is incidental to pavements and shoulders, roadsides or structures, and drainage work; that would provide or replace traffic control devices, including pavement markings and highway lighting; that would provide for the installation of new guardrail or other traffic safety devices to protect traffic from hazardous areas; that would provide for the upgrading to current standards of existing guardrail or other devices, or the replacement of guardrail or other devices; that would provide for the installation of monitoring devices of facilities for speed monitoring or weight enforcement; that would provide for the installation, restoration or replacement of facilities for roadside rest areas; that would provide for emergency communication equipment, and/or, that would replace, restore, or rehabilitate a failed highway component that has served its useful service life.

1.2.1.4 Scheduling Maintenance

Seasonal or annual events and routine planning produce most maintenance schedules. The need to clean, repair, or perform maintenance and service functions is dictated considerably by seasonal variations in weather. However, the most effective maintenance is based on anticipating a need and scheduling the proper resources and corrective actions to achieve the best results. The continued evaluation of Strategic Highway Research Program (SHRP) test sections for pavement maintenance treatments

should provide equations that can be used to estimate the effectiveness of a given pavement surface treatment based on the condition of a roadway surface, the traffic it is subjected to, and the general climatic zone in which it is located. Aids like these that are being developed have the potential to project preventive maintenance beyond an annual cycle for investment preservation. Scheduling maintenance activities of in-house forces must be coordinated with maintenance activities devoted to contract relationships. Ideally, in-house force maintenance schedules and contract schedules would be seamlessly integrated.

New requirements are constantly increasing the scheduling responsibilities of maintenance managers. More sophisticated traffic control devices, mechanized equipment with greater capabilities and cost, the introduction of robotics equipment, a wide range of new materials, increased training and safety requirements, public concern for ecological and aesthetic aspects of highways, energy availability and cost, and tort liability are some of the factors influencing the maintenance manager's role. As more of the managerial decisions move down to the field level, maintenance teams and crews will increasingly perform the scheduling of maintenance. These people need to be trained in how to make rational trade-offs in setting priorities with conflicting objectives. These conflicts result from the factors listed above and others, including political considerations, demands from various constituencies, and general public concerns. It is unfair to thrust decision making in such an environment onto field personnel without also equipping them to process such conflicts.

A number of scheduling factors influence the manner and effectiveness of highway maintenance activities. Many of these factors are subject to a wide range of variables. Some of these factors are as follows:

- Distance of work sites from the base of operations and the time and expense to transport personnel, materials, and equipment to site. (Upper levels of the maintenance organization, need to consider how the location of maintenance garages and stockpiles limit team and crew scheduling.)
- Weather conditions that can influence whether a repair can even be made or the nature of the materials and equipment that will be required. (The developing research started in SHRP on the use of weather information systems and more precise weather forecasting applied to maintenance has the potential to reduce the weather's disruption of maintenance schedules significantly.)
- Availability of skilled personnel, equipment suited to the task, and the proper materials (in sufficient amount and appropriate quality).
- Size and grouping of each work package, if it is within the scope of resources available, and if it will result in a high unit cost because of transportation distance.
- Problems caused by competition for resources between work projects, influence of unanticipated events, and preparation requirements.
- Influence of budgets on priorities and amount of work that can be accomplished within a budget period.
- Traffic conditions at different time periods and the degree to which maintenance operations can be expected to trigger congestion, delays in traffic, and accidents.
- Outside influences such as labor contracts and political requests.

To ensure effective highway maintenance, management systems should employ scheduling methods that, in consideration of the factors listed above, will accomplish the most work with the resources available—as balanced against the most important needs of the highways in the network.

To determine the most important scheduling needs or priorities, management should have a reporting and evaluation system to identify maintenance requirements.

Highway maintenance has become more mechanized and less dependent upon hand labor. Few maintenance functions remain that are completely performed by hand labor. Equipment-oriented personnel have become the basic employees in maintenance, replacing common hand laborers. Remote-control and robotic equipment is the newest technological transition in maintenance. The use of more expensive equipment and a larger work potential imposes greater obligation on maintenance management to schedule work efficiently.

A state maintenance organization manages personnel, equipment, facilities, and material valued at many millions of dollars. In every respect, it has a large responsibility that justifies the most effective use of resources.

- A poorly trained employee or an investment in equipment that is seldom used represents a loss to the organization. They may also affect indirect losses in the use of other resources. Obsolete or underused equipment should be disposed of to recover any remaining value. Equipment use should be regularly monitored.
- The considerable dispersal of personnel, equipment, and facilities over a large area makes efficient control difficult. Highway maintenance departments have difficulties in planning for efficient use of resources—difficulties that exceed similar problems in most other industries. This is one reason there is hope that empowerment of field-level supervisors through the TQM process may lead to significant increases in efficiency and effectiveness, since these persons are at the level where trade-offs and sharing of resources can have the most impact.
- The relationship of material costs to transportation costs presents a special problem. There are few situations in other industries where the cost of basic materials can double because of transportation costs.

Travel time is a large contributor to high unit costs in highway maintenance. If every pothole or crack were within one mile of the maintenance yard and the stockpile, the productive rate of a maintenance unit could be much higher. To schedule labor, materials, and equipment to travel 40 miles to repair one pothole is the extreme of poor scheduling in terms of cost-effectiveness. There may be times, however, when such scheduling will be done and cannot be avoided for traffic safety or other reasons. The most effective means for maintenance to improve efficiency and to achieve a high level of production is through scheduling and, particularly, reducing the ratio of travel time to production time. Some maintenance organizations find that four 10-hour days per week are more cost-effective than five 8-hour days. Again, as field-level units of the maintenance organization become responsible for determining how maintenance tasks are to be carried out to a larger degree than has been true in the past, the crews may improve production by making radical schedule adjustments.

Standby time is difficult to avoid in maintenance. However, scheduling based on experience and planning can foresee and avoid much lost time caused by delays in delivering materials, work bottlenecks, breakdowns, etc. Scheduling needs to include time for employees to sample data required for estimating maintenance level of service to support a Maintenance Quality Assurance Program.

1.2.1.5 Data Systems to Support Maintenance

As maintenance management moves toward employing the techniques from operations research, management science, industrial engineering, and business management, it will require refining the current data systems available to support maintenance management. Bridge management systems, pavement management systems, and the existing maintenance management systems all share much common data, which is good. Maintenance management also interacts with payroll systems, material and equipment inventories, and so on, all of which are resident within the entire DOT information system databases.

What is evolving now is the way in which these various databases can be accessed or queried for specific items (if it is possible to do so in a particular department's information management system)

to provide input to mathematical programming models, statistical quality control models, engineering economy models, and other optimization methods. Cost-benefit models have been used for decades. Now cost-effectiveness models are beginning to be used. Before embarking on a management strategy that depends on a particular optimization model or optimization strategy, determine what data needs apply to the model or strategy, then assess if it is economically feasible to retrieve the necessary data from the existing databases.

While it might be tempting to create a new computer system to collect and analyze data perceived to be needed for the more integrated analysis required for asset management, much can be gained by rigorously examining existing data inventory systems and the potential to gain needed data through data sharing. NCHRP Synthesis 288 succinctly reviews this topic and notes that few states actually capitalize on the potential rewards of data sharing among state and local agencies within their jurisdictions (32). Just as there may be data efficiencies to be gained by sharing data across offices, agencies, and organizations, it is important to critically examine the data collection processes that directly support the maintenance function. The principles of NCHRP Report 422 (31) should be examined for application to data that are regularly collected for maintenance support to evaluate whether some statistical sampling of a particular data item can provide managerial information with the same or equivalent level of information confidence at less effort and less cost than an existing routine process. Sometimes, having more data actually provides less information because the volume of data requires excessive interpretation and analysis effort. NCHRP Report 422 offers helpful guidance in making any decisions regarding reducing internal data collection duplication.

1.2.1.6 Incident Management and Emergency Response in Maintenance

Incidents are unplanned, unscheduled events to which highway maintenance is expected to respond in some way. Examples of incidents include hurricanes, tornadoes, floods, or fuel tanker accidents on a freeway. Proper management for maintenance response to incidents includes making certain that highway maintenance managers are included in the immediate information control and planning loop. Emergency response and disaster response teams must have someone from highway maintenance as a liaison to the maintenance organization if maintenance is expected to play a significant role. Persons who are not aware of the capabilities and limitations of highway maintenance to respond may make commitments on behalf of the maintenance organization that are nearly impossible to keep.

Some events that the general public sees as incidents are the result of phenomena for which it may be possible to obtain enough advance warning to be prepared to respond with the appropriate people, equipment, and materials to do the job expected of maintenance. For example, storm-tracking capabilities can give some lead time on when, where, and with what intensity a snowstorm is expected to hit. Likewise, a hurricane can be tracked sufficiently to give advance warning for response planning. Stream-gauging stations can provide estimates of when critical bridges may be threatened by rising flood waters.

Some events are random but have a statistically predictable pattern, such as the relationship between accidents and traffic flow-density patterns. If maintenance is supposed to respond to certain levels of accidents in the traffic stream, then traffic operations and surveillance centers need to inform maintenance managers when the traffic is reaching levels that increase the probability of a major accident.

If maintenance crews are to be involved in the response to hazardous material spills, their involvement must be clearly spelled out in response policies. Crews must be provided training in what they can and cannot do and must be properly equipped to carry out any role assigned to them.

Systematic study has been given to the various processes states are using to reduce further negative impacts of “traffic incidents” resulting from roadway maintenance or emergencies (30, 33). Studies have found that, when maintenance is planned and scheduled, many agencies use public media and enhanced work zone signing, traffic control, and non-traditional work times to alleviate the impact of maintenance upon traffic. Many states are installing changeable message signs and intelligent transportation systems (ITS) sensors and monitors that detect traffic congestion resulting from an incident and inform drivers of alternate actions they might take to mitigate the impact of incidents. Most incidents do not result from maintenance work. However, with increased awareness of the national security implica-

tions of transportation system reliability, maintenance organizations need to consider all resources that may be available to improve management of the traffic impact of roadway incidents.

1.2.1.7 Work Zone Safety

The fundamental guide for all maintenance managers, at all levels, in the control of maintenance work zones is Part VI of the *Manual on Uniform Traffic Control Devices* (MUTCD) (13). Each state may have its own version of the MUTCD that contains some local special features, but all states have the essential elements of the MUTCD in their own manual.

Keep in mind that the principles and guidelines, including the examples shown in the MUTCD, were never intended to be all-encompassing or totally definitive. The MUTCD synthesizes generally accepted research and engineering practice, and should be applied with good engineering judgment to the specific situation that the maintenance forces encounter at each site.

For commonly encountered work zone situations, many agencies adopt a traffic control plan that gives specific guidance to be followed in the absence of any highly unusual nature of the site or the traffic conditions.

Work zone safety has two aspects that are sometimes not kept in balance when there is too much pressure for production efficiency or there is too much fear of a lawsuit resulting from a traffic accident. Each maintenance worker is entitled to have a work environment that is reasonably safe, considering that working on the roadway has a certain inherent risk. Each motorist (and any passenger) is also entitled to have a traffic environment that is reasonably safe, considering the fact that driving on the roadway has a certain inherent risk. Generally speaking, a work zone that is organized (including placement of equipment, storage of materials, placement of workers) for worker safety will be a work zone that is controlled for traffic safety (has sufficient warning devices, is properly delineated, for example).

This manual contains two sections on traffic control for work zones. One has been provided for roadway maintenance and one for bridge maintenance. While there are significant similarities between the two topics, there are also some unique requirements for each.

Maintenance personnel may have an innovative idea that will create a better or an improved technique for traffic control or for worker protection in the work zone. If the innovation or improvement involves a change in signing, marking, or signalization from that approved in MUTCD (or the state manual), consult the state traffic engineer to obtain formal approval to test and evaluate the idea in the field. (Such approval will limit agency liability if motor vehicle collision occurs while the test and evaluation are being conducted.) If the innovation or improvement involves a barrier, attenuator, or other crash safety device, remember that NCHRP Report 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* (38), discusses how all such devices should be crash tested before they are placed on the roadway.

As frequently as possible, maintenance engineers and managers should encourage law enforcement personnel to be present in work zones. Some agencies have adopted formal policies of reimbursement to law enforcement agencies for increased presence beyond routine patrol activity. The presence of law enforcement personnel near work zones increases safety and motorist compliance with traffic control regulations. The reader is directed to the National Work Zone Safety Clearinghouse (wzsafety.tamu.edu) for the latest developments.

1.2.2 Human Resources

1.2.2.1 Motivation

A variety of management training courses emphasize learning how to motivate employees to produce superior work. This aspect of human relations was largely treated, in the past, as a matter of recognizing the human needs that can be provided by an employer and exchanging some measure of their fulfillment for a measure of successful work. The development of TQM principles has shifted motivation to providing employees with more responsibility, authority, and control over their work environment. Recent investigations by general news media reporters found that young workers are not motivated by the older “needs”-based traditional incentive programs. Young workers are more often responsive to “relational” motivation incentives. Thus, maintenance organizations must be aware of the different

motivational styles that are appropriate to younger versus older workers if high-quality maintenance is to be achieved.

Maintenance engineers and maintenance managers will increasingly be asked to function as leaders rather than as managers who allocate resources to solve maintenance problems. To provide maintenance managers with tools to become effective leaders and properly motivate the people for whom they are responsible, one organization has developed the following motivation guidelines (25):

- Set clear standards of performance that are difficult but attainable. Remember that employees must have a high expectation of achieving the goal in order to be motivated.
- Rewards should always be contingent upon performance. If rewards are given when they are not deserved, they lose their value.
- Do not give too much reinforcement. Too much reinforcement is almost as bad as none at all.
- Reinforcement depends upon the individual. What reinforces one person may not reinforce another. Find out what reinforces employees and use it at appropriate times.
- Reinforce good performance as soon as possible.
- Do not unnecessarily threaten or punish. Threats and punishment are negative and encourage a person to avoid performing a certain task rather than changing the way that the task is performed.
- Make the individual employee feel important and recognized. Exhibit interest in and knowledge of each employee.
- Provide employees with the responsibility for task completion. Do not just assign duties, assign responsibility.
- Exhibit confidence in an individual's abilities. A great deal of research supports the contention that people who are expected to achieve will do so more frequently than people who are not aware of any expected performance.
- Communicate the job requirements and ensure that all employees understand them. We all know what we mean when we say something, but often others do not. Unclear expectations can lead to confusion.
- Listen to, and deal effectively with, employee complaints. Handle problems and complaints before they get blown out of proportion. In addition, people feel more important when their complaints are taken seriously. Conversely, nothing hurts as much as when others view a personally significant problem as unimportant.
- Demonstrate personal motivation through behavior and attitude. Nothing turns people off faster than supervisors who do not practice what they preach.

1.2.2.2 Training

The wide range of tasks, the need for special skills to maintain certain activities or equipment, and the requirements for safety precautions, justify good training programs for all levels of maintenance employees. Training programs can be developed for special purposes, limited to a few selected personnel, or developed broadly for all maintenance employees. The resources of the National Highway Institute (Federal Highway Administration) and the network of resources that can be accessed through Local Transportation Assistance Program centers should be used to maximize the impact of the training budget. While training has long been recognized as important for highway maintenance agencies,

it continues to be a deficiency in many agencies. For further information, consult www.nhi.fhwa.dot.gov or www.itap.org.

Technology changes rapidly in material quality control testing, surface deterioration measurement, environmental quality measurement, traffic control techniques, instrumentation for weighing trucks, and communication and signal equipment. These areas are some in which the training of personnel is key to effective use of new technologies. Implementation of TQM techniques will require an extensive commitment to training personnel in setting priorities, in group dynamics, and in team-building skills (20).

Personnel who complete training courses satisfactorily should be recognized for their accomplishment. Where it is appropriate to ensure an interest in quality maintenance, completing appropriate training courses should be a condition for advancement.

Certain maintenance tasks require special skills or involve performing operations in a hazardous environment. Where maintenance personnel involved in these tasks have to be certified as qualified to conduct these operations or to operate certain equipment units, the certification process should be conducted in conjunction with other training programs, minimizing operational downtime for training.

In many states, an effective network of community colleges and vocational-technical colleges exists. Highway maintenance agencies should not overlook these organizations as a training resource.

If no attempt is made to evaluate the effectiveness of training programs, it may be difficult for agencies to justify maintaining funds for such programs at appropriate levels. NCHRP Synthesis 248 provides some basic guidelines and methods to evaluate training (14). At a minimum, basic evaluation should be made of in-house training procedures, and contract training should always be evaluated in order to ascertain the degree to which the contractor has fulfilled the terms of the contract.

1.2.2.3 Personnel Safety

Personnel safety involves the safety of maintenance personnel while using the equipment and materials required to conduct a maintenance task and their protection from through traffic entering the work area.

The safety of maintenance personnel while using their equipment and materials relates to two kinds of training: (1) proper training and proper qualification to operate any equipment assigned to a worker and (2) safety training in materials handling and in equipment safety.

Protecting workers from hazards associated with traffic through the work zone requires providing them with signing, barricades, attenuators, or shadow vehicles as needed to separate the workers from the traffic and to warn the traffic away from the workers. Getting a maintenance activity done quickly and efficiently is important in minimizing the time that workers are exposed to traffic danger.

Refer to the section on work zone traffic control in the chapter on roadway maintenance and the chapter on bridge maintenance containing discussions relating to personnel safety. Further discussion of personnel safety can also be found in the section on environmental aspects of roadway maintenance and in the section on environmental aspects of bridge maintenance. (See the index for page references.)

The topic of “personnel safety” is broader than work zones. It encompasses preparing workers to safely handle chemicals and materials that introduce hazards into their work activity such as herbicides and high temperature asphalts. It encompasses employees properly handling high-voltage connections to electrical equipment. Proper use of all manner of power equipment from chain saws to front-end loaders is included. The brevity of this section is not intended to convey in any way that “personnel safety” is not an important activity and responsibility for training under the maintenance engineer or maintenance manager purview. The intent is to communicate that maintenance engineers and maintenance managers are responsible to see that employees under their authority are properly informed regarding all manner of safety issues in their work place environment, and then supervised and instructed to follow the appropriate guidelines.

1.2.2.4 Recruitment and Development

Highway maintenance organizations need to create a profile of the kind of person they want to have in maintenance. Do you want more females, more minorities, high school graduates, or technical school

graduates? Do you want people with welding skills or general mechanic skills? Once you have a sense of the type of persons that you desire, work with the human resources office to recruit them. A companion long-term personnel development strategy includes targeting high schools, technical programs, and job placement organizations.

Develop a process of selecting individuals who seem to have promise and can be trained in skills needed in the maintenance organization. Then create a training opportunity that upgrades these individuals to the needed skill levels. If skill upgrades demand some significant investment on the agency's part, perhaps a minimum-term contract that requires the individual to stay in the agency after completing the training is needed. An in-house effort to upgrade people is as important as a recruitment effort.

In order to facilitate the recruitment and development of persons who will meet the short- and long-term needs of maintenance organizations, each agency should consider participating in the types of activities outlined in the FHWA International Scan Tour report on transportation workforce development (23). This report suggests that a variety of activities needs to be undertaken, including creating career awareness in young people, workforce development for persons brought into the agency, monitoring and evaluating program effectiveness, and enhanced recruitment efforts. Clearly, this is not just a matter of posting advertisements for open positions or contacting the local "job service agency," but of creating and operating an active program to select and cultivate people who are strong assets to the agency.

1.2.3 Technical Resources

Management often focuses on people relationships. It is equally important to consider the technical, nonhuman resources in managing maintenance.

1.2.3.1 Equipment for Maintenance

The equipment appropriate for maintenance varies as much as it does for the construction industry. The most important aspect of maintenance equipment is to determine the right size and capability of equipment to do the task needed. For instance, in utility maintenance, trenches for communication cable used to be excavated with a tractor-mounted backhoe. However, the backhoe outriggers often damaged private property outside the narrow easement limits of the utility corridors, creating undesirable private property damage claims. In response to this problem, equipment manufacturers began offering a "miniature crane" bucket digger that is crawler track driven. In the same way, if a standard piece of construction equipment does not accomplish your maintenance task, talk to other maintenance engineers whose personnel perform the same activity. If you need specially modified equipment and several maintenance areas will use it, a product will eventually be developed to fill that market need.

1.2.3.2 Materials for Maintenance

The same materials used in construction are available for maintenance repair. However, it behooves maintenance managers to review the materials science literature continually for nontraditional materials that could be used to maintain roadways and bridges. Sometimes a material that is too expensive for initial construction is cost-effective for maintenance because it reduces traffic delays and worker exposure times by enabling the job to be completed in less time or increasing the life of the repair. While maintenance is cost and budget driven, the lowest initial cost for a maintenance activity may be false economy with respect to maintenance materials.

New materials are constantly being developed. Before any new material is accepted for local testing and evaluation, it should be reviewed by any "new products committee" the agency may have that coordinates the study of new products. Maintenance engineers and maintenance managers should periodically check the list of new materials that may be under evaluation (or that have been evaluated) by the National Transportation Product Evaluation Program (NTPEP) at AASHTO (at www.ntpep.org) and in the technology evaluation activities of the Civil Engineering Research Center (CERF) at the American Society of Civil Engineers (ASCE) (at www.cerf.org/evtec/eval).

1.2.3.3 Models Available for Management of Resources

Maintenance engineers should begin to investigate the application of industrial engineering and management science models to maintenance activities. For instance, queuing theory models can estimate the traffic delays that can be expected at various traffic volumes when a lane is closed. Queuing analysis can also estimate the efficiency of a trucking operation in moving material from a stockpile to the roadway location where it is being placed. Linear programming and other mathematical programming techniques can assist in the development of a strategic plan for the location of material stockpiles, the location and distribution of maintenance garages, and the selection of equipment phase in-out strategies. Network analysis methods that urban transportation planners use can be applied to selecting the best detour routes around road sections that are closed because of a bridge washout or similar localized disaster.

1.3 ISSUES OF CONTINUING CONCERN

1.3.1 Sustainable Development

There is, and will continue to be for years to come, a push for all transportation infrastructure to achieve “sustainable development.” The ASCE has attempted to make the principle of sustainable development a part of its code of ethics. However, the term means different things to different people. In any case, most definitions of sustainable development encompass maximizing the capability to recycle components of the infrastructure and to minimize use of nonrenewable resources. This philosophy will be a driving social and political force that maintenance engineers and managers will have to consider in the foreseeable future while planning maintenance methods and processes.

1.3.2 Designing for Maintainability

Designing a weapons system that can be easily and effectively maintained has been a principle of defense weapon systems procurement for many years. Likewise, highway transportation agencies are beginning to provide formal interaction between maintenance engineers and design engineers to ensure that the designer’s concept can be maintained safely and effectively. For hints on how to set up such a process or for ideas on how to effectively participate in such a process, see NCHRP Report 349, *Maintenance Considerations in Highway Design* (7).

1.3.3 Environmental Sensitivity

Maintenance is a highway agency’s most exposed activity with respect to environmental pressures. Painting, sanding, salting, herbicide application, mowing and brush control, equipment maintenance, material storage, landscaping, and maintaining drainage are activities that can raise environmental objections. All material handling can have environmental safety implications for both workers and the general public. As environmental and health research continue to advance, both areas will further the need for an effective information dissemination program within maintenance forces.

NCHRP Synthesis 272 provides a concise overview of the best maintenance practices with respect to environmental issues (29). Maintenance managers and maintenance engineers should consult this document for practices and strategies having the least possible environmental impact on their operations. While much of NCHRP Synthesis 302 deals with mitigating wetlands impacts in new route locations or the expansion of existing routes, there is a maintenance management application for ditch and drainage way maintenance (34). Media attention and wildlife advocacy groups are increasingly concerned about the design and maintenance of highways with respect to wildlife migration, road kill, and vehicle safety. NCHRP Synthesis 305 (35) and FHWA International Scan report FHWA-PL-02-013 (22) offer specific examples of actions for mitigating the impact of highway maintenance on wildlife. For example, policies that minimize roadside mowing activity may, in some areas, contribute to roadside grazing by deer. Likewise, the establishment of drainage detention basins may encourage wildlife to seek water sources within the highway right-of-way during seasons of drought. Clearly, such policies need to be examined for their possible impact on wildlife. Also, certain materials used in maintenance

and repair may have short- or long-term adverse effects on water quality due to trace elements or chemical compounds that can build up toxins in water. NCHRP Report 448 provides a method by which materials can be evaluated for negative environmental impacts on surface and ground water (3).

1.3.4 Application of TQM Principles and Quality Assurance

Product manufacturing industries have demonstrated the benefits of applying TQM principles to their operations. As a result, educational institutions, service industries, and government agencies are now applying TQM to their operations. Maintenance engineers and managers need to consider learning TQM and seeking ways to apply it. However, they also need to be prepared to revise the concepts to fit their own organization's unique needs. More important than attempting to apply TQM concepts directly to maintenance is the need to continue establishing information reporting and analysis and performance evaluation systems in the move toward better quality control and assurance for maintenance activities. NCHRP Report 422 provides a clear and concise manual approach to improving a maintenance agency's quality assurance program (31).

1.3.5 Litigation Involving Maintenance

The United States continues to be a lawsuit-oriented society. As the design and construction of new roadways and bridges continues to decline as a proportion of the total transportation budget, maintenance will share an increasing proportion of the litigation burden on transportation agencies, indicating that maintenance engineers and managers need at least minimal training in serving as effective expert witnesses. Every maintenance crew should carry with it every day some means of making a photographic record of an accident and should have at least some minimal instruction in how to use it to document the conditions surrounding every incident (road surface conditions, traffic controls, for example), even accidents involving maintenance workers only. Acceptable photographic equipment includes a 35-mm camera and film, video camera and tape, video minicam and cassette, or disposable camera. Perhaps the best of these alternatives might be the disposable camera, which contains film, eliminating the problem of inventory control. Digital media have become commonplace, but in many jurisdictions, little weight is placed on the evidence provided by digital media. It is too easy to modify digital images. Until the courts in a particular state establish a definitive position on the acceptability of digital images as evidence, it is best to stay with film and analog images.

1.3.6 Rational and Probabilistic Models to Predict Maintenance Needs and Effects

Pavement research continues to develop statistical models and damage equations that refine predictions of pavement deterioration for pavement management systems. Most bridge management systems are based on neural network theory, which enables users to predict the future date at which a specified level of damage will appear. These and other advanced mathematical techniques are foreign to most maintenance engineers and managers. However, maintenance engineers and managers will need a rudimentary understanding of these concepts to integrate the predictions from such models in other management systems into the maintenance management system.

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2.0

Roadway Maintenance and Management

2.1 ROADWAY MAINTENANCE

Maintenance of the roadway is the primary way in which a highway agency carries out its goal of providing a safe, efficient transportation system on a day-to-day basis. Roadway maintenance includes maintaining the traveled lanes, the shoulders, minor drainage structures and drainage surfaces, safety hardware, and other appurtenances. Bridges are covered in a separate chapter of this manual, although certain aspects of roadway maintenance relating to bridges are covered in this chapter.

2.1.1 Introduction

To some people, planning, design, construction, and materials research are activities that are more sophisticated and perhaps more important than roadway maintenance. However, maintenance and maintenance operations are an activity that is the most visible to the roadway user, the most urgently needed in permitting the public to use the roadway, and the activity that requires the most ingenuity to be done effectively.

2.1.1.1 Preventive Roadway Maintenance Philosophy

The American Association of State Highway and Transportation Officials (AASHTO) recently adopted a definition of preventive maintenance (43). Preventive maintenance activities include work that

- prevents the intrusion of water into the pavement structure—for example, with seal coats, joint seals, crack seals, and thin overlays;
- provides for the removal of water from the pavement structure—for example, with underdrains and restoration of drainage systems;
- restores pavement rideability—for example, with profiling and milling; and
- prevents deterioration of bridges—for example, with cleaning and painting, scour countermeasures, deck rehabilitation, and deck drain cleaning.

This concept is further clarified by Galehouse (41) on page 4 in the September 2003 *Pavement Preservation Compendium* published by the Federal Highway Administration, where he states: “Preventive maintenance applies low-cost treatments to retard a highway’s deterioration, maintain or improve the functional condition, and extend the pavement’s service life. With various short-term treatments, preventive maintenance can extend pavement life an average of 5 to 10 years. Applied to the right road at the right time—when the pavements are mostly in good condition—preventive maintenance can improve the network condition significantly at a lower unit cost.”

As asset management has been strongly emphasized in conducting maintenance, preventive maintenance and preservation of the roadway asset has become central to maintenance and roadway management philosophy. Galehouse et al. (42) offer a concise discussion of pavement preservation in the context of asset management in which they discuss the advantages of preventive maintenance in terms of life-cycle cost and maximizing the return on funds expended to justify pavement preservation. The California DOT has found that chip sealing, once de-emphasized, has re-emerged as a major tool for preserving pavement under a preventive maintenance philosophy (13).

Common sense and the application of good engineering judgment to conventional maintenance activities would be expected to cause all maintenance to maximize the preservation of the pavement while expending the minimum resources. However, without an intentional plan to pursue preventive

maintenance, the data collection process for maintenance activities, and the analysis and interpretation of that data, will likely not always cause the lowest life-cycle cost pavement system to be developed.

2.1.1.2 Interaction with Bridge Maintenance and the Management of Other Functions

Frequently, the engineers and managers responsible for bridge maintenance and for minor construction repairs to both roadways and bridges are in separate operating units with different maintenance engineers or managers. Regular coordination and liaison among these groups can be invaluable in coordinating the schedule of preventive maintenance activities, minimizing the traffic impact of work zones and the exposure of maintenance personnel to traffic hazards.

For example, if bridge maintenance is planning to rehabilitate a bridge deck in a section of roadway for which roadway maintenance has future plans to do rigid pavement joint repairs, perhaps the priority for the joint repair can be shifted so the work will be done simultaneously with the bridge deck repair. Then one work zone traffic control pattern can be used to protect both workers and the motoring public for two activities, with half the disruption.

On a broader scale, interaction, coordination, and liaison with other agencies responsible for maintenance can often permit performance of maintenance through contract relationships in ways that can get the whole job done with fewer crews and fewer traffic control setups. This is particularly the case in urban freeway maintenance (12). See NCHRP Synthesis of Highway Practice 170, *Managing Urban Freeway Maintenance*, for examples and details (12).

2.1.1.3 Interaction with the Design of Facilities

Most highway agency managers and administrators believe that designers consider all aspects of planning, construction, materials, operations, and maintenance in the process of creating a roadway or bridge design. However, as a practical matter, most highway agencies continue to construct roadways and bridges from designs that create difficulties in maintaining and operating the roadway and bridge network. It may be something as simple as a W-beam guardrail anchor placed in a structure location so that a maintenance worker has to be dangerously exposed to traffic when checking the anchor bolts. Many of these problems seem to stem from lack of cross-function experience between design engineers and maintenance engineers.

Many highway agencies have a regular process whereby various divisions of the agency participate in periodic reviews of a roadway or bridge design as it progresses. In highway agencies where such a process exists, if maintenance personnel are not represented among the design review participants, the top-level maintenance manager should volunteer the division's staff to participate in such reviews, communicating to all parties the long-term value to the public of such input. An in-depth study of processes by which maintenance issues could be integrated with the design process was developed and pilot tested in the Utah DOT (16). Any highway agency beginning to work through how to incorporate maintenance input and feedback into roadway and bridge design processes should see NCHRP Report 349, *Maintenance Considerations in Highway Design*, for ideas and helpful guidance (16).

2.1.1.4 Role of Roadway Maintenance in the Safe, Efficient Operation of Facilities

As stated earlier, roadway and bridge maintenance is the primary means by which a highway agency keeps the transportation network a safe, efficient facility for the public road user. While the trend is to increase preventive maintenance practices, "there is a practical limit or point of diminishing returns for the preventive activities that can be afforded or justified" (14). Maintenance assumes a primary role in monitoring the safety and efficiency of the roadway network by responding to short-term maintenance needs such as potholes, damaged guardrails, washouts, knocked-down signs and signals, traffic accident cleanup, explosion damage, material and cargo spills, flood damage, landslide damage, rock falls, blizzards, and debris from windstorms.

Maintenance engineers and managers must have sufficient flexibility in their planning, budgeting, and scheduling of preventive maintenance to suspend or shift preventive maintenance activities and perform maintenance and repairs to "fix" short-term maintenance needs as they arise. The roadway user and general public will judge the maintenance organization's effectiveness largely on the basis of how it responds to these needs, because they directly and immediately affect the safety and efficiency of roadway use.

See NCHRP Synthesis of Highway Practice 173, *Short-Term Responsive Maintenance Systems*, for a detailed discussion of methods and processes that effectively and efficiently deal with short-term maintenance needs (14). The basic rudiments of dealing with short-term maintenance needs exist in almost all highway maintenance agencies:

- Have formal inspection processes for bridges, roadways, roadsides, and appurtenances.
- Incorporate informal inspections (i.e., from in-house resources).
- Verify or incorporate external observations.

Policies must define what the immediate, on-the-spot emergency response will be for critical, short-term needs. For example, if a maintenance patrol is placing a Type II barricade with a flasher unit on it and encounters a crushed, breakaway cable terminal (BCT) guardrail end section, then each patrol must always leave the maintenance garage with sufficient Type II barricades for the expected number of BCT hits in their patrol area for one shift.

All highway agency personnel should be informed of the procedure to report a roadway or bridge defect and should be encouraged to submit reports of all incidents observed. Thus, personnel doing field traffic counts, planners traveling to public hearings, and administrative officers traveling to meetings become additional “eyes and ears” of the maintenance forces, similar to the concept of military scouts.

External observations are reports from private citizens and from organizations outside the highway agency. Because of wide variation in precision and credibility of these observations, an agency may choose to verify them to determine the urgency of response or may choose to use them as significant input. For example, some cities and counties depend almost exclusively on citizen calls to identify the need to respond to downed traffic signs.

In the continual search for improved safety and efficiency, maintenance engineers and managers must be willing to examine concepts and products previously not used. For instance, FHWA Scan Tour Reports FHWA-PL-01-001 and FHWA-PL-03-006 (53, 55) contain examples of European practices that may be appropriate when U.S. maintenance agencies replace older existing installations. As an example, the Oklahoma DOT adopted a British guardrail innovation when making an installation in Oklahoma City (48).

2.1.1.5 Value of Roadway Maintenance to Agency

A method that can estimate the intrinsic value to the highway agency of conducting roadway maintenance is greatly needed. Lacking any means of estimating the value of doing roadway maintenance, the importance of not doing roadway maintenance is easily demonstrated. In Transportation Research Board State of the Art Report 6, *Relationship between Safety and Key Highway Features*, three of the seven sections deal with roadway features for which maintenance is the primary way to retain safety of an existing roadway (110). If any agency examines its litigation pressures as measured by number of actions filed, situations related to maintenance will figure prominently in the total. These two points are very general but suggest that maintenance is a key activity of a highway agency in carrying out proper public service.

Two things that can be done, as a minimum, to begin tracking the value of roadway maintenance to the agency are the following:

- Coordinate with the legal staff responsible for defending the agency in tort liability actions to develop a history of the number of maintenance-related claims and the amount of damages awarded for them.
- Coordinate with the staff responsible for pavement management to develop an index of the effect of maintenance on preservation of the paved roadway network.

Galehouse (41) has shared some additional insights into establishing value through the preventive maintenance process. He points out that in Michigan, by collecting pavement condition data on half the highway network every other year (thereby having a complete network inventory every two years), analyzing the data for condition improvement with respect to maintenance treatments