CONFERENCE PROCEEDINGS 5

Maintenance Management

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Proceedings of the Seventh Maintenance Management Conference

Orlando, Florida
July 18–21, 1994

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Foreword

This proceedings contains papers presented at the Seventh American Association of State Highway and Transportation Officials–Transportation Research Board Maintenance Management Conference held in Orlando, Florida, July 18–21, 1994. The objective of this series of conferences is to provide a forum every 4 to 5 years for the exchange of new ideas and developments in the maintenance and operations management of transportation facilities. The conference was hosted by the Florida Department of Transportation and jointly sponsored by the American Association of State Highway and Transportation Officials, the Transportation Research Board, and the Federal Highway Administration.

The papers are grouped into sections on maintenance management, roadside maintenance, snow and ice control, pavement maintenance, bridge maintenance, and environmental maintenance. The maintenance management section addresses the topics of customers' viewpoints, data collection technologies, integration with other management systems, strategies for managing expenditures, and ways to maintain a responsive maintenance management system. Issues involved in worker exposure to herbicides are discussed in the roadside maintenance section. The snow and ice control section presents information on the Swedish winter maintenance system, technologies in Europe and Japan, and overseas use of deicing and prewetting procedures. The pavement maintenance section describes the use of deflection measurements to manage network maintenance in England, institutional issues in the implementation of pavement management systems, maintenance for life cycle–designed pavements, and evaluation of pavement maintenance materials, procedures, and equipment. The tracking of maintenance activities in Pennsylvania's bridge management system is discussed in the bridge maintenance section. The environmental maintenance section provides information on roadside litter programs, effects of regulations on highway maintenance, training for hazardous materials management, and strategies for storm water management.

MAINTENANCE MANAGEMENT

Maintenance Management from the Customer's Viewpoint

Jerry Miller, *Minnesota Department of Transportation*

Technicians in the maintenance operation field must start thinking like their customers and use measurements to meet the customer's expectations. In 1991 the Minnesota Department of Transportation (MnDOT) began developing a business plan to improve its customer orientation. MnDOT's maintenance staff developed a mission statement, and to guide it in defining maintenance products and services were defined as outcomes. These outcomes include smooth pavement, roadways clear of obstructions, pleasing roadsides, highly visible signs and stripes, and the availability of motorist services. Pilot tests have been implemented through the district offices of MnDOT to assess products and services and methods of evaluating those services. This is in addition to the measurement of inputs and activities within the present maintenance management system. Customer research has also been initiated to further define products and services and to help MnDOT evaluate its response to customer concerns.

The problems we face today seem to have always been with us: increasing public demands, increasing operational costs, decreasing budgets, deteriorating infrastructure, increasing traffic congestion, and increasing traffic volumes. Legislators and other leaders are telling us to cut costs, to make the equipment last longer, to reduce the work force, to take on new programs without adequate funding, and to measure outcomes that really make a difference to the public.

In 1991 the Minnesota Department of Transportation maintenance staff reviewed these customer issues. We already had a maintenance management system that seemed to measure everything related to maintenance, such as tons, miles, number of signs, and overtime hours. We also had a cost-accounting system that could generate a lot of numbers. But these systems would not help us manage all the issues confronting us.

We started looking at maintenance activities from the customer's viewpoint. Customers can and will tell us if we are successful in maintaining the transportation system they use. They can determine whether we stay in the maintenance business or whether budget and prioritization pressures will prompt them to try someone else.

The following story illustrates the point of this paper. The state maintenance engineer received a telephone call from a citizen who owns a house along the state highway. She stated that her house shook due to the potholes.

The state maintenance engineer called the district engineer, who notified the appropriate maintenance crews. The maintenance crews repaired the potholes quickly.

A week later the lady called the state maintenance engineer saying the maintenance crews were out and filled the potholes but her house still shook when the semis went by. The maintenance crew had fixed the problem the normal way by leaving the material high. The crew was sent back with the message to make it smooth.

Our usual way of doing business, whose success is measured by the number of filled potholes, was not what the customer wanted. The customer measured our performance by smooth pavement.

Here is another example: during a major snowstorm, we gather and monitor information on the tons of salt and sand used, dollars spent, overtime costs and hours, number of trucks deployed, and so forth. These are not the direct concerns of our customers. When the customer calls, he or she wants information on when the roadway will be safe at a normal driving speed, whether it is safe to drive now, how long it will be before ice and snow are completely cleared, and the roadway and weather conditions here and at the destination.

With the customer's viewpoint in mind, MnDOT decided to develop a business plan. We hired a consultant to help us in this process.

Our typical way of doing business was for the customers through the legislature and governor to supply the funding. The maintenance department used the money on its activities. More money meant more activities. At the end of each fiscal year, legally our budget must be zeroed out. We have to spend it. Thus, we have focused our resource management on making our expenses equal our available funds.

But the customers' viewpoint is that for their taxes, maintenance has to provide value in the form of products and services. They see the results by their interaction with the transportation system. The expense to us is the same (taxes, people, material, equipment, resources). But customers want to know if expenditures result in maintenance they value.

Highway maintenance professionals must both balance the budget and determine the value of our activities to the customer (see Figure 1).

The transformation model (see Figure 2) illustrates how MnDOT's maintenance process works. The funding buys inputs such as people power, equipment, materials, and money to perform maintenance activities. Maintenance personnel determine how to get the job done. Outputs are accomplishments measured in quantifiable terms, such as the number of acres mowed, miles overlaid, tons of mix used, tons of salt and sand, and number of signs replaced. Results or outcomes that our customers use to evaluate our performances include smoothness, ability to see, and visibility of signs and markers.

As a beginning step in the business plan effort, MnDOT's maintenance staff developed a mission statement. It reads, "Our maintenance function mission is to ensure that Minnesota's existing highway system is structurally sound, safe, convenient to use, and attractively maintained." Three paragraphs following the mission sentence dealt with the need to keep up with technology, serve the customer, and develop our work force:

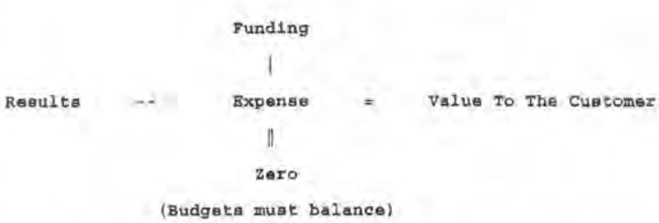

FIGURE 1 Combining budget and customer value processes.

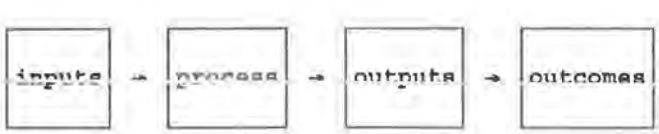

FIGURE 2 Transformation model.

We will strive to be a national leader in the quality of our highway maintenance and provide Minnesota with the best possible value from its existing highway system. We will carefully select and manage our resources to give the best possible service for the funds available to us. We will analyze the underlying causes of highway maintenance, and identify ways these causes could be eliminated or reduced. We will continually evaluate new maintenance techniques, methodologies, technology and materials, selecting those that will improve our quality and are cost effective. We will seek our partnerships with other public and private organizations that will enable us to provide more and better quality services.

We will serve our customers by working to understand and meet the needs of the individuals and businesses who use or are affected by our highway system. We will be flexible and adaptable in identifying and providing new and enhanced services to meet our customers' changing needs and expectations. We will provide information and assistance that will help them use the system easily, safely, and conveniently. We will maintain an attractive highway system to minimize its impacts on those who use or live next to it. We will keep all our highway facilities in a safe, clean, welcoming condition. We will respect the environment in which our highways are located.

We will work with the Maintenance Function employees to maintain a healthy, challenging work environment. We will maintain a cooperative, flexible work environment in which the members of our diverse work force are respected as individuals and perform well as members of the team. Our people are our most important resource. We will identify the skills the Maintenance Function will need to accomplish our mission, and provide each employee with the opportunity to grow and develop these skills to their highest level of ability.

Our maintenance activities are listed in Figure 3. Seven basic products and services were developed. Our present maintenance management helps manage our activities but does not do much for monitoring how well we are delivering our products and services. We had to develop a means to measure the products and services (outcomes).

Measurements of the outcomes were reviewed by considering the following factors: accuracy versus precision, relevance, timeliness permitting action, simplicity versus complexity, and the use of statistical measurements. We wanted the measurements to be understandable to the frontline workers since they will help obtain the outcomes. The measurements should help these people do their job, so sampling must be easy and accurate. The results have to be available to maintenance workers quickly so they can make good decisions.

For example, we decided on five key areas of measurement for the "clear of obstruction" product/service: prevention of snow and ice accumulation, removal of snow

Activities (Example of Processes)	Products and Services (Outcomes)
• Remove Snow & Ice	• Clear of Obstructions
• Fill Potholes	• Smooth Pavement
• Fix Bridges	• Structurally Safe Bridges
• Mow Grass	• Pleasing Roadsides
• Pick Litter	• Bright Signs/Stripes
• Replace Signs	• Permit Trips
• Paint Skip Stripes	• Motorist Services
• Roadway Regulations	

FIGURE 3 Maintenance products and services.

- Prevent Snow & Ice Accumulation
- Snow & Ice Removal
- Sweeping
- Removal of Road Debris
- Emergency Response

INDICATOR	UNIT OF MEASURE
Reduction in Average Speed	Hours of Added Travel Time
Increase in Travel Distance	Miles of Detour
Bareness of Pavement	Road Surface Friction
Response Time Rate	Time From Notification to Completion
Comfort/Confidence Level of Service	Number of Predictable Events Not Prevented

FIGURE 4 Measuring outcomes for "clear of obstruction" product/services.

and ice, sweeping, removal of debris, and ability to respond to an emergency. Five indicators were used to measure whether roadways were being cleared, and these had units of measurement so results could be quantified (see Figure 4). Similar outcome indicators and units of measure were compiled for smooth pavement and well-maintained roadsides (see Figures 5 and 6).

During the summer of 1993, various indicator pilots for the product and services were conducted in all maintenance areas throughout Minnesota. We are trying to find out if the indicators and units of measurement really do meet our needs and the customers' concerns. Are we getting good information? Are we measuring what we can manage? Is the indicator pilot applicable? By conducting indicator projects in all areas within the state, we are also trying to expose all maintenance workers and supervisors to this new way of viewing their work and their customers.

We will group indicator pilots in certain maintenance areas. Also, we will try to pilot all the product/services in one district to see if it can be done and is worthwhile. The effort of many people is required to make the pilots work.

The initial development of indicators was driven by MnDOT staff's internal understanding of customer value.

- Surface Repair
- Shoulder Maintenance
- Crack Sealer
- Overlays
- Pothole Repair

INDICATOR	UNIT OF MEASURE
Road Posting (Less than 10 ton)	Presence/Absence of Availability
Spring Road Restrictions	Miles/Duration of Restriction
Roadway Strength	Strength Rating
Rideability and Comfort	Ride/Comfort Rating
Pavement Structure and Condition	Condition Rating
Shoulder Structure and Condition	Shoulder Reliability Rating

FIGURE 5 Measuring outcomes for "smooth pavement" product/services.

- Mowing Grass
- Weed & Brush Control
  Tree Trimming
- Drainage Maintenance
- Wildflowers
- Fence & Noise Wall Maintenance
- Litter Control

INDICATOR	UNIT OF MEASURE
Neatness of Mowing	Quantity of Strips Not Mowed
Visible Litter	Density/Duration of Litter Present
Dead Tree/Shrubs	Quantity of Deadness Per Mile Or Acre
Noxious Weeds	Acres of Weeds/Duration
Sight Restriction	Vegetation Height at Sight Corners

FIGURE 6 Measuring outcomes for "pleasing roadsides" product/services.

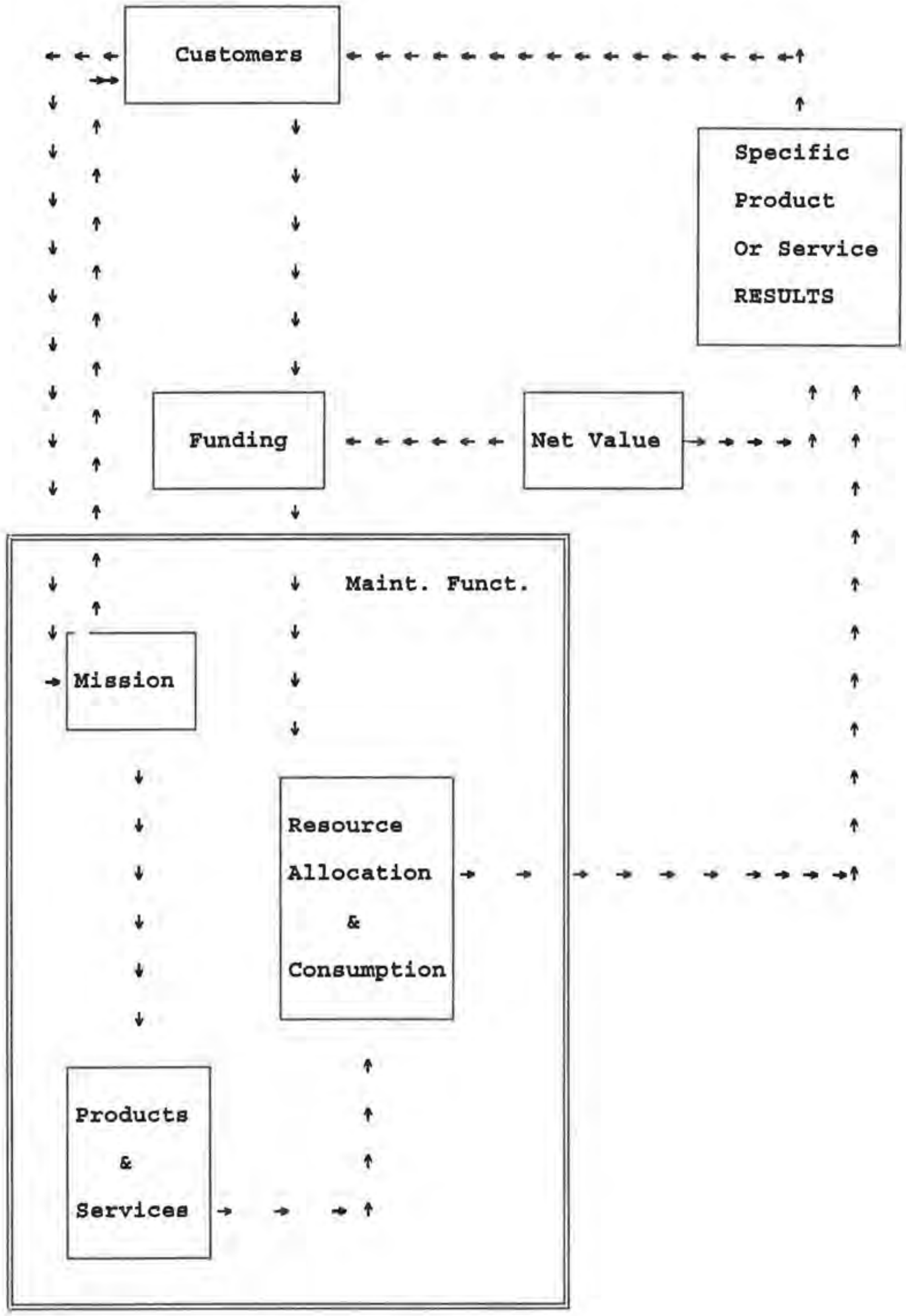

FIGURE 7 View of the maintenance function.

In spring 1994, MnDOT began checking with the customer directly. Four focus groups and other interviews in rural southwestern Minnesota were held in April to find out if customers view the maintenance products and services MnDOT delivers as MnDOT perceives they do. MnDOT asked a series of questions of participants, including what value the customers see in the products and services, and what satisfies or dissatisfies them. The market research consultant retained by MnDOT will recommend a plan for market research in the rest of the state.

Why didn't we start with the focus group first? We wanted to apply the "know thyself" principle. In other words, how could we communicate with the customer if we did not know what we were doing? We work with our customers nearly every day and we are our own customers, thus our understanding of value should be fairly similar to what the customer values. By starting internally, we also believe we can change the MnDOT maintenance culture to one that puts the customer first. By having many of our staff involved in the pilots, we have exposed many of them to business planning and to customer satisfaction.

This information will help us to proceed in our business plan process. The four focus groups and customer interview surveys are the first of many steps in checking with the customer and monitoring the customer's satisfaction. Information from the focus groups will qualify our products and services. A telephone survey throughout Minnesota will have to be done to quantify the results, which will validate the focus group's information and check for differences in the various areas of Minnesota.

We intend to tie our business planning work with other MnDOT projects. This winter our department has just conducted focus groups in Intelligent Vehicle Highway System. Part of their survey dealt with issues that overlap with maintenance activities, such as striping, safety, roadway information signs, and roadway condition reporting.

As part of a commissioner-sponsored strategic effort, MnDOT pathbuilding project teams are looking at three issues: the true cost of providing a specified maintenance activity, preservation of the system, and market research for a highway segment during wintertime operations. Their projects will be completed by July 1, 1995. We really need these true costs of all the products and services to help us manage our limited resources.

All our business planning activities will help us to get to total quality management. We will know what the customer's viewpoint is and what we need to do to serve the customer. Because of this knowledge, our business plan process, as shown in Figure 7, will be off to a good start.

We view the business plan as a dynamic system. We have to be continuously improving to meet the customer's needs and wants. Any time one part changes, the rest of the business plan has to change.

SUMMARY

We need to serve the customers and look at our activities from their viewpoint. It is an ongoing process of continuous improvement by staying close to the customers, understanding how well we are meeting their needs, knowing the quality of our products and services, and being sure we are efficiently delivering them through our maintenance operations.

We believe the Minnesota Department of Transportation is now starting to manage its maintenance from the customer's viewpoint.

Field Testing and Evaluation of Innovative Technologies for Maintenance Data Collection

William A. Hyman and Roemer M. Alfelor, *Urban Institute*[1]

Automated electronic procedures for data capture and transmission appear to be superior compared with manual paper-based methods. Many highway agencies are now either using or exploring some of these innovative technologies for many of their data collection activities. For maintenance management, a variety of recording and data entry procedures involving pen and paper could be considerably improved using electronic equipment such as portable and pen-based computers, identification technologies including barcoding and voice recognition, and location systems such as global positioning system and geographic information system. In addition, data transmission can be accomplished much faster and in real time between distant locations using telecommunications systems such as mobile phones. The application of advanced data acquisition technologies for maintenance management in state highway departments is summarized.

Maintenance management has suffered from slow and tedious procedures for inspecting highway condition, scheduling maintenance work, reporting field maintenance accomplishments, updating changes in roadway and stock inventories, and in transferring and posting information from the field reports to the headquarters for processing. It takes a significant amount of time and effort to conduct field inspections, prepare biweekly and daily schedules, check and enter daily maintenance reports, and record changes in the agency's field and warehouse inventories. Indeed, in all these aspects of maintenance management, there is a need for "one-time, quick and easy" data collection, entry, and verification systems for directly entering information into maintenance management systems. In addition, location reference systems such as route-milepost and discursive methods are unable to identify exact locations of maintenance work and field inventory items.

Innovative technologies can be used by maintenance supervisors and field workers in lieu of their current data collection methods. Automating existing procedures can reduce or eliminate paperwork, create more accurate and reliable information, provide quick turnaround of data from field to office, and improve the overall productivity of the maintenance unit.

This paper presents the approaches and findings of a number of research projects undertaken by the Urban Institute on the application of field data collection equipment for maintenance management. One project was conducted for the National Cooperative Highway Research Program (NCHRP) and consisted of two-phase research and investigation on improvements in data acquisition technology for maintenance management systems (NCHRP 14-10). During the first phase, the research identified requirements and design considerations for applying new technologies to various maintenance data collection scenarios (*1*). With assistance from several equipment vendors, some of these technologies were field-tested and evaluated in three state transportation departments: those of Maryland, Connecticut, and Arizona (*2*). Analyses indicate the potential for these agencies and possibly others to reduce costs and improve the overall efficiency of maintenance data collection. Pen-based computers (including electronic clipboards and tablets), barcode scanners, voice recognition systems, global positioning system (GPS) receivers, regular and cellular telephones, and digitized maps were customized for applications involving work scheduling, work reporting, and the updating of roadway feature inventories by maintenance crew leaders and supervisors. In addition, these technologies were applied to sign inven-

[1] Current affiliation: Cambridge Systematics, Inc.

tory and sign maintenance management. After completing the NCHRP project, the Virginia Department of Transportation (VDOT) requested that the Urban Institute develop demonstration-level field data collection applications. Two portable electronic tablets with handwriting recognition capabilities were customized and field-tested for the evaluation of highway pavement maintenance by VDOT staff (*3*).

This paper first discusses the general characteristics of the maintenance activities for which the technologies were customized. Specific methods by which the activities are performed in the four field sites are briefly described, including the average lengths of time needed to record various types of data. Hypotheses concerning how innovative technologies can improve the existing methods are stated. The design and evaluation of the field tests are discussed. General findings drawn from the field tests are summarized in the conclusion.

Maintenance Data Collection Activities

Four different but interrelated maintenance data collection activities were the focus of the equipment field tests:

1. Work scheduling,
2. Work reporting,
3. Roadway feature inventory updating, and
4. Maintenance quality evaluation.

Applications of innovative technologies for the first three activities (referred to as a three-part process) were examined in Maryland, Connecticut, and Arizona as part of the NCHRP 14-10 (Phase 2) study. Maintenance quality evaluation was performed exclusively in Virginia.

Although the elements of the three-part process are common to most states, their implementation varies from state to state. The NCHRP project involved examination of the specifics by which the three-part process is conducted in Maryland, Connecticut, and Arizona. Detailed analyses, interviews, and focus group sessions with DOT staff were necessary to understand existing maintenance management practices and customize the design of the technologies to the host states. For maintenance quality evaluation, the research team worked closely with VDOT in identifying specific equipment design considerations. A description of the activities demonstrated and how the states normally carry them out follows. Hypotheses concerning how innovative technologies can improve these activities are briefly noted.

Work Scheduling

Highway maintenance work is usually scheduled to attain agency-specified level-of-service goals as well as address emergency or urgent repair needs. Scheduling helps management efficiently allocate its labor, equipment, and material resources, which are often limited. Management also seeks to ensure that all short-run work (daily, weekly, or biweekly) conforms to the state's annual work program and at the same time meets the local needs of the constituencies. Short-run scheduling considers various inputs, which differ among states and may include all priority listings based on maintenance needs surveys (including pavement evaluation), monthly schedule based on annual work program, leftover work from previous daily assignments, supervisor patrol survey forms, service requests, and emergency and urgent repair needs.

Biweekly schedules in Maryland are often subject to changes, making them informal and optional in most places. Scheduling supervisors have developed their own procedures for scheduling upcoming work. In the Westminster shop, Carroll County, where the field tests were conducted, it is common practice to assign activities to maintenance workers on a daily basis. The supervisors usually require 30 min to prepare the daily assignments on their forms. The supervisor relies on his expert judgment and familiarity with the scheduling process to identify which activities will be done and how they will be carried out.

Section superintendents and supervisors in Connecticut conduct biweekly scheduling meetings to determine the types and amounts of routine maintenance work needed and their locations. Like Maryland, the basis for the schedule is the annual maintenance work program for districts throughout the state. Litchfield garage, the site of the field tests, has 20 maintenance field workers including the supervisor. The procedure is informal and may involve preparing the schedule on the standard form, which takes about 45 min. Daily work assignments are made by the supervisor on a piece of paper.

In Arizona, the schedule is prepared by a supervisor and approved by the area superintendent. The supervisor fills out a standard weekly schedule form for the crew (a crew is also called an "org") and lists the activities in priority order. The scheduling practices of sign orgs in Tucson and Phoenix (those who participated in the field tests) are not significantly different from those in Maryland and Connecticut. Maintenance operations, however, are more ad hoc, since in most cases the crews respond to urgent needs such as repairing damaged signs.

Analysis of these practices and those of other states indicates that short-run scheduling can be aided by a laptop computer or electronic clipboard. Such equipment can combine data bases used for scheduling and allow incorporation of expert system functions. To be accepted by the schedulers, however, computer-aided scheduling should be simple, convenient, and practical. One perceived advantage of computer-aided scheduling is that the forms for daily work reports or crew cards (assumed here to be created by the computer as well) can be automatically filled with some or most information from the schedule, thereby eliminating the need to write the same information when preparing the daily work reports.

Work Reporting

Daily work reports provide maintenance headquarters with a basis for comparing planned work with actual work and assessing the adequacy of the maintenance budget. These reports also provide data for evaluating the productivity of maintenance jurisdictions; keeping track of labor, materials, and equipment use; and determining whether adjustments to quantity and performance standards are necessary. In many states, daily work reports are combined with time sheet preparation, payroll documentation, and accounting.

Maryland DOT uses crew day cards with preprinted data for daily work reporting. Each card issued by the central office is related to the maintenance budget for the county or area and represents a certain amount of resources for 1 day's work on a particular activity. Crew leaders usually fill out their crew day cards at the maintenance shop after completing the day's work, using field notes written in a notebook or on scratch paper in the field. Information on crew cards is turned over to a timekeeper who manually fills out the time sheets. Crew cards are then passed on to another clerk who fills out the maintenance activity summary worksheet. On the average a crew leader takes 5 min to fill out a card for an average crew of four persons. The clerks need about 5 min to transfer data from each crew card to the time sheet, 3 min to the maintenance summary, 2 min to the equipment inventory (18 min during winter), and 2 min to the budget balance (18 min during winter). This means a total data entry time of between 12 and 44 min for a single crew card.

A standard daily job assignment form or a crew leader's daily assignment sheet, or both, is used for daily work reporting in Connecticut. Each crew leader in the garage fills out a separate form. At the end of the day all the data are combined in the general supervisor's daily report for the entire garage. Information from this report is manually transferred every day onto a maintenance management system summary sheet, the biweekly time sheets, and the equipment rental report. These are sent to the district office for processing. In the Litchfield garage, the crew leaders spend an average of 5 to 20 min each filling out their work reports for an average crew size of three. It takes 3 to 4 hr every day for the clerk to transfer the information from the crew work reports to various forms in the garage.

A lead worker or senior crew member in Arizona fills out the standard crew work report form. Like other states, the Arizona crew work report has entry fields for describing their day's activity, labor, equipment use, materials, and accomplishments. Each completed report is given to a data entry staff or clerk, who checks it before entering the data into a PC-based maintenance management system, PeCos, which most org computers have. Arizona DOT has a network communications system that allows an org to upload work reports, planning files, and materials inventory to the area terminals. Orgs that are away from the area office submit their work reports by courier. It takes crew leaders between 6 and 20 min to fill out their daily work reports. A clerk collects the reports and keys in the information to PeCos. For each daily work report, the average time to transfer the data into the computer is 2 to 5 min, depending on how much error the crew leader makes.

A review of the states' daily work reporting procedures indicates that electronic data capture can help decentralize the activity to the level most appropriate for maintenance management—the field. However, new procedures would have to be easy to use and reflect actual practices. Equipment that provides feedback and useful information for field workers also has the potential to improve staff performance. Finally, automatically created time sheets, equipment and material inventory reports, and other summary reports can increase the efficiency of field and office maintenance management.

Roadway Feature Inventory Updating

Regular updating of maintenance features inventory allows an accurate accounting of the quantity and status of all maintainable elements throughout the state. This inventory is often the major input for annual work programs and budgets. Allocation of maintenance resources among districts or lower-level organizational units also depends on the quantity of maintainable items in each jurisdiction. Generally for the three demonstration states, the task of updating roadway feature inventory is not the responsibility of general supervisors and crew leaders.

Maryland DOT maintains a roadway feature inventory on logs. The inventory is updated using the back portion of the maintenance improvement crew day card. Crew leaders and general supervisors are required to fill out this card in place of the regular crew day cards when the activities performed involve safety improvements, maintenance improvements, or new installations. The maintenance management system, which prints the crew day cards and resides in the central office, has a feature inventory program that updates the master inventory file and carries out the procedures for planning the statewide annual work program. In the Westminster shop, crew leaders rarely use the back of the improvement card because they seldom do work that involves addition to or deletion from the inventory. Shop requests for updated inventory of their maintainable elements from the central office takes a lot of time to process.

In Connecticut, roadway inventory data are used to compute and define work programs. The district planning section is responsible for maintaining an up-to-date roadway inventory record. Inventory data are updated before creation of the annual work program. Adjustments are made if there are additions to or subtractions from the highway inventory as a result of new construction, betterment work, or changes in pavement surface. The nature of maintenance activities and the manner in which quantity standards are defined determine which roadway features are included in the inventory. In the Litchfield garage, the supervisor does not have an updated record of the roadway inventory for his jurisdiction. There is currently no reliable feature inventory in place for maintenance management nor a means to update it.

The org supervisors in Arizona are responsible for maintaining an accurate feature inventory of roadways. A periodic condition assessment is conducted with the help of the area superintendent. Maintenance features include roadway and roadside elements, shoulders, drainage installations, landscape, and signs and striping. Field inventory forms are used by field personnel. An inventory of all maintenance features for each district is compiled, showing quantity and location of existing features. Arizona DOT maintains a link feature file on a mainframe computer. This file contains the inventory values on which the maintenance management system depends. Information contained within this file is also used, either directly or indirectly, in establishing the annual work program and budget. In addition to the link feature inventory file, Arizona maintains a sign record system that stores the sign inventory (field tests in Arizona focused on sign management). The sign orgs fill out the sign record forms as various actions are taken on each sign. However, sign managers have problems getting updates of the sign inventory because the clerks have no time to transfer the information from the forms into the mainframe computer.

It appears that roadway feature inventory updating is most effectively performed by crew leaders and supervisors. Accuracy, ease of use, and perceived value of information are the most influential factors for acceptance of field data collection devices for inventory updating. The integration of inventory updating with daily work reporting may result in cost savings.

Sign Inventory and Maintenance Management

Signs and traffic control devices are valuable to highway agencies. Large inventories of signs and materials used to fabricate signs are usually kept in stock, in addition to those already in the field. The central sign and striping warehouse in Phoenix, for example, maintains an inventory worth over $10 million in 1992 (excluding interstate signs). In addition, districts and yards all over the state have their own inventories.

The tasks involved in managing and maintaining field and warehouse sign inventory can be enormous, as is the case in Arizona. Automating many of these recording and data updating tasks would substantially reduce the level of effort. Moreover, these valuable assets can be effectively managed if the warehouse inventory is tied to the roadway inventory. Sign inventory is probably best performed by crew leaders who are responsible for these features. Automated location and attribute-point data collection for signs, especially if carried out in conjunction with a map, is valuable for sign inventory and maintenance management.

Maintenance Quality Evaluation (Virginia DOT)

One mission of VDOT's maintenance division, headquartered in Richmond, Virginia, is to ensure that the state highways are adequately maintained, meaning that their conditions are within acceptable limits. This is the main goal of the department's maintenance quality evaluation (MQE) program, which involves field inspection of sample highway sites and sections to determine whether the conditions of the sites pass or fail statewide standards. The site selection is based on a statistical process that randomly generates a list of highway segments, each 161 m (0.1 mi) in length, for every district throughout the state. The highway segments are classified by district, county, route number, section number, and other location identifiers.

In 1993, only three persons in VDOT conducted the site inspections. These inspectors identify the locations of sample sites on a map before going out in the field. The inspector rates each site on the basis of visual assessment of various characteristics of five major elements of the highway: traveled way, shoulders, drainage, traffic control/safety, and roadside. The inspector also enters the data from the survey forms into a Lotus 1-2-3 spreadsheet application on a computer in Richmond. On the average, it takes 30 min to enter the information for 60 sample sites.

Virginia has 9 districts and 100 counties. The computer generates 1,000 sample sites on the average for each district. Also for each district, about 3 months are needed to complete the evaluation, including surveys, computer processing, and report generation.

The existing procedures for recording and uploading site condition data can be significantly improved using field data collection equipment. Inspection surveys recorded in the field device can be uploaded to a computer for processing, thereby eliminating the paperwork and time required by each inspector to enter survey data into the computer. The calculations of both individual and aggregate site ratings can also be performed by the field device, allowing quantitative evaluation of the sites to be carried out in the field and immediately presented to the district or residency.

Field Tests and Evaluation

Very detailed software design and customization of equipment for each testing site were performed prior to actual field tests. Data specifications and functions that conform to actual practice were built into each piece of equipment. Field tests and evaluations lasting between 1 and 2 weeks were conducted in the field sites on various dates. The following describes the technologies used and the software applications that were developed for various activities.

Computer-Aided Work Scheduling

Scheduling is the first stage of the three-part data collection process described earlier. For the field demonstrations in three NCHRP host states, a biweekly or weekly scheduling procedure was developed on an electronic clipboard with glass screen. The scheduling procedure was customized for the three states using their standard short-run scheduling forms. An innovative method was developed that permits the scheduler to create a weekly or biweekly schedule from candidate projects in six categories of potential work: (*a*) annual work program, (*b*) service requests, (*c*) patrol reports, (*d*) leftover work, (*e*) emergency needs, and (*f*) recommendations of a pavement management system (PMS). Information from these lists can either be downloaded into the electronic clipboard or built up daily. A master list is built by selecting activities from the various categories to allocate activities to various workdays. Each activity is identified by the location of work, crew size, and number of days. The scheduling system generates and fills out portions of work orders in the form of crew day cards. The crew leader fills out the remaining portions of these crew day cards, including actual labor, equipment, materials, and accomplishments, when the job is done.

The time and effort required to fill out a schedule using pen and paper are approximately the same as those using electronic clipboard. The main advantage of computer-aided scheduling is in letting a person build a schedule from a more complete list of candidate activities. Very few if any states have the means to combine recommendations from their PMS with other candidate projects. Automated generation of work reports with some preloaded information reduces data entry time for crew leaders.

Daily Work Reporting Using Electronic Clipboards, Barcode Scanner, and Voice Recognition

Two types of pen-based systems, one with glass screen and the other with paper overlay, were programmed for daily work reporting of maintenance activities (see Figure 1). A digitized image of the crew day card shows up on the screen as work reporting is initiated. The user can tap different portions of the screen to access different portions of the crew card for project description, labor, equipment, materials, and accomplishments. The user can provide information simply by selecting from a pick list, writing in block characters or numbers, or hunting and pecking from a typewriter or calculator keyboard displayed on the screen. The equipment displays the lists of personnel, equipment, and materials for each activity as defined by performance standards. These performance standards can also be viewed on the screen.

FIGURE 1 Pen-based electronic tablets can replace paper as the means to collect field maintenance data (photograph taken in Connecticut).

The other clipboard requires a paper form to be placed over the digitizing tablet. The user simply writes in block letters in the appropriate fields on the form. The tablet is programmed to accept data entry for all the blocks on the form, showing each entry on the screen. The equipment was also programmed for validating and checking user inputs. The record can be saved in memory and the paper copy kept for records.

Both pen-based tablets accept graphics input but only the glass-screen device could display it on the screen, although a recent version of the other clipboard can display graphics. Both also allow the user to work on any sections

FIGURE 2 Maintenance workers were impressed with the capability of voice recognition system for data collection (photograph taken in Maryland).

of the crew card in any order or save a partially completed report and fill out the rest of the data later.

To use barcoding technology, a preprinted menu with barcode labels pertaining to the sections and elements of the daily work report was created. A barcode scanner, which has an alphanumeric keypad, was programmed for recording crew card data. This data terminal prompted the crew leader with various inputs for the daily work report. The crew leader could either scan a label from the menu or use the keypad to record data on the terminal. The equipment also has a data validation function and an editing feature that allowed the user not only to review the crew work report but also to modify data inputs.

Finally, two crew leaders in Maryland tried and evaluated a voice recognition system, which consists of a belt-mounted battery pack connected to a headset with microphone and earphone (see Figure 2). Using a software development tool kit, the data entry task was developed on the equipment using a vocabulary list applicable to the particular maintenance work. Before the system can be used, it has to be trained to recognize the operator's voice. The system asks a series of questions pertaining to different elements of the report and repeats what the operator says. The system also compares the operator's responses with a list of acceptable responses. The user can control the type of information he or she wants to enter by specifying the appropriate section of the work report. In addition, the system can be commanded to change volume if noise interferes with reception. Every time the system is initiated by an operator it goes through a short training period during which it filters the noise in the background. Different operators can use the system by simply specifying the operator's name or identification. However, the interaction between the user and the system is limited by the system's vocabulary. The training time is also a function of the size of the vocabulary.

All equipment described and tested in the field operated reliably. The software that drives the applications worked well, except that the software for the electronic tablet with glass screen was quite elaborate, resulting in slow processing speeds (a recent upgrade of this equipment would overcome this problem). Surprisingly, most field workers were not bothered by the slow equipment response. Generally speaking, software development tools for programming the different pieces of equipment provide high reliability and convenience. Crew leaders were mostly very receptive to the equipment. However, there was no general preference for one piece of equipment over another. Some disliked all pieces of equipment and prefer to continue using pen and paper.

Crew leaders recommended greater flexibility in data entry to make notes concerning traffic control procedures, variations from normal procedures, problems, and special conditions. The equipment varied in its capability to record this type of information. Some crew leaders expressed concern about keeping the equipment secure from theft, damage, weather, and other conditions in the field.

Time savings, cost savings, and productivity enhancements resulting from the use of the equipment differ among states. In Maryland, for example, the adoption of field data collection devices and the automation of time sheets and maintenance summary reporting can reduce the total time for a shop clerk to post data into the computer from 12 to 44 min to around 6 to 15 min per crew card. This does not include the potential time savings that will be generated in the district as a result of more efficient data transfer from the shop.

If crew leaders in Connecticut were to use the field acquisition devices, the time it would take to complete their work reports would be reduced to about 3 to 10 min. With the computer-automated reporting system in place, the upload time from the devices to the computer (in the Litchfield garage, for instance, with four crew leaders each using electronic equipment) would be less than 20 min (a maximum of 5 min per crew leader).

In terms of automating the processing and consolidation of maintenance data, Arizona DOT is the most evolved among the three host states. The incremental benefits from adoption and full-blown implementation of advanced data acquisition technologies would be minimal for an organization like Arizona DOT, which at the time of the field tests had already automated most of its in-office data handling procedures. However, the incremental cost associated with making the best use of the field devices is also minimal for Arizona DOT, since computer systems are already in place. Daily work reporting using the field devices can be reduced by half the time (about 3 to 10 min) per daily work report. The data stored in the devices can be uploaded electronically into PeCos in less than 2 min per device.

Locating Maintenance Work Using GPS

Aside from the standard data items recorded on the daily work reports, geographic coordinates of work locations were added to the data fields on the field data entry devices. Crew leaders used an unaided GPS receiver to determine their location in latitude and longitude. Accuracy of the location measurements is an important issue for the use of GPS in the field. All the data collection devices tested were programmed to receive data describing geographic coordinates. Whereas the GPS can and should be interfaced with the electronic devices for automatic transfer of coordinates, for this demonstration the crew leaders were asked to read the coordinates from the GPS receiver and write or key in the coordinates on the equipment.

All three states have a route-milepost system established to identify highway locations. However, only Arizona uses this system for identifying the location of maintenance work and highway assets. The Maryland and Connecticut DOTs use the route number and a discursive location description (e.g., road intersections) to identify the location of maintenance work. The use of GPS for daily work reporting and roadway feature inventory updating makes the most sense for organizations that have or are committed to implementing a geographic information system (GIS) for representing their roadway inventories. None of the three states had such a system in place, but all three states were taking steps in that direction. Some supervisors and crew leaders realize the usefulness of the technology in establishing roadway inventories that can be recalled on a computer in the form of a map. Many of them also believe that the GPS can give them a more accurate description of location than their current procedures, which are only exact in terms of identifying route number. Even elapsed distance measurements, which are accurate to within 16 m (approximately 50 ft), lack the required accuracy for identifying specific roadway inventory features, especially in urban areas. The GPS unit used in the demonstration was unaided and had an accuracy of about 100 m (approximately 300 ft) because of selected availability. Accuracies of between 2 and 5 m were obtained with differential GPS during field tests in Arizona.

Roadway Feature Inventory Updating Using Field Data Entry Devices

The roadway feature inventory updating procedure was programmed on the two types of electronic clipboard. Inventory updating on the electronic clipboard with glass screen was demonstrated in all three states and was demonstrated on the one with paper overlay in Maryland and Arizona. The data recording application was generic and included only a number of representative inventory elements such as guardrail, signs, and roadside parks. The user could record the changes (i.e., additions and subtractions) to these inventory elements using either clipboard. In addition, the electronic clipboard with glass screen was programmed to display a digitized map of the locality and to permit the user to mark a specific location of a maintainable feature by placing an icon there. A mock-up of data entry facility for capturing geographic coordinates from a GPS receiver was also provided under the assumption that the receiver would be directly attached to the device with an RS-232 cable, or possibly integrated into the device. The mock-up required the user to touch a button on the display screen to obtain the coordinates from the GPS receiver.

An electronic version of the roadway feature inventory updating form used in Maryland was developed on the paper-overlay clipboard. This application was part of the crew card data collection application on the same equipment used by a crew leader in Maryland to record maintenance improvements information. In Connecticut, roadway feature inventory updating was demonstrated only on the electric clipboard with glass screen. The Arizona sign org staff used both electronic clipboards to enter sign record data on a form separate from the daily work reports. A barcode wand was connected to the clipboard with the paper overlay and used to scan barcode labels affixed to installed signs to associate a unique number to sign attributes, which include type and geographic coordinates (see Figure 3).

The hand-held data terminal with barcode scanner was also demonstrated for updating roadway sign inventory in Arizona. This was the principal piece of equipment investigated in a "cradle-to-grave" sign inventory and management demonstration.

Much of the feature inventory updating process can be automated using the electronic clipboards. The procedure will also enable the crew leaders and general supervisors who are in daily contact with these highway features to update the inventory in conjunction with preparing their daily work reports. Inaccurate procedures for reporting location are part of the reason why inventory updating is not effectively carried out by these individuals. Digitized maps (i.e., GIS) and GPS equipment were received with great enthusiasm by crew leaders and supervisors who evaluated the technologies. In general they believe that these technologies can significantly increase locational accuracies.

Maintenance Quality Evaluation Using Pen-Based Systems

The Urban Institute customized and field-tested a data collection program that allowed VDOT inspectors to record maintenance quality evaluation data on two portable pen-based systems: a notebook computer that converts to

FIGURE 3 Barcoding and pen-based systems are ideal for sign maintenance and inventory management (photograph taken in Arizona).

a pen-based electronic tablet and an exclusive pen-based system. This equipment was field-tested for one week and evaluated by VDOT staff to determine its desirability for field use.

Field testing and evaluation of pen-based systems for VDOT's maintenance condition surveys allowed the Urban Institute and VDOT to examine the pros and cons of using the equipment, and other similar devices, in the field. The greatest source of benefits was the ability to perform all the calculations and generate the reports on site. The same capabilities could have also been demonstrated if the Lotus 1-2-3 spreadsheet application were loaded onto a laptop computer or a notebook computer and used in the field. In fact, key-based data entry was possible with the convertible computer. However, VDOT inspectors prefer a portable pen-based system to carry with them during their site inspections.

VDOT operators needed very little training to use the equipment. The handwriting recognition function of the equipment was reliable, although there was very little writing involved in the process. The keyboard pop-up utility gives the operators the option to choose character/numeric keys with the touch of the pen instead of writing the characters in. The touch-button utility of the equipment was very convenient, reducing the amount of writing involved and simplifying the data entry procedure. The prototype data collection program also allows the operator to review previously saved records.

Cost-Benefit Analysis

To assess the attractiveness of the data collection technologies, a cost-benefit analysis was performed for each maintenance unit in the three states that participated in the NCHRP projects. Two sources of benefits were investigated: time savings in recording, verifying, and checking field data, and time savings involved in automatically posting the data from the field device to the computer and creating the summary reports. These time savings were determined from interviews with field and office personnel in each state, which enabled us to compare current manual data entry procedures with automated methods. The number of years to recover (or break even with) the setup was computed. Statewide extrapolation of results showed that the break-even period for adopting the technologies is from 1 to 3 years (voice recognition was excluded from the analysis because equipment was too expensive to be cost-effective, although the cost is expected to decrease significantly in the future). These break-even periods, however, are sensitive to assumptions about costs and benefits and the discount rate.

The analyses also indicated that the improvements in productivity associated with automating the manual procedures significantly offset the cost of implementing them. Likewise, incremental benefits from field data collection devices are smaller for maintenance units that have already installed personal computers and automated most of their postprocessing methods. Savings were found to be greatest for maintenance units that record much information in the field and transfer the same information by hand to a form in the office. For detailed discussions of the cost-benefit analyses of the field data collection devices, the reader is referred to *NCHRP Report 361* (*2*).

Conclusions

The substantial savings in time and resources that result from automating current procedures for recording, error-checking, transmitting, and processing maintenance data suggest that new technologies are desirable for these purposes. The magnitude of savings relative to costs depends on the nature of the data acquisition process; the number of times that the initial data are processed for posting onto various forms and subsequently entered into the management information systems; the susceptibility to error of the current procedures; the adaptability of the agency and staff to the new technologies; the improvements in managing agency field and office operations, labor, and physical assets; and the amount of resources (personnel, computer and communications facilities, other physical infrastructure, and funds) needed to implement the changes.

Field tests and evaluation of new technologies in Maryland, Connecticut, Arizona, and Virginia provided an opportunity to assess how these factors influence the relative benefits and costs of adopting advanced data capture equipment and methods. It was not possible to control all the factors during the field tests as one might in an ideal situation. Technologies also continue to change, as we found out with much of the equipment used in the field tests. Current costs, sizes, processing speeds, storage capacities, and other functional features differ extensively from those in the past 2 years. The trend, however, is toward better and less expensive products. Highway maintenance agencies should definitely take advantage of what the new technologies have to offer.

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Integrating Maintenance Management and Pavement Management Systems

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Considerable effort has been directed toward the development and implementation of maintenance management and pavement management systems over the past 25 years. Unfortunately, these two systems have for the most part been developed in isolation from each other. These systems have typically been developed by engineers to meet the specific planning, design, and operation needs of engineering staff. Further, maintenance management and pavement management systems are not typically integrated into the overall management and financial information systems of most agencies. Maintenance management and pavement management systems should and can be integrated together and made an integral part of the overall engineering and financial management systems within public-sector agencies.

Provincial and state highway and city engineering departments around the world are experiencing serious difficulties in obtaining the money required to properly maintain and rehabilitate the roads, bridges, sewer lines, water lines, and other transportation facilities for which they are responsible. Terms like deficits, budget cutbacks, downsizing, right-sizing, value-for-money audits, accountability, efficiency, effectiveness, and performance were either unheard of or of no particular concern as recently as 5 years ago. Today, however, they are the words of the chorus now heard in virtually every public-sector agency.

Highway engineers have been working at the development and implementation of pavement management, maintenance management, and bridge management systems since the 1960s. These management systems have been directed at determining and implementing cost-effective or optimal maintenance and rehabilitation strategies for the assets of concern. By the late 1980s most highway departments had what they considered a pavement management system, many had maintenance management systems, and some had bridge management systems in operation.

These systems were, from the perspective of the engineers who developed them, directed at providing a systematic approach to providing factual information on the present state and future evolution of the assets' conditions and logical procedures for evaluating repair and rehabilitation options, taking into account economic constraints and social requirements. It was argued that by using a systematic approach based on objective data, it would be easier to apply available funds in an optimal manner (*1*).

If engineers have had systems in place to determine optimal maintenance and rehabilitation strategies for implementation since the 1980s, then why are so few agencies able to successfully justify their budget requirements to their political masters or successfully respond to value-for-money audits by auditors general? The failure of public-sector agencies charged with managing society's civil infrastructure to convince political leaders of funding requirements is demonstrated by budget cuts of 15 to 50 percent in recent years. One might conclude from what has happened to budgets for public infrastructure in the past 5 years that we either spent too much in previous years or are seriously underfunding the preservation of our civil infrastructure at present. No matter which of these is correct, it is clear that those charged with the responsibility of managing our public infrastructure have been unable to do this in an optimal (or even near-optimal) manner in recent years.

Considerable insight into the reasons for the current situation can be gained by reviewing events over the past 10 years in Canada, the United States, and Australia. This will not be a comprehensive review, but will provide the theme of recent events (*2–7*).

As previously noted, engineers have been formally working to develop systems for allocation of funds to the preservation of civil infrastructure since the 1960s. Parallel to this, but seemingly in near complete isolation, accountants have become concerned with the ability of public-sector accounting methods to provide managers, politicians, and the public with a clear picture of the efficient and effective allocation of public expenditures on civil infrastructure.

The concern of the accounting fraternity is aptly illustrated by a Canadian study (*2*). Like many other studies by accountants concerned about public finance and accountability, this study makes the point that the financial statements of federal, provincial, state, and municipal governments should help to express their accountability for how well they administered public affairs. This means that the financial accounting systems of public-sector agencies should be able to demonstrate value for money spent as well as perform the traditional function of demonstrating compliance with authorized spending and financing limits. The Canadian study concluded that in order to demonstrate value (i.e., economy) as well as compliance, public-sector agencies charged with managing civil infrastructure should set up physical assets and write them off to expenses as they are consumed in service.

Similar concerns have been addressed by accountants in the United States and Australia, and largely because of the nature of cost sharing for infrastructure construction and maintenance among various levels of government, were translated into action on the financial accountability side. This concern about the financial accountability of public-sector agencies was translated into Australian Accounting Standard AAS27 (*7*) and into the requirement for new management systems under the Intermodal Surface Transportation Efficiency Act (ISTEA) in the United States.

An in-depth discussion of the details of the above-cited legislation is beyond the time and space available here. The essence of this type of legislation can be gleaned from recent auditor general reports in Canada. It is important to note that whereas Canada has not implemented new legislation such as that in Australia and the United States requiring particular types of accounting methods, in essence the same value-oriented accounting principles were applied in Canada simply from the perspective of requiring accountable government.

To illustrate, the auditor general in one province in Canada found that the Department of Highways and Transportation could not show that it fully complied with the applicable Department of Highways and Transportation Act, which states that the minister "is responsible for determining the most feasible and economic methods for constructing and improving and maintaining public highways" (Saskatchewan Government Auditor's Report, Chapter 17, 1993). This, in effect, translates into a requirement to be able to demonstrate value for money spent. This is clearly beyond the traditional accounting view of being able to demonstrate compliance. In this case the auditor general went so far as to recommend that the department prepare its maintenance budget on the basis of current highway conditions. That is, the department should prepare a condition-based budget.

Whereas the preceding is from an auditor general report in one province in Canada, accountability and measures of efficiency, effectiveness, and performance are becoming general requirements even at the political level (*5*). See, for example, the "New Approach to Government: A Financial Plan for Alberta," that province's 1993 budget.

The world has changed, and the current requirements of public-sector engineering and financial management systems can only be met by producing an auditable, condition-based, zero-based maintenance and rehabilitation (preservation) budget for civil infrastructure. This, as illustrated in the next section, cannot be done without integrating pavement and maintenance management systems. Further, neither the pavement management nor the maintenance management systems will be credible (i.e., auditable) unless they are condition-based, where condition is measured in terms of the severity and extent of individual distresses.

The issues and principles involved at a pavement management system and maintenance management system operational level are best illustrated by example.

EXAMPLE

You are the engineer responsible for a road network consisting of 100 segments. For simplicity assume that each segment is 1 km long and 10 m wide, for an area of 10,000 m^2. The condition of your network is as indicated in Table 1 and Figure 1. You have the treatments indicated in

TABLE 1 Initial Network Condition

Condition	Number of Segments
Good	30
Fair	20
Poor	20
Very Poor	30

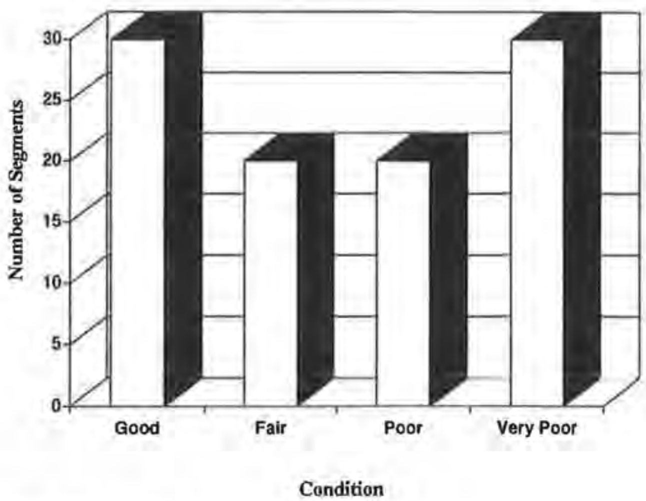

FIGURE 1 Initial network condition.

TABLE 2 Available Treatments

Treatment	Cost
Nothing	-
Routine Maintenance	$5/m^2$
Seal	$10/m^2$
Overlay	$40/m^2$

Table 2 available to you at the costs noted. Your job is to determine the most appropriate maintenance and rehabilitation strategy for the network. This is what a pavement management system should do.

To determine the most appropriate strategy, we must (*a*) decide on how to measure appropriateness and (*b*) know the budget constraint. How should we measure appropriateness? What is our objective? What are our constraints?

One objective might be maximizing roadway condition subject to the budget constraint. Let's leave aside the issue of the objective at this point and start by evaluating several different strategies in relation to each other to illustrate the method. Presumably we could keep comparing alternative strategies until we came up with the most appropriate one.

We will compare two strategies: (*a*) treat the worst roads in the network first (i.e., bottom up) and (*b*) perform routine and preventive maintenance first (i.e., top down). Both strategies will be subject to the same budget constraint. For this example, assume the budget constraint is $4.5 million per year.

The first issue we encounter is how to compare conditions under the different strategies from year to year. We need to know how the condition of the road will change with time for the various types of treatment. Let's try to estimate the effects of different treatments on our road network.

We will consider the effect of "do nothing" as our first maintenance option. Roads considered to be in good condition this year are most often still rated as good next year. But our experience tells us that this is not always the case. Sometimes a road declines from good condition to fair or poor condition from one year to the next. Sometimes, though rarely, good roads fail and drop to very poor condition in 1 year. On the basis of historic data (or experience), let's assume that for 70 percent of the time good roads remain good from one year to the next, 20 percent of the time good roads become fair 1 year later, and 10 percent of the time good roads become poor 1 year later under a "do nothing" maintenance strategy.

The assumptions above might be summarized as in the first row of Table 3. The remaining cells in Table 3 might also be filled in on the basis of experience or judgment. These are really Markovian transition probabilities such as those used in modern pavement management systems.

Similarly, under the routine maintenance option (Table 4), roads are somewhat more likely to stay in their current condition for the next year and decline less from year to year if routine maintenance is applied. To illustrate, while only 70 percent of roads in good condition are likely to remain so 1 year later with no maintenance, 90 percent are likely to remain in good condition if routine maintenance is applied.

How a seal might influence condition from one year to the next is less obvious (Table 5). For example, if a road is in good condition and a seal is applied, how has the seal changed the likelihood of moving down to fair or poor? The seal will likely improve or help maintain the current road condition if the distress is cracking. On the other hand, if the condition of the segment tends to move from good to fair because of rutting, the seal is unlikely to alter this probability much, if at all.

Similarly, if the road was in fair condition because of rutting problems, its condition is unlikely to improve with a seal. If it was in fair condition because of cracking problems, its condition might very well be improved with a seal.

Perhaps a better way to rate road condition would be to define condition by the type of distress present. Doing this makes it possible to predict with greater confidence what will happen to a particular road when it receives a specific treatment. To keep things simple, let's assume that there are only two types of distress in our network (rutting and cracking), only two levels of severity (none or some), and one level of extent (uniform throughout). Roads may be classified into four condition states using this system (Table 6).

Using these more meaningful descriptions of condition states, we can now reevaluate our probability tables. Let's assume that we come up with the probabilities given in Tables 7 through 10.

TABLE 3 Probabilities for "Do Nothing" Option

		To State			
		G	G	P	VP
	G	.7	.2	.1	-
From	F	-	.7	.2	.1
State	P	-	-	.6	.4
	VP	-	-	-	1.0

TABLE 4 Probabilities for Routine Maintenance Option

		To State			
		G	G	P	VP
	G	.9	.1	-	-
From	F	.1	.8	.1	-
State	P	-	.1	.8	.1
	VP	-	-	.1	.9

TABLE 5 Probabilities for Seal Maintenance Option

		To State			
		G	G	P	VP
	G	?	?	-	-
From	F	?	?		-
State	P	-			
	VP	-	-		

TABLE 6 Condition States

Condition	Designation
No Rutting, No Cracking	None, None (NN)
No Rutting, Cracking Only	None, Some (NS)
Rutting Only, No Cracking	Some, None (SN)
Rutting and Cracking	Some, Some (SS)

Now consider what might happen to our road network from one year to the next using the "do nothing" option. We begin by determining what is likely to happen to the 30 roads in the NN state. From the first row of Table 6 and Figure 2, we can see that 70 percent of the roads will likely remain in the NN state, 15 percent of the roads will have sufficient cracking to be classified as NS, 10 percent will be sufficiently rutted to be in state SN, and 5 percent will be sufficiently cracked and rutted to be in state SS. The calculations for all roads in the four condition states under the "do nothing" option are summarized in Table 11 (refer also to Figure 2).

If we adopted a strategy of routine maintenance for all NN condition roads and "do nothing" on all other roads, we need Row 1 of Table 8 and Rows 2, 3, and 4 of Table 7 to carry out the calculations. We would arrive at the result in Table 12.

If routine maintenance were done on only 10 of the roads in class NN, we would use Row 1 of Table 8 for these 10 roads and Row 1 of Table 7 for the other 20 roads. We would add them together to arrive at the net effect. In this way we could estimate the future condition of the road network under any defined maintenance strategy. We can now compare the two maintenance strategies mentioned earlier, subject to a budget constraint of $4.5 million per year. Under the "treat-the-worst-first" strat-

TABLE 7 Probabilities for "Do Nothing" Option—Reevaluation

		To State			
		NN	NS	SN	SS
	NN	.7	.15	.1	.05
From	NS	-	.7	-	.3
State	SN	-	-	.7	.3
	SS	-	-	-	1.0

TABLE 8 Probabilities for Routine Maintenance Option—Reevaluation

		To State			
		NN	NS	SN	SS
	NN	.9	.05	.05	-
From	NS	-	.9	-	.1
State	SN	-	-	.9	.1
	SS	-	-	-	1.0

TABLE 9 Probabilities for Seal Maintenance Option—Reevaluation

		To State			
		NN	NS	SN	SS
	NN	1.0	-	-	-
From	NS	.8	-	.2	-
State	SN	-	-	1.0	-
	SS	-	-	.8	.2

TABLE 10 Probabilities for Overlay Option—Reevaluation

		To State			
		NN	NS	SN	SS
	NN	1.0	-	-	-
From	NS	1.0	-	-	-
State	SN	1.0	-	-	-
	SS	1.0	-	-	-

egy, we will overlay the worst roads in the system until the funds are exhausted. With this budget, we could rehabilitate 11.25 of our 30 SS class roads. If we perform the calculations and repeat this strategy year after year, we get the result in Table 13 and Figure 3. Note that the strategy of treating the worst first—subject to a $4.5 million budget and given the condition of the network in Year 1, the costs of the treatments, and the models of pavement performance under various treatment options—we ended up in Year 4 with slightly more of our network in good (NN) condition, slightly less of the network in fair (NS) and poor condition (SN), and slightly more of the network in very poor (SS) condition.

If we used the same $4.5 million budget for as much preventive maintenance as we could in states NN, NS, and SN, and then spent the rest of our budget sealing roads in state SS, we would get the result in Table 14 and Figure 4.

Figure 4 shows that a strategy of doing preventive maintenance first (i.e., top down) resulted in more of the network being in good condition (NN) in Year 4 relative to Year 1, slightly fewer roads in fair condition (NS), more in poor condition (SN), and substantially fewer in very poor condition (SS).

The overall effectiveness of the two strategies (worst first versus preventive maintenance first) can be evaluated by comparing Figures 3 and 4. Clearly, the two strategies had different results, although in each case the same amount was spent each year.

Which strategy is better? It is hard to tell. The more important question is whether either strategy is optimal. You cannot tell without an objective function, but it is highly unlikely that either strategy yields the most for the money spent. Rather some combination of treatments (i.e., doing nothing on some, routine maintenance on some, sealing some and overlaying some) probably gets the best results for the funds available. A pavement management system that is capable of true optimization would determine the optimal strategy.

A number of approaches could be taken to determine the most appropriate strategy, but first an objective must be defined to describe what is most appropriate in quantifiable terms. One objective function might be to determine the budget for each of the next 4 years so as to maintain the distribution across conditions as in Year 1. Another objective function might be to determine the budget in each of the next 4 years to reduce the proportion of the network in very poor condition to less than 10 percent. It is possible to determine the condition distribution for any given annual budget (these can be different each year), or determine the budget required to maintain the network

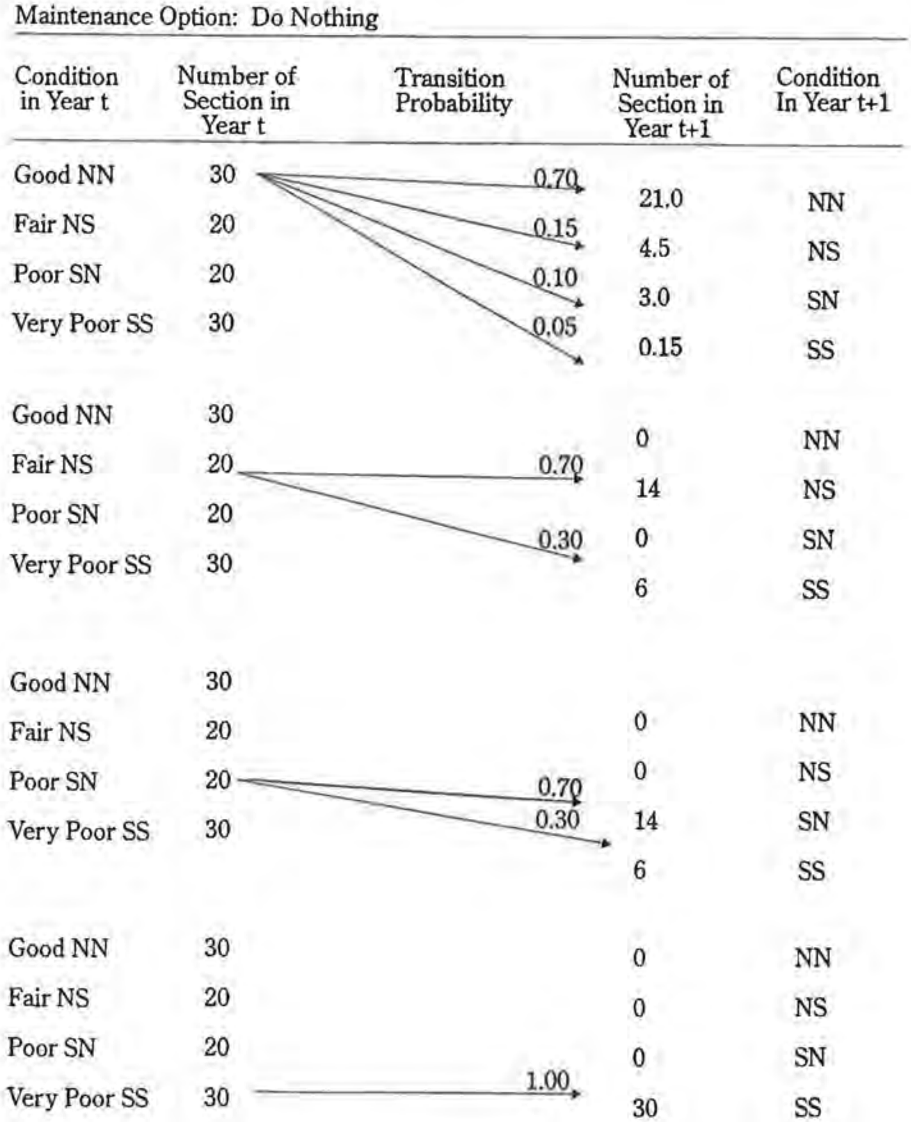

FIGURE 2 Condition transitions from Year t to $t + 1$.

TABLE 11 Transition of Roads in Good (NN) Condition

Condition	Year 1	Do Nothing Calculations	Year 2
NN	30	30 x 0.7 = 21	21
NS	20	30 x 0.15 + 20 x 0.7 = 18.5	18.5
SN	20	30 X .1 + 20 x 0 + 20 x .7 = 17	17
SS	30	30 x .05 + 20 x .3 + 20 x .3 + 30 x 1 = 43.5	43.5

TABLE 12 Combination Strategy

Condition	Year 1	Do Nothing Calculations	Year 2
NN	30	30 x 0.9 = 27	27
NS	20	30 x 0.05 + 20 x 0.7 = 15.5	15.5
SN	20	30 x .05 + 20 x 0 + 20 x .7 = 15.5	15.5
SS	30	30 x 0 + 20 x .3 + 20 x .3 + 20 x .3 + 30 x 1 = 43.5	42

TABLE 13 Network Condition Treating Worst First (Bottom Up)

State	Year 1	Year 2	Year 3	Year 4
NN	30	32.25	33.825	34.93
NS	20	18.5	17.788	17.52
SN	20	17	15.125	13.96
SS	30	32.25	33.26	33.56

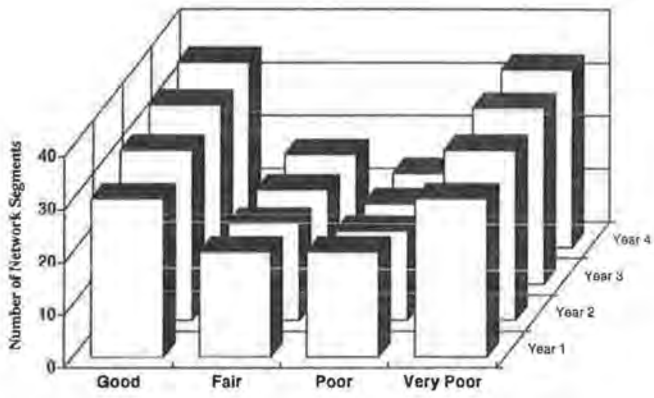

FIGURE 3 Distribution of network condition (treating worst first).

to any defined condition distribution. These are only two objectives from a large range of possibilities.

Discussion of Issues

The preceding example has identified and illustrated a number of critical issues related to pavement management systems, maintenance management systems, and the need to integrate the two in order to demonstrate value for money spent on road maintenance.

First, determining the appropriate (optimal) road maintenance and rehabilitation strategy must be a condition-based process, where condition is expressed in terms of individual distresses (e.g., rutting, cracking) to be meaningful in relation to treatments. In fact, condition must be expressed in terms of the severity and extent of individual types of distresses because severity, extent, and type of distress are all important in determining the feasible treatments (e.g., sealing or crack-filling), the methods (hand or machine), and therefore the costs.

TABLE 14 Network Condition Using Routine Maintenance First (Top Down)

State	Year 1	Year 2	Year 3	Year 4
NN	30	35	37.9	34.1
NS	20	19.5	19.3	19.3
SN	20	19.5	19.3	24.7
SS	30	26	23.5	21.9

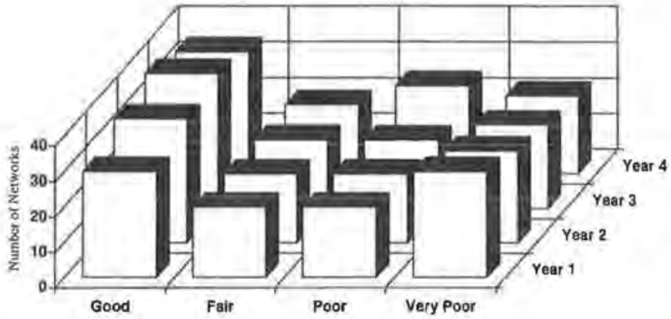

FIGURE 4 Network condition routine maintenance first (top down).

The methods used in the condition survey must also be reproducible over time and among individuals or machines performing the condition surveys. That is, the results must be consistent whether one person or machine surveys the same section 10 times or 10 different people or machines survey the same section. A reproducible condition survey is fundamental to both a pavement management system and a maintenance management system if the systems are to be auditable and provide the information required to demonstrate value for money.

Finally, a pavement management system can determine the optimal maintenance and rehabilitation strategy only if representative costs of treatments and changes in condition resulting from various treatments are available. The transition probabilities for road condition for various treatments could be obtained on a relative frequency basis by tabulating the results of a series of annual condition surveys relative to the maintenance and rehabilitation activities each year. This is one of the places where the pavement management system and maintenance management system must interact. Only a maintenance management system can keep track of which maintenance and rehabilitation activities were actually applied to each road section over the years. Needless to say, this is no small job. It is impossible without a condition-based maintenance management system.

In our simplistic example the costs of treatments varied only by treatment type (i.e., routine maintenance versus seal versus overlay). All of our treatments were assumed to be applied uniformly throughout the road section. This is unrealistically simplistic. For example, the costs of filling cracks or patching potholes are both a function of the severity of the distress (e.g., narrow cracks versus wide ones, small potholes versus large ones) and the extent of the distress (e.g., transverse cracks every 5 m versus 50 m, or potholes in 2 percent of the total area of the road section versus 20 percent). To estimate representative costs for various treatments, you must know the severity and extent of each type of distress. That is, you must have condition-based cost estimates for your pavement management system, where condition is expressed in terms of the severity and extent of each type of distress. Again, the only reasonable way to keep track of this level of detail is within a modern condition-based maintenance management system.

Conclusions

The findings of this paper illustrate that the world is changing, and those charged with managing civil infrastructure are now expected to demonstrate economy (i.e., value for money) as well as compliance (i.e., that funds were spent on what was designated in the budget). To demonstrate value for money, public-sector infrastructure managers require a modern pavement management system. Further, to credibly demonstrate value for money, a pavement management system requires condition-based costs. The only reasonable way to keep track of the details required to develop condition-based costs is within a modern condition-based maintenance management system. As such, integrating a modern condition-based maintenance management system with a modern pavement management system is fundamental to meeting the new financial accountability requirements of public-sector agencies.

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Integration of Management Systems for Maintenance Activities

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Pennsylvania's Maintenance Operations Resource Information System (MORIS) is a large and complex mainframe system that has been fully operational since 1986. MORIS captures information on all aspects of maintenance operations, including personnel, equipment, and materials. It is a "real-time" system, updated daily through transactions—such as payrolls, invoice documents, equipment usage information, and work activities—at terminals in the 11 district and 67 county offices and the three central warehouse functions (sign shop, equipment division, consumable supplies). Since 1986, MORIS has continually evolved through enhanced integrations with other management systems. These include the Roadway Management System, Bridge Management System, Accident and Reporting System, and the Fiscal Management and Information System. Each of these five systems is large and can operate independently. MORIS integrates functions and obtains key information from these systems to better manage the maintenance of Pennsylvania's roadways.

The Location Referencing System (LRS) is the key to the collection, storage, and integration of all roadway information within the Pennsylvania Department of Transportation (PennDOT). This common reference is specific to all location data and information shared among all management systems and data bases within PennDOT. It is the "common denominator" that allows these major mainframe systems to be integrated.

An integral part of PennDOT's computerized management systems for storing roadway data is the 14-digit location reference number, which designates the county, state route, segment, and offset of a point or feature on a state route (CO/SR/SEG/OFFSET).

Pennsylvania is divided into 67 counties. Each county (CO) has a number that represents the first two digits of the LRS number. In each county, the state route (SR) is assigned a four-digit number subdivided into approximately $\frac{1}{2}$-mi segments (SEG). Finally, the four-digit offset number (OFFSET) is the distance (feet/meters) to a particular roadway feature from the beginning of the segment. Wherever practical, the beginning and end of a segment are established at permanent physical features such as intersections, bridges, railroad crossings, and so forth.

The LRS is not complicated, and anyone can easily take advantage of the benefits it offers. It adds permanence, accuracy, and stability to PennDOT's location signing system. It is easy to understand and inexpensive to maintain, and it generates a computerized representation of the state highway network.

For example, in the reference number (41/0220/0320/1036), CO (41) denotes Lycoming County, SR (0220) denotes U.S. Traffic Route 220, SEG (0320) denotes Segment 0320, and OFFSET (1036) denotes the distance to a feature from the beginning of Segment 0320.

The Maintenance Operations Resource Information System (MORIS) uses the LRS to reference its location-specific data. This is essential to efficient system integration.

MORIS Components

Within (MORIS), three separate operational components are integrated, as shown in Figure 1: equipment management, materials management, and highway maintenance management.

EQUIPMENT	MATERIALS	HIGHWAYS
20,000 PIECES	$100,000,000/YR	200 ASSISTANT MGRs
-INVENTORY	-COUNTY/STOCKPILE	700 FOREMEN
-EQUIPMENT #	-SIGN SHOP	-PLAN WORK
-W.O.	-WAREHOUSE	-DOCUMENT WORK
-E.C.C	-CENTRAL GARAGE	-ACCOUNTING
RENTAL RATES		
-UTILIZATION		
-813 COSTS		

FIGURE 1 Operational components of MORIS.

Equipment Management

The equipment management subsystem monitors the status and location of each unit of equipment in the PennDOT fleet, calculates equipment repair costs, and calculates equipment usage costs. The equipment subsystem conducts seven major processing activities:

1. It collects repair tasks reported to MORIS and provides a mechanism for the equipment manager to create repair work orders.
2. It maintains the accuracy of equipment inventory, both PennDOT-owned and rented units.
3. It maintains the accuracy of the tool inventory for the garage storeroom.
4. It allows equipment management to add and maintain standards for repair task completion, equipment use, and fuel consumption.
5. It helps equipment managers identify equipment retirements and acquisition by allowing the development of equipment age profiles by equipment type, and organization and analysis of maintenance cost versus purchase/rental cost analyses.
6. It calculates equipment rental rates once per year.
7. It allows the ability to request reports when they are wanted or needed.

Materials Management

The materials subsystem monitors inventory by location, estimates materials requirements on the basis of production units planned by activity in the annual work plan, and assists field personnel in acquiring and accounting for materials.

The materials subsystem performs five major functions:

1. It provides the tools to more accurately determine each organization's short- and long-term materials needs, as specified by the various highway work plans.
2. It records changes of on-hand balances of all materials controlled on MORIS. These changes occur through materials receipts, issues, and transfers. The system also provides the ability to plan physical inventories, record actual counts, and calculate variances. This component allows authorized personnel to set reorder points and quantities for materials controlled on MORIS.
3. It supports material acquisition by accepting validated orders from users.
4. It interfaces with the Fiscal Management and Information System (FMIS). It generates all accounting transactions related to material acquisition and usage and sends them to FMIS electronically each night.
5. It accesses all of the data generated by this subsystem to prepare operating and management reports.

Highway Maintenance Management

The highway maintenance subsystem supports maintenance planning, both short and long term, and records the actual production of highway maintenance crews for management reporting and accounting. The planning component develops long-range planning by using the Road Information File. The data for this file are collected throughout the year by field personnel and obtained through integration with the department's Roadway Management System (RMS).

PENNSYLVANIA'S RMS

Five major process components of Pennsylvania's RMS combine to provide pavement management system functionality. The key processes are described in this section.

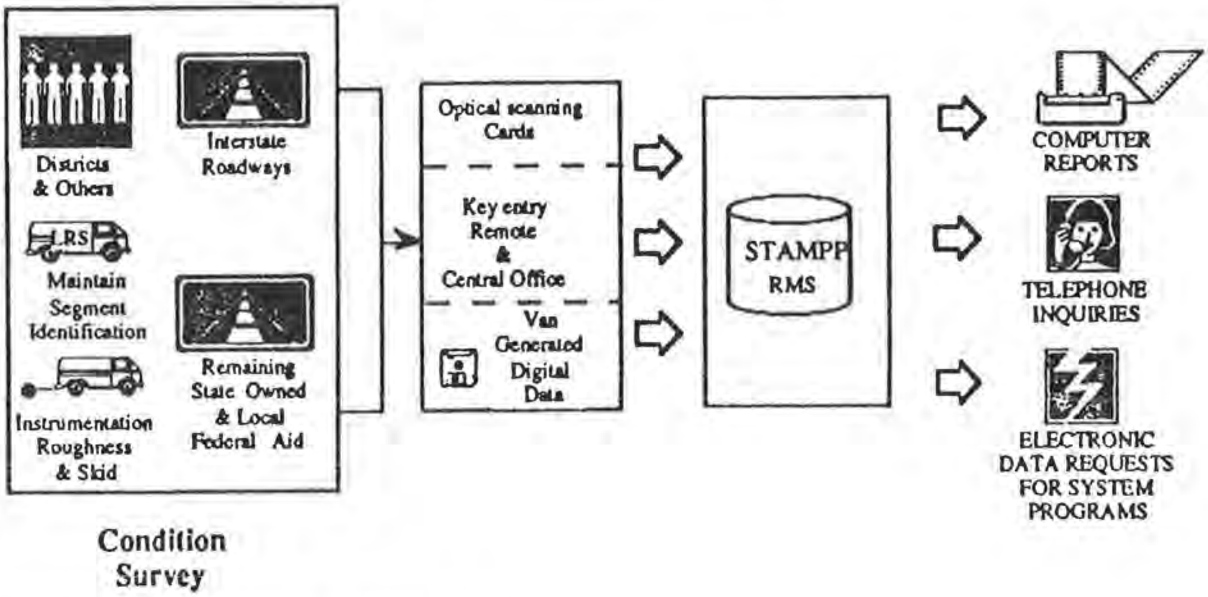

FIGURE 2 Data collection—condition survey.

Data Collection

The data collection process flow diagram is shown in Figure 2.

Inventory

Pennsylvania's RMS contains an inventory of approximately 41,000 mi of PennDOT-owned roadways. RMS includes approximately 100,000 roadway segments. Of these, about 91,000 are actual roadway segments, approximately ½ mi long. The remaining segments are miscellaneous roadway facilities such as roadside rest areas, truck escape ramps, and interchanges. The segment length and feature locations are continually monitored while data are collected.

Condition Survey

Roadway condition data are collected each year as part of the regular pavement survey program. Visual inspections are made by two-person teams of evaluators who drive the shoulders at low speed and evaluate the pavement and shoulders. Guardrail and drainage surveys are also done. Condition data are recorded on computer-formatted paper forms and entered into RMS at district offices or other remote locations. Pavement data are collected annually for all Interstate roadways and biannually for the rest of the state system.

Roughness, skid, and structural strength data are collected at the network level by automated data collection equipment. International Roughness Index (IRI) data are collected using a South Dakota–type road profiler. Skid resistance data are gathered using a locked-wheel skid trailer. Structural adequacy of the pavement is measured using a falling weight deflectometer.

Treatment Specification

The specification of maintenance treatments is shown in Figure 3.

Pennsylvania's RMS contains the subsystem called Systemic Technique to Analyze and Manage Pennsylvania's Pavement (STAMPP). STAMPP uses a matrix of treatments and distress levels to determine a preliminary treatment.

The STAMPP program maintains distress conditions for bituminous and concrete pavements. These conditions are used to calculate the 14 possible treatment strategies for bituminous pavements and 10 possible treatment strategies for concrete pavements shown in Figure 4.

PennDOT also maintains treatment strategies for continuously reinforced concrete pavement, unpaved roads, drainage facilities and appurtenances, and guardrails.

A segment's roadway condition data, pavement history, average daily traffic (ADT), and class of highway are used to calculate the treatment. This pavement treatment matrix is maintained by PennDOT's Bureau of Maintenance and Operations, Roadway Management Division.

Cost Assignment

The RMS STAMPP unit price index is used to assign costs to recommended treatment levels. This index contains

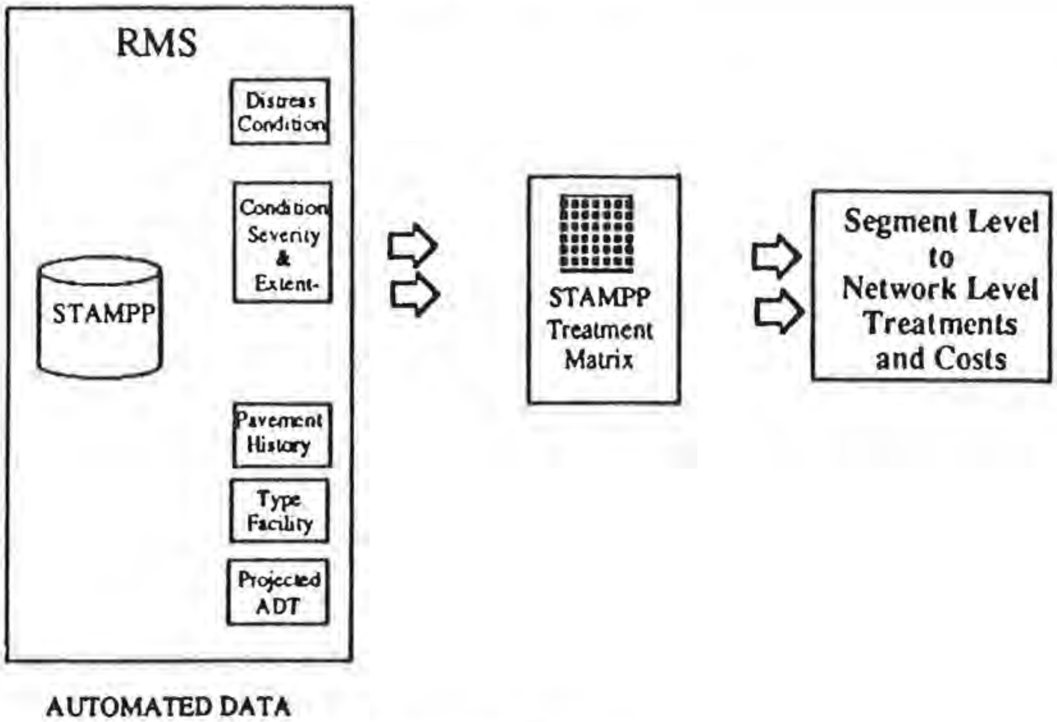

FIGURE 3 Pavement management—treatment alternatives.

statewide unit cost data that are updated annually and reflect regional differences. An average statewide unit price index also is maintained.

Life-Cycle/Performance/Optimization Analysis

The PennDOT Pavement Performance Modeling Program is a performance modeling, life-cycle cost analysis, and a PC computer program for network/project optimization. The program consists of four major modules:

- The grouping module defines groups of pavements with similar deterioration characteristics.
- The modeling module builds a performance model for each group, developed for variable conditions on the basis of historical data.
- The application module applies the developed performance models to a life-cycle costing analysis and an optimization process for maintenance and rehabilitation planning.
- The data base module imports data to and from the RMS, PennDOT's central roadway data base.

Planning, Programming, and Project Selection

Using these pavement data sources and working knowledge of the roadway network condition, the county manager and the PennDOT central office establish county goals for surface improvements and estimated budgets. The county manager assembles a preliminary list of projects for district committee consideration. The district planning and programming process uses the following seven criteria:

1. Pavement conditions,
2. County maintenance budget,
3. Equitable geographic distribution of improvements,
4. Roadway functional class,
5. Impact of improvements on overall roadway network,
6. Safety, and
7. District mileage goals for surface improvements.

The Annual Work Plan (AWP), Surface Improvement Program (213 Program), and Period Plan (PP) are developed from these processes using the RMS, Bridge Management System, and Accident Record System data.

The AWP is typical of most maintenance management systems. This plan is developed on the basis of available budgets and prioritized pavement, bridge, and safety needs.

213 Program projects are programmed from deficiencies identified by the road survey. Maintenance overlays, seal coats, and shoulder upgrades are developed on the basis of the AWP.

Bituminous Treatment Strategies
Routine Maintenance
Crack Seal
Skin Patch
Manual Patch
Mechanized Patch
Base Repair
Joint Repair
Widen
Seal Coat
Level and Seal Coat
Mill, Level, and Seal Coat
Resurface
Level and Resurface
Mill, Level, and Resurface

Concrete Treatment Strategies
Routine Maintenance
Spot Joint Seal
Joint Seal
Joint Rehabilitation
Spall Repair
Joint Replace
Slab Stabilization
Slab Stabilization and Grind
Slab Replacement
Major Rehabilitation

FIGURE 4 Bituminous and concrete treatment strategies.

The PP is also developed using data from the road survey. Surface improvement projects and routine maintenance such as sealing cracks, replacing pipe, and grading shoulders are scheduled by route on the period plan.

The labor, equipment, and materials necessary to do the planned activities are added to the weekly plan screen in MORIS. Once the weekly plan is built, the daily payroll documents are printed from the weekly plan screen. MORIS preprints most of the information required on the daily payroll, including the names and social security numbers of the crew members, activities to be done, location of the work, and equipment unit identification. The foreman adds hours, production, and weather and work break information, and makes any necessary modifications. MORIS passes all cost accounting data to FMIS. Crew costs from the payroll and invoices from purchasing are also integrated with FMIS. Maintenance activities and costs are then passed to the Roadway and Bridge Management Systems for maintenance history records.

CONCLUSION

The integration of maintenance activities with other mainframe management systems in Pennsylvania is vital to the day-to-day operations of PennDOT. Many examples of system integration exist within PennDOT, and a few were summarized in this paper. System development and integration efforts continue to evolve at a rapid pace with the explosion of information technology and the ever-changing needs of the user community.

Highway Maintenance and Integrated Management Systems

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Maintenance management systems were among the first applications of rational management principles and the then-new technology of computers to highway operations. Recent changes in the composition and funding of highway programs, the organizational structures and missions of highway agencies, and federal legislation governing the development and use of management systems have focused increased attention on the design and use of such systems, as well as how to integrate maintenance management with other departmental management functions. The conceptual design of an idealized maintenance management system, the integration of this system with other management systems, and potential applications of new management capabilities and technology within these next-generation systems are described.

The development of maintenance management systems (MMSs) 25 years ago was followed by systems for pavements, bridges, equipment, materials, capital programming, contract administration, and other applications to help highway agencies do their job better. Each new system took advantage of new ideas and the ever-improving technology in computer hardware and software. Because of this evolutionary process, however, today's assortment of management systems in highway agencies is based on a range of hardware systems extending from large mainframe computers to personal computers and organized in various ways from centralized to decentralized management structures. As a result, the systems are often incompatible with one another, impeding the efficient and timely flow of information among them.

Recent changes in the composition and funding of highway programs, the organizational structures and missions of highway agencies, and federal legislation governing the development and use of management systems have focused increased attention on the design and use of such systems, as well as how to make them work better together. At the same time, highway departments are revisiting their MMSs to see how they can be updated to meet new demands for maintenance program management and to take advantage of new concepts, analytic procedures, and technologies that have benefited management systems in the past two decades.

This paper looks to the next generation of MMSs to determine how they must respond to the organizational, political, and technological trends that have emerged in recent years:

- The role of highway maintenance is evolving. There is growing demand for maintenance services, which are increasing in sophistication and are in limited supply.
- The growing use of computerized management systems in the past two decades will continue as the result of recent federal legislation. The concept of a coordinated and integrated approach to system development and use promises not only to eliminate duplication of effort but also to make better use of shared information and to coordinate decisions.
- Emerging technologies will enable improved data acquisition and locational-based processing, retrieval, and display of information in support of maintenance and other management information systems.
- A model maintenance management information system must respond to the different organizational and administrative needs that exist among departments of transportation (DOTs) across the country.

The current maintenance management systems were right for their time, helping in the planning, budgeting, monitoring, and evaluation of maintenance work and fostering standard methods and productivity guidelines. Many changes have occurred since these systems were first developed, however. In light of these changes, several improvements are needed in current systems.

At both the strategic planning and operational levels, the use of MMSs should be better integrated into other types of decision-making processes governing capital improvements and operations. More recent systems developed for pavements and bridges, for example, are based on life-cycle cost approaches and a longer analysis horizon than the 1- to 2-year outlook of most MMSs, and they include methods to identify the recommended levels of service to be provided by different activities.

Traditional MMSs adopted a highly centralized approach to maintenance planning, scheduling, and control, which is beneficial in some ways but has limited system effectiveness in many respects. For example, centralized, outmoded data processing and reporting methods are burdensome and time-consuming for field personnel and are unable to produce reports timely enough for effective management use.

Current MMSs are not flexible enough to adjust work plans and schedules to reflect changing conditions, nor does their design approach accommodate easily to variations in work load rates (or quantity standards) and performance standards to reflect variations across a state due to geography or the availability of labor, equipment, materials, or dollar resources.

Current systems "force fit" all activities into the same planning and analysis framework, ignoring the considerable variation in the types of activities encompassed by maintenance. Current systems also do not adequately consider the interaction among activities (precluding the analysis of trade-offs).

Recommended Advances in Maintenance Management

Three broad classes of improvements are recommended to help achieve an idealized MMS:

1. System components and features should be reformulated to overcome the problems identified above in current systems.
2. New types of analyses should be incorporated within maintenance management planning and budgeting, following the leads established by pavement management and bridge management systems.
3. Maintenance management should be integrated within the larger framework of management systems and functions within an agency.

Each of these recommendations is described in the sections below.

Updates of System Features and Components

Many of the system components and features that have formed the building blocks of maintenance management systems in the past will continue to be key elements in an idealized MMS, but the ways in which these features are defined and used should change. The following are examples of recommended changes:

- The list of maintenance activities should be reformulated to accommodate the needs of both high- and low-level maintenance management.
- Inventories of physical assets to be maintained should be accompanied by data on their condition and functional obsolescence. Inventories of nonphysical assets (e.g., grass to be mowed) should be accompanied by data on the level of service actually being achieved (e.g., current actual frequency of mowing).
- Resource requirements and estimated production rates should be defined more flexibly to reflect local conditions, actual availability of resources, and level-of-service standards.
- Distinct measures of levels of service, or quality standards, should be defined and incorporated within the planning and budgeting routines of MMS.
- Traditional MMSs produce work programs based on needs, regardless of budget availability. An important capability of an idealized MMS is to allow quick, realistic adjustments in work programs to meet budget constraints and shifts in priorities.
- Calendars showing the crew days needed each month to have a leveled work load should be extended to cover not only scheduled activities but also responses to emergencies, service requests, and other demand-driven requirements.
- An improved MMS needs the capability to adjust resource requirements on the basis of the degree of contracting expected to occur.
- Improved scheduling methods are needed to account for all factors affecting the assignment of resources to activities, including the work calendar, service requests, emergency and urgent work, leftovers from the previous scheduling period, and condition and distress surveys from the pavement and bridge management systems.
- Work reporting should involve a single source and instance of data entry to avoid duplication, wasted effort, and possible sources of inconsistency or error.
- Reports to various management levels should be more timely, present only the information needed, and allow reporting by sections of road in addition to current reporting by organizational unit or area.

New Analyses

The next-generation MMS should build on the experience gained through pavement management and bridge management systems over the past 15 years, to base planning and budgeting on a combination of engineering, economic, and management principles. The MMS should be able to analyze trade-offs between routine maintenance and capital activities (e.g., resurfacing, rehabilitation) and trade-offs in the levels of service to be provided in one or more activities, including the impacts of deferred maintenance. It should take into consideration both agency and user costs within a life-cycle cost framework. It should be able to perform needs analyses (assuming both unconstrained and constrained budgets), optimal resource allocation, and reduction of data and summarization for management purposes.

These types of analysis can be performed within a framework referred to as a "demand-responsive" approach to maintenance management. This approach, similar to that used in pavement and bridge management systems, views maintenance activities as a response to the demand for maintenance work—in other words, the deterioration of the highway system, or changes in its condition. Furthermore, this approach builds on an economic framework rooted in life-cycle cost estimation and a prediction of both the impacts (or consequences) of maintenance and its costs. Also, variations in the levels of service (or quality standards) by maintenance activity serve as expressions of maintenance policy, with the goal of identifying the particular levels of service among all activities that provide the optimal balance between the costs and the consequences of the maintenance program.

Integrated Systems Concepts

For most agencies, the next generation of MMSs will feature a higher level of integration among maintenance functions, and between maintenance systems and other systems, than now exist. Indeed, several of the analytic advances proposed in the preceding section entail information from other sources besides maintenance. Almost certainly, the next generation of systems will feature better, more appropriate integration than is typical today, taking advantage of newer technology in information processing, communication, and display, and a clearer understanding of the role that maintenance and integration play in the overall management of a transportation agency.

The particular approach recommended to achieve integration among maintenance and other systems, the integrated system concept that can be applied at different levels of the maintenance organization, is shown in Figure 1. The approach used is referred to as a hub-and-spoke concept. All data and analytic capabilities needed on a shared basis by a particular organizational unit (or level of management) are located in the hub for that unit or level. Information from other hubs is communicated when it is needed. Application packages or data needed by specific units are located either at the satellite hubs for that unit (if they are to be shared by several users) or at the terminals along the spokes of the particular users responsible for those analyses and data. Thus, the hub handles only the minimum amount of data necessary to serve its satellite hubs and terminals. Most important, the hub software does not have human "users" per se; its users are the analytic programs, data reporting tools, and data entry routines that exist at the terminals or the satellite hubs at the ends of the spokes.

The hub itself is not just a computer, however. It is an organizational unit with a complete set of duties related to its prime objective of facilitating data sharing. These duties include, for example, the following:

- Building, maintaining, and updating the corporate data base;
- Establishing and maintaining the necessary telecommunications links among hubs and spokes;
- Exercising quality control, monitoring consistency, and enforcing needed precision on all data submitted to the corporate data base;
- Providing and maintaining common-use software and utilities;
- Working with various groups within the agency to build consensus and set standards for data coding, timeliness of data submission, handling of missing values, required data precision and accuracy, locational and temporal reference systems, and so forth;
- Ensuring compatibility among future enhancements to hardware, software, and the central, satellite, and terminal data bases; and
- Providing needed support services.

A key advantage of the hub-and-spoke concept is its flexibility and adaptability: it is not based on any assumptions of current system configuration or future plans. The hub-and-spoke approach may be implemented within a mainframe, minicomputer, or microcomputer environment, including situations with different mixes of these types of hardware. Similarly, the hub support group alluded to above should not be confused with a centralized MIS or ADP group such as those existing in state agencies today. The hub support group is a provider of services, not a centralized computer agency; in fact, its staff may not even come from the MIS or ADP organization. A hub support group that provides quick, effective, forward-looking responses to systems users is critical to the success of the integrated system concept.

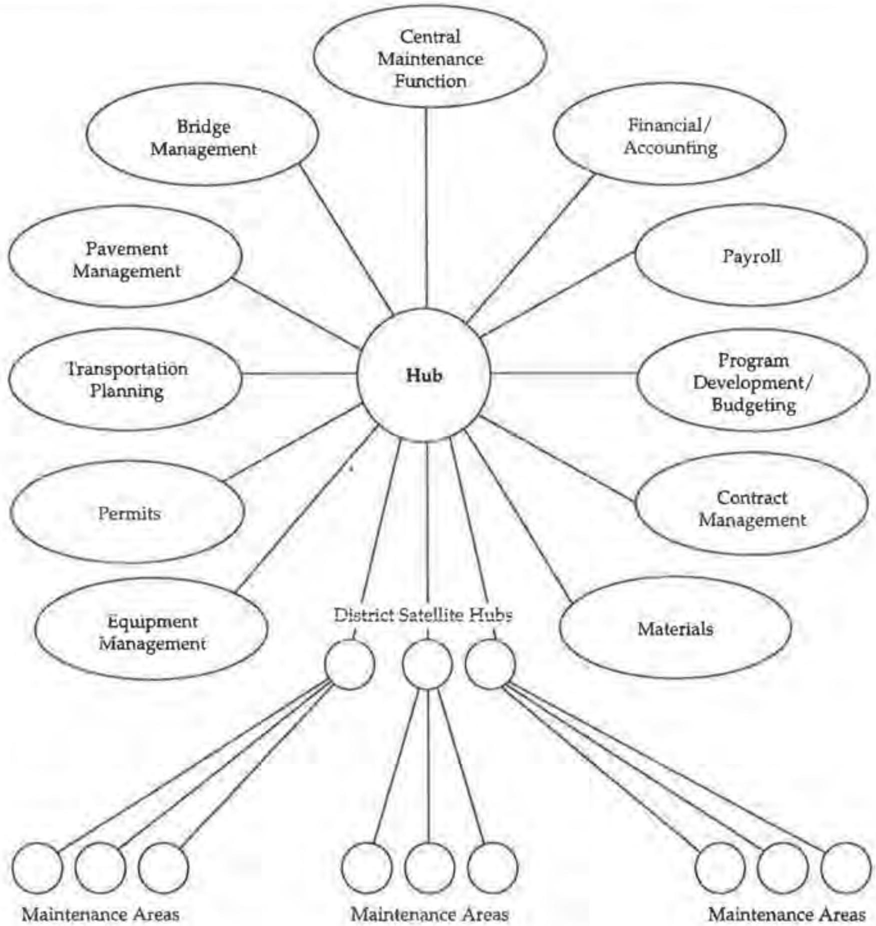

FIGURE 1 MMS concept: hub-and-spoke approach.

New Technology

Several types of new technology that could assist in gathering, processing, and display of information for an integrated MMS are now commercially available. In addition to advances in computer hardware and software, examples of this technology include the following: geographic information systems (GIS); global positioning systems (GPS); technology for highway inventory and inspection (e.g., video and photo logs, nondestructive testing or monitoring of pavements and bridges); and technology for work scheduling, reporting, and inventory management (e.g., palm-size and notebook computers, hand-held portable data entry terminals, barcode scanners, electronic clipboards, and voice recognition systems).

Technology enables an agency to perform tasks more economically or more effectively and at higher quality. Where new technology can play a role in the idealized MMS, the recommendations of this study have indicated how an agency may best take advantage of these advances. However, the choice of new technologies and how they are to be used is left to the discretion of individual agencies. The recommendations for an integrated system do not depend on any specific technological approach.

Example System Structure

The conceptual design of a maintenance management system meeting the criteria in the preceding sections is shown in Figure 2. Key facets of the system in terms of analytic components, operational elements, and interactions with other systems are as follows:

- The central data base contains inventory data on pavements, bridges, and other maintainable features as well as data that come from other management systems and data bases (e.g., traffic, congestion, safety, equipment, materials accounting).
- The inventory is tied to a locational reference system based on elapsed distance from reference markers and with a further tie (highly desirable but not necessary) to a GIS/network map.

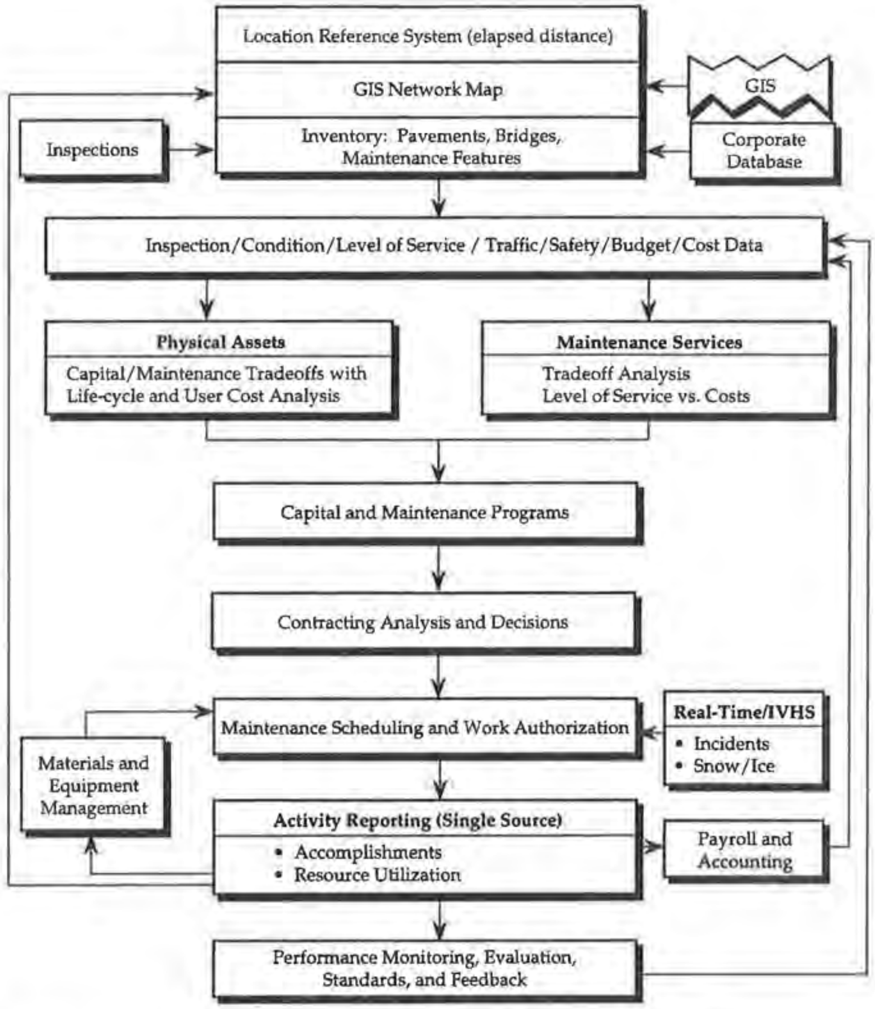

FIGURE 2 Example of an integrated management system approach.

- Life-cycle and user cost analyses are used to make capital and maintenance trade-offs.
- Other analytical procedures assess trade-offs between level of service and costs for other maintenance activities.
- Capital budget development is coordinated with the maintenance plan and program. The maintenance plan is based partly on maintenance methods and standards (crew sizes, equipment types, materials needed, quantity standards, quality standards), but also includes activity levels, level of service to users (benefits), resources and budgets, and costs.
- Short-run schedules are derived from the maintenance plan with response-based inputs including real-time data on traffic incidents and snow and ice conditions. Ingredients include annual work program; daily patrols; service requests; urgent and emergency needs; leftover work from previous schedule period; and condition survey data from bridge management system, pavement management system, and so forth.
- Resource utilization is reported to appropriate management systems, such as materials inventory, equipment, and finance/accounting/payroll.
- There is performance evaluation and feedback.

This figure provides an important example, but by no means the only example, of how an integrated maintenance management system may be configured. The descriptions above are necessarily brief; additional information is contained in a recently published National Cooperative Highway Research Program report on this study (*1*).

Agencies implementing an integrated maintenance management information system have a broad array of choices about the functions and organizational levels to be included. A common and effective implementation strategy is to begin with a core system that can stand alone and then expand by adding new modules to bring in new users and build bridges to new outside systems. Generally, the data-sharing hub, such as a corporate data base, is the first to be implemented, and it is connected with a few existing systems, including the existing MMS, to begin operation and prove its value. A total organizational commitment is necessary to make this a success, so the involvement of top management is essential. In many states, the management systems required under the Intermodal Surface Transportation Efficiency Act (ISTEA), which also benefit greatly from data sharing, have been a driving force in the establishment of a data-sharing unit. Similar activities are occurring extensively in the private sector, making data-sharing architectures a hot issue among data-processing professionals. A sensible expansion path for a new MMS may be as follows:

1. Concurrently with the hub, the development or adaptation of maintenance-related systems that depend on the hub can begin: maintenance control and reporting, work order generation and tracking, monitoring, and planning.
2. Migration of the system through organizational levels also happens simultaneously through the establishment of appropriate data transfer, summarization, and allocation procedures between crews and depots, depots and districts, districts and headquarters, and headquarters maintenance management and upper management.
3. Integration can continue for closely related functions: equipment management, materials management, cost tracking, payroll, and contract management.
4. Integration can continue for the ISTEA management systems: pavement management systems, bridge management systems, safety management systems, intermodal facility management systems, congestion management systems, and transit facility management systems.
5. These uses also provide a natural extension to planning and development functions: programming and budgeting, transportation planning, and permitting.

Figure 3 shows the potential of a broad-based integration of systems, based on a hub-spoke or client-server architecture.

Implementation of Concepts

The concepts described in this paper are now being implemented in a project for the Nevada Department of Transportation (NDOT). Nevada's current maintenance management system was installed over 20 years ago, based on the prevalent design concept of the day: an independent system with associated data files, using batch processing on a centralized mainframe. An assessment of user needs of both headquarters and field staff identified several system deficiencies and desires for new maintenance management capabilities. At the same time, a major shift is now occurring in the department's management practices and computer resources toward the following: networks of personal computers in a client-server environment; more streamlined administrative procedures (e.g., consolidated input of labor time sheet data and data on equipment and material use for maintenance); integration of highway data within a system of corporate data bases to serve a number of highway management systems, including those for pavements, bridges, safety, fence and guardrail, signs, and road maintenance; integration of the maintenance management system with other systems serving highway management functions; and implementation of GIS for highway planning.

A new maintenance management system has been proposed for Nevada, embodying the concepts shown in Figures 1 through 3. The conceptual design responds to a number of aspects of the DOT's current redefinition of its management system tools and, more broadly, its system environment. For example, the design addresses explicitly the implementation of the department's client-server architecture built around local-area and wide-area personal computer networks served by a minicomputer hosting the integrated highway data base. The design builds on this architecture in the manner suggested in Figure 3 and recommends direct linkages among headquarters and field staffs, extending from the DOT director to the crew level, to serve various management functions (e.g., budgeting, work load balancing, resource allocation, and work reporting and monitoring). Recommendations have also been made to the department in the following areas:

- Integration of maintenance management with other systems now being developed to meet the management system mandates of ISTEA, plus other systems (e.g., sign inventory, fence and guardrail, finance and payroll, equipment management, and materials and stockpile management);
- Highway maintenance applications of the department's GIS in conjunction with location referencing using its GPS;
- Consolidation of field data input within a "single-source" scheme allowing greater electronic processing of source information on labor, equipment, and materials use (with direct read-write ties to the accounting system); and
- An implementation plan illustrating different migration paths for staged development and related costs and benefits.

Acknowledgments

The work reported herein was performed under National Cooperative Highway Research Project 14-9(4). Bill Dear-

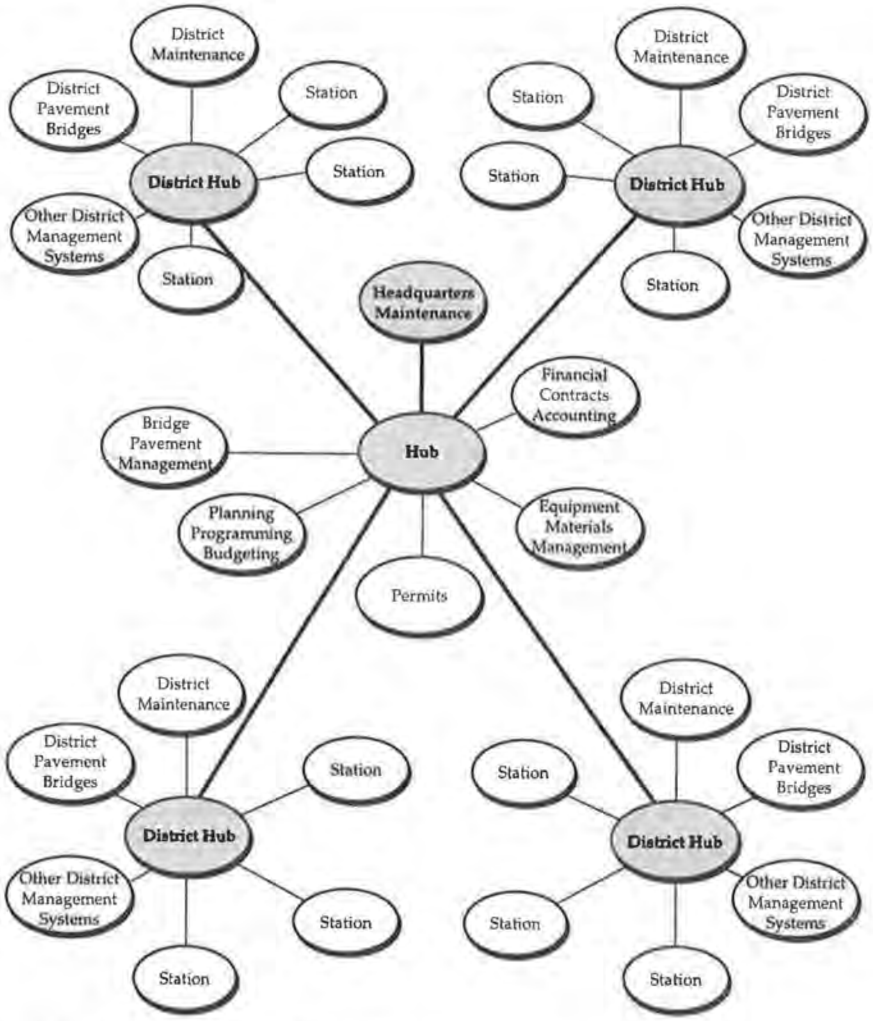

FIGURE 3 Application of hub-and-spoke and systems integration concepts within an organization.

asaugh and Amir Hanna served as Senior NCHRP Program Officers on this project. Assisting on this project from Cambridge Systematics were Frances Harrison, Paul Thompson, and Elizabeth Harper. Roemer Alfelor of the Urban Institute, William Mortenson of Bergstralh-Shaw-Newman, Inc., and Timothy Alexander of Space Development Services provided technical expertise in maintenance management history and practices, DOT and maintenance organizational issues, and potential applications of GPS technology.

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Strategies for Managing Public Expenditures for Road Maintenance

Frannie Humplick and Asif Faiz, *The World Bank*

Public disbursements for highways include investments in network and capacity expansion and expenditures on current operations and maintenance. A number of factors contribute toward complicating the process of managing public expenditures: (*a*) a multiplicity of budget-making bodies, (*b*) the propensity to favor new construction, (*c*) disparate treatment of activities relating to new construction and maintenance, and (*d*) divergence in analytical approaches for cost estimation. The result is a profusion of budgeting techniques, including line-item, lump-sum, and program or performance budgets. Alternative approaches to predicting life-cycle expenditures for highways are examined to derive a unifying methodology for sound management of public expenditures. Aggregate techniques, such as indices of absolute or relative expenditures, are contrasted with disaggregate procedures using detailed predictions of maintenance work volumes and activity costs. The advantages and disadvantages of each method vis-à-vis a budgeting process are also presented. Of special concern is the treatment by each technique of the following: (*a*) variation in unit costs, (*b*) modalities of highway failure and their maintenance consequences (catastrophic, monotonic degradation, nonmonotonic drift), (*c*) configuration of highway network characteristics (age and use levels), and (*d*) trigger mechanisms for maintenance (user costs, capacity and structural constraints, asset depreciation, employment generation, economic productivity). The methodology is applied to the evaluation of a typical country's budget for road maintenance.

Public expenditures on highways include investments in network and capacity expansion, reconstruction, rehabilitation, and upgrading of existing highways, as well as expenditures for current operations and maintenance. A number of factors complicate the process of managing public expenditures.

First, there are many budget-making bodies: (*a*) central units within ministries of transport that may be in charge of programming the expenditures for the trunk or primary network; (*b*) state and local government agencies that may have operational responsibility for state and local roads (secondary and tertiary network); (*c*) ministries of planning, economy, and finance with an overall responsibility for planning and prioritizing public investments; and (*d*) ministries of agriculture or tourism with responsibilities for maintaining part of the network such as rural and special (historic or scenic) roads. The budget-making process involves intensive interagency interaction and coordination. The complexity of these interactions is mainly due to an unclear alignment of functions and responsibilities, as well as nonintegrated policies.

Second, the various bodies involved in planning and budgeting for highways may treat similar investments disparately. For example, a budget-making unit within a ministry of economy and finance may assume a different planning horizon, unit costs, and standards of construction from that used by a programming unit within a ministry of transport for the same type of construction. Such practices may lead to different estimated allocations within a budgeting year.

Third, planning units that are politically appointed may tend to favor new construction, since such investments are more clearly linked to voting outcomes than are maintenance or small-scale improvements. Such biases may lead to unbalanced investment profiles, with larger allocations to new construction as opposed to maintenance, encouraging a cycle of new construction–deferred maintenance–reconstruction.

Finally, each budget-making body may use different analytical approaches for cost estimation, leading to large variations in estimated budgets. Budgeting for new construction involves projecting lumpy, discrete, and quantifiable expenditures at specific locations. Deviations in budget estimates for this type of project derive mainly from unit cost variation as a consequence of assumptions for standards and methods of construction. Maintenance and operation expenditures, on the other hand, are recurrent, incremental, and difficult to quantify. Differences in budget estimates for these projects are mainly due to the spatially diverse nature of maintenance activities, the wide span of management control, and disparities in delegation of authority for maintenance between centralized and decentralized units, as well as contract and force account (in-house) work.

As a result, a profusion of budgeting techniques exists for public infrastructure expenditure, including line-item, lump-sum, and program or performance budgets.

This paper examines alternative approaches for predicting life-cycle expenditures for highways and suggests a unifying methodology for sound management of public expenditures. Aggregate techniques such as indices of absolute or relative expenditures are contrasted to disaggregate procedures using detailed predictions of maintenance work volumes and activity costs. The advantages and disadvantages of each method vis-à-vis the budgeting process are also presented. Of special concern is the treatment by each technique of the following: (*a*) variations in unit costs, (*b*) modalities of highway failure and their maintenance consequences (catastrophic, monotonic degradation, nonmonotonic drift), (*c*) configuration of highway network characteristics (age and use levels); and (*d*) trigger mechanisms for maintenance (user costs, capacity and structural constraints, asset depreciation, employment generation, economic productivity). The methodology is applied to the evaluation of a typical country budget for road investments.

TYPES OF HIGHWAY BUDGETS

The main purpose of a budget is to provide a meaningful and operational framework for accountability, while allowing for sufficient flexibility in the application of allocated funds.The budget serves as a contract between the road agency and the government, with the road agency committed to producing a quota of work outputs for the financial resources it receives from the government. The government is responsible for making the necessary financial allocations in a timely fashion. A good budget clearly spells out the obligations and responsibilities of each party, so that a clear basis exists for auditing and assessing budget performance and for evaluating the effectiveness of public expenditures against desired economic and social outcomes. There are three types of highway budgets in common use: line-item, lump-sum, and performance-based (see Table 1 for examples). In addition, zero-based budgeting (ZBB) has been used as a tool for budget justification. For a detailed discussion of alternative budgeting practices for highways see Faiz (*1*), Kelley (*2*), and Premchand (*3*).

Line-Item Budgets

A line-item budget determines expenditure allocations in money terms rather than on the work to be accomplished. The budget lists amounts under proposed expenditure categories such as personnel services, contractual services, commodities, and other charges (see Table 1). In a line-item budget, funds are used on the basis of individual judgment rather than work objectives or comparative levels of service. This type of budget offers some advantages, such as the ease of preparation and simple projection from historic expenditure patterns. It is also easy to administer since the budget items are the same as the expense items incurred during budget execution. However, a line-item budget is highly restrictive and offers little flexibility in changing allocations across itemized categories. For example, transferring funds from materials to personnel is not allowed, even if there is an excess of funds for materials and a shortage for personnel.

Line-item budgets are suitable for relatively stable situations with no changes in personnel, technology, or materials needs, and where historical patterns are relatively representative of expected patterns of expenditure. As a result, they may be suitable for new construction projects in areas with little topographical or geological variation, where work is carried out by force account. They are not suitable for most maintenance and emergency projects, due to their spatial and temporal variability and associated expenditures.

Lump-Sum Budgets

In lump-sum budgeting procedures, a single-line item represents all the expected expenditures for a particular agency (see Table 1). Such a budget offers the greatest flexibility for allocating across highway construction, reconstruction, rehabilitation, and maintenance activities; across particular road links; and across expenditure categories such as personnel and materials. However, the budget preparation must be based on a sound physical program, and performance must be closely scrutinized to ensure accountability. Such budgeting procedures are most suitably used where there is an advanced maintenance programming and evaluating capability and good capability for estimating costs and work requirements.

TABLE 1 Types of Road Budgets

PERFORMANCE BUDGET

Fiscal Year: 1982 | Department: HIGHWAYS | Activity: ROAD MAINTENANCE

No.	ACTIVITY Description		WORK AND COST In-House	Contract	Total
1101	Spot Premix Patching	Work	8,050.00	0	8,050.00
	Units: Sq. Feet	Cost	33,407.50	0	33,407.50
1103	Recycle Asphalt Pitch	Work	2,010.00	500.00	2,510.00
	Units: Sq. Feet	Cost	10,271.10	2,485.00	12,756.10
1100	**Roadway Maintenance**	**Cost**	**43,678.60**	**2,485.00**	**46,163.60**
3201	Roadway Mowing	Work	873.00	315.00	1,188.00
	Units: Swath Mi	Cost	3,622.95	1,332.45	4,955.40
3204	Litter Pickup	Work	375.00	0	375.00
	Units: Man Hrs.	Cost	5,632.50	0	5,632.50
3200	**Roadside Services**	**Cost**	**9,255.45**	**1,332.45**	**10,587.90**
Activities (1100 + 3200)			52,934.05	3,817.45	56,751.50
Other Activities + Administrative Overhead			35,683.32	2,573.09	38,256.41
Total			88,617.37	6,390.54	95,007.91

LINE-ITEM BUDGET

Fund: GENERAL | Department: HIGHWAYS | Activity: ROAD MAINTENANCE

CLASSIFICATION	ACTUAL 1982	BUDGET 1983	BUDGET 1984
Personal Services	65,429.18	83,198.00	87,927.00
Contractual Services	6,312.18	7,000.00	7,500.00
Commodities	4,450.02	3,540.00	4,450.00
Other Charges	19,946.15	22,000.00	26,500.00
Gross Expenditures	96,137.53	115,738.00	126,377.00
Reduction of Costs	1,129.62	2,500.00	2,500.00
Net Expenditures	95,007.91	113,238.00	123,877.00

LUMP-SUM BUDGET

Fiscal Year: 1982 | Department: HIGHWAYS | Activity: ROAD MAINTENANCE

CLASSIFICATION	ACTUAL 1982	BUDGET 1983	BUDGET 1984
Net Expenditures	83,113.23	102,240.00	112,843.00

Program or Performance Budgets

Program or performance budgets are relatively recent, appearing after the development of maintenance management systems and cost accounting procedures around 20 years ago. Such budgets are based on detailed activity, work, and cost estimates (see Table 1). Achievement targets are specified for levels of service, and the method of execution—whether by force account or contract—is indicated. This type of budget indicates both what is to be accomplished (in units of work such as man-hours of litter pickup or square feet of roadway patched) and what it will cost. Whereas the expenditures may not exceed the allocations for specific activities, the performance or program budget allows for considerable flexibility in the use of component resources (labor, equipment, material), which are not appropriated by each object of expenditure as in the line-item budget. The performance-based budget offers the best balance between accountability and flexibility principles underlying highway expenditure budgeting.

PREDICTING LIFE-CYCLE EXPENDITURES

Aggregate Approaches

Aggregate approaches for predicting life-cycle costs are used in conjunction with lump-sum budgeting procedures. They have the advantage of flexibility of use and are usually based on an index or ratio at the beginning of the analysis period, which is updated at each period. Such an index may be derived from a function relating the average cost of an activity like maintenance to indicators of the need for maintenance, such as the time since the last major rehabilitation and the level of deterioration. Alternatively, projecting a ratio of the relative expenditure categories (ratio of maintenance to capital expenditures) over time may be useful as an aggregate measure of need if the techniques for projecting one type of expenditure (e.g., new construction) are well specified. The major disadvantage of such budget estimation techniques is the inability to incorporate different types of activities, varying effectiveness of activities, and other factors affecting the efficacy of planned activities.

Absolute Expenditures

Absolute indices for predicting future expenditures are generally log-linear functions of the following form:

$$\ln(C_m) = aX + b\ln(U) \quad (1)$$

where

C_m = average cost of an activity such as maintenance (dollars/km),
X = indicator of the need for the activity such as the time since the last major rehabilitation (years),
U = indicator of the scale of an activity such as the level of deterioration on a highway due to accumulated use, and
a, b = estimated coefficients.

An example of an aggregate road maintenance cost prediction model is given by Sharaf and Sinha (*4*), where the total routine maintenance cost per year per lane mile is predicted as a function of the age of the pavement since the last rehabilitation and the accumulated traffic is measured in equivalent axle loads.

Relative Expenditures

Relative expenditure prediction methodologies are useful when there is a good basis to relate a particular category of costs, such as capital and maintenance expenditures. Generally, coefficients of the expected balance between categories of investments are calculated and used to project the necessary allocations between categories. Heller (*5*) suggested such a measure for detecting the degree of underfinancing of recurrent development costs for a variety of road investments. The functional form used for relative expenditure models is

$$E[C_m/C_c] = \text{coeff} \quad (2)$$

where

C_m = annual maintenance expenditure (dollars/km),
C_c = total capital expenditure (rehabilitation, reconstruction, new construction) (dollars/km), and
coeff = expected value of the relative balance between investment categories.

The table that follows (*5*) gives an example of estimated coefficients for feeder roads and paved roads. This table demonstrates the high variability in such coefficients, especially for feeder roads, where the design and maintenance standards are disparate:

Road Standard	*r Coefficient*
Feeder roads	0.06–0.14
Paved roads	0.03–0.07

Limitations of Aggregate Approaches

Aggregate approaches are useful for managing highway expenditures at the network level. These approaches implicitly assume that estimated coefficients are stable over time. This assumption is difficult to justify for most highway systems, for a number of reasons. First, they are insensitive to variations in unit costs and the rhythm of highway system failure. In addition, they are not easy to adjust to multiple criteria for undertaking activities, and are useful when there is a stable set of well-established policies for maintenance and rehabilitation. These factors will be discussed in more detail later.

Disaggregate Approaches

Disaggregate approaches require detailed models for predicting work volumes and costs of activities. These are of two general types: (*a*) models predicting the volumes of work to be done, measured in production units (lane miles of joints sealed, linear feet of cracks sealed, number of potholes patched), total manhours required, and types and quantities of materials (tons of patching mix); and (*b*) cost prediction models that estimate the cost of a particular activity such as crack-sealing by the kilometer or mile. The two approaches differ significantly in the type of data required for projecting highway expenditures.

Work Volume Predictions

Several models have been used extensively to project the work volumes required to carry out life-cycle expenditure analysis for highways: (*a*) a study by the Federal Highway Administration to predict damage and performance of pavement systems that have received a wide variety of alternative maintenance and rehabilitation actions (*6*); (*b*) a simulation model called EAROMAR-2 for predicting highway performance, maintenance, and rehabilitation costs (*7*); (*c*) a pavement management system developed by the U.S. Army Corps of Engineers (*8*); (*d*) a highway design and maintenance model developed by the World Bank (*9*); and (*e*) the Transportation Research Laboratory (TRL) Overseas Unit Model RTIM (*10*).

Such models require a variety of data types:

1. Route characteristics such as geometry, capacity, and administrative sections;
2. Pavement characteristics such as strength, layer thickness, age, traffic loadings, quality of construction, and type of materials for the pavement layers;
3. Pavement history including the time since the last rehabilitation and pavement age since construction;
4. Pavement condition including the extent and severity of cracking, rutting, potholes, and roughness, as well as factors retarding distress, such as preventive maintenance actions;
5. Maintenance policies, including local work scheduling practices, and unit costs of maintenance labor, equipment, and materials;
6. Planned activities such as routine maintenance, preventive treatments, rehabilitation measures such as resealing and overlay, and reconstruction;
7. Environmental and climatic variables such as landslide frequencies, precipitation levels, and freeze and thaw cycles;
8. User consequences such as vehicle operating costs, travel time, accident costs, and pollution emissions; and
9. Economic data such as discount rates, differential inflation, and costs of safety.

Such models can be represented by the following system of equations:

$$S(t+1) = S(t)\, f(C_r, C_m, U)$$

$$\Psi(t) = g[S(t), C_r\,(j, t), C_m\,(i, t)]$$

$$C_r\,(j, t) = a + bS(t)$$

$$\log[C_m(i, t)] = \alpha + \beta \log[S(t)]$$

$$\$(t) = \gamma_j\, C_r(j, t) + \mu_i\, C_m(i, t) \qquad (3)$$

where

S = condition of a predefined pavement segment;
f = deterioration function relating the condition of the pavement to the utilization, maintenance, and rehabilitation activities performed;
t = analysis year;
U = measure of utilization of the pavement such as accumulated vehicle loads or age;
$\Psi(t)$ = a selected set of maintenance and rehabilitation activities to address the pavement condition problems observed at the time period t;
g = function mapping the observed condition to a set of maintenance and rehabilitation activities (usually based on the maintenance policies followed);
$C_m(i, t)$ = annual maintenance cost (dollars per lane-km) for a package of maintenance actions i at time t;
$C_r\,(j, t)$ = rehabilitation cost (dollars per lane-km) for activity j at time t;
a, b, α, β = estimated coefficients;
$\$(t)$ = estimated highway expenditure for the year t; and
γ_j, μ_i = unit costs of the selected rehabilitation and maintenance activities, respectively.

The first equation is a condition-prediction model as a function of the utilization and efficacy of maintenance and rehabilitation activities. Condition is defined either in index form, such as the pavement serviceability index (PSI) or the pavement condition index (PCI), or is a physical measure of deterioration such as percentage cracking or pavement roughness level.

The second equation represents a mapping process whereby activities are selected to address the current condition $S(t)$ in order to obtain the desired condition $S(t + 1)$. Maintenance and rehabilitation activities are classified according to frequency (annual, periodic, or infrequent) and expected impact (no change in surface condition, change in surface condition, change in life of pavement, change in pavement strength, change in all parameters).

The effect of such activities on the condition of pavements is generally captured as (*a*) a discrete correction of a fixed amount of damage (square meters of cracks patched per km) represented by the coefficients in the third and fourth equations a and α; and (*b*) a continuous measure of retardation of future deterioration or improvement in condition as measured by the coefficients in the third and fourth equation b and β. The log transformation for the maintenance cost function is used here because it has been demonstrated by past studies to be the best available model specification. Humplick (*11*) summarizes best practices in highway maintenance expenditure cost modeling, and Sharaf and Sinha (*4*) apply such a model for road maintenance expenditures in Indiana.

The last equation is the major input into budgeting processes because it represents the estimated expenditures for a selected set of maintenance and rehabilitation activities.

Cost Per Activity

Other models in use are based on predicting the cost of a given set of activities. Examples include the Ontario Pavements Analysis of Costs (OPAC) and the Program and Financial Planning in Pavement Rehabilitation (PARS), both developed for Ontario. The OPAC model (*12*) uses the concept of repeatability of expenditures and performance cycles to estimate future expenditures as a function of rehabilitation activities such as overlay. This model estimates the expected life of a rehabilitation investment in years, where the rehabilitation activity is measured by the thickness of overlay. The expected cost of the investment is consequently estimated from a preestimated function (the second function in Equation 4). The approach is summarized as follows:

$$T = \alpha q_r^{\beta}$$

$$\$ = C_m + C_r * q_r \qquad (4)$$

where

T = life-cycle length (the life of the proposed rehabilitation) (years);
q_r = the unit quantity of the rehabilitation work, such as the thickness of overlay (cm or in.);
α, β = estimated coefficients;
C_m = constant cost of maintenance per km;
C_r = variable cost of rehabilitation per km and unit work volume; and
\$ = estimated expenditure.

The PARS model (*13*) is similar to the OPAC model. This model predicts pavement performance as a function of utilization variables (age, traffic) and quantities of rehabilitation work planned (thickness of overlay). This is represented by the first of the following equations. The expected cost of the works is estimated from the second of the following equations.

$$S = S_{\max} - \kappa U^a q_r$$

$$\$ = C_m + C_r * q_r^{-b} \qquad (5)$$

where

S = the performance condition (PCR or PCI),
$S_{\max}$ = maximum pavement performance level that can be achieved (e.g., 100),
κ = estimated coefficient,
U = measure of utilization (age and traffic),
q_r = thickness of overlay, and
a, b = estimated constants.

The advantages of these types of models is the ability to predict the total cost of an activity such as rehabilitation, its impact on the pavement, and its expected life. It can therefore be used as an input to the performance budget mentioned previously.

Factors Affecting Maintenance Costs

The predictions that can be made by the various methodologies are subject to a number of factors that render them uncertain. Among these are (*a*) variations in unit costs, (*b*) modalities of highway failure, (*c*) configuration of highway network characteristics, and (*d*) trigger mechanisms for maintenance.

Variations in Unit Costs

Highway expenditures as described so far comprise construction, reconstruction, rehabilitation, and maintenance costs, over the planning and budgeting horizon. These expenditures are included in the budgeting process as unit

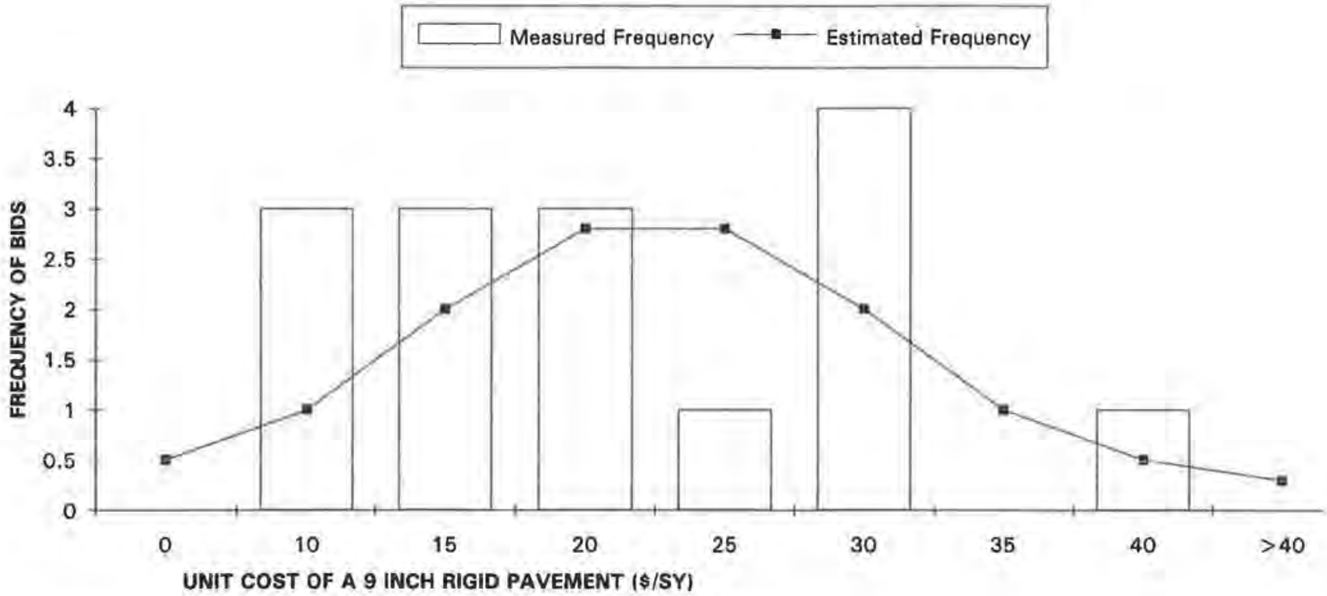

FIGURE 1 Variation in unit costs for a single pavement design (*11*).

costs per unit of work done or as annual expenditures. The common practice in budget preparation is to derive a single estimate of unit cost for a particular activity, as described earlier, which is then used as a parameter in the cost estimation. Estimates of unit costs are extracted from engineers' previous estimates, highway bids, or publications of current unit prices. A number of factors introduce uncertainty in the cost estimates, such as design and construction practices, traffic levels, weather and geography, maintenance policies and technologies, and bidding procedures. An analysis of the variation of unit costs for rehabilitation of rigid and flexible pavements (see Figures 1 and 2 respectively) indicates the wide differences that can be expected in highway expenditures. Figure 1 shows the variation in the unit cost for a single pavement design (a 9-in. rigid pavement), and Figure 2 shows the variation as a function of different designs (thickness).

For example, there is a high variability in the types of work required at a given time, ranging from spot maintenance to minor rehabilitation, making the maintenance budget difficult to estimate. The ratio of maintenance to capital expenditures would be affected by such variation, reducing the utility of the aggregate budget projection procedures previously described.

Modalities of Highway Failure

Many of the models described in this paper require a mechanism for triggering an activity such as maintenance or rehabilitation. Highway infrastructure may suffer three different types of failure: (*a*) catastrophic failure, such as when a bridge collapses; (*b*) monotonic deterioration, such as when pavement surfaces crack; and (*c*) nonmonotonic failure, such as when a highway is periodically congested. Figure 3 gives a summary of these types of failures along with analogies to failures in other infrastructure systems. The corresponding expenditure responses to the failure modalities in Figure 3 are shown in Figure 4. Catastrophic failures are addressed by lump-sum and discrete expenditure to address the particular condition once and for all. Monotonic failures require continuous outlays of expenditures on a period-by-period basis, such as an annual budget for carrying out routine and preventive work. Nonmonotonic failures fluctuate with levels of demand (such as the congestion example) or with climate (such as flooding, rock slides, and icy roads, which are cyclically dependent on the weather). All these factors affect the accuracy of budgeting procedures and must be accommodated.

Configuration of Highway Network Characteristics

Highway networks are typically made up of a collection of roads with varying age profiles, design and construction methodology, and use patterns. As a result, there are numerous combinations of systematic and random patterns of failure for a given network. Systematic failures are due to the rhythm of building whereby a typical highway will last around 20 to 40 years with the proper design and maintenance. Random failures result from variations in construction quality, spatial variations in roadway strength, climatic and other factors, as well as actual main-

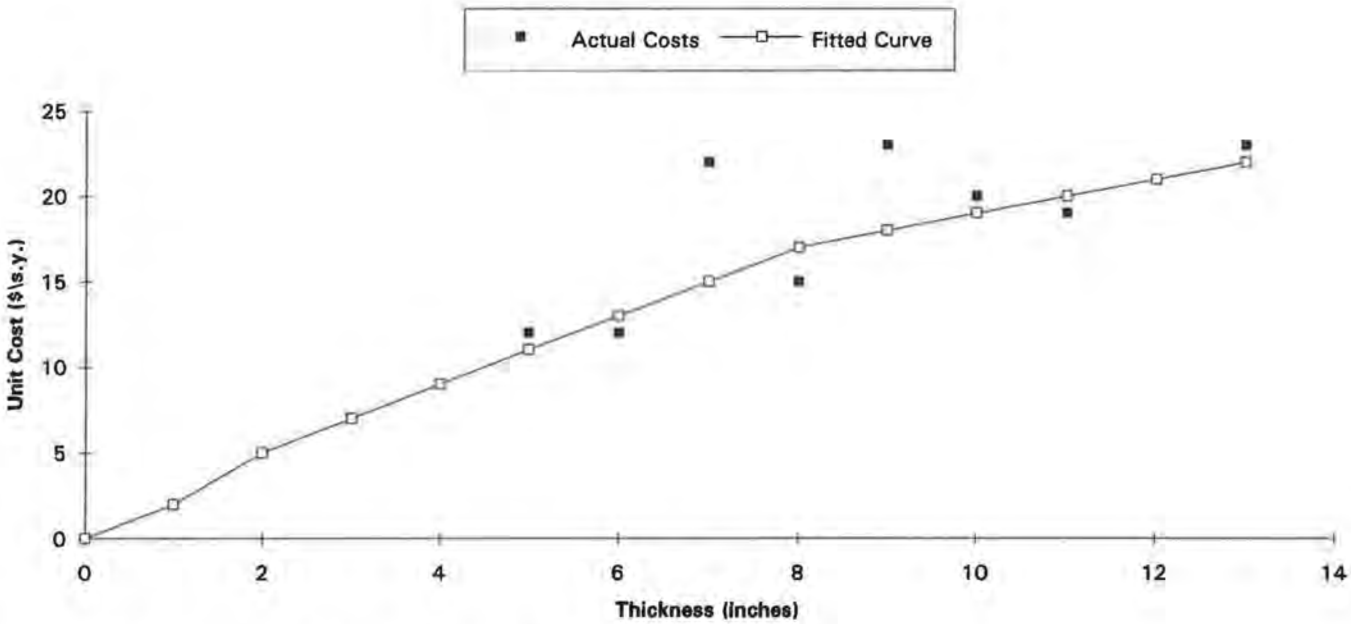

FIGURE 2 Variation in unit costs as a function of different designs (*11*).

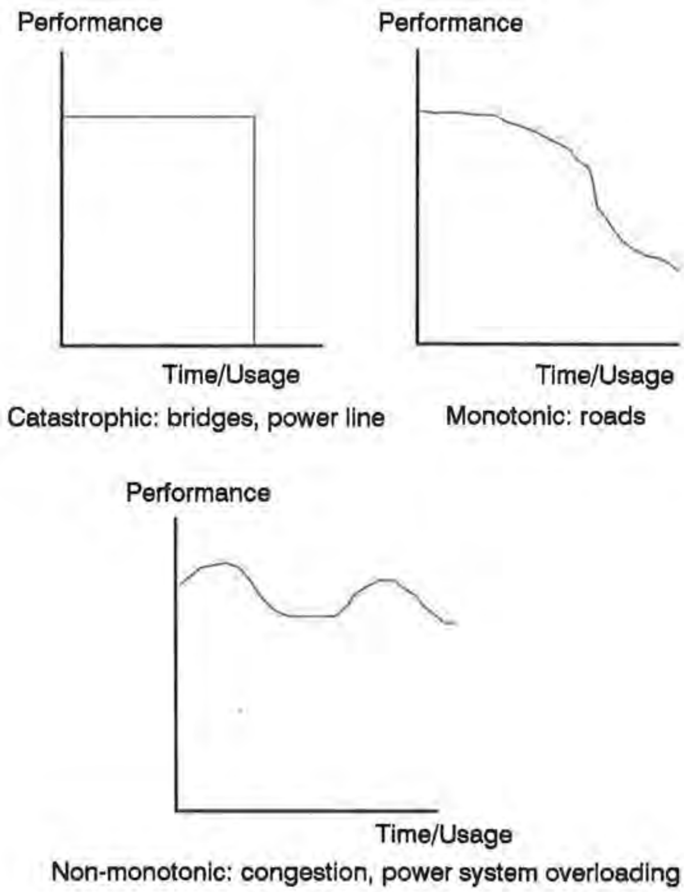

FIGURE 3 Characteristics of infrastructure failures.

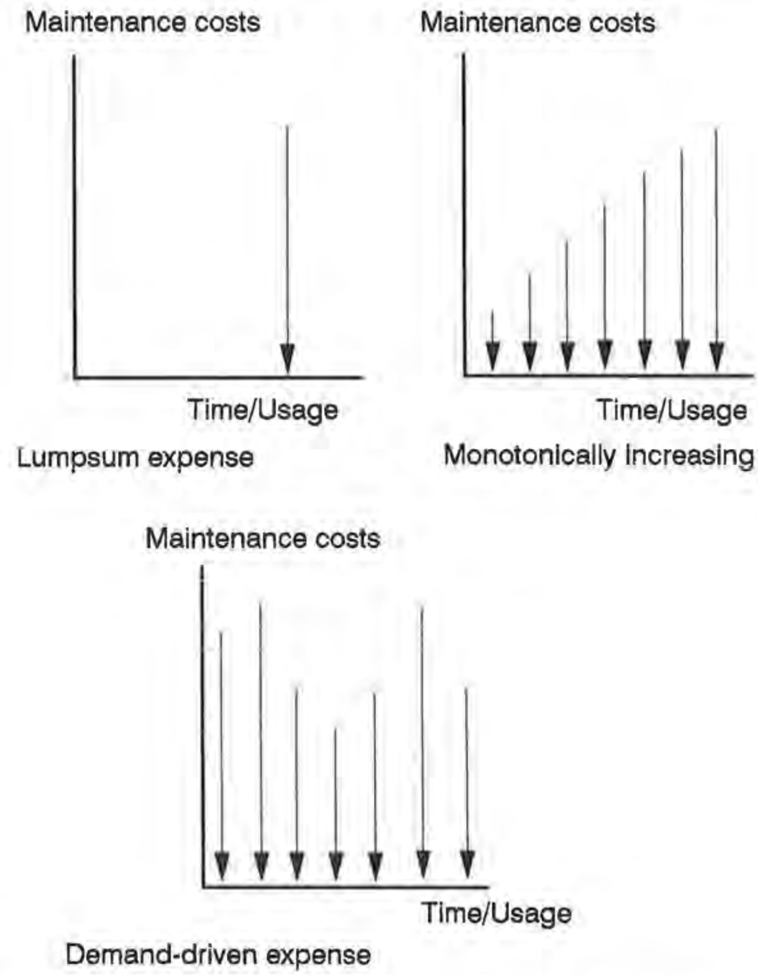

FIGURE 4 Maintenance responses to the three types of infrastructure failure.

tenance history. These factors make it difficult to assess the relative size of the maintenance allocations without more detailed modeling of failure and deterioration patterns. The aggregate prediction approaches are more affected by these factors than the disaggregate modeling techniques presented previously.

Trigger Mechanisms for Maintenance

There are different reasons for doing maintenance or capital works, ranging from responding to user complaints to generating employment. Figure 5 summarizes the perspectives, perceptions, and preferences for doing maintenance work. As an illustration, maintenance may be undertaken to satisfy a user or a manager of a highway system. Users are more concerned with the quality of service and whether there has been a cessation in service. Highway managers care about capacity and structural concerns. The users' preference would therefore be for reparative and restorative work, whereas the managers' preference would be for capacity expansion and rehabilitative actions. Many budgeting procedures do not relate the type of activity and its related expenditure to the reasons for undertaking these activities. As a result, it is difficult to project future expenditures.

Diagnosing a Typical Country Budget

We will now use a case study to illustrate some of the points made in this paper. The case study involves the analysis of highway expenditures in Peru from 1985 to 1993, for the purpose of suggesting adjustments to its budgeting procedures. Figure 6 shows the actual ratio of maintenance to capital expenditures in Peru from 1985 to 1993. As can be seen from this figure, there is a high variability of this coefficient over time. It was highest in 1991 and lowest in 1989. An average ratio from these data is around 0.5, a figure well above those suggested

PERSPECTIVE	PERCEPTION	PREFERENCE
Micro		
User	quality and cessation of service	reparative and restorative actions
Manager/operator	capacity and structural deficiencies	capacity expansion and rehabilitative actions
Owner	value of assets	preventive actions to slow depreciation
Macro		
growth	unreliability of service and productivity	all of the above
employment	infrastructure investments and employment	labor-intensive actions

FIGURE 5 Trigger mechanisms for maintenance actions.

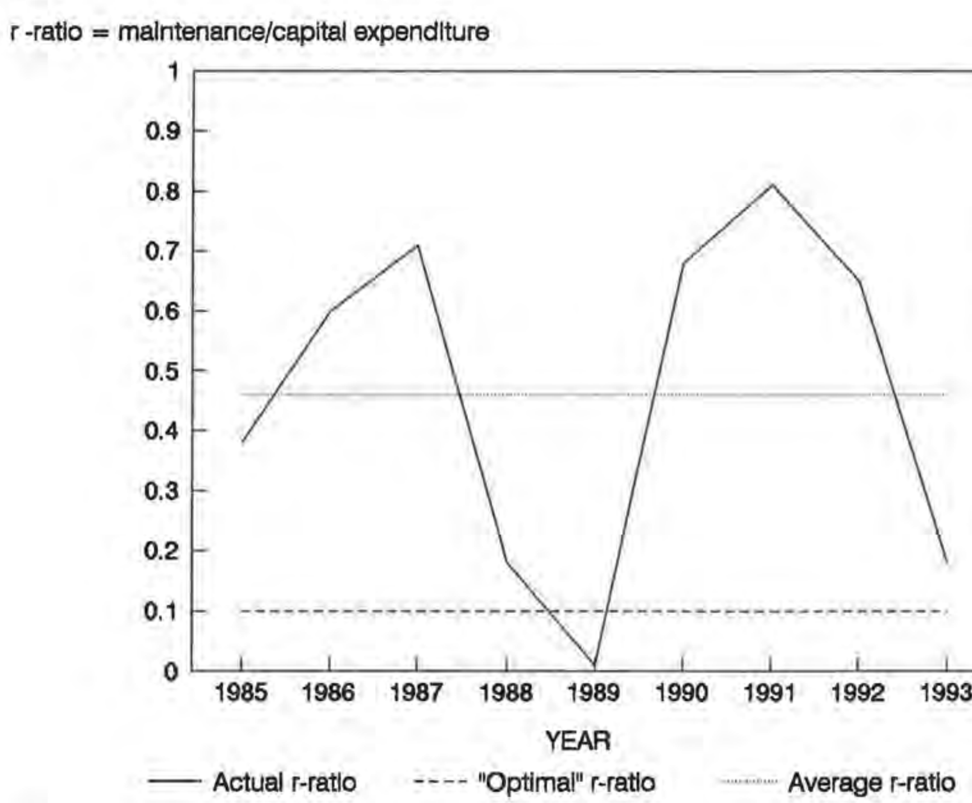

FIGURE 6 Impact of deferred maintenance (*14*).

TABLE 2 Conditions of Peru's Road Network (*14*)

JULY 1990			DECEMBER 1992		
Rating	km	%	Rating	km	%
Good	1,936	12	Good	2,668	17
Fair	6,815	44	Fair	8,474	54
Bad	6,942	44	Bad	4,551	29
	15,693			15,693	

by Heller (*5*), which were around 0.03 and 0.07. Using the HDM model and past data, an optimal ratio was calculated. The optimal ratio is an average ratio based on the assumptions that maintenance is triggered to minimize user and highway agency costs. As can be seen from Figure 6, the optimal ratio is well below the average ratio, indicating that Peru was seriously deferring maintenance and resorting to a cycle of reconstruction–deferred maintenance–reconstruction.

To check whether the diagnosis was correct, the condition of the highway network before and after the maximum point of the ratio in Figure 6 was compared in Table 2. This table shows that in 1990 the proportion of the network that was in good condition was 12 percent, compared with 17 percent in 1992. Similar improvements were found in the highway network rated in fair condition, which was 44 percent in 1990 and 54 percent in 1992. Therefore, the relative ratio method was picking up the right overall pattern. However, if we were to use this ratio to project future allocations between maintenance and capital expenditures (reconstruction and rehabilitation), we would have arrived at the wrong result, because the average ratio we calculated from actual data was far higher than the optimal ratio, if the correct reasons for maintenance were considered.

Summary and Further Work

We have presented alternative methodologies for preparing highway budgets, citing their advantages and limitations, as well as the factors affecting their robustness. These methodologies can be used as a tool kit for diagnosing past expenditures and recommending strategies for highway expenditure budgeting. These methodologies should be tested further using a variety of policy scenarios, to provide measures of robustness and general recommendations suitable for particular country situations. Field data, such as global condition surveys using randomly selected samples, would provide a basis for calibrating and testing the models developed in this paper.

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How To Keep Your Maintenance Management System from Growing Old

Dennis H. File, *Illinois Department of Transportation*

Most states now have a maintenance management information system (MMIS). Many states, including Illinois, have extensively revised or replaced their original system. Now states are facing the same dilemma with their second systems as they did with the first: how to keep their new MMIS from growing old. The new MMISs are much different from their predecessors in terms of the equipment used to support them and the experience of the managers who use them. In addition, the investment in these systems is often substantial. It is important that these systems not be allowed to grow old and require total replacement when they can remain dynamic, growing, and emerging systems that keep up with management and organizational requirements.

The Illinois Department of Transportation's (IDOT's) original maintenance management information system (MMIS) dated back to the 1960s. The original system was a batch system with time cards and invoices submitted from the field to the district or state offices where data was keypunched and edited. Reports were created by a mainframe computer at the central office from information stored on magnetic tapes. The reports were then collated and mailed to the districts, which were expected to further collate and distribute them to the field engineers and team sections. Reports reaching the field contained data about activities performed 60 to 90 days before.

IDOT's new MMIS, implemented in 1987, is much different in its overall objectives and equipment support. First, the new system was developed on the basis of information managers' need to make decisions. Each area of maintenance management was explored with the managers involved. They were asked about their daily decisions and what information they needed to make those decisions. Second, reports were designed to provide exactly the information required. Selection criteria for reports were emphasized so each requester could specify the data to be included in each report. The report requirements included not only the decision-making information required, but also the time demand (how soon) and report selection criteria (what to include or not include in the report). Therefore, the design requirements were for the MMIS to provide meaningful and timely reports for a broad range of subjects when requested by managers at all levels of the organization.

After the reports and their requirements were known, the MMIS was designed, taking into account these needs and the location of the person who needed the information. This concept is much different from the original because information is tailored to fit each manager's need and is requested and received by the managers themselves.

There is no central sourcing of the data and report generation. All information is available to all users at all times.

This system resembles the systems many states have or are moving toward today. When implemented, IDOT's MMIS addressed the three basic functions in the cycle of management:

- Work planning,
- Execution, and
- Evaluation and control.

It consisted of 44 reports pared from a total of 102 as originally designed. Users were trained to input data and, most important, how to request and use the 44 reports.

The equipment to support the MMIS now consists of 252 Digital Equipment Corporation (DEC) VT 220 and

320 terminals located in 160 highway maintenance and traffic operations headquarters, 9 district offices, and the central bureaus. The terminals are connected by dedicated telephone lines, and the data are stored on a central data base in Springfield from which uniform, quick access is guaranteed to all terminals. At least 350 employees access and use the terminals every workday. Inquiry into the data base is guaranteed within 5 sec, and most reports run within 1 hr of their request. Some reports can be requested to be run overnight at the user's option to alleviate the work load on the central processing unit during the workday. Two ad hoc report writers are now in the system to enable users to program the reports they need for specific applications or reports for which no standard report "fills the bill." Today, IDOT's MMIS provides more than 100 reports to address nearly every aspect of the functions and tasks performed in the field. These include sets of reports for needs assessment, annual work planning, budget allocation, work scheduling, expenditure tracking, performance and cost reporting, equipment management, weather forecasting, and electronic mail.

Keeping the System from Growing Old

Many departments are now developing ways to keep their MMIS up-to-date and applicable to current situations and management needs. Because many of the systems are online and involve so many adept users, the new systems offer many advantages over the original systems.

The following describes how IDOT keeps its MMIS evolving and fresh.

Management Involvement and Support

Establishing and maintaining top management involvement, understanding, and support is not an easy or simple task. Developing an MMIS requires funding, the securing of which is often how top managers first become involved. To win the competition for funding requires the creators of the MMIS to provide top managers with the information they need to understand why an MMIS is needed.

Several factors were involved in the early development of the new MMIS at IDOT. First, the development group that created the MMIS was composed of the bureau chiefs of maintenance (now operations) of three of the nine districts. The consultant met frequently with them as a group in developing each report. Through the time invested and the reports they created, these managers became major proponents of the MMIS. Their signatures and that of the state maintenance (now operations) engineer were required at the bottom of each report as confirmation that the report had a customer and specific purpose.

Second, the department's Bureau of Information Processing was included in all meetings. The MMIS was one of the largest they had endeavored to program and install. The bureau's people understood the genesis of the MMIS, its magnitude, extent of benefits, and possibilities for future enhancements. They, too, were anxious to see the MMIS implemented.

Finally, the issue of funding became a factor when the design of report delivery required a terminal in all highway maintenance headquarters (there were 106 at the time). At a meeting of the directors, district engineers, and central bureau chiefs involved, there was considerable discussion of various options and recommendations. At the conclusion of that meeting, the decision was made to provide the funds for the required computer equipment so the MMIS could operate as designed.

The MMIS has produced the benefits expected. For example, performance and cost data on snow and ice control, flood response, and overtime are available at the close of the workday or shift on request. The documentation of costs for reimbursement meets audit requirements. The department knows what equipment is owned ($125 million inventory), where it is located, how it is used, and how much it costs to use. Information for funds allocated, expenditures made, and account balances is available on line, at the push of a button.

Continued management support is important. At IDOT this is not only assured through the MMIS's delivery of promised benefits but also through constant updates and training. Notification of MMIS updates and enhancements are addressed to the district engineers for distribution. An overview of key reports they can use has been presented to each as a training course. Finally, results of the MMIS evaluation conducted by the central bureau at the 4-year mark, with recommendations collected from their field people, were sent to each for information and action by either the central bureau or their own staffs.

User Group

Illinois has found that success is best achieved through the establishment and involvement of a "user group." IDOT established a user group at the beginning of the process. The user group developed the MMIS objectives, concept, and reports. They tested and evaluated each MMIS module for a 6-month period in 20 highway maintenance headquarters they selected.

Today the user group has evolved to the point that all nine districts have at least one MMIS contact person who maintains contact with field users and provides training and system support. The contact persons form the nucleus of IDOT's ongoing user group.

In fact, there is a need for more than one user group. Equipment managers meet regularly, as they have in the past. MMIS applications, needs, and introductions of new products make up a large part of these meetings. The bridge engineers meet regularly and continue to develop enhancements in bridge inspection, maintenance repair needs, and various reports. Traffic operations personnel have unique needs that must be addressed. At their meetings time is devoted to MMIS topics. The district data processing managers and administrative services managers' work is affected by the MMIS. These groups often discuss topics that involve the MMIS in their meetings. Finally, overall user group meetings are held twice a year for any and all comers to discuss the MMIS. Discussions in the other meetings produce many of the agenda items used in the overall user group meetings. IDOT has learned that successful user group meetings include

- Updates of accomplishments,
- Introduction of new products,
- Topics suggested by members,
- Discussion of problems,
- Presentations by members of the group,
- Request for new products, and
- Establishment of priorities for enhancements.

The user meetings are consensus builders and major contributors to the success of the MMIS.

Training

The information that MMIS gathers and produces is only valuable if it is used. Training is the major component for connecting users with the MMIS. It cannot be a one-time effort. It must be constant and incorporate everyone who is (or should be) interested in using MMIS reports.

From the beginning, the emphasis has been on what the MMIS produces and what it can do for the person being trained. The most important aspect of the training is for the user to know how to get what he or she wants or needs from the MMIS. After that, the user is more willing to learn what must be put into the MMIS to have the report or information.

A second key aspect of training is to show how the particular module fits in with the overall MMIS concept of the cycle of management. The MMIS in Illinois is totally integrated with one-time entry as a prerequisite. The same data item may appear in many reports and be accessed by many users. The MMIS itself is organized with reports and screens designed to address one (and sometimes more) of the functions of the cycle of management. After users are able to see how the particular part (report and reporting) fits into the overall schema, the interest and learning level increase. Many, if not most, field personnel want to see improvements and are willing to make changes when they see the change as an improvement. For example, this approach enabled planning and scheduling to be introduced more successfully in locations where these concepts had not been formalized in the past.

When the MMIS was introduced, a training plan was developed to allow one trainer to work with two people for 2 hr on each module. Using three pairs of trainees full time for 6 months, IDOT staff installed the 18 modules in the system with the respective users in the districts. Users signed up for 2-hr time slots with each trainer. For each module, trainers stayed in the district as long as necessary to work with the users selected by the districts.

As new modules have been developed since that time, training has been tailored to fit the application and people involved with the module. For example, a new ad hoc program, In-Touch, was recently introduced. To train people who would use In-Touch, three separate sessions were given in Springfield with a maximum of 18 users in each. A conference room with terminals was established for the training. Each session required 4 days. The training was centralized to maintain concentration and develop a mix and support group from the sessions themselves.

On the other hand, group sessions to introduce the new radio management program are being taken to each of the nine districts. Districts may send as many as they feel necessary to this 2-hr training session because it deals with reviewing output reports, understanding their application, and becoming familiar with the brief user manual. Most of these people are already cognizant of both the MMIS and radio management.

The department also offers overview sessions for new managers and workers in the organization and for those who want to update their knowledge of the system. The newcomer sessions have been offered in the field headquarters, on request to the districts when the bureaus of traffic and maintenance were reorganized into the bureau of operations, and at the central bureau. All the courses are offered periodically, if numbers warrant, in the district or at Springfield.

Some modules are introduced using pilot or prototype installations. IDOT's new hazardous materials management software is being introduced in a volunteer district and the applications manual written as the installation is accomplished. From there, it will go to other districts as requested.

On the basis of an evaluation study conducted on site in 65 team sections, additional training programs have been developed. Update sessions, where a panel of leaders review the new modules introduced in the last 12 or 18 months and spend as much time as the group feels is warranted on each, have generated considerable interest and attendance. These are usually 1-day sessions. "Train the trainers" is another important and very useful approach. The central bureau has produced an overall training package that is complete in scope and flexible in application. All system reports and applications are included in a special manual with tabs for each application area. Helpful hints concerning shortcuts for data entry, suggested frequency of report requests, and applications are noted in the manual. Two or more trainers in each of the nine districts are trained to use the manual. In turn, the district trainers are now equipped with copies of the manual and are able to make contact with those in each of the field headquarters or with any new lead workers when necessary. Users can select training in the areas of interest to them and within their area of responsibility.

New Applications

As evident, it is important to constantly evaluate MMIS performance with people in the field and provide enhancements and improvements when requested. New modules are continually being added to the system. This ensures that the system remains relevant to those in the field staff. The introduction of a new module often leads to the definition and request for another. Recent additions to the MMIS include electronic mail, radio equipment management, mechanistically designed pavement maintenance and monitoring, stockroom inventory, weather information, a new ad hoc program, and hazardous materials management. IDOT is currently doing additional work to tailor work planning and scheduling for the bridge crews and traffic operations, revise the stockroom inventory to handle "satellite" locations, and develop a traffic sign management module. Each new development increases user experience and broadens the knowledge of needs so the next application can be better than the last.

Task Forces

Often requirements are presented that are unique or untried. IDOT has been successful in establishing task forces to concentrate on particular applications, develop their specifications, review the initial programs, and help install the new modules. The task force members for each application often gain self-actualization through their contributions and become some of the best salesmen for the application. For example, programs for electronic mail, word processing, and mechanistically designed pavement maintenance and monitoring were developed using the task force concept. In each case, the module was successfully completed, often in one of the task force member's areas first, where training assistance and support were available through that task force member.

Recognition

During the original installation of the system, users who attended one of the 2-hr training sessions for any application received a certificate of completion to show they were trained in basic MMIS operation. Letters of appreciation have been sent to supervisors and members of the various task forces who assisted in developing and installing the modules. Several people involved with the MMIS have been nominated for engineer of the year or technician of the year awards for accomplishments connected with the MMIS. Recognition encourages users to be involved and continue to offer their suggestions and recommendations.

Introduction of New Hardware or Software

Originally, IDOT's MMIS was supported by a VAX cluster consisting of two DEC VAX 8700s. This provided 5-sec response time for on-screen information inquiries and entries for the approximately 150 VT 220 terminals in the field at that time. Since then, IDOT has added a VAX 6510 to the cluster necessitated by the expansion of the system and is now installing additional VT 320s in the field. Second, IDOT has researched and selected software packages from vendors that can be integrated into the MMIS with little or no investment by department staff. For example, through Reflections software, users are able to purchase, incorporate, and use PCs instead of VT 320s in the district offices. These serve both as terminals to the MMIS and for typical PC applications. Through the use of Monarch software, users are able to produce a report from the MMIS, take the report information into a Lotus spreadsheet, manipulate it, and move it into Harvard Graphics, where graphs and charts can be produced on color laser printers. IDOT has also considered and purchased DEC graphics, the stockroom inventory system, and the hazardous materials management module from outside vendors. Last, IDOT allows the department's weather forecasters to use Kermit software to transfer the routine weather and storm warning forecasts directly into the MMIS. Therefore, the latest weather forecasts for all nine districts are available and accessible instantaneously to all 252 terminals in the system.

Support

The system is supported by an information systems unit in the Central Bureau of Operations consisting of two civil engineers and a technical manager. The Bureau of Information Processing has devoted one programmer full-time to the system. These two elements are very important to the continued success of the system. Because of the staff assignments, IDOT is assured that enhancements and "fixes" are handled on a timely basis in a mutually acceptable priority scheme.

The computers to support the MMIS are operational 24 hr per day, 7 days a week. When the MMIS was implemented, a telephone number for the central computer center was made available to field personnel to report and request response to hardware failures. The maintenance, traffic, and operations personnel are often called to work during emergencies and on shifts outside the normal work schedule. The computer center is staffed 24 hr per day, 5 days a week. In addition, anytime there is a problem at any terminal in the state, the operations field personnel notify the Bureau of Operations' central communications center, which is staffed at all times. Communications technicians have the pager number of the Bureau of Information Processing staff persons assigned to equipment troubleshooting and resolution. If the staff person cannot work out the problem, the central communications center can contact a district staff member using telephone or pager to work with the central person in resolving a problem any time, any day of the week.

Increasing Scope

Although the MMIS terminals are operational and online around the clock, most are used about 2 hr per day for entering and retrieving reports. Therefore, time on the terminals is available for other applications. There is no reason to limit the scope of the system only to users in the bureaus of operations, maintenance, or traffic. Therefore, system applications such as electronic mail, hazardous materials management, inventory control, vehicle preventive maintenance, and equipment inventory have been expanded for use by other bureaus. Personnel in bureaus such as construction, materials and physical research, design and environment, and administrative services need some of the same components, information, and modules first made available to those in operations. Some of the most enthusiastic users of the system are those in administrative services, because the data from the field headquarters in the system are as current as any data available. Accountants can monitor orders and expenditures for salt, aggregate, and commodities very accurately. Vehicle coordinators can find out when the last preventive maintenance was performed on any vehicle in their district or bureau. The staff industrial hygienist can offer notices about the handling of hazardous materials and transmit them and the material safety data sheets to all terminals in one action. These additions make the system vital to the department as well as to the bureau.

Conclusion

Because of these accomplishments, the MMIS in Illinois will continue to expand and be exciting for users and others involved. The implementation of the MMIS and its maintenance is too great an investment to lose through obsolescence or redundancy. IDOT has successfully built momentum and interest in the system through the means described in this paper. It is important to continue to invest time and effort to keep the MMIS from growing old and to increase its longevity.

ROADSIDE MAINTENANCE

Herbicide Fate and Worker Exposure

Ray Dickens, *Auburn University*

A conference of state and federal highway personnel and university researchers was held in Auburn, Alabama, to ascertain interest in and the feasibility of a regional approach to studying the safety of vegetation management practices for workers, the general public, and the environment. It was agreed that a cooperative research project should be developed to obtain the needed information and develop it into a form useful to highway roadside personnel, to better prepare them to deal with questions from regulatory officials and the general public about the safety and environmental aspects of their state's vegetation management program. It was further agreed that Alabama and Georgia personnel would develop a draft of the proposal for a regional project using a regional pooled-funding approach through the Federal Highway Administration, with Alabama as the lead state for consideration.

Vegetation management along roadsides is especially demanding of equipment and labor in the southeastern United States. The mild temperatures and abundant rainfall in that region combine to create ideal conditions for rapid growth of a very dense and tall vegetative cover. Control of species such as kudzu and Johnsongrass by mowing is very difficult and expensive. Therefore, most states in the Southeast have resorted to the use of herbicides. The application of these materials along roadsides has led to numerous questions from the public concerning the effects of these materials on the environment. Additional concern is also voiced regarding any effects of exposure to these chemicals on workers or the traveling public. Unless factual information is readily available to support the safety of these practices to workers, the traveling public, and the environment in general, it is very likely that pressure brought to bear by activist groups will result in the elimination of herbicides as tools for vegetation management on roadsides.

Information is available to support the safety and efficacy of these vegetation management materials, but there is presently no single source of reference available to state highway personnel for this information. A second problem is that most of the testing has been done in other use situations, such as forestry or utility rights-of-way. The development of definitive data under highway use situations is probably too expensive for an individual state because of the number of materials and methods of application involved. A possible solution to this problem is the development of a cooperative effort among the southeastern states to share the costs of obtaining these data.

Assessment of Needs

A 2-day conference involving southeastern transportation and highway department personnel, along with university researchers involved in vegetation management, was held at Auburn University to ascertain the interest in and feasibility of a regional approach to conducting the needed studies. Ten states—Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Tennessee, and Virginia—sent representatives. Representatives from state and regional offices of the Federal Highway Administration also participated in the meetings. Information was presented by each state concerning its current vegetation management programs and the perceived need for development of exposure, toxicology, and environmental fate data. Research needs addressed involved-worker and public exposure hazards, along with the effects of these vegetation management practices on the environment.

Experts in the fields of applicator and public exposure, movement and persistence, and pesticide toxicology were invited to make presentations concerning needs for specific information and methods of obtaining this information.

Potential for Movement of Pesticides in Surface and Groundwater

Although most of the drinking water for rural areas comes from groundwater, much of the drinking water in urban areas is derived from surface water containments such as reservoirs. It is estimated that as much as 95 percent of the drinking water for some major metropolitan areas comes from reservoirs. Turfgrass nutrients and pesticides are transported to surface water in runoff water and eroded sediment. Erosion and surface runoff processes have been examined in relation to water quality and environmental impacts. The movement of pesticides in surface water is considered the major source of potential pesticide movement into drinking water sources.

Using the best estimated parameters for predicting groundwater contamination potential (GWCP) according to the equation presented by Weber (soil scientist, North Carolina State University) on 37 soil series common to roadsides in the southeastern United States, 11 soil series would have a soil leaching potential (SLP) rating of high and 10 soil series would have a rating of moderate. The GWCP for the acid herbicides (i.e., 2,4-D; dicamba; MCPA; mecoprop; and triclopyr) with high herbicide leaching potential (HLP) would be classed as hazardous for use on the 11 soils with the high SLP rating and risky for the 10 soils with a moderate SLP rating.

Results of research conducted at the University of Georgia using lysimeters in the greenhouse and in the field containing a sandy soil subtending bermudagrass and bentgrass sod indicated that the models such as the Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) mathematically overestimate by a factor of 10 the quantity of 2,4-D found to pass through the sandy-soil system. Similar research conducted outside using larger lysimeters indicated that the mathematical models, developed for agronomic (row crop) situations, have a tendency to overestimate the potential for herbicides, used on grassed areas, to move into groundwater.

Research on Worker and Bystander Exposure

Pesticides are biologically active chemicals, often not uniquely specific to the target pest, and thus they potentially pose a threat to human health and wildlife. To assess the risks associated with pesticide exposure, it is necessary to determine the likely level of exposure, the extent to which pesticide is absorbed, and the toxicity of the pesticide. Most research on human exposure to pesticides has been obtained from worker application and reentry exposure in forest ecosystems, orchards, vineyards, or airboat application to aquatic sites. However, because of the differences in spraying equipment and procedures, occupational exposure levels cannot be equated with exposure levels on roadsides or residential lawns. Once a pesticide has been applied to the turfgrass surface, pesticide loss occurs through volatilization to the air, leaching through the soil, degradation, or some combination of these. Environmental, edaphic, management, and other factors affect pesticide loss. Because of the complexity of this system, it is important to use a systems analysis and a modeling approach to summarize all findings that can potentially be used for predictive applications under diverse systems such as roadsides. To develop dependable data for predicting bystander and reentry exposure for roadsides, much research must be conducted.

Proposed Response to Problem

Other discussions at the conference included proposed costs and possible methods of sharing expenses among states with common needs. At the conclusion of the conference an informal business meeting was held, presided over by Ray Dickens of Auburn University. It was agreed that the lack of scientific data to support the safety of vegetation management programs is a serious problem in all of the states. The lack of supporting data has already caused problems in some states and represents a threat to the continued existence of the programs in many states.

It was further agreed that the group should develop a proposal for a regional project using a regional pooled-funding approach through the Federal Highway Administration, with Alabama to be the lead state for the administration of the project. Alabama and Georgia personnel agreed to work together and develop a draft of the proposal for consideration by all states involved. It was suggested that another meeting similar to this one be held to exchange information between state personnel, work out any problems in the draft, and prepare the proposal for submission to the appropriate organizations for possible funding. It was understood that the proposal would rely on the expertise of researchers in the various member states in a unified, comprehensive research program to provide the needed information and prepare the necessary publications and other educational materials for use by all the states involved.

Progress to Date

Researchers from Georgia and Alabama met in Auburn, Alabama on May 20, 1994, and developed a draft proposal for a regional research project dealing with aspects of roadside pesticide applications as they relate to the exposure of workers and the traveling public, both during and subsequent to the application of the material. Approval and support of the basic principles and procedures of the proposed research by an adequate number of states will result in a formal request for a pooled-funds program administered by the Federal Highway Administration and the Alabama Department of Transportation.

SNOW AND ICE CONTROL

Winter Road Maintenance System

Lennart B. Axelson, *Swedish National Road Administration*

VVHS is a data-base tool for improving winter maintenance and making it more effective. VVHS supports all sorts of work, including preseason planning, implementation of follow-up measures, and evaluation of completed work. During the planning phase, VVHS allows users to optimize resource utilization and timing of maintenance. Optimized plans for different situations such as skid control and snowplowing can be used to yield expected results at the lowest possible cost. The consideration of time improves the quality of plans. During work, any deviation from planned ending times for activities can be pinpointed and compensated for by VVHS. VVHS can help gather information on ongoing operations, making information on completion times, resource utilization, and material use easily available for future decision making. In turn, agencies can make information about their winter maintenance operations and traffic conditions available to the public.

The development of the Swedish winter road maintenance system (VVHS) began in 1990, initially as a technical test of Automatic Vehicle Location with the aid of the Global Positioning System (GPS). A further aim of VVHS development was to study various ways of increasing precision and covering the gaps caused by satellite shadow. The project was gradually extended to include other components in a transportation management system—such as digital maps and reliable communication—as software in vehicles and control centers. A requirements specification for the system was produced from spring 1991 to spring 1992, based on improving planning, management, and follow-up capabilities for winter road maintenance. During the winter of 1992–1993, technical tests and certain tests of operations were performed outside Gothenburg in southwest Sweden. The tests showed that the system improves the possibilities for more efficient road maintenance in the following ways:

- Improved road user information;
- Quality assurance for the contractor's commission;
- Improved planning and more efficient resource utilization;
- Simplified management of operations and overview in real time;
- Better follow-up of actions, results, and costs;
- Improved quality and reduced quality variations;
- Improved safety for vehicle drivers; and
- Improved work content for truck drivers.

Components of VVHS

Basic data

Information on the road network is obtained from the Road Database (VDB) of the Swedish National Road Administration. The follow-up information can therefore be related to other information in VDB. The basic data include information on resources, materials, equipment, methods, types of action, and reason for action.

Planning

Since winter road maintenance often has the character of emergency action, it is essential that as much maintenance as possible be planned. Planning allows suitable routes to be created for different given situations such as skid control, snowplowing, and the combination of both.

Management

When an action is to be implemented, the most suitable material, equipment, and routes are chosen on the basis

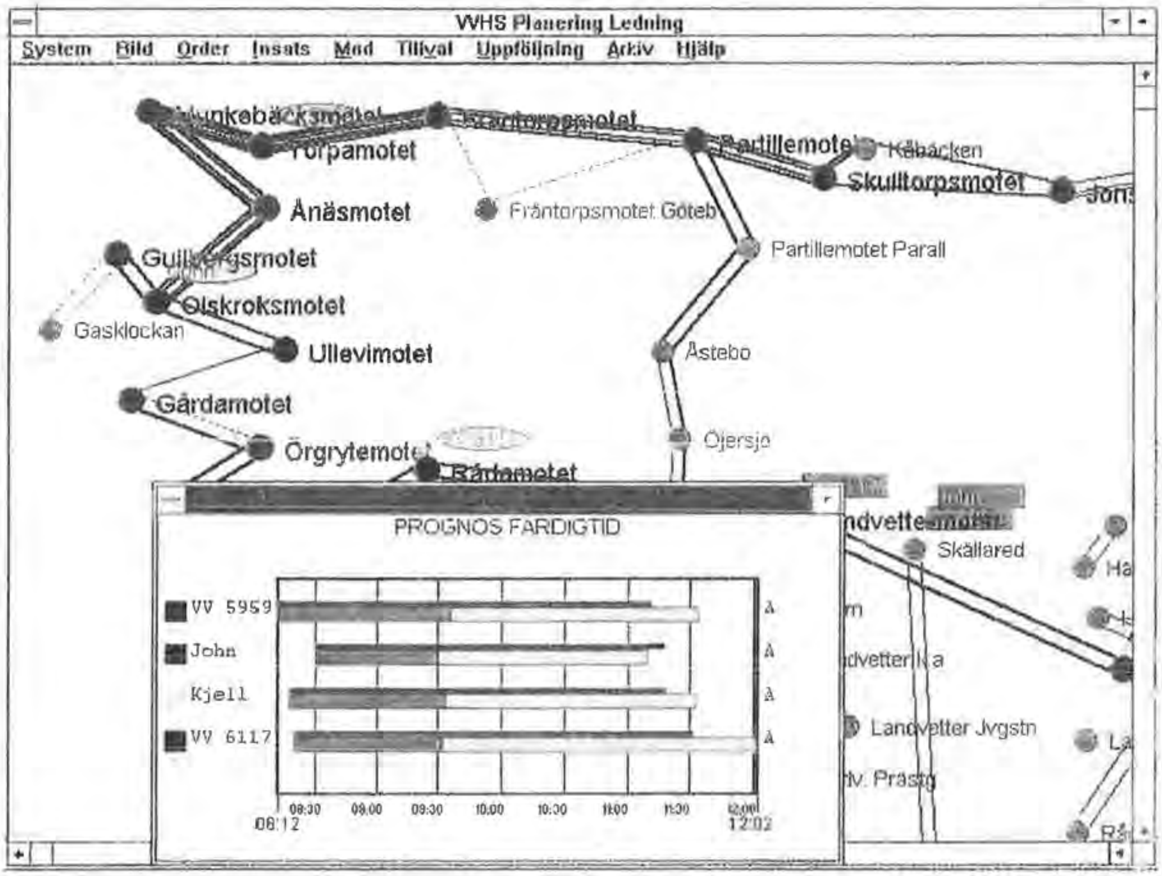

FIGURE 1 Management phase of the VVHS, showing completed actions as unbroken lines and uncompleted actions as broken lines.

of current conditions. The assignments are then communicated automatically to the pertinent vehicle with the aid of mobile data communication. The driver confirms that he is available and is then given information on the required equipment and materials. When the equipment has been fitted, this is confirmed and the vehicle can then set out on its route. Using GPS, the vehicle is tracked along the whole route, and position information is reported as nodes or junctions are passed. This information is immediately displayed to the supervisor on a monitor. The vehicle's own color is shown on a schematic map as well as in a diagram containing start times, forecast completion times, and deviations from plan (Figure 1).

Follow-Up

Using the follow-up section of VVHS, it is possible to display diagram information for a selected period on the number of actions per month, action times for road sections and routes, completion times, material consumption, resource utilization, and costs. This information then provides a basis for reviewing the plan and improving operations.

Test of Operation

During the winter of 1993–1994, an extensive test of operation was carried out in two areas centered on Västeras and Varberg. In Produktion Ost (PO) Västeras district, the system was tested on the E18 highway from Västeras to Stockholm and on parts of trunk road 55. Here, a total of 10 trucks owned or leased by SNRA were fitted with equipment. PO supervises its winter road maintenance from a center in Västeras, where VVHS and a computer system for personnel assignment have been installed. The test involved 30 truck drivers and 10 operators/supervisors at the control center. Road user information was managed from the traffic control centers in Stockholm and Eskilstuna.

Produktion Vast (PV), Production Area Varberg, equipped 12 trucks, both owned and leased by SNRA. The test was carried out by 30 drivers and led by 4 supervisors. The road network consisted of the E6 highway and trunk road 41, in addition to a number of minor roads. Road user information was managed by the traffic control center in Gothenburg.

Results

The clearest results of the winter's tests in Västeras and Varberg were that the planned time consumption was often greater than the actual, the work being completed sooner than expected. When these results had been fed back to the system and replanning performed, it was found that the maintenance assignments could be carried out with fewer trucks.

In both test areas, it has been possible to reduce the number of vehicles from 13 to 11 with the same quality of work. In some types of preventive antiskid action, two vehicles were used instead of five. The savings resulting from the system's use provide a very significant measure of the economic value of VVHS.

From the results that have been analyzed, it can also be seen that different drivers drove at different speeds. Where the optimal action time was 180 min, action times of 110 min (minimum) and 260 min (maximum) were also recorded. This means that with short action times, the quality of antiskid action and snow clearing deteriorates considerably, more salt being deposited outside the carriageway and more snow left on the carriageway. Excessive action times increase the action cost, and slippery conditions may occur before the action is completed, contributing to accidents. During snowfalls, the snow remains on the carriageway for a longer time, causing trafficability to deteriorate. These results, together with the supervisors' experience, provide a valuable basis for changing and improving operations. Actions can thereby be optimized to the advantage of both the orderer and the contractor.

Technical Concept of VVHS

VVHS is based on a technical concept comprising mobile data communication, a communication platform, positioning, mobile application in a DOS or Windows environment, an application for the control center for several users in a Windows-based network environment, a graphic interface, and schematic maps.

The communications platform comprise a transport protocol with a facility for choosing data network and running several applications simultaneously.

Positioning is achieved with the aid of GPS. When operating to detailed plan, route-matching is used and completion time can be forecast. When operating without a detailed plan, map-matching is used.

The application is implemented in a text-based DOS version, where the route is displayed in the form of a list with nodes, and a Windows version, where the route is presented on a schematic map.

In a control center, the application is implemented with client server technology for a single user or several users in a network.

The graphic interface allows the user interacts with the system by means of diagrams, schematic maps, and authentic maps.

Schematic maps allow road network–related information to be displayed in a clear manner configurable by the user.

Japanese and European Winter Maintenance Technology

Leland D. Smithson, *Iowa Department of Transportation*

Snow and ice control operations in the United States differ from those of other countries. A Winter Maintenance Scanning Panel visited Japan and Europe to study these differences. The visits were sponsored by the U.S. Department of Transportation's Federal Highway Administration's Office of International Outreach Programs, the American Association of State Highway and Transportation Officials, and the National Cooperative Highway Research Program of the Transportation Research Board. The panel consisted of six United States managers responsible for snow and ice control operations. They came from federal, state, county, and municipal authorities. General topics of interest to the panel included anti-icing operations, road weather information systems, weather forecasting services, equipment, public information systems, policy, roadway level-of-service criteria, visibility, and environmental issues. The panel visited Japan from March 12 to March 19, 1994, and Germany and Austria from March 20 to March 27, 1994. While in Austria the panel attended the 9th Permanent International Association of Road Congress, the International Winter Road Congress, and the International Road Weather Conference. The panel proposes the development of a winter maintenance program to demonstrate, evaluate, and acceptance-test promising U.S. and foreign technologies. This program should be a joint effort of federal, state, and local authorities with snow and ice control responsibilities.

Japan, one of three countries visited by the Winter Maintenance Scanning Panel in March 1994, deals with complex winter maintenance conditions. Population density, terrain, and weather are the major contributors to these conditions. Japan has a high urban population density. Its population is half that of the United States in an area $\frac{1}{30}$ the size of the United States, with $\frac{2}{3}$ of the area covered by mountains. In addition to the high population density, Hokkaido, the northern island of Japan, receives more than 500 cm (more than 16 ft) of snow each winter. Heavy snowfall and high traffic volumes create difficult snow and ice control conditions.

Studded tires were introduced in Japan in 1962 to provide winter mobility. Before 1962 mobility was achieved by putting chains over summer tires. By the late 1970s nearly all drivers were using studded tires. The studs rapidly eroded the road surface, creating a heavy concentration of dust and causing an air pollution problem. To solve the problem, the Japanese Ministry of Trade and Industry introduced a studless tire in 1982. The government joined with private industry to promote studless tires by offering rebates on new studless tire purchases. The government also provided winter driving training courses. This program changed motorists' driving and buying habits so that today very few vehicles use studded tires and the air is much cleaner.

Snow removal standards were established to make mobility possible without chains and studded tires. Main trunk roads are kept clear of snowpack while lesser-traveled roads are allowed to develop snowpack and ruts several centimeters deep. Trucks and plows similar to those found in the United States are used on the main roads, and motor graders with serrated blades, scarifier, or milling heads are used to smooth and texture snow-packed and rutted local streets. Sand (because of air pollution problems) and salt (because it costs $200 per short ton and contributes to groundwater problems) are used very sparingly.

Japan has developed some unique high-performance snow-control equipment to combat the 500 cm of snowfall the country receives each winter. The Hokkaido Development Bureau used a partnering relationship with private companies, universities, and research institutes to produce heavy-duty snow-removal trucks, plows, blowers, and blower/loaders. The use of mechatronics (joysticks, display panels, and video cameras) makes possible one-person operation of a three-plow (forward, underbody, and rear plows) heavy-duty truck. An open-vane snowblower auger allows for cutting through and loading hard-packed snow. Packed and plowed snow is hauled to snow-melting facilities or stored outside the city in huge piles, which melt during the following summer. Snow-melting facilities use warm effluent water from the wastewater treatment plant to melt the snow. The result is an environmentally sound, colder effluent entering the river water.

Japan uses an advanced global positioning satellite (GPS) system to track vehicles and provide location information for management systems. Nearly every government vehicle that transported the panel in Hokkaido used GPS technology to control a video display of the vehicle's position and direction of travel on a moving screen grid background.

European Winter Road Technology

The panel visited road maintenance facilities in Germany and Austria. They found that roads, bridges, equipment, and support facilities in Japan and Europe were of high quality and well maintained. Fuel taxes in excess of $2 per U.S. gallon and tolls of approximately 25 cents per kilometer (combined with a $1.50 terminal fee) provide an excellent funding base for roadway construction and maintenance. The equipment display at the Permanent International Association of Road Congresses meeting in Seefeld, Austria, was the largest display and demonstration in Europe. Snowblowers, plows, trucks, loaders, and spreaders demonstrated advanced technology and greater capacity than found in the United States.

The price of salt in Europe is about the same as in Japan ($200 to $300 per short ton). Both European and Japanese authorities use chemicals sparingly and prewet salt at the spinner with brine or liquid calcium chloride to reduce deicing chemical loss from the road surface and speed up the melting process. Hopper spreaders are commonly designed with plastic liquid storage tanks in the sloping undersides. Many have fifth-wheel sensing to monitor chemical spread rate with improved accuracy. Japanese and European snowplows are usually heavier than U.S. plows and are often made of independent 1-m sections to improve conformance to pavement cross section or varying crown. The cutting edges incorporate tripping action and are made of metal, plastic, or rubber. Foldout wings are used to extend plowing width. To reduce snow overspray and increase operator visibility, a canvas snowshield is installed 30 to 50 cm above the snowplow. This shield traps the snow spray and forces it under the truck.

Winter Traffic Management Systems

Roadway weather information systems in Europe and Japan provide impressive amounts of information to road maintenance operators and the motoring public. The typical climate sensors monitor ambient air and pavement temperature, wind speed and direction, humidity, and deicing chemical concentration. This information is brought to a central processing and control station via land line or radio data link. The traffic management center also makes extensive use of video monitoring of traffic and roadway conditions. Experienced meteorologists are on staff at these management centers. The dominant intervention feature of these systems is the ability to remotely change the speed limit and information signs on a section of roadway or selectively close or limit access to sections of roadway from the management center.

The traffic management center is also equipped to handle automated call-down for locally managed emergency services such as fire, ambulance, and police. In addition to the roadway weather sensors and imagers, the Construction Machinery Engineering Center of the Hokkaido Development Bureau has a winter maintenance information vehicle under development. This vehicle has a suite of sensors and visibility imagers on board, allowing a roving assessment of roadway weather and pavement conditions. Among the sensors' capabilities is infrared imaging of pavement and pavement friction. The ability to link the information from this winter maintenance management vehicle to a central location via radio is an integral element of this novel system.

In Europe and to an even greater extent in Japan, the motoring public is actively educated about current and anticipated winter driving conditions and winter maintenance operations. One motorist information center the panel visited had nine television monitors with the latest road and weather information, plus dial-up information for hundreds of monitoring stations along the national expressways.

Intelligent Vehicle Highway Systems for Winter Motorists

A major thrust in traffic management in Japan is the integration of intelligent vehicle highway systems technology into the vehicle fleet. Though not the dominant force in the introduction of this technology, winter maintenance and winter driving hazard elements are planned for this future system. These include intermittent/minimum zone mod communication (I/MZMC) coupled with digital route maps that will provide the motorist with information on winter maintenance operations in progress, winter driving hazards, and alternative route planning.

Technology Transfer

The panel prepared a brief summary of international practices identified with technology transfer recommendations. One of the proposals is the establishment of a winter maintenance program (WMP) where technologies developed in the United States and other countries can be demonstrated, evaluated, acceptance-tested in an operational setting, and compared with the current practices in the United States. The WMP has three goals:

- Achieve equal or improved levels of winter maintenance service with benefit/cost improvements;
- Provide an enhanced degree of environmental sensitivity; and
- Increase the safety of winter driving.

Implementation of a comprehensive WMP will involve four steps:

- Conduct of a national workshop to develop a work program;
- Establishment of a voluntary funding pool for snow and ice control;
- Establishment of a snow and ice technical working group to develop test protocols, evaluate testing, and approve test reports for national distribution; and
- Establishment of a policy coordinating committee—with membership drawn from federal, state, and local organizations—to monitor and advise on the development and implementation of the WMP.

Candidate technologies and policies identified by the panel for evaluation by the technical working group are as follows:

- Snow and ice control: Japanese rearward (one-lane) snow-conveying rotary snowplows, European spreaders with prewetting equipment and aerodynamic tailoring, European snowplows, and improved anti-icing and deicing materials and application management;
- Winter maintenance management systems: improved roadway/weather information system technology, coupling weather information with GIS/GPS, improved road user information systems, and fleet management;
- Blowing snow and avalanche hazard: blower-type snow fence demonstration project and hazardous-highway traffic-management systems demonstration project; and
- Policy: translation of foreign-language snow-engineering manuals, work process management in winter maintenance, strengthened public/private sector partnering, and public education, cooperation, and involvement.

The winter maintenance policy coordinating committee and the snow and ice technical working group will actively develop research problems statements and provide direction for further winter maintenance research.

Summary

Both Japan and Europe provide road users with a higher level of service on major highways than does the United States. Environmental sensitivity is emphasized in Japan and Europe. Japan uses public/private partnering in achieving winter maintenance technology advances, and achieves public cooperation in dealing with winter's perils through education and citizen involvement. The advanced international technology used by Japan, Germany, and Austria can be economically transferred to domestic use through the proposed winter maintenance program.

Observations on Overseas Use of Deicing Chemicals

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In March 1994 a winter maintenance panel conducted a study tour of Japan, Germany, and Austria. The tour was sponsored by the Federal Highway Administration and the American Association of State Highway and Transportation Officials, through the National Cooperative Highway Research Program administered by the Transportation Research Board. The panel of U.S. maintenance engineers reviewed winter maintenance equipment; pavement condition policies; and the use, characteristics, and costs of deicing chemicals. Most organizations responsible for winter maintenance in the United States pursue a "bare pavement" policy on all or at least on their major roadways. By contrast, Japan does not advocate that philosophy; the city of Innsbruck, Austria, uses only a minimal amount of chemical deicing; and the state of Bavaria in Germany has progressed to a more environmentally friendly philosophy for deicing chemical use.

Japan was the first country surveyed by the winter maintenance panel in March 1994. Although some individuals in Japan believe that snow removal programs do not address public needs because a "bare pavement" policy is not followed, the general philosophy is that chemicals, notably salt, should be used only in minimal quantities because of their adverse effect on the environment. In the Hokuriku region on Honshu, the main island of Japan, 98 percent of the deicing chemical used is salt (sodium chloride) and 2 percent is calcium chloride. The annual salt use for this area is approximately 700 tons for 1000 km (622 mi) of roadway. Noncorrosive deicing chemicals have not been used in the Hokuriku region. This region has not experienced environmental problems, primarily because of the high amount of precipitation it receives. This dilutes the salt runoff and transfers the salinity to the rivers and seas. The salt application rate varies from 2 to 40 g/m^2 (25 to 500 lb per 12-ft-wide lane-mi). When discussing application rates, ranges were identified, but emphasis was placed on rates at the lower end of the range.

The salt used in Japan is of a finer consistency than that normally used in the United States. Japan's salt is imported from Mexico in 1-ton bags at a price of approximately $300 per ton. Salt applications are normally made with liquid sodium chloride as a prewetting agent (25 to 30 percent by weight of the chemical being liquid). Approximately 70 percent of the sodium chloride used in the Hokuriku region is in solid form. The salt is stored inside, normally on the balconies of buildings, and gravity-loaded through hoppers into the salt spreaders. Because of the high humidity of the region, salt can only be stored for about 10 days before it must be used.

Whereas salt is the primary deicer in Japan, Sapporo, the largest city on the northern island of Hokkaido, uses some calcium magnesium acetate (CMA) imported from the United States. This city of 1.7 million people, with an annual snowfall ranging from 500 to 700 cm (200 to 275 in.), uses about 10,000 tons of CMA per year.

Austria

The Austrian Highway Authority uses salt as a deicer and prewets it with liquid calcium chloride. The authority purchases calcium chloride in flake form and places it in suspension for use as a wetting agent. The salt has the consistency of table salt. The salt application rate varies from 10 to 70 g/m^2 (130 to 910 lb per 12-ft-wide lane-mi). All salt is stored inside and costs about $200 per ton.

The annual salt use in the city of Innsbruck, with a population of 120,000 and 300 km of roadway, is 500 to 600 tons. Salt is used whenever icy conditions exist. Under those circumstances, all streets are treated. The city stores its salt in overhead silos and gravity-loads its trucks. The salt supplier "blows" the salt into the silos. Innsbruck does not prewet its salt applications. The city's salt costs about $200 per ton and has the consistency of sugar.

Germany

The Transportation Administration in the state of Bavaria, Germany, purchases salt primarily from its salt mines at a cost of $70 per ton. The administration prewets the salt, which has the consistency of sugar, so that 30 percent by total weight is liquid sodium chloride. The fine-graded salt, prewetted, is spread with the consistency of a thick soup. The salt is treated with an anticaking agent and a coloring agent. The purpose of the coloring agent is to distinguish the deicing salt from table salt because the latter is taxed. Bavaria's primary emphasis for snow removal is on plowing, with salt used to prevent the initial snow-and-ice bond to the pavement. Applications are repeated at the operator's discretion.

Several years ago, Bavarian officials evaluated anti-icing, but imprecise forecasting methods used at that time contributed to wasted presalting applications. This raised environmental concerns and led to the abandonment of the effort. With improved road weather information services, further consideration is being given to anti-icing technologies. Currently, salt applications are made just as roads become slippery.

All of Bavaria's salt was applied in solid form until about 10 years ago. Now approximately 80 percent of its trucks are capable of applying prewetted salt, with the wetting agent applied at the spinner. The objective is to have all trucks capable of applying prewetted salt. Salt used in Bavaria has a nominal top size of 5 to 6 mm and an average size of 2 to 3 mm. In comparison, the standard gradation for deicing salt used in the United States (ASTM D632, Type 1) has 95 to 100 percent passing the 9.5-mm sieve, 20 to 90 percent passing the 4.75-mm sieve, and 10 to 60 percent passing the 2.36-mm sieve.

In maintenance yards, all salt is stored in a wooden building having a capacity of approximately one-half a season's salt demand. The salt is loaded into truck-mounted spreaders by a self-propelled conveyor/loader. They produce their own liquid sodium chloride by mixing granular sodium chloride and water in a tank. Air is injected from the bottom of the tank, thus agitating the mixture and placing the solids into solution.

The adoption of the fine salt gradation and prewetting techniques has led to an impressive reduction in salt use. From the winter of 1978–1979 to the winter of 1990–1991 total salt use in Bavaria was reduced from 361,000 to 174,000 tons. Even more descriptive of the reduction is the fact that the amount of salt applied per kilometer of road was reduced by 54 percent (46.4 to 21.3 kg/km annually) during the period.

Application of Prewetted Snow and Ice Control Materials

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Interest in the use of prewetting systems for the application of snow-and-ice-control materials is growing within the United States. This interest has been facilitated by activities in the Strategic Highway Research Program, the cooperative efforts between the Minnesota Department of Transportation and Scandinavian countries, the Federal Highway Administration study on anti-icing technology, and recent travel by U.S. maintenance engineers to Europe and Japan. Prewetting of snow-and-ice-control materials may be an important element in improving the efficiency and effectiveness of snow-and-ice-control processes. However, there is a need to evaluate the operational and economic impacts of prewetting systems on winter road maintenance activities. Once evaluated, prewetting systems for snow-and-ice-control materials could become an effective tool in a roadway agency's winter maintenance operation.

Each year, about $1.5 billion is spent on roadway snow-and-ice-control programs in the United States, and approximately one-third of these funds are used for chemicals. Because of improved weather information systems, pavement condition information systems, and material spreader controls, there is a need to evaluate the winter maintenance processes used in the application of snow-and-ice-control materials. By improving material application processes, material use can be reduced and improvements achieved in the level of service.

Interest in using prewetting systems for the application of snow-and-ice-control materials is growing within the United States. This interest has been facilitated by such activities as Strategic Highway Research Program (SHRP) Project H-208 on Development of Anti-Icing Technology (*1*); cooperative efforts between the Minnesota Department of Transportation and Scandinavian countries; the Federal Highway Administration's Test and Evaluation Project 28 on Anti-Icing Technology; and the March 1994 International Winter Maintenance Technology Scan trip to Europe and Japan sponsored by the American Association of State Highway and Transportation Officials, the Federal Highway Administration, and the National Cooperative Highway Research Program of the Transportation Research Board.

Prewetting systems for snow-and-ice-control materials should be investigated to determine the efficiency and cost-effectiveness of their use under winter conditions. In determining the prewetting system of choice, all of the factors that influence the winter road maintenance operation should be evaluated. These factors include, among other things, management policy, climatic conditions, snow-and-ice-control material properties, equipment, personnel, and funding. Since salt (sodium chloride, or $NaCl$) is the predominant snow-and-ice-control chemical used on roadways, it will be the focus of this paper. However, other materials may receive similar benefits from prewetting operations.

Prewetted Salt

What is prewetted salt? Generally, prewetted salt refers to salt that is moistened shortly before spreading. Why use prewetted salt, as opposed to traditional, dry-salt application processes? Under many conditions prewetted salt will adhere to the road surface better than dry salt, the reaction time is less, the temperature range of effectiveness is increased, and control of material distribution is improved.

Prewetted salt will stick to the road surface better than dry salt under many conditions (*2*). By reducing the material lost to the roadside, less material is needed for each application. With less material used, the following benefits may be realized: less material will enter the environment; the size of the spreading routes for each truck will be increased, resulting in fuel savings and less downtime spent heading back to reload; and the labor and equipment needs could decrease. Improved material effectiveness will also be realized because more of the prewetted material will remain on the road surface compared with the same spread rate of dry material. This is especially true when combating black-ice conditions or when the roadway is damp and the potential exists for the development of a slippery condition.

Salt requires moisture to dissolve into a solution to become effective. However, at temperatures below freezing, there may be little unfrozen moisture available to facilitate the transformation of the solid salt to a solution. Prewetted salt has moisture supplied from an external source, which allows the salt to dissolve into a solution and become effective more quickly than dry salt. Besides having a quick reaction time, prewetted salt is more effective at lower temperatures than dry salt from an operational perspective. From experience, when the temperature is lowered to about −7°C (19°F), the time needed for the melting process to begin is longer than acceptable for operations. With prewetted salt, a solution is present from the outset, even at temperatures below −7°C (19°F).

When using prewetted salt, the spreading width of the material on the pavement can be controlled better since the material will bounce less than dry salt. The reduction in bouncing may also allow the spreading vehicle to travel at a greater speed, which will reduce the differential speed between the spreading vehicle and the traveling public.

If designed properly, a prewetted salt system can decrease cost and increase effectiveness compared with conventional dry-salt systems.

Factors to Evaluate

Changing to a prewetted salt operation requires more than just adding moisture. There are other factors to consider. All aspects of winter road maintenance operations must be reviewed when a change is being considered for one component of the system. An evaluation is needed to determine how each change will affect the rest of the system. Some areas that should be reviewed to achieve the potential benefits of prewetting salt are particle size, prewetting liquid, liquid manufacturing and storage requirements, and prewetting methods.

The conventional salt gradation was developed several years ago for deicing operations that required the dry particle to penetrate into snowpack. With the addition of a liquid, the particle will embed in the snowpack more efficiently, facilitating the penetration of the particle to the pavement surface. As the profession moves toward a more preventive approach as opposed to the conventional reactive mode of operation, the particle size will be a factor that should be evaluated. Anti-icing is such a preventive approach. In implementing anti-icing strategies, many highway agencies are opting to apply snow-and-ice-control material early in storms and follow up with additional applications in a timely manner during the storm to prevent the formation of a bond between the snow and ice and the pavement surface. This approach requires a change in the material application process. A finer gradation of salt will allow more moisture to be added to the dry salt, reduce the time for the salt to go into solution, and reduce the undesirable scattering of large salt particles during both the application process and subsequent wind turbulence caused by passing vehicles.

As noted, prewetted salt is salt with moisture added. However, questions such as what liquid should be used to supply the needed moisture and how much moisture is appropriate need to be addressed. The answers to these questions will depend on the conditions existing at the site. The more moisture available, the less time it will take for the salt to dissolve into solution. If moisture is readily available from slush on the pavement surface, for example, a different amount of moisture may be necessary than if the pavement surface were dry. As mentioned earlier, the salt particle size is another factor that should be considered in determining how much moisture to add. In general, the amount of prewetting liquid is from 5 to 30 percent by weight. If the only important characteristic of the liquid is that it wet the salt during the spreading operations, water will suffice. However, the material-handling requirements of water below freezing temperatures may not make it the most appropriate material. Because of the potential problems associated with water, a low-cost liquid with better low-temperature handling characteristics may be more appropriate, such as NaCl brine, which in a saturated solution has a eutectic temperature of −21°C (−6°F). If the prewetted material is applied to prevent a black-ice condition from occurring, use of calcium chloride ($CaCl_2$) may be appropriate. The hygroscopic properties of $CaCl_2$ will cause it to retain moisture better on spread material at lower relative humidities than NaCl. Other liquid materials, such as magnesium chloride, calcium magnesium acetate, and potassium acetate, should also be reviewed.

Factors to consider when selecting the liquid type are the manufacturing, storage, and handling requirements. The following questions should be addressed.

- Will the liquid be manufactured on-site or delivered ready for use?
- What is the quality of the liquid needed?
- What percentage of nonsolubles is acceptable?

• What are the potential hazards associated with material handling?

• What are the storage requirements? Do they require indoor storage, external heat, or agitation?

• How much time is acceptable to reload the spreader?

These questions and others must be answered, and the results will differ depending on the sites' specific conditions.

There are several acceptable methods for moistening salt. Some common examples are as follows:

• Inject liquid into the salt in the loader bucket during loading of the spreader hopper.

• Shower or inject liquid on or in the salt in the spreader hopper during loading or after loading is completed.

• Shower or inject liquid on or in the salt at the spreader auger on the tailgate spreaders.

• Shower liquid on the salt as it is transferred from the hopper onto the spreader chute where the prewetted salt will be conveyed to the spreading disk.

• Apply liquid to the salt as the materials come in contact with the spreading disk.

There are advantages and disadvantages to each method. Among the factors that will influence the decision are the liquid-to-solid ratio, available resources, liquid capacity on spreader vehicle, efficiency of material handling, and liquid type.

Summary

The winter maintenance policy for a highway is provided by the assignment of a level of service. The maintenance engineer has many options available to achieve the prescribed level of service. Systems for prewetting snow-and-ice-control materials are improving and should be evaluated. They could become additional tools for winter road maintenance operations.

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PAVEMENT MAINTENANCE

Use of Deflections To Manage the Structural Maintenance Requirements at Network Level in England

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A major task for the manager of a maintenance program is to collate and present a robust case for funds to ensure that the network is maintained at an appropriate level. In England a project was conducted to collate and analyze deflection data collected, principally for project-level design, for the benefit of network-level planning. The total national highway network in Great Britain is some 11 000 km long, representing only 4 percent of total road length but carrying 30 percent of all traffic and 60 percent of heavy traffic. Deflection data usually are collected under contracts let by some 90 maintenance agents. Between 1985 and 1991 some 80 percent of the length of flexible roads was surveyed, some of it more than once, and the results analyzed. On the basis that the most cost-effective strategy for strengthening is to overlay the surface at the critical point, the network has been shown to be in suboptimal condition. The project collated deflection data and presented them in a consistent and easily understood format to illustrate requirements for restoring the network to its optimal condition. Condition data were also analyzed through a network model to investigate alternative strengthening strategies over the medium and longer terms. Collection and analysis of data in this way offers the opportunity to carry out valuable audits of the range of projects put forward—and not put forward—by agents. It therefore improves the management of maintenance at both network and project levels.

Major highways in developed and many developing countries constitute an enormous capital asset that requires correspondingly high investment to maintain its serviceability and load-carrying capacity. Understandably, bids from highway authorities to their national governments for the funds necessary to service and strengthen major roads must stand up to rigorous analysis if the required funds are to be secured.

At the same time as bids for network-level funding are being prepared, the highway authority must collect various condition data so that when funds become available it can make objective decisions on how and where they should be spent. It is logical and possibly cost-effective to investigate the potential for using the large amount of condition data collected routinely to support the bid for network-level funding.

This paper describes how the Highways Agency in England has used deflection data for project-level design to set out a robust case for funding to strengthen the motorway and all-purpose trunk road networks. Strengthening treatments that provide thicker structural overlays have been identified as offering optimum value for the money when carried out at the critical condition. The output from this analysis of deflection data, known as "The Residual Life Report," has shown clearly that the network is in suboptimal condition. The report also provides data from which a strong case can be made for a coordinated program of structural strengthening to restore the network to the desired condition.

Considerable effort has been devoted to presenting the output in a form that can be understood by the layman and politician, since it is the latter who must be convinced of the case for additional funding. A thoughtful mixture of simple graphics and concise text has illustrated the soundness of the work. Moreover, the case for adequate funds to achieve the optimal condition of the network has been recognized, so that even in the present difficult financial climate, provision for strengthening the national network has held up well, though understandably not as well as had been hoped.

The English Road Network

Responsibility for managing and maintaining the 274 000 km of public roads within England is delegated by Act of Parliament to 108 highway authorities. Within this total length of highway, the Department of Transport (DOT) is responsible for the national strategic network, that is, the motorway and all-purpose trunk road (APTR) networks, which total some 3000 and 8000 km, respectively. Even though this length of network only represents 4 percent of the country's total road mileage, it carries 30 percent of the total vehicle kilometers traveled annually and some 60 percent of heavy goods traffic. The remaining 70 percent of all traffic (and 40 percent of heavier traffic) is carried on the lower hierarchical levels of road, managed by local government highway authorities.

The day-to-day management of the motorway and APTR networks is carried out on a geographical basis by maintenance agents reporting through a regional office to a headquarters division in London. As of April 1, 1994, there were some 90 maintenance agents reporting through 9 regional offices. Of these agents, 84 were local government highway authorities and 6 were consulting engineering practices from the private sector. Within this organizational structure, the local government highway authority agents operate under a single agency agreement, which sets out in broad terms the duties delegated to them by DOT, the information flows required from them to DOT before work can be approved and funds allocated, and the fee scales. The consulting engineering practices operate under individual contracts covering the functions similar to but more specific than those contained within the single agency agreement, with the level of reimbursement governed by the tendered fee rates.

Maintenance Expenditure

Current levels of annual expenditure by DOT in maintaining these networks is running at approximately £670 million, with £360 million spent on the rehabilitation of pavements, £150 million on the rehabilitation of structures, and £160 million on routine cyclical maintenance. As with any organization, public or private, that undertakes this level of annual expenditure, business activities must be monitored continually to ensure adequate value for expenditure and to strive for efficiency improvements by introducing new initiatives. Part of this process in England involves the Public Accounts Committee (PAC) of the House of Commons, which receives reports of studies undertaken by the National Audit Office (NAO). NAO is authorized by Parliament to investigate issues of value-for-money and propriety associated with programs and policies managed by government departments and agencies with expenditure authority.

In 1991 PAC received a report from NAO on the "Management of Road Maintenance." Following a committee hearing with senior DOT officials, a report was published that included the following two recommendations:

> We consider that the Department need to have better information on the condition of roads in order to deploy their funds most cost-effectively;
> We are concerned about past inadequacies of the Department's data on road condition, and note that the national structural survey of the condition of roads had to be abandoned because the data provided by their agents were incomplete and inconsistent. (House of Commons Committee of Public Accounts Third Report—Management of Road Maintenance, November 1991)

In the DOT's published response to these recommendations it stated:

> The Department shares the Committee's concern over past inadequacies and has instigated a programme to improve the monitoring and reporting of the condition of roads. The report by consultants on the structural condition of the network (The Residual Life Report) is the first example of this process. (Treasury Minute in Response to the PAC Report into Management and Road Maintenance)

Management of Maintenance

A highway network, especially a busy one, should be monitored regularly to assess its physical condition and change in condition. However, such monitoring is inherently dangerous for operators of survey equipment, and slow-speed survey methods inevitably cause disruption for road users. In practice, therefore, a hierarchical approach to condition surveys is required. High-speed and low-unit cost surveys that minimize disruption to traffic while maximizing the safety of the operation are undertaken most frequently as part of a first-pass program before subsequent detailed investigation using other survey methods. Routine surveys by slower-speed equipment must still be carried out to define the physical state of the network, but at less frequent intervals than previously. Slower-speed surveys are also now targeted, based on information from the first-pass surveys.

A high-speed first-pass survey is carried out using the High-Speed Road Monitor (HRM) (*1*), which utilizes laser technology. This defines the present functional condition of the network. Also, results from two HRM surveys (at intervals of 1 or 2 years) can be compared to identify sections of road where the condition is changing. More detailed surveys, such as deflection surveys and visual condition surveys—in England we use Computerized Highway Assessment, Ratings and Treatment (CHART)—can then be carried out to determine the reason for the change in condition as well as to define the residual life of the whole network from routine surveys. These more detailed surveys are normally repeated on a 3- to 5-year cycle. The texture results obtained from the HRM support the skid-resistance measurements obtained from network-wide surveys carried out on a 3-year cycle, using the Sideway-force Coefficient Routine Investigation Machine, SCRIM (*2*).

Deflection Surveys

Highway maintenance design methods that include prediction of the need for strengthening and estimates of the treatment thicknesses required are based on a structural evaluation of the existing pavement. The considerable and rapid variation in structural condition, or strength, that occurs along most flexible roads, particularly as they approach a critical condition and require strengthening, dictate that routine measurements of strength be taken at closely spaced intervals to allow strengthening proposals to reflect the variation. The additional need to survey large lengths of road each year effectively limits the possible measurements to those that can be taken on the road surface. In practice, therefore, the evaluation of the structural condition of flexible pavements is based on the measurement of the maximum displacement of the road surface generated by the application of a test load. These measurements can be obtained with a Pavement Deflection Data Logging Machine, PDDLM (*3*), which is the United Kingdom version of the Deflectograph.

The primary function of the PDDLM equipment is to measure, simultaneously in both wheelpaths, the maximum, transient deflection of the road surface produced by the passage of the loaded rear wheels along a road. The beam assembly, which measures deflection, is positioned beneath the vehicle chassis and between the two rigid axles. It is raised clear of the road when traveling between sites at normal operating speed. During operation, when the vehicle speed is constrained to 2.5 km/hr, it rests independently on the pavement surface.

The downward movement of the road surface produced by the approach of the rear wheel assemblies is monitored by a pivoted deflection beam. A displacement transducer, located near but ahead of the beam fulcrum, converts the beam's downward movement into an electrical signal. Deflections are measured and recorded for routine purposes at intervals of about 3.8 m in both wheelpaths.

The equipment can monitor 12 to 20 lane-km per day, producing 3,000 to 5,000 individual measurements in each wheelpath. Machines of this sort currently monitor about 18 000 lane-km of the United Kingdom road network each year.

Design of Strengthening

The deflection measurements provide the major input to the United Kingdom structural maintenance design system for flexible pavements (*4,5*). The survey and design procedures are integral requirements to be included in the submission of bids to obtain funds for structural maintenance of national roads. The method uses the PDDLM deflection measurements to characterize the structural condition of a pavement. The output from the PDDLM is used to (*a*) predict the residual life of an existing pavement and (*b*) estimate the thickness of overlay required to extend the life of a pavement for a specified period (expressed in terms of standard axles).

The design method is based on correlations of measured deflection and pavement performance from a large number of full-scale road experiments. The method has undergone a process of continuous development and validation by the United Kingdom's Transport Research Laboratory (TRL) over 20 years.

Residual life as defined by the design method relates to the onset of critical conditions in a road pavement. The critical condition is defined as the point in the life of a pavement at which the rate of deterioration becomes less predictable, and where deterioration accelerates, leading over a period of several years to a failure condition. During the period of acceleration to failure, the existing strength in a pavement may diminish rapidly, and the cost of maintenance implemented beyond the critical condition can be expected to increase. In the short term, a road will remain serviceable to vehicular traffic beyond its critical condition, providing that patching and other palliative measures, such as surface inlay techniques, are implemented. These measures become increasingly costly to carry out and inflict ever-increasing disruption on the road user.

Survey Coverage

The analysis reported in this paper includes the deflectograph results from the most recent survey recorded on about 3900 slow-lane km of the motorway network and on about 9500 km of APTR network. All sections tested by the deflectograph from 1985 to 1991 for which sufficient information is available to enable them to be located accurately are included.

The overall results from about 76 percent of the total network in England, excluding known lengths of rigid and elevated sections, have also been included in this study: about 91 percent of the total for motorways and 71 percent of the total for trunk roads.

The analysis procedures reported are updated annually, with each successive year's survey results added. In addition, since 1992, the method of analysis and reporting has been extended to the next lower category of road, principal roads; in 1992 the results for approximately 25 000 lane-km were included. This is expected to increase to about 60 000 lane-km by the end of 1995.

Deflection Analysis

The residual life has been determined for 100-m-long sections of road on the basis of the 85th percentile deflection level. The 85th percentile level has been calculated from the combined wheelpath individual deflection values. The 85th percentile deflection levels have been converted into equivalent residual-life values, defined in years, using construction and traffic-load data supplied by the maintenance agents.

For the purpose of analysis and presentation, residual lives have been corrected to the reporting year (1992 in the case of this paper) and grouped into the residual life bands (in years) given in Table 1.

For effective map-based presentation of the residual life along the network, the residual life has also been calculated for section lengths in excess of the basic 100 m. Where alternative section lengths have been adopted, the residual life has, in all cases, been based on the 85th percentile level of combined wheelpath individual deflections.

The deflection results used in the analysis have been collected from cyclic surveys carried out over 6 years. The calculated residual lives cannot automatically take account of maintenance work undertaken during the 6-year period, unless a subsequent survey has been undertaken on the maintained lengths. Without modification, the residual lives calculated would therefore present a very pessimistic view of the state of the network. To correct for this effect, the calculated residual lives have been modified where subsequent maintenance work has been undertaken by updating the calculated values to an assumed 20-year design life (the norm in England) from the date of maintenance. Details of the location of strengthening and the deflection files are supplied by maintenance agents and edited over the appropriate lengths to take account of these construction updates.

Reporting Style

With the work being targeted as much at a nontechnical audience as at a technical one, the presentation of the results was of major importance. Results are presented separately by motorways and APTRs and, for each of these groups, further classified at the national, regional, and agent level. Four basic forms for presenting results have been adopted on the basis of the six residual life bands defined in Table 1:

1. Pie charts showing percentage of 100-m-section residual lives for each 100-m section within each of the life bands (Figures 1 and 2);
2. Color-coded maps showing the location of lengths of road falling within each of the life bands;
3. Tables, such as the example of Table 1, summarizing the pie charts; and
4. Moving cursor plots.

Typical pie charts for the conditions in 1992 are shown in Figure 1 for motorways and APTRs. The figure shows the distribution of residual life in segments representing the percentage in four separate 5-year bands plus the percentages that are past critical and have a residual life greater than 19 years.

Figure 2 shows the distribution of residual life on sections of the road immediately prior to strengthening; the distributions show that very large proportions of the lengths receiving maintenance have short residual lives, demonstrating good targeting of maintenance treatments.

Figure 3 shows the distribution of residual life on strengthened pavements. The relatively high proportion of short lives shown in this figure points to the need for more detailed studies. Procedures for updating traffic files and for referencing deflection surveys may partially account for these results.

The English motorway network is relatively modern, as shown in Figure 4, but because of very high increases in traffic loading in the last 10 to 15 years, much of the network has been or will need to be strengthened in the next few years.

Color-coded maps are developed against plain backgrounds at the national and regional level and against a relief background at agent level (1:50,000 scale). These could not be reproduced satisfactorily for this paper.

The distribution of residual life at network level on the motorway and trunk road networks is given in an alternative style in Table 1. Despite improvements in survey coverage, the general condition has remained broadly similar over the study period. However, the survey trend of slowly deteriorating condition recorded between 1989 and 1991 was arrested in 1992, and results for 1993 confirm a small improvement.

What has been termed a moving cursor presentation has been produced for the motorway and trunk road networks. This presentation involves the display of 85th percentile values of 100-m sections graphically with a 4-km moving average superimposed (nominal maximum length

TABLE 1 Comparison of Changes in Condition

Motorway Network

Residual Life Band	1992	1991	1990	1989
<0	16.13	16.57	15.45	14.37
0-4	23.55	23.40	22.64	21.31
5-9	18.14	19.05	19.37	17.73
10-14	10.06	10.59	11.16	11.45
15-19	16.76	14.65	13.92	6.84
>19	15.36	15.74	17.47	28.30
Total Length (km)	4299	4265	4265	4408
Coverage (%)	91	91	83	69

Trunk Road Network

Residual Life Band	1992	1991	1990	1989
<0	14.66	15.48	13.86	12.75
0-4	12.91	12.92	12.94	11.33
5-9	12.83	12.17	12.68	11.84
10-14	10.31	10.26	10.50	9.99
15-19	13.13	11.31	9.73	8.14
>19	36.16	37.86	40.28	45.45
Total Length (km)	13421	13951	13796	13863
Coverage (%)	71	71	67	55

for maintenance schemes). Moving cursors show previous moving averages so that consistency of prediction can be confirmed on a routine basis. The plots also present information on the age of the carriageway and details of traffic loading. Again, these plots could not be reproduced with sufficient clarity for this paper.

Uniformity of Results

Routine deflection surveys have been tested to assess the uniformity with which the design method predicts the residual life both at network and at project levels. The uniformity study was based on an analysis of more than 1500 km of carriageway where repeat independent deflection surveys separated by between 1 and 5 years had been completed during the period between 1985 and 1991. The residual life of 100-m-long sections was used in the study. An analysis of the distribution of differences in the residual lives predicted by the most recent and earlier survey showed that, at the network level, the predictions from the two populations differed by only 1 to 2 years. For sections of the network with residual lives predicted by the most recent survey to be between 0 and 5 years (i.e., approaching the time for maintenance), the error in predictions at the network level reduces to 1 to 1.3 years. At the project level, 70 percent of all paired residual life predictions for 100-m-long sections from a second survey on the same section of carriageway are shown to be within ±3 years of the prediction made by an earlier survey.

Modeling of Future Needs

A subsidiary aspect of the commission was to undertake a comparison with a TRL research model of a budget

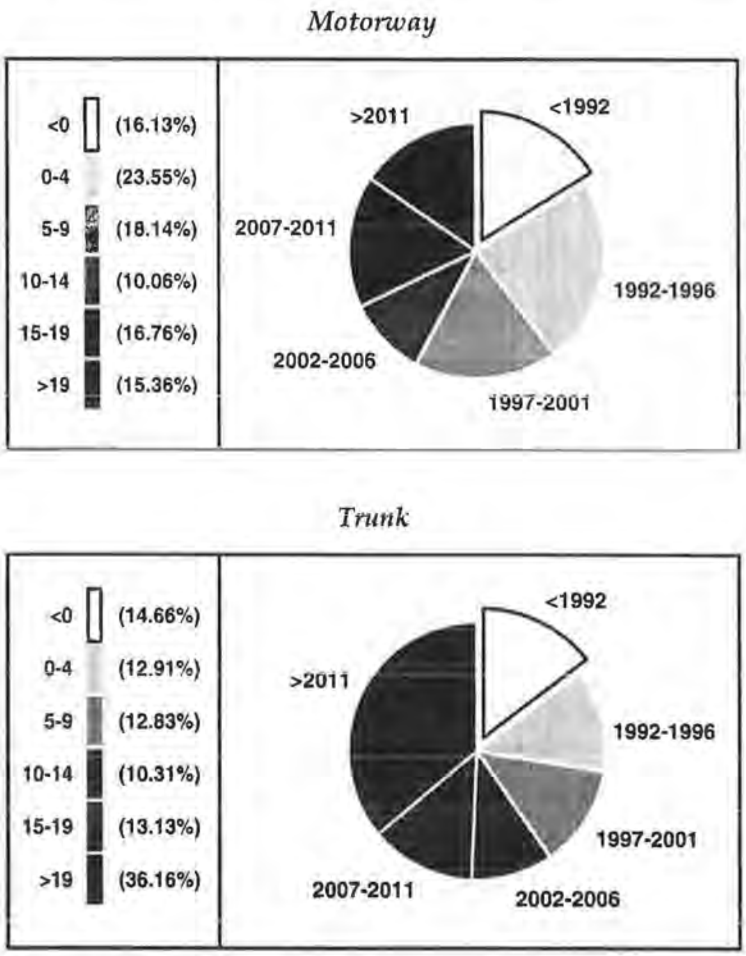

FIGURE 1 Residual life of the network corrected to 1992, including data from 1985 through 1991.

profile analysis for the motorway network. The main objectives of the budget exercise were to investigate (*a*) the structural maintenance budget options over a 30-year period, based on real schemes, and (*b*) the location of candidate schemes over the study period.

Several assumptions and rules have been applied to the model for this comparison:

1. There is no variation in treatment costs with time.
2. Treatment costs are based on three lanes plus hard shoulder carriageways (the normal cross-section standard for motorways).
3. No traffic delay costs are included in the analysis.
4. The maximum overlay is 250 mm and the minimum overlay is 50 mm with possible overlays in steps of 25 mm between these limits.
5. No treatments other than reconstruction or overlays are applied in the analysis, and these treatments restore the scheme lengths to a residual life of 20 years.
6. Residual lives greater than 30 years will form one band of the residual life distribution, as will residual lives less than zero.
7. Reconstruction is only permitted at residual life = -7 years.
8. Overlay is only permitted at residual life = 0.
9. The maximum permissible scheme length is 8 km and the minimum permissible scheme length is normally 1 km.
10. No buffer zone restriction is placed on gaps between schemes in any one year.

The Modeling Process

The modeling for budget analysis is based on 10-m length, 85th percentile deflections from the network residual life files.

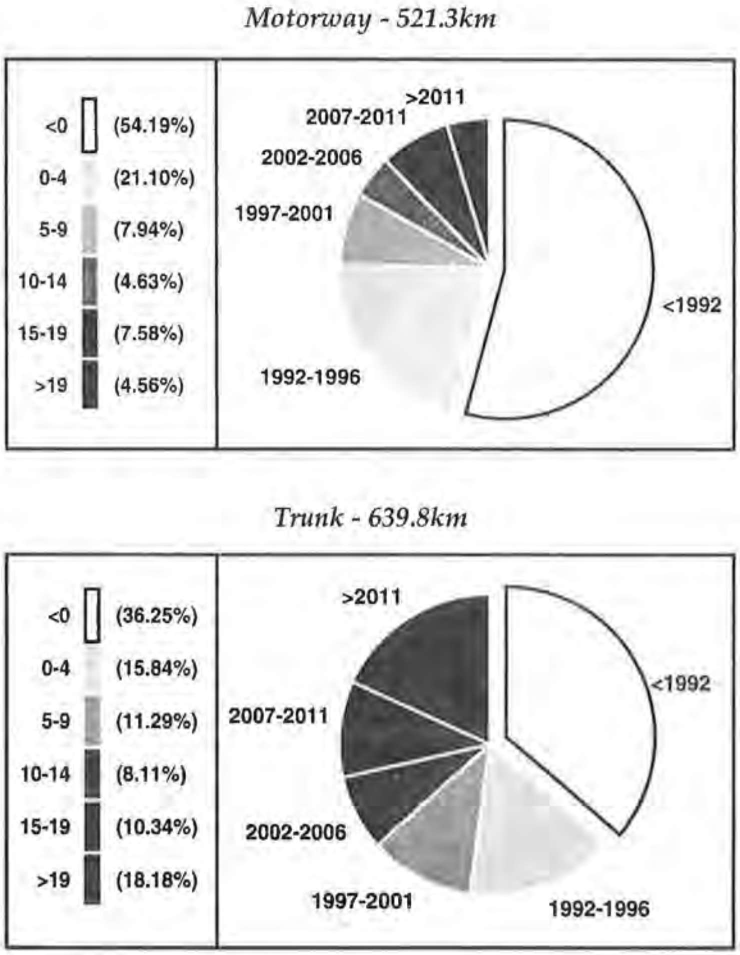

FIGURE 2 Residual life of renewal sections before any work was undertaken.

The results of the deflection surveys are trended forward in time to define residual life and overlay requirement for each 10-m length. An interactive statistical analysis of the residual life data is then used to create "schemes" representing lengths of carriageway that are statistically homogeneous in terms of condition. The year in which maintenance is required is defined for each scheme, and the maintenance policy, rules, and assumptions are applied across the whole motorway network over the 30-year budget period. Strengthening requirements for each scheme are then defined with its location. Two forms of output are produced from the budget analysis:

1. Costings, both discounted and undiscounted, to maintain the network over the study period can be presented in diagrammatic form.
2. Map-based presentation can show, for the 10-year period 1992 to 2002 an array of information: the location of schemes, the year they should be implemented, and a broad indication of treatment requirements (e.g., at regional level).

Future Developments

The analysis described uses full referenced network data held on a relational data base. It is possible therefore for traffic delay costs and other condition indicators such as the results from HRM and SCRIM surveys to be added to the analysis, and for full optimization to be undertaken against either cost-benefit analysis or condition of the network. At a much simpler level, more realistic rules on maintenance scheme lengths and gaps between scheme could be implemented to make the automatic scheme definition module even more realistic. The system in its present state could be used to evaluate alternative maintenance intervention policies, for instance, adding thin overlays after 10 years of a 20-year design life, to compare net present values.

Use of Results at Network Level

The information contained within the annual reports from the consultants on the structural condition of the mo-

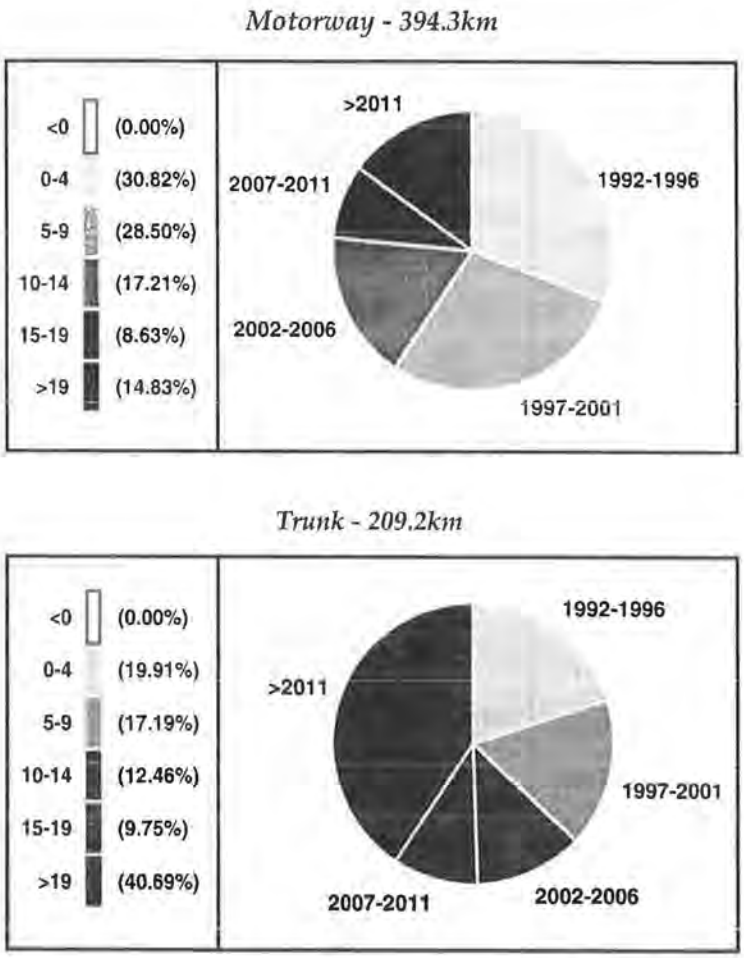

FIGURE 3 Performance of renewal sections.

torway and APTR networks, as given in Table 1, has helped the agency to respond to the recommendations of PAC, listed earlier in this paper. In addition it provided the department with robust information to program a national package of maintenance works.

Having assembled this information, the agency is now in a position to develop a stronger case, based on value for money, for funds to achieve these targets on a needs-led basis. The case has continued to be convincing and has helped to secure additional funds.

USE OF RESULTS AT PROJECT LEVEL

The color-coded maps and moving cursor plots have enabled the department at both regional and national levels to adopt a more hands-on style. This has been the first time that comprehensive information on the entire network has been made available to these parts of the organization. In the past agents were only required to put forward structural information on lengths of the network they had identified as being in need of treatment. This extra information has enabled the department to be more proactive in identifying schemes that should be put forward by agents, and it is anticipated that this will improve the targeting of maintenance schemes, as shown in Figure 2, and possibly reduce the time required to eliminate the backlog.

Confidence in the department's use of the deflection design system in targeting schemes has been enhanced following the delivery of the uniformity report. The results of this study show that the design system, which includes collection and measurement of deflection and associated data as well as the performance models themselves, makes consistent predictions of residual life and that the maintenance schemes identified are located in a reproducible manner.

The results from the budget analysis study agreed closely with the analysis undertaken by TRL using its own

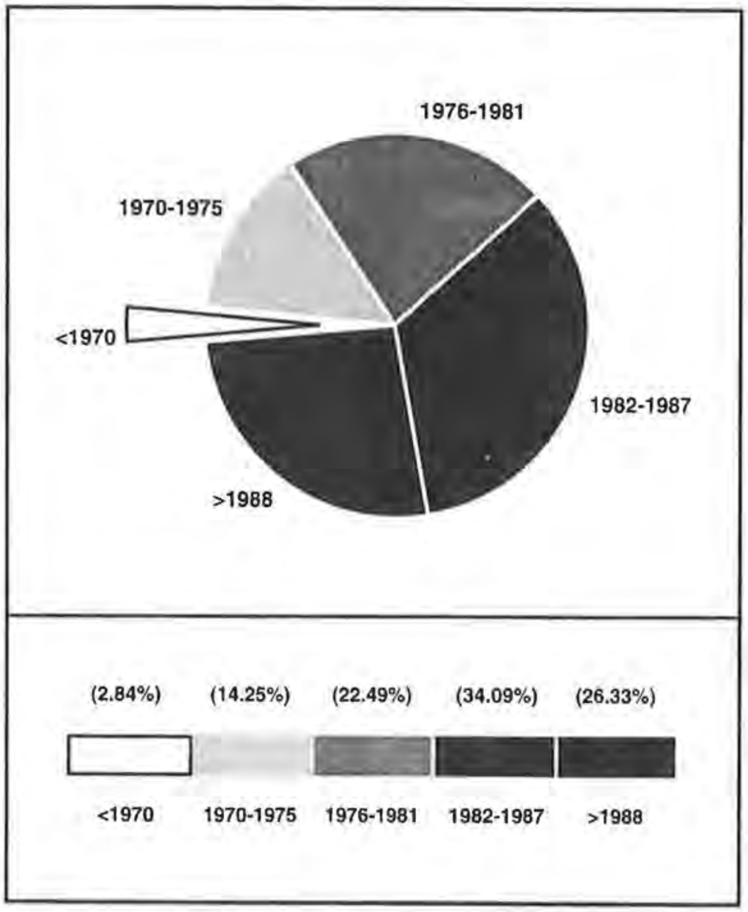

FIGURE 4 Distribution of age of motorways.

model and in broad terms with the current budget profile identified by DOT. The scheme locations, their extent, and the estimate of overlay treatment thickness generated automatically in the study were compared by the regional offices with those generated by the agents using more traditional manual techniques of data analysis. They concluded that there was sufficient agreement between the two to enable the automatically generated program to be used as one of the source documents in formulating an indicative national program of schemes over a 5-year period.

CONCLUSION

This project has shown the condition of the national network. The work has cost only about 0.1 percent of the cost of carriageway maintenance and, because it uses the data collected by agents for project-level design, offers the opportunity for checks on the consistency between the two exercises. Work will continue to improve the quality and reliability of the Residual Life Report, but it has already proved to be a very effective tool for determining network-level requirements from project-level data.

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Taxonomy of Institutional Barriers to the Implementation of Pavement Management Systems

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The benefits of a pavement management system when fully implemented are well known, and the history of successful implementation is rich. Implementation occurs when the pavement management system is the critical component for making pavement decisions. However, there are barriers to the full implementation of pavement management systems. Institutional barriers, not technical and financial barriers, are more commonly responsible for a pavement management system's falling short of full implementation. In general, highway agencies should put more effort into overcoming these barriers. The Iowa Department of Transportation has designed an implementation process to overcome institutional obstacles and facilitate the implementation of its pavement management system.

Pavement management technology has matured in the past two decades, and excellent and inexpensive pavement management system software packages are now available. But the implementation of pavement management systems and the use of state-of-the-art pavement management techniques have been far less successful than expected, despite the beneficial experiences defined in the literature on this subject.

To understand the contention that pavement management implementation has not been as broadly successful as expected requires a common definition of implementation. Operating a pavement management system is not the same as implementing it. Smith and Hall have defined the implementation of a pavement management system as occurring "when pavement management becomes the critical component for making pavement management decisions" (*1*). Under this definition, an agency may operate a pavement management system, but if the system's results are not a critical component of decision making, the system has not been implemented. Smith and Hall's definition thus extends beyond the purchase of a pavement management system and even the development of supporting data bases and personnel.

State agencies have developed excellent pavement management systems, but they only give the system's results lip service when making actual resource allocation decisions. Other agencies restrict the use of the pavement management system's results to supporting resource allocation decisions for a limited portion of the highway network (e.g., only applying to Interstate highways) or for a specific category of activities (e.g., major restoration projects).

The likely benefits of pavement management systems have encouraged federal policy to mandate their operation. For example, in March 1989 the Federal Highway Administration established a policy requiring all state highway agencies to have an "operational" pavement management system by January 13, 1993 (*2*). The Intermodal Surface Transportation Efficiency Act of 1991 requires all federal-aid-eligible highways to be included in a pavement management system and, at the risk of federal sanctions, the pavement management must be implemented by October 1, 1997 (*3*). However, it is unlikely that federal pavement management mandates will result in complete adoption of pavement management systems as a critical element in pavement resources decision making. States may successfully develop operational pavement management systems, but actually integrating them into decision making is a separate matter.

This paper discusses the barriers to true implementation of pavement management systems. Institutional barriers, not technical or financial barriers, are more commonly responsible when a pavement management system falls short of actual implementation. The paper groups institutional issues into a general taxonomy. The final portion of the paper summarizes the implementation process of the Iowa Department of Transportation (IDOT). The Iowa approach is deliberately designed to overcome institutional issues and facilitate the complete implementation of a pavement management system.

Barriers to the Implementation of Pavement Management Systems

The three fundamental barriers to the implementation of pavement management systems are technical issues, financial and resource issues, and institutional issues.

Technical Issues

Technical issues relate to the methods necessary to conduct pavement management, to the technology and methods needed to collect data, and to available data base tools. There are three major technical barriers to viable pavement management systems:

1. Lack of a technically viable methodology to perform pavement management;
2. Lack of a knowledge base in pavement management processes and procedures; and
3. Lack of viable technology including field data collection, data base, and data processing technology.

Pavement management was first conceived in the mid-1960s (*4*). By the mid-1970s pavement management had expanded primarily for employment at the network level and involved the planning, programming, and budgeting of funds. Early network pavement management systems involved large mathematical-programming computer packages, which required massive efforts for development and were operated on expensive mainframe computers. In the 1970s and early 1980s, pavement data collection methods were still developing. Data collection strategies were often subjective, involving manual data collection methods. Both the pavement management analysis systems and the data collection methodologies in the 1960s, 1970s, and early 1980s presented significant technical barriers to the adoption of pavement management systems. By the late 1980s and early 1990s, however, pavement condition evaluation methods became more structured. Several technologies are currently available to automatically measure pavement condition. Also by the early 1990s, mainframe computer pavement management systems had been adapted to operate on inexpensive microcomputers. In fact, the currently available microcomputer versions of pavement management system software and data bases are more robust than their mainframe predecessors.

Clearly, barriers due to a lack of pavement management system methodologies, lack of a pavement management knowledge base, and lack of adequate technology have been overcome. This does not mean that no additional technical issues remain to be solved, but that pavement management systems have matured and technical issues should no longer create a barrier to implementation.

Financial Issues

Financial issues relate to the cost of implementing the system. For example, the original mainframe network pavement management systems cost several hundred thousand dollars to develop and install. Currently, more robust microcomputer pavement management software systems that cost only a few thousand dollars are available. As a result, the cost to operate and install pavement management system software has diminished considerably. Although the costs of implementing a pavement management system may have acted as a barrier to implementation in the past, system costs should not currently present an obstacle.

Institutional Issues

Institutional issues that impeded the implementation of pavement management systems result from the inability of highway agencies to truly incorporate pavement management systems into resource allocation decisions. Highway agencies have operated without fully effective pavement management systems for most of their existence. As a result, these agencies have well-established decision-making patterns that are independent of pavement management approaches. The inflexibility of these patterns prevents effective pavement management. Institutional issues may range from simple issues involving a lack of communication between the relevant offices within a highway agency to troublesome issues involving independence of decision making between the central office and field offices (turf battles).

The institutional issues that bar implementation of pavement management systems are particularly problematic because pavement management cuts across the boundaries of several functional disciplines within a highway agency. Pavement management should involve the functional areas of materials and material testing, construction, highway design, maintenance, highway program planning, highway improvement planning, research, and others. Individuals from all the functional areas must cooperate for implementation to succeed. Obviously, the interdisciplinary nature of pavement management creates opportunity for many institutional problems to arise, and the specifics of each are unique to the organization. However, these institutional issues can be grouped into four broad categories:

1. Lack of an agency mandate or directive to implement pavement management and to use the pavement management system as a critical part of the pavement resource allocation process (lack of a champion);
2. Lack of ample or appropriate resources to implement pavement management;
3. Incompatibilities or inconsistencies between groups, offices, or divisions within the organization; and
4. Laws, administrative rules, organizational charter, or codes that preclude the implementation of pavement management.

Lack of an Agency Mandate

Because pavement management systems require cooperation among several functional areas within a highway agency, successful implementation calls for a top manager to serve as a pavement management champion to promote collaboration among the various functional areas (e.g., between maintenance and design). Particularly in state highway agencies, pavement management is commonly promoted by one office, often the office involved in materials and material testing or the research office. A single-office initiative is an outcrop of the traditional view that pavement management implementation is a technical issue. Because the development of a pavement management system appears to be an issue of system design and development involving engineers, systems analysts, and technicians, implementing a pavement management system is perceived to be just another technical problem.

Top management may mistakenly believe that implementation of a pavement management system is a technical issue and does not need top management's support and attention. However, incorporating the system into the decision-making process requires the resolve and focused support of top management, who must champion and promote the acceptance of the pavement management process by all participating offices.

Typical symptoms of the lack of a top management mandate are resistance to change and resistance to incorporating new techniques into the pavement resource allocation process because an approach is different from traditionally accepted methods. Agencies without top management direction may also suffer from balkanization. For example, pavement management may be placed under the direction of one office or one individual to expedite development without considering its links with other offices or individuals important to implementing the pavement management system recommendations. Without top management's promotion of collaboration between offices and the substantial opportunity for other offices to participate in system design, achieving cooperation among functional disciplines is likely to be difficult.

Lack of Ample or Appropriate Resources

The availability of ample or appropriate resources relates to the ability of highway agencies to provide the personnel, intellectual skills, and material resources necessary to implement pavement management systems. As previously stated, pavement management system costs have declined considerably, and highway agencies typically have the financial resources to implement such systems. However, institutional issues may preclude an agency from bringing to bear the appropriate intellectual resources or budgeting ample resources to completely implement pavement management.

The appropriate use of pavement management systems requires knowledge of systems approaches, pavement design, pavement maintenance, automated testing equipment, and computer systems. Traditionally, highway agencies are very knowledgeable about pavement design and management. Although a highly specialized knowledge of systems approaches is not a requirement for operating a pavement management system, a good working knowledge of systems concepts and engineering economy is needed. On the other hand, development of a customized pavement management system requires specialized knowledge of systems approaches, computer software, and data base development tools. To develop a customized system or operate a commercially available package may require particular intellectual resources that are unavailable within a highway agency. Even large agencies may have difficulty in attracting specialized individuals to develop and implement the pavement management process.

Further, in an era of downsizing (sometimes euphemistically referred to as rightsizing), it may be difficult for agencies to devote the personnel resources necessary to fully implement a pavement management system. Although pavement management systems may ultimately save an organization financial resources through better pavement resource allocation decisions, public agencies are seldom given the opportunity to transfer savings from expenditures on physical assets to increased expenditures for management personnel, data processing resources, and pavement testing equipment. Even though a pavement management system may ultimately provide significant savings, finding appropriate and adequate resources for implementation may be a significant institutional barrier.

Organizational Incompatibility or Inconsistency

Pavement management systems require resource allocation decisions to be made in a more open and systematic environment, and the system provides an overarching conduit for decision making among offices and divisions. In the past, decisions may have been made more subjectively and in relative isolation. Replacing old approaches with open and systematic approaches often results in turf battles over decision-making authority and conflicts between parts of the organization with inconsistent objectives. Inconsistency in the definition of objectives may result from an agency attempting to develop centralized control over pavement management decisions and reducing the autonomy of field offices. Inconsistency in objectives may also result from a data processing office's need to justify its investment in expensive mainframe computers and skilled data-processing staff while pavement managers may want to operate in a more robust microcomputer environment requiring little data-processing support. Inconsistency in objectives between offices and within organizations can become the most significant barrier to the implementation of pavement management.

Incompatible Laws, Rules, Charters, or Codes

The least common of the institutional issues, legal and administrative issues, include those barriers presented by laws, administrative rules, organizational charter, or codes. However, an agency facing such barriers may find them difficult to overcome. For example, local legislation identifying specific street maintenance policy may conflict with a pavement management system, or a legislated organizational structure may place maintenance and construction of highways under the domain of separate political jurisdictions (i.e., townships and counties), complicating the highway agency's task. An administrative or legislated decision may require each subdivision (a ward of a city or district of a state) of the entire jurisdiction to receive equal proportions of maintenance or capital investment, thus overriding resource allocation decisions based on pavement management criteria.

Implications of Institutional Issues

Internal institutional issues have left some highway agencies incapable of even beginning the implementation process, or have caused them to start developing a pavement management system only to later retrench and abandon it. Other agencies have developed pavement management systems but have not incorporated them into the pavement management decision process, or have limited their use to specific programs. At the very least, the contentiousness of pavement management system implementation has resulted in a conservative approach to pavement management systems among highway officials and a lack of willingness to adopt innovative pavement management processes.

Probably the best example of how reluctance to take risks has stymied up-to-date pavement management is the current state-of-the-practice of pavement management analysis tools used by state highway agencies. Even though in the last 10 years the state of the art of pavement management analysis tools has progressed tremendously through the use of different mathematical programming tools, use of knowledge-based systems, and applications of artificial intelligence, all decision support models currently in use by state highway agencies are based on formulations developed in the late 1970s and early 1980s (5). The predominant improvement in the state-of-the-practice has been the refinement and miniaturization of decision support models for operation on microcomputers.

Iowa Implementation Case Study

The Iowa Highway Commission began very early to develop tools to support pavement management. The commission began collecting pavement condition data in the 1950s and since then has maintained the information in various uncoordinated forms (6). In the late 1970s, IDOT began developing the Iowa Pavement Management Information System (IPMIS), which integrated its pavement condition measurement surveys and automated its condition data processing.

At roughly the same time, IDOT developed a scheme to rank restoration and reconstruction projects using a composite of several pavement condition measures. The ranking was sent to field office for review but was poorly accepted and was eventually dropped.

During the mid-1980s and early 1990s, IDOT improved its location referencing system, refined its pavement condition measures and performance models, improved pavement condition testing and data-collection equipment and methods, and further developed the IPMIS. Two full-time systems analysts were assigned to improving the IPMIS, data management, and information support, and they have made the information system into a highly useful tool to support development of program plans.

In 1992, IDOT initiated a multiyear project to develop automated decision support capabilities in the pavement management process. At the same time, the agency began integrating total quality management (TQM) philosophies into departmental actions. Accordingly, the pavement management system implementation project is being conducted in a manner compatible with TQM concepts. Several nontechnical actions have been taken, including the development of specific statements of purpose, use of a multidisciplinary team to steer the project, and provision of both agencywide educational and informational programs and focused, small, core group training programs. All nontechnical actions are intended to assist in avoiding institutional issues and barriers.

The project is being directed by a committee designed to bring together the functional disciplines required for successful implementation of an IDOT pavement management system. Accordingly, the committee consists of individuals from the offices responsible for data processing, pavement design, materials, research, and planning. The project is divided into five phases.

Phase I is objective-setting, which consists of the following activities:

- Identifying the purpose of the pavement management decision support program,
- Determining the decision support tools available and their assumptions,
- Gathering information on pavement management decision support tools used by highway agencies in the United States and internationally,
- Presenting a workshop on the findings of the first phase for all staff likely to be involved in pavement management decision making, and
- Developing criteria through the workshop for the selection of decision support tools.

Phase II is the selection of a decision support methodology or tool, which consists of the following activities:

- Allowing the entire committee to visit other agencies with operational pavement management decision support systems;
- Reviewing decision support software options, including commercially available packages, computer programs in the public domain, and customized development of software;
- Bench-testing the most desirable software options using an IDOT data set;
- Developing a system selection recommendation through the committee; and
- Presenting a workshop covering model selection steps, the bench test, and the selection recommendations.

Phase III is the development of an implementation plan, which includes the following activities:

- Developing a physical and logical structure for the pavement management process before and after the implementation of the pavement management decisions support system,
- Developing a description of the physical architecture of the future computer pavement management system,
- Identifying likely personnel and equipment resource requirements and functional changes as a result of the implementation of the pavement management system, and
- Identifying the software that needs to be developed or purchased.

Phase IV is system development, which includes calibrating the models within the analysis package, populating the data base, and training IDOT employees in the program's operation.

Phase V is system operation, training, and maintenance, which includes the routine and continuous improvement of the system.

To date, Phases I through III of the project have been completed. Many significant milestones were reached in carrying out these activities. During Phase I, the pavement management workshop was attended by 50 to 60 staff members from offices throughout the IDOT. Follow-up presentations were made at formal and informal meetings by members of the steering committee. Steering committee members also made presentations at all the district field offices, explaining the status of the project and demonstrating the use of the IPMIS.

As part of Phase II, visits to other agencies provided the members of the committee with tremendous insight into institutional issues. To varying degrees, each agency visited had its own institutional barriers to complete implementation. Seeing these barriers first-hand provided the committee with an understanding of the importance of overcoming institutional issues.

During Phase III activities to identify resource requirements, all the relevant office directors were asked to identify specific numbers of full-time equivalent personnel who will be committed to pavement management. The commitment of personnel was seen as a critical step toward implementation.

At this writing, the project is starting Phase IV. After 2 years of work, the project team and steering committee expect that the project will continue for at least an additional year before reaching Phase V. The slow pace of the project is a result of the effort necessary to promote staff participation, carry on continuous communication, and develop open statements of purpose and objectives. The project has been endorsed by top IDOT management, and sufficient personnel and financial resources have been allocated to the project. In all, a very deliberate attempt is being made to avoid serious institutional issues.

Conclusions

Having an operable pavement management system is not the same as implementing a pavement management system. To implement a system requires that the pavement management system become a critical part of the resource allocation process. As described in this paper, technical and financial issues are usually not barriers to system implementation. However, institutional issues continue to be the most contentious obstacles and have resulted in several agencies failing to reach complete system implementation.

Recognizing that institutional issues may become barriers to implementation, agencies should develop strategies to overcome institutional issues. Such an approach, taken by IDOT, is outlined in this paper. Other agencies wishing to implement pavement management may need to find their own unique strategies to diminish the impact of institutional issues. Whatever the approach taken, highway agencies must recognize the need to deal with institutional issues as part of the implementation strategy for a pavement management system.

ACKNOWLEDGMENT

The authors are grateful to the Iowa Department of Transportation for its support of the research project "Evaluation, Selection and Planning the Implementation of a Pavement Management Optimization Model." This paper describes activities conducted under the sponsorship of that research project.

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Maintenance for Newly Designed Pavements Using the Maintenance Management Information System

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In recent years several states, including Illinois, have developed or revised their pavement design procedures and selection processes. These procedures and selection processes usually include an evaluation of the expected traffic and projected maintenance costs required for a given period of time. Since 1987 in Illinois, pavements have been designed, selected, and constructed using these procedures. One key to successful development and application of the pavement design procedures and selection processes is to compare and analyze field performance with expected results and make necessary adjustments. To do so requires a systematic data collection and reporting mechanism so the pavement sections are carefully monitored and all work performed is accurately reported. Illinois has established such a monitoring plan and a program of maintenance for newly designed pavement sections. The state expects to use the monitoring plan and to follow the program of maintenance for the 40-year design life of the selected pavement sections. Other states are likely to be concerned with the need to monitor pavement sections in order to check expected performance against actual performance and to summarize the maintenance activity and costs so predictive models can be evaluated. It is important that pavement maintenance models be realistic and accurate so that the economic analysis used in their selection produces correct results. Future pavement design models can be improved if complete information of past performance is available for evaluation. The procedures used by Illinois and its use of the Maintenance Management Information System to collect and produce the informational reports needed for long-term analysis are described.

In July 1990 the Illinois Department of Transportation, Division of Highways, began to develop a procedure for scheduling and financing the maintenance of newly designed pavement sections to ensure timely maintenance in accordance with pavement design models. The Bureau of Operations organized a technical task force with representatives from the executive office, the highway districts, and the Bureaus of Design and Environment, Construction, and Materials and Physical Research to develop a system for monitoring these pavement sections and including them in a program of maintenance corresponding to the prediction models for the first 40 years of pavement life.

In Illinois several miles of pavement sections had already been constructed using the new mechanistically based pavement design procedures and selection process by the time the monitoring project and program of maintenance were initiated in July 1990. Additional pavement sections have been constructed since that time. More will be constructed in the next few years. Industry, as well as the department, is very concerned with evaluating the new pavement design procedures and selection process. Therefore, it was necessary for the department to develop a rational and logical system to monitor, program, and report all maintenance performed on these pavement sections.

To meet these objectives, the task force determined the basic requirements:

- Logical selection criteria to decide which pavement sections to include and which to exclude from the monitoring;

- An accurate inventory of all pavement sections included;
- A means to identify the selected pavement sections to the operations personnel in the field who perform maintenance work activities;
- A way to ensure the performance of annual needs surveys and the inclusion of noted maintenance requirements in the annual district program for state highway maintenance;
- A mechanism to produce projected contract program funding requirements at least 5 years in the future from any point in time;
- A means to enter and report actual maintenance activity quantities and costs for each pavement section, whether by state forces or by contract;
- A means to compare the pavement selection model's projected work activities with actual maintenance work activities needed and performed; and
- An evaluation of the cost per mile to maintain the various types of pavements for comparison purposes.

After consideration of the requirements, reports were designed that the task force agreed would supply the necessary information. The task force decided the department's maintenance management information (MMI) system was the most suitable means to support the program of maintenance and produce all management reports. The MMI system was chosen primarily because terminals were readily available across the state to the source persons responsible for entering the data needed and the system already served the department as the "information highway" to provide reports on highway maintenance operations.

The MMI system consists of 252 terminals located in all highway maintenance team sections, traffic operations headquarters, the district offices, and the central bureaus. Dedicated lines are used to connect the terminals to the VAX cluster located in Springfield. The VAX cluster consists of two DEC 8700s and one 6510 central processing unit. Users anywhere on the network can access real-time data and produce reports from data base information. They can enter, change, and delete data within their area of responsibility. The MMI system has been operational in Illinois since July 1, 1987. At least 350 of the approximately 2,700 people on the operations staff are trained and already use the system frequently in reporting and managing their work.

Selection of Pavements

One of the first goals of the task force was to select which pavement sections should be included in the monitoring plan and program of maintenance. The new design procedures had been and are applied not only to design new pavement sections, but also for the design of additional lanes, intersections, ramps, and short relocations. Many believed that it would be difficult to monitor these isolated pavement sections and to ensure accurate reporting from field forces who more routinely report their work to longer pavement sections known as "subsections."

"Subsections" are the standard cost centers to which the operations field personnel report their work. To operations field personnel, a subsection is a pavement section that is contained within logical boundaries delineated by intersections, county lines, or city limits and that has a uniform cross section and number of lanes. A subsection may be any length. Most are 10 centerline mi in length or more. Since reporting is so important to the monitoring plan and program of maintenance, the task force recommended—and the department approved—the use of the following criteria to select pavement subsections:

- Only pavement sections greater than 3,000 yd^2 in surface area would be considered.
- Pavement sections must be at least 1 mi long, unless they are unique and require inclusion to ensure that a sample of that particular type of pavement is included in the monitoring plan and program of maintenance.
- Subsections must contain no more than one construction contract.

A subsection is designated for each pavement section selected.

Several bureaus are involved in selecting pavement sections based on the criteria. The Bureau of Design and Environment reviews each set of plans received for letting to select sections greater than 3,000 yd^2 in size. These sections are entered into a data base, which is monitored by the Bureau of Materials and Physical Research. The Bureau of Materials and Physical Research reviews each of the pavement sections selected by the Bureau of Design and Environment. It requests the Bureau of Operations to monitor and include in the program of maintenance those pavements at least 1 mi long or those meeting the "unique and required" criterion.

The Bureau of Operations reviews the request from the Bureau of Materials and Physical Research with the district. If the district agrees, the pavement section is made a subsection and is entered into the subsection inventory of the MMI system, and the process begins. If the district disagrees with the selection, it can appeal with the Bureau of Operations to the Bureau of Materials and Physical Research and give reasons why the pavement section should not be included.

Districts sometimes appeal for the following reasons:

- A pavement section is part of a larger pavement section already being reported,

• A section is not all-inclusive (for example, it includes a northbound lane with the new design and the southbound lane as an overlay), or

• A section has termini that are not easily delineated in the field.

Subsection Inventory

The MMI system includes a subsection inventory of physical features that require maintenance within its limits. Each subsection is denoted by a three-digit number and "from and to" descriptive limits. Subsections are entered into the MMI system by the district office and field personnel. Maps are kept that signify the stationing, construction sections, and construction contract involved with each subsection. If a section of new pavement design is to be monitored and become part of the maintenance program, the information is entered into the MMI system's subsection inventory and printed as the subsection inventory report (see Figure 1) with the following fields unique to the new pavement design sections: new design monitored pavement (yes or no), pavement type (code), pavement thickness (in.), shoulder type (code), contract number, letting date, maintenance date (date maintenance of the pavement became the responsibility of the district), and old subsection. This information is entered only for those pavement sections noted as monitored pavements. It is used to identify these subsections to the field personnel and serves as a basis for the subsequent reports for the new pavement designs. In some instances, highway maintenance field forces have erected signs at the ends of these subsections to assist in identification and to ensure the integrity of data collection.

Inspection Notification

At their option, districts may collect and store information from the needs survey for any or all subsections. The needs survey is a "windshield survey" of each subsection. It collects estimated quantities of maintenance work as it exists just before the new budget year, which begins on July 1. Pavement, shoulder, and drainage work are of primary concern. The information is entered into the MMI system and is integrated into and serves as a basis for the program/budget spreadsheet and work planning process.

The needs survey contains work quantities for the work activities (e.g., pothole patching, culvert cleaning, and curb repair), which state highway maintenance forces normally handle. Survey takers indicate the work priority as they take the survey. Priority 1 must be accomplished within the next year by state forces. Priority 2 must be accomplished by state forces, but is not Priority 1. Priority 3 work is recommended to be contracted (e.g., permanent patching and resurfacing).

The Priority 1 and 2 work information is passed directly into the highway maintenance program/budget and work planning process. Information for Priority 3 work is provided when requested to those who are responsible for pavement management and contract development.

The maintenance needs survey information cannot be used for the pavement condition rating survey, which is taken by others and used for other purposes.

One of the important requirements of the monitoring plan and program of maintenance is to ensure that the pavement sections are reviewed each year for maintenance needs. The MMI system provides the means to collect and store the necessary information from annual maintenance needs surveys.

To ensure that needs surveys are conducted for all of the monitored subsections whether or not the district is performing them for other subsections, an additional report was developed. The annual inspection notification report (see Figure 2) ensures that highway maintenance staff in the field, who may not be directly involved in the administration of new pavement design sections, are notified of the requirements for monitored subsections. A report creation process reviews the subsection inventory and needs surveys on file. On request, the system produces the annual inspection notification report, which lists each subsection in the monitoring plan and program of maintenance, the from-and-to limits, the pavement description, and the last needs survey date. Team section personnel, including field engineers and technicians, are responsible for performing the fiscal year inspections and entering the information. All can request and run the report. As each needs survey or inspection is accomplished and entered into the system, the annual inspection notification report is automatically updated.

In addition, an inspection report by fiscal year (see Figure 3) can be requested and printed for each of the subsections. This report shows the subsection involved and lists only those maintenance work activities involved in the pavement selection process. The report lists predicted future needs based on the model, the previous year's needs survey quantities, the previous year's accomplishments, and any current year or program needs entered into the system. The report information enables managers to compare work that has been noted before or that should be of special concern during the upcoming fiscal year, according to the models. The report draws information from the subsection inventory, the needs survey of the current and prior year, the programmed needs, and the predicted future needs according to the models. Last, a needs survey report may be requested and produced to show the summary of the information collected by field engineers and field technicians. If there are no needs for the pavement section in terms of these pavement and shoulder work activities, the report indicates that the survey was taken and that no needs were found.

MMIS302 MMIG3301 MMIR303 ILLINOIS DEPARTMENT OF TRANSPORTATION PAGE: 2
12/09/94 151944 BUREAU OF MAINTENANCE
SUBSECTION INVENTORY REPORT
DISTRICT 2

**** LOCATION INFORMATION ****
LAST CHANGE DATE: 08/18/94

TEAM SECTION: 231 SUBSECTION: 726 FROM: 596+50 COUNTY: OGLE CITY: ROUTE: S026
TO: 791+00 HIGHWAY CLASS: R M/R: R FIELD ENGINEER: 20
ROUTE NAME: IL 26

**** PAVEMENT INFORMATION ****
LAST CHANGE DATE: 11/18/92

AVG. R.O.W. WIDTH	A.D.T. IN 100S	SURF. TYPE	TOTAL PAVT. WIDTH	CENT. LINE MILES	PAVEMENT LANE MILES 8 FT	9 FT	10 FT	11 FT	12 FT	13 14	15 FT	VAR	RAMP # MI	FRONT ROAD # MI.	ACC. CTL.	COMMITS	MONITOR PAVE
70	21	4	24	2.2	0.0	0.0	0.0	0.0	4.4	0.0	0.0	0.0	0.0	0.0	N		Y

**** SHOULDER INFORMATION **** **** DRAINAGE INFORMATION ****
LAST CHANGE DATE: 11/18/92 LAST CHANGE DATE: 08/10/92

SURFACED HIGH MI.	HIGH WID	LOW MI.	LOW WID	AGGREG. MI.	AGGREG. WID	TURF MI.	TURF WID	BARRIER MEDIAN MILES	OTHER MEDIAN MILES	CURBS & GUTTERS 100 FT.	NO. OF DRAIN STRUCT	STORM SEWERS (100 FT.) --MAIN DRAIN-- TO 36" D.	36" D. & OVER	LATERAL	--DITCHES-- EARTH MILES	OTHER 100 FT	NO. OF CULV. CROSS ROAD	MISC	NO. OF ENT. & SIDE APP
4	4	0	0	0	0	0	0	0.0	0.0	0	0	0	0	0	0	0	0	0	0

**** ROADSIDE INFORMATION **** **** SAFETY INFORMATION ****
LAST CHANGE DATE: 08/10/92 LAST CHANGE DATE: 08/10/92

NO. OF LANDSCAPING FEATURES	NO. OF REST AREAS FLUSH	PIT	MINOR	TOTAL MOWABLE ACRES	MOWING POLICY ACRES	R.O.W. FENCE MILES	NO. OF WEIGH STATIONS	NO. OF PUMP HOUSES	NO. OF HIST. MARKERS	SLOPE WALLS, CRIBBING, &RIP-RAP FT.	BARRIER WALL MILES	--GUARDRAIL-- LINEAR FEET STEEL PLATE	OTHER	NO. OF IMPACT ATTEN.
0	0	0	0	0	0	0.0	0	0	0	0	0.0	0	0	0

**** MONITORED PAVEMENT INFORMATION ****
LAST CHANGE DATE: 06/30/94

PAVEMENT TYPE	PAVEMENT THICKNESS (INCHES)	SHOULDER TYPE	CONTRACT NUMBER	LETTING DATE	MAINTENANCE DATE	OLD SUBSEC
10	11.8	81	84199	03/13/90	12/01/91	026

**** SUBSECTION BRIDGE INFORMATION **** **** SUBSECTION STATUS ****
DEACTIVATE DATE / /

LINEAR FEET	NO. UNDER 100 FT.	NO. 100 FT. & OVER
0	0	0

SUB SECTION REMARKS: TWO LOCATIONS STA 596+50 TO 651+00 AND STA. 713+00 TO 791+00 11.75" F.D. BIT.

*** END OF REPORT ***

FIGURE 1 Subsection inventory report for a monitored pavement section.

MMIS3062 MMIG3300 MMIR356 ILLINOIS DEPARTMENT OF TRANSPORTATION PAGE: 1
04/21/94 175446

BUREAU OF MAINTENANCE
MONITORED PAVEMENT
ANNUAL INSPECTION NOTIFICATION REPORT
DISTRICT 6

FISCAL YEAR: 95 TEAM SECTION: ALL

TS	SUB SEC	CONTRACT NUMBER	ROUTE NO.	FROM	TO	PAVEMENT DESCRIPTION	
611	120	92038	U03600	ADAMS CO. LINE (STA. 999+99.8)	ILL. 96 (STA.1395+00)	CONT. REINFORCED CONCRETE-CRCP	
611	127	92230&231	U03600	STATION 442+50	BARRY (STA. 18+50)	ASPH-TF LT 15.0	(R)
611	128	922290000	U03600	FA-408 & TRUMPET INTCHGE	1.5 MILES SOUTH OF TRUMPET	ASPH-TF LT 15.0	(R)
611	122	921090000	U03600	IL 100	ILLINOIS RIVER BRIDGES	ASPH-TF LT 15.0	(R)
611	124	921100000	U03600	ILL RIVER BRIDGES	IL 107	ASPH-TF LT 15.0	(R)
611	126	921770000	U03600	BARRY	IL 96 (STA.1395+00)	ASPH-TF LT 15.0	(R)
611	125	92232&231	U03600	STATION 245+00	STATION 442+50	ASPH-TF LT 15.0	(R)
622	141	921080000	I01550	JUST N. OF I-55	2 MILES S. OF US-136	ASPH-TF LT 15.0	(R)
622	142	922280000	I01550	LOGAN/TAZWELL CO. LINE	2MILES SO. US 136	ASPH-TF LT 15.0	(R)
624	990	923280000	000000	W. OF WILLIAMSVILLE OVHD	TWELVE MILE HOUSE	ASPH-TF LT 15.0	(R)

*** END OF REPORT ***

FIGURE 2 Annual inspection notification report for upcoming fiscal year with subsection, contract number, route number limits, and pavement description.

MMIS3064 MMIG3353 MMIR357 ILLINOIS DEPARTMENT OF TRANSPORTATION PAGE: 2
04/21/94 175941

BUREAU OF MAINTENANCE
MONITORED PAVEMENT
FY 95 INSPECTION REPORT
DISTRICT 2

**** LOCATION INFORMATION ****

TEAM SECTION: 231 SUBSECTION: 726 FROM: IL 26 - FORRESTON TO IL 72(W.) COUNTY: OGLE CITY:
TO: MECHANISTICALLY DESIGNED PVT. ROUTE: S026 ROUTE NAME: IL 26
CONTRACT NUMBER: 84199 HIGHWAY CLASS: R M/R: R FIELD ENGINEER: 20

LAST SURVEY DATE: 03/17/94 PAVEMENT TYPE: 10 ASPH-TF LT 15.0 (R)
LETTING DATE: 03/13/90 PAVEMENT THICKNESS (INCHES): 11.8
MAINTENANCE DATE: 12/01/91 LANE MILES: 4.4 PROJECT AGE: 4

WRK ACT	DESCRIPTION	UNIT MEAS	DESIGN PROJECTED NEEDS	FY 94 NEEDS	FY 94 ACCOMP.	FY 95 NEEDS	FY 95 CONTRACT NEEDS
411	PART DEPTH PATCHES	SQYD					
412	FULL DEPTH PATCHES	SQYD					
413	BITUMINOUS OVERLAY	SQYD					
416	CRK&JT SEAL-HD POR	GALS					
515	PAVEMENT MILLING	SQYD					
516	CRK&JT ROUTING	L FT					35600
517	CRK&JT CLEAN&SEAL	L FT					35600
919	OTHER PAVEMENT	HRS					
420	PATCH&REPAIR SHLDR	TONS					
929	OTHER SHOULDER	HRS					

FIGURE 3 Inspection report by fiscal year with design projected needs, previous year's needs, previous year's accomplishments, and current year's needs (by state forces and contract) for each work activity.

MMIS3066 MMIG3354 MMIR358 — ILLINOIS DEPARTMENT OF TRANSPORTATION — PAGE: 2
05/11/94 115513

BUREAU OF MAINTENANCE
MONITORED PAVEMENT
PROPOSED BUDGET BY SUB SECTION
DISTRICT 2 FY 95

**** LOCATION INFORMATION ****

TEAM SECTION: 231 SUBSECTION: 726 FROM: IL 26 - FORRESTON TO IL 72(W.) COUNTY: OGLE CITY:
TO: MECHANISTICALLY DESIGNED PVT. ROUTE: S026 ROUTE NAME: IL 26
CONTRACT NUMBER: 84199 HIGHWAY CLASS: R M/R: R FIELD ENGINEER: 20

LAST SURVEY DATE: 03/17/94 PAVEMENT TYPE: 10 ASPH-TF LT 15.0 (R)
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MAINTENANCE DATE: 12/01/91 LANE MILES: 4.4 PROJECT AGE: 4

			** FY95 MAINTENANCE PROGRAM **			** FY95 CONTRACT PROGRAM **		
WRK ACT	DESCRIPTION	UNIT MEAS	NEEDS QUANTITY	UNIT COST	TOTAL COST	NEEDS QUANTITY	UNIT COST	TOTAL COST
411	PART DEPTH PATCHES	SQYD						
412	FULL DEPTH PATCHES	SQYD						
413	BITUMINOUS OVERLAY	SQYD						
416	CRK&JT SEAL-HD POR	GALS						
515	PAVEMENT MILLING	SQYD						
516	CRK&JT ROUTING	L FT				35,600	.90	$ 32,040
517	CRK&JT CLEAN&SEAL	L FT				35,600		$
919	OTHER PAVEMENT	HRS						
420	PATCH&REPAIR SHLDR	TONS						
929	OTHER SHOULDER	HRS						
	SUB SECTION TOTAL:				$			$ 32,040

MAINTENANCE PROGRAM TOTAL:	$
CONTRACT PROGRAM TOTAL:	$ 32,040
REPORT TOTAL:	$ 32,040

*** END OF REPORT ***

FIGURE 4 Proposed budget report by location (subsection) with quantities and cost of projected maintenance by state and contract forces.

Budget Reports

The first report in the budget series is the proposed budget report (see Figure 4), which lists each subsection, the needs quantity, the unit cost, and the estimated total cost of the maintenance or repair. When they conduct the annual needs survey, the field engineers and field technicians indicate which maintenance needs they recommend be met by state forces and which should be contracted to outside forces. A second version of the report shows the total of all maintenance and repair by work activity and the corresponding unit price and total cost.

Districts use this information to develop contracts and direct the following year's work for each activity on the selected pavement sections. The department plans to fund all contracts for work needed on these pavement sections.

The department also prepares a multiyear road program for future maintenance and repairs. The 5-year budget report (see Figure 5) provides the information needed for the multiyear road program. It shows the cost to maintain these pavements on the basis of the needs survey data and the design models. The report contains information for the current year and for the upcoming 4 years on the basis of predicted future needs. The user can insert an inflation factor if desired. The report can also be requested and printed to show the projected costs for the current and next 4 years by project age and by work activity. Finally, users can request the report on a location (subsection) basis.

Another version of the budget report is a statewide report that shows the pavement types and the projected maintenance cost for each type by district (see Figure 6).

BUREAU OF MAINTENANCE
MONITORED PAVEMENT
PROPOSED 5 YEAR BUDGET
DISTRICT 2 FY 95 BY WORK ACTIVITY

TEAM SECTION OREGON COUNTY OGLE
SUBSECTION 726 FROM IL 26 - FORRESTON TO IL 72(W.) HIGHWAY CLASS R M/R R
TO MECHANISTICALLY DESIGNED PVT. ROUTE NAME IL 26

WORK ACTIVITY	UNIT MEASURE	UNIT COST	****** FY95 COST ****** SURVEY	MODEL	FY96 COST	FY97 COST	FY98 COST	FY99 COST
412 FULL DEPTH PATCHES	SQUARE YD	75.00	$ 0	$ 0	$ 12,012	$ 0	$ 0	$ 0
516 CRK&JT ROUTING	LIN FEET	.90	$ 32,040	$ 0	$ 0	$ 2,261	$ 0	$ 0
517 CRK&JT CLEAN&SEAL	LIN FEET	.00	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0
SUBSECTION 726 TOTAL			$ 32,040	$ 0	$ 12,012	$ 2,261	$ 0	$ 0
TEAM SECTION 231 TOTAL			$ 32,040	$ 0	$ 12,012	$ 2,261	$ 0	$ 0

TEAM SECTION MT CARROLL COUNTY CARROLL
SUBSECTION 773 FROM LANARK TO IL 72 HIGHWAY CLASS R M/R R
TO MECHANISTICALLY DESIGNED PAVT. ROUTE NAME ILL 73

WORK ACTIVITY	UNIT MEASURE	UNIT COST	****** FY95 COST ****** SURVEY	MODEL	FY96 COST	FY97 COST	FY98 COST	FY99 COST
412 FULL DEPTH PATCHES	SQUARE YD	75.00	$ 0	$ 2,362	$ 0	$ 0	$ 0	$ 0
516 CRK&JT ROUTING	LIN FEET	.90	$ 0	$ 0	$ 444	$ 0	$ 0	$ 0
517 CRK&JT CLEAN&SEAL	LIN FEET	.00	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0
SUBSECTION 773 TOTAL			$ 0	$ 2,362	$ 444	$ 0	$ 0	$ 0
TEAM SECTION 241 TOTAL			$ 0	$ 2,362	$ 444	$ 0	$ 0	$ 0

TEAM SECTION STOCKTON COUNTY JO DAVIESS
SUBSECTION 720 FROM US 20 - ELIZABETH TO BECKER RD HIGHWAY CLASS R M/R R
TO MECHANISTICALLY DESIGNED PAVT. ROUTE NAME US 20

WORK ACTIVITY	UNIT MEASURE	UNIT COST	****** FY95 COST ****** SURVEY	MODEL	FY96 COST	FY97 COST	FY98 COST	FY99 COST
412 FULL DEPTH PATCHES	SQUARE YD	75.00	$ 0	$ 0	$ 0	$ 6,814	$ 0	$ 0
516 CRK&JT ROUTING	LIN FEET	.90	$ 0	$ 17,448	$ 0	$ 0	$ 1,282	$ 0
517 CRK&JT CLEAN&SEAL	LIN FEET	.00	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0
SUBSECTION 720 TOTAL			$ 0	$ 17,448	$ 0	$ 6,814	$ 1,282	$ 0
TEAM SECTION 242 TOTAL			$ 0	$ 17,448	$ 0	$ 6,814	$ 1,282	$ 0
DISTRICT 2 TOTAL			$ 32,040	$ 19,810	$ 12,456	$ 9,075	$ 1,282	$ 0

FIGURE 5 Five-year budget report by work activity with projected costs for the current and next 4 fiscal years.

MMIS3072 MMI03357 MMIR361 ILLINOIS DEPARTMENT OF TRANSPORTATION PAGE: 2
04/21/94 181835 BUREAU OF MAINTENANCE
MONITORED PAVEMENT
PROPOSED 5 YEAR BUDGET
SUMMARY FY 95

CATEGORY TYPE: FLEXIBLE

DIST	LANE MILES	FY95 SURVEY	FY95 MODEL	FY 96	FY 97	FY 98	FY 99
1	27	$ 25,020	$ 0	$ 133,248	$ 12,746	$ 21,355	$ 6,892
2	7	$ 32,040	$ 19,810	$ 12,456	$ 9,075	$ 1,282	$ 0
3	2	$ 0	$ 0	$ 6,188	$ 1,370	$ 0	$ 0
4	48	$ 0	$ 339,463	$ 19,971	$ 158,936	$ 24,468	$ 0
5	25	$ 0	$ 133,771	$ 9,631	$ 182,879	$ 9,834	$ 52,026
6	193	$ 0	$ 395,165	$ 296,321	$ 103,781	$ 10,779	$ 689,210
7	2	$ 120	$ 0	$ 8,044	$ 1,781	$ 0	$ 0
8	21	$ 44	$ 0	$ 59,647	$ 129,310	$ 32,143	$ 74,064
9	11	$ 1,020	$ 0	$ 47,247	$ 8,086	$ 0	$ 0
SUBTOTAL:	341	$ 58,244	$ 888,212	$ 592,756	$ 607,968	$ 99,865	$ 822,194

CATEGORY TYPE: RIGID

DIST	LANE MILES	FY95 SURVEY	FY95 MODEL	FY 96	FY 97	FY 98	FY 99
1	13	$ 530,073	$ 0	$ 0	$ 0	$ 0	$ 0
3	268	$ 0	$ 0	$ 42,387	$ 0	$ 35,135	$ 363,470
4	6	$ 0	$ 0	$ 0	$ 11,754	$ 0	$ 0
6	29	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0
SUBTOTAL:	317	$ 530,073	$ 0	$ 42,387	$ 11,754	$ 35,135	$ 363,470
STATEWIDE TOTAL:	659	$ 588,317	$ 888,212	$ 635,144	$ 619,722	$ 135,001	$ 1,185,664

*** END OF REPORT ***

FIGURE 6 Proposed 5-year budget report summarized by district with projected costs for the current and next 4 fiscal years.

```
MMIS376/MMITA368/MMIFF368                                  04/21/94 16:19:34
                           MONITORED PAVEMENT
                     CONTRACT/DAY LABOR INFORMATION

 ACTION IND:    (Add,Inquiry,Change,Delete)
 TEAM SEC:      SUBSEC:      FY:     CONTRACT (C) OR DAY LABOR (D):

   S =      WORK     CONTRACT      CONTRACT
  SELECT    ACT.     QUANTITY        COST       REMARKS
  ------    ----    ----------   ------------  ------------------------------
                             .    $        .
                             .    $        .
                             .    $        .
                             .    $        .
                             .    $        .
                             .    $        .
                             .    $        .
                             .    $        .
                             .    $        .

 (ENTER PF1 THEN 'E' TO EXIT)  *** MESSAGES ***  (ENTER PF1 THEN 'C' TO CLEAR)
```

FIGURE 7 Contract/day labor information screen to enter quantities and costs by location (subsection) and work activity.

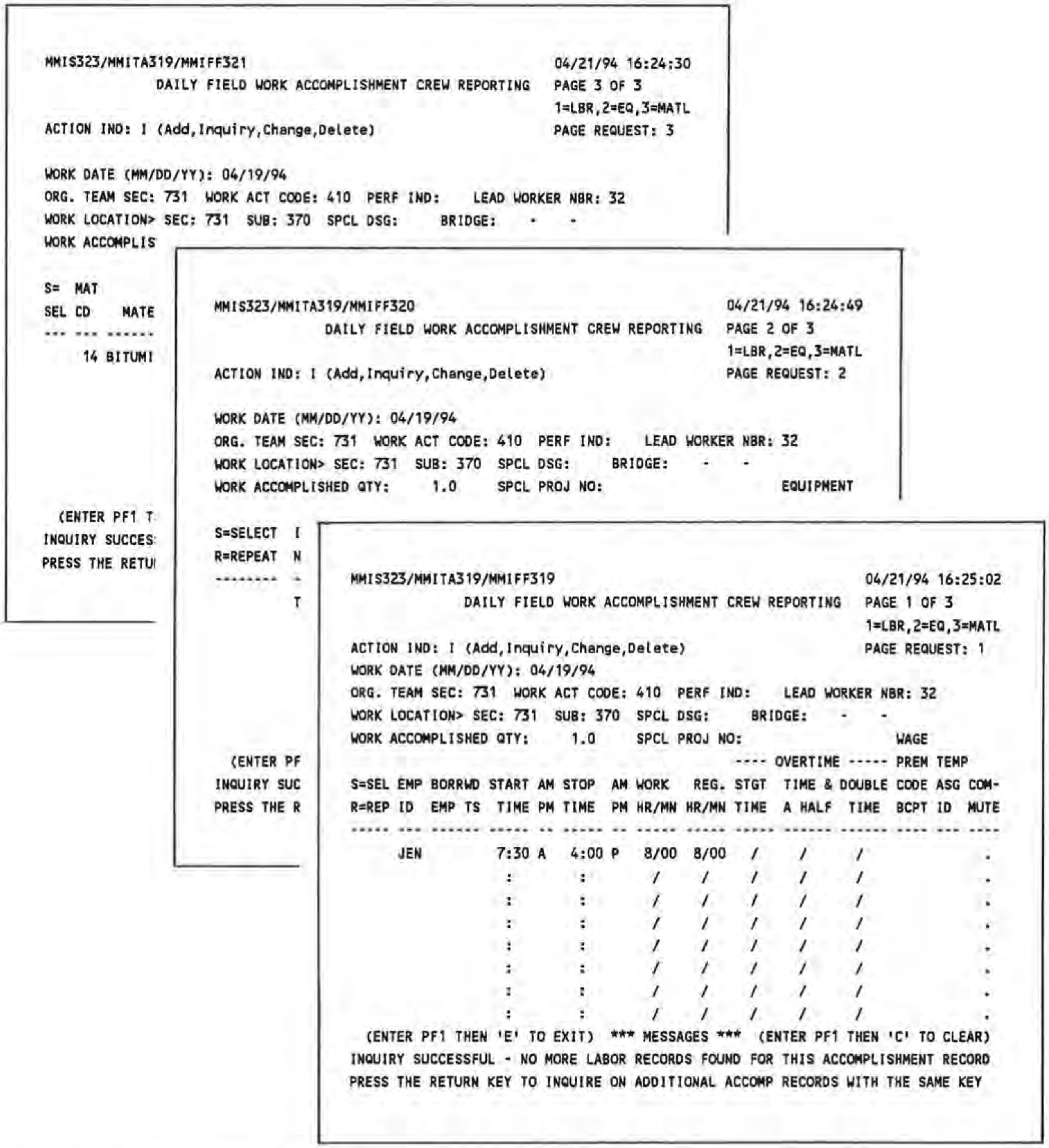

FIGURE 8 Daily field reporting of labor (page 1), equipment used (page 2), and material (page 3).

```
MMIS3074 MMIG3359 MMIR365                 ILLINOIS DEPARTMENT OF TRANSPORTATION                         PAGE:  2
      04/21/94 181844                            BUREAU OF MAINTENANCE
                                                  MONITORED PAVEMENT
                                           PERFORMANCE, COSTS AND ADHERENCE
                                               FISCAL YEAR: 1992 - 1994

FISCAL YEAR: 1992

                               ------------------ QUANTITY ---------------  --------------------- COST ----------------------
WRK                       UNIT  DSGN.  NEEDS  TOTAL            DAY    DIST   DSGN.    NEEDS    GRAND    CONTRACT  DAY      MAINT
ACT  DESCRIPTION          MEAS  PROJ.  SRVY.  ACCOMP. CONTRACT LABOR  MAINT  PROJ. $  SRVY. $  TOTAL $  $         LABOR $  $
--- ----------------- ---- ------- ------- ------- ------- ------- -------  -------- -------- -------- -------- -------- ------
TEAM SECTION: 221  SUB SECTION: 702

411 PART DEPTH PATCHES SQYD
412 FULL DEPTH PATCHES SQYD
413 BITUMINOUS OVERLAY SQYD
416 CRK&JT SEAL-HD POR GALS
515 PAVEMENT MILLING   L FT
516 CRK&JT ROUTING     L FT
517 CRK&JT CLEAN&SEAL  L FT
919 OTHER PAVEMENT     HRS

420 PATCH&REPAIR SHLDR TONS
929 OTHER SHOULDER     HRS

                                   MONITORED WORK ACTIVITY COSTS:

                                              SUB SECTION COSTS:

TEAM SECTION: 231  SUB SECTION: 726

411 PART DEPTH PATCHES SQYD
412 FULL DEPTH PATCHES SQYD
413 BITUMINOUS OVERLAY SQYD
416 CRK&JT SEAL-HD POR GALS
515 PAVEMENT MILLING   L FT
516 CRK&JT ROUTING     L FT
517 CRK&JT CLEAN&SEAL  L FT
919 OTHER PAVEMENT     HRS

420 PATCH&REPAIR SHLDR TONS
929 OTHER SHOULDER     HRS

                                   MONITORED WORK ACTIVITY COSTS:

                                              SUB SECTION COSTS:

TEAM SECTION: 241  SUB SECTION: 773

411 PART DEPTH PATCHES SQYD
412 FULL DEPTH PATCHES SQYD
413 BITUMINOUS OVERLAY SQYD
416 CRK&JT SEAL-HD POR GALS
515 PAVEMENT MILLING   L FT
516 CRK&JT ROUTING     L FT
517 CRK&JT CLEAN&SEAL  L FT
919 OTHER PAVEMENT     HRS
```

FIGURE 9 Performance cost and adherence report comparing actual quantity and cost of work activities for each location (subsection) with design model projections and needs surveys.

MMIS366/MMITA343/MMIFF364 04/25/94 09:42:20

PAVEMENT TYPE TABLE

ACTION IND: I (Add, Inquiry, Change, Delete)

S = SELECT	PAVEMENT TYPE CODE	PAVEMENT TYPE DESCRIPTION		PAVEMENT CATEGORY CODE
	10	ASPH-TF LT 15.0	(R)	F
	11	ASPH-TF LT 10.0	(U)	F
	20	ASPH-TF GT 15.0 & LT 24.5	(R)	F
	21	ASPH-TF GT 10.0 & LT 16.3	(U)	F
	30	ASPH-TF GT 24.5 & LT 34.0	(R)	F
	31	ASPH-TF GT 16.3 & LT 22.7	(U)	F
	40	ASPH-TF GT 34.0	(R)	F
	41	ASPH-TF GT 22.7	(U)	F
	50	HINGE-JOINTED CONCRETE		R
	60	CONT. REINFORCED CONCRETE-CRCP		R

(ENTER PF1 THEN 'E' TO EXIT) *** MESSAGES *** (ENTER PF1 THEN 'C' TO CLEAR)

INQUIRY SUCCESSFUL - TO CONTINUE IN THE INQUIRY MODE, PRESS THE RETURN KEY

FIGURE 10 Pavement type table with pavement type description and pavement category code.

Districts and state budget and program planners also make use of this information in developing the funding requirements for the multiyear program.

Performance and Cost Entry

The contract information screen enables district personnel to enter the work activities that have been contracted, as-built contract quantities, and final contract costs (see Figure 7). Correspondingly, the work by state maintenance forces is entered through the normal MMI system procedure of daily field reporting of work accomplishments (see Figure 8). This reporting includes the work accomplished and calculated cost for labor, equipment, and materials consumed. These entry screens support the remaining reports.

Performance, Cost, and Adherence Reports

An important facet of the program of maintenance for these pavement sections is to ensure that maintenance and repair are performed as required and according to the predicted needs. The department's policy is to perform maintenance of these pavement sections when needed. A special contract maintenance fund has been established to support the policy.

The performance, cost, and adherence report (see Figure 9) provides information concerning the quantities of maintenance projected by the models or collected by the needs surveys to compare with actual accomplishments either performed by contract, the state's day labor forces, or district maintenance forces. It also includes a comparison of the cost of the work and the projected or estimated cost of the work. This is a feedback report to district managers, field engineers, and field technicians to help them determine which maintenance tasks have been performed and which remain.

A second report in the series, the maintenance cost/mile/year summary report, shows the overall cost per mile to maintain these pavements by year. Using this report, department executives can compare the long-term cost of maintenance for each of the various types of pavements.

Tables

Several tables and entry screens are required to support the system. The first is the pavement type table (see Figure 10). In Illinois, six pavement types are included in the monitoring plan and the program of maintenance. The pavement type table contains the pavement type code, the description, and the pavement category code. A monitored pavement cost analysis schedule table (see Figure 11) is included for each pavement type. This table contains the design model information: pavement age at which the

MMIS368/MMITA365/MMIFF365 04/25/94 09:43:08

MONITORED PAVEMENT

COST ANALYSIS (SCHEDULE) TABLE

ACTION IND: I (Add,Inquiry,Change,Delete)

PAVEMENT TYPE: 10 ASPH-TF LT 15.0 (R)

S =

SELE

(ENTER PF

INQUIRY SUC

MMIS368/MMITA365/MMIFF365 04/25/94 09:43:08

MONITORED PAVEMENT

COST ANALYSIS (SCHEDULE) TABLE

ACTION IND: I (Add,Inquiry,Change,Delete)

PAVEMENT TYPE: 10 ASPH-TF LT 15.0 (R)

(ENTE

INQUIRY

MMIS368/MMITA365/MMIFF365 04/25/94 09:43:08

MONITORED PAVEMENT

COST ANALYSIS (SCHEDULE) TABLE

ACTION IND: I (Add,Inquiry,Change,Delete)

PAVEMENT TYPE: 10 ASPH-TF LT 15.0 (R)

S = SELECT	PROJECTED AGE	WORK ACT.	WORK ACTIVITY DESCRIPTION	QUANTITY PER LANE MILE
	3	516	CRK&JT ROUTING	8078.00
	3	517	CRK&JT CLEAN&SEAL	8078.00
	5	412	FULL DEPTH PATCHES	35.00
	6	516	CRK&JT ROUTING	528.00
	6	517	CRK&JT CLEAN&SEAL	528.00
	10	412	FULL DEPTH PATCHES	211.00
	10	420	PATCH&REPAIR SHLDR	42.11
	12	516	CRK&JT ROUTING	10296.00
	12	517	CRK&JT CLEAN&SEAL	10296.00

(ENTER PF1 THEN 'E' TO EXIT) *** MESSAGES *** (ENTER PF1 THEN 'C' TO CLEAR)

INQUIRY SUCCESSFUL - TO CONTINUE IN THE INQUIRY MODE, PRESS THE RETURN KEY

FIGURE 11 Monitored pavement cost analysis (schedule) table with projected age for the work activity and quantity per lane mile.

```
MMIS374/MMITA366/MMIFF366                              04/25/94 15:56:59
                          MONITORED PAVEMENT
                           UNIT COST TABLE

 ACTION IND: I (Add,Inquiry,Change,Delete)
 DISTRICT: 2  FY: 95  PAVEMENT CATEGORY: R  RIGID

      S =
      SELECT
      ------

 (ENTER PF1 THE

INQUIRY SUCCESSF
```

```
MMIS374/MMITA366/MMIFF366                                        04/25/94 09:47:29
                              MONITORED PAVEMENT
                               UNIT COST TABLE

 ACTION IND: I (Add,Inquiry,Change,Delete)
 DISTRICT: 2  FY: 95  PAVEMENT CATEGORY: F  FLEXIBLE

          S =       WORK   WORK ACTIVITY
          SELECT    ACT.   DESCRIPTION          UNIT COST
          ------    ----   ------------------   -----------
                    412    FULL DEPTH PATCHES   $     75.00
                    413    BITUMINOUS OVERLAY   $    116.26
                    420    PATCH&REPAIR SHLDR   $     26.88
                    515    PAVEMENT MILLING     $       .75
                    516    CRK&JT ROUTING       $       .90
                                                $        .
                                                $        .
                                                $        .
                                                $        .

 (ENTER PF1 THEN 'E' TO EXIT)  *** MESSAGES ***  (ENTER PF1 THEN 'C' TO CLEAR)

INQUIRY SUCCESSFUL - END OF DATABASE HAS BEEN REACHED
```

FIGURE 12 Unit cost tables by district, pavement category, and work activity.

maintenance or repair is expected, work activity to be performed, and the projected quantity per lane mile to be accomplished. The unit cost table (see Figure 12) contains the work activity codes and their unit costs for each pavement type. These tables apply statewide. Therefore, they can be altered or changed only by engineers in the central bureau.

CONCLUSION

The Illinois Department of Transportation has embarked on a procedure to monitor and include in a program of maintenance selected newly designed pavement sections built by the state. Pavements included are those meeting certain criteria. The monitoring plan and the program of maintenance are to collect data for 40 years on each of these pavement sections. The department now has an up-to-date inventory of the pavement sections included. The pavement sections are inspected each year, and maintenance needs are noted and entered into the MMI system. As maintenance is performed by contract or state forces, the department is assured that quantities and actual costs are recorded and compared with projected or estimated quantities and cost. The department has reports readily available that enable department managers at all levels to review projections of needs for the current and the next 4 years for budget planning and program development. In the field the pavements are maintained properly and according to standard engineering practice. None are neglected.

Through use of the data collected and stored by the MMI system, the department has the information to ensure (*a*) that department managers, including field technicians, field engineers, and the bureau chiefs in the districts and central bureaus receive data useful for making decisions and carrying out the required maintenance on these pavement sections and (*b*) that the predicted needs models can be evaluated against actual performance so changes can be made as needed.

The pavement sections in the program of maintenance are in the early years of their design life. Maintenance and repair needs have been minimal so far. More pavement sections will be added to the program of maintenance as required. The department is prepared for the time when maintenance and repair of these pavements sections are needed. As a result, the department will have information available to enhance their design, alter maintenance models, improve pavement selection, and build even better pavements in the future.

Evaluation of Materials, Procedures, and Equipment for Pavement Maintenance

L.D. Evans, C.A. Good Mojab, A.T. Patel, A.R. Romine, K.L. Smith, and T.P. Wilson, *ERES Consultants, Inc.*

Beginning in March 1991, the Strategic Highway Research Program (SHRP) Project H-106 began installing 22 test sites for the investigation of various pavement maintenance materials and procedures for four different pavement maintenance activities: pothole repair in asphalt concrete (AC) pavements, crack sealing and filling in AC pavements, joint resealing in portland cement concrete (PCC) pavements, and partial-depth spall repair in PCC pavements. Since the installation of the test sites, all of the 1,250 pothole repairs, 1,600 partial-depth spall repairs, 6700 m (22,000 ft) of crack sealing, and 1,600 resealed joints have been periodically evaluated to document their performance under actual field conditions. The SHRP H-106 project concluded in March 1993, with the production of final reports, manuals of practice, and training and implementation packages. A continued monitoring contract was awarded by the Federal Highway Administration beginning in September 1993 to ensure that the H-106 test sites continue to provide valuable information as the repairs are subjected to further traffic and environmental stress through September 1998. The test site installation process for each of the four experiments and the results of the most recent analysis effort are summarized. For the crack seal, joint reseal, and partial-depth spall repair experiments, the most recent data were collected during fall 1993. For the pothole repair experiment, the most recent data were collected in April 1994. Future activities to be completed under the current monitoring project are described.

The Strategic Highway Research Program (SHRP) Project H-106 installed and monitored 22 test sites situated in the four climatic regions in the United States beginning in March 1991 and continuing through March 1993. Figure 1 shows the locations of the test sites and the boundaries of the four climatic regions. Products developed during the H-106 project included a final report, manual of practice, and training and implementation packages for each of the four experiments (*1–3*).

Pothole Repair

Test Site Installation

The eight pothole repair sites were installed in two separate phases: spring 1991 (Texas, Illinois, New Mexico, Utah, California, and Vermont) and winter 1992 (Ontario and Oregon). At each of the test sites, potholes were created by removing previously placed pothole patches to allow for placement of the experimental repairs. An adverse moisture condition was created by filling the manufactured potholes with water brought to the test site. All repairs were placed with cold mix asphalt materials, with the exception of the spray injection repairs.

Four different procedures were used for repairing the potholes:

- Throw-and-roll: Pothole patches were placed by simply placing the cold mix into the pothole, through the water that had been placed in the hole. Once the holes were filled, the material was compacted using the tires of the vehicle that transported repair materials to the test site. Between six and eight passes of the truck tires were performed before moving onto the next repair.
- Edge seal: Throw-and-roll patches were allowed to set for 1 day to allow the moisture on the pavement surface to dry. Once the patch and pavement had dried, a band

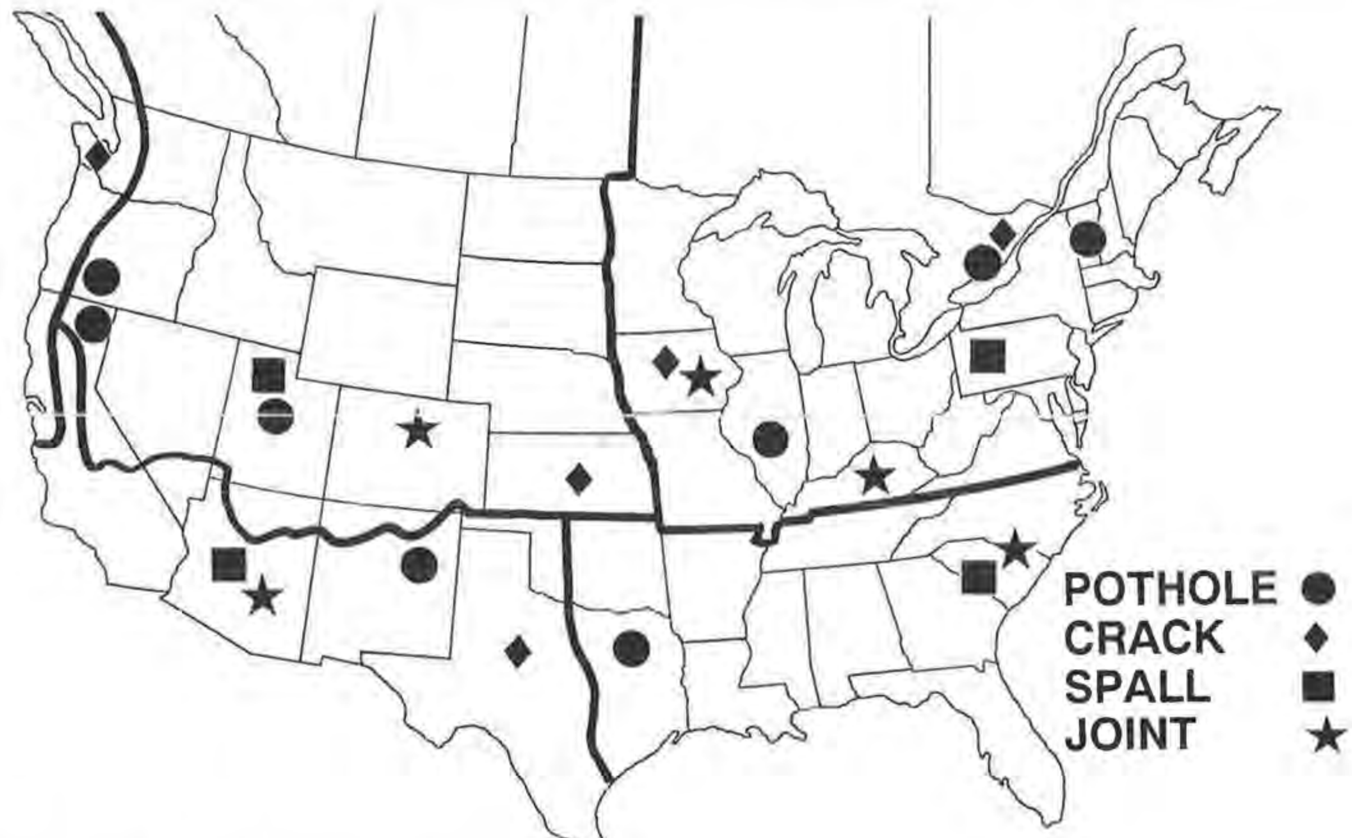

FIGURE 1 SHRP H-106 test sites and climatic regions.

of asphaltic tack material was placed on the interface of the patch and pavement to prevent the intrusion of additional moisture. A layer of sand was placed on the band of tack to prevent tracking by passing vehicles.

- Semipermanent: The first step for this procedure was to remove the moisture and debris from the pothole. This was done using equipment ranging from shovels and brooms to compressed air. Once the potholes were clean, the edges of the pothole were straightened using a pavement saw, jackhammer, or milling machine. Cold mix was then placed into the cleaned and squared pothole, where it was compacted using a device other than the truck tires. The compaction devices included vibratory plate compactors, single drum rollers, dual steel-wheel rollers, and rubber-tire rollers.
- Spray injection: The three spray injection devices used at the eight test sites operated on the same principle: shoot virgin aggregate and heated emulsified asphalt simultaneously into the pothole. This basically mixed the patching material in the pothole, with a cover of aggregate being placed on the top of the patch to prevent tracking.

During the installation, data were collected on the size of the repairs and the time required for each of the different stages of the repair process. This information was used to calculate the productivity of the different repair procedures, found in Table 1.

Eight different materials were used for placing repairs at the eight test sites: UPM High Performance Cold Mix, QPR 2000, Perma-Patch, PennDOT 485, PennDOT 486, HFMS-2 with styrene butadiene, local material, and spray injection.

The first three of these materials are proprietary. The second three represent typical state-specified materials. The local materials were simply the cold mixes used by the participating agencies on a daily basis. These local materials ranged from inexpensive cold mixes ($20 per ton) to expensive proprietary materials ($100 per ton). The results for the local materials generally reflect the types of materials used. The final "material" type was simply the spray injection described in the previous section.

Repair Performance Evaluation

Each of the test sites was evaluated periodically to document the survival of the various repair types. For those

TABLE 1 Summary of Pothole Patching Productivity

Procedure	Average Productivity (1,000 kg/hr)	Laborers Recommended	Average Productivity (1,000 kg/person-day)
Throw-and-roll	1.45	2	2.90
Edge seal	1.27	2	2.54
Semi-permanent	0.27	4	0.27
Spray injection	1.54	2	3.08

1,000 kg = 1.10 tons

repairs still performing at the time of the evaluation, each was evaluated for seven different distress types: bleeding, cracking, dishing, edge disintegration, missing patch, raveling, and shoving.

Experimental Analysis

The primary comparison between the various pothole repairs has been on the basis of survival over time. Two basic patch arrangements were used for the experiment, depending on whether there were two sets of experimental repairs or only one. For two sets the placement order was E1, A1, G1, G2, A2, E2, E3, A3, G3, G4, A4, E4, ... The order for one set of experimental patches was H1, A1, H2, A2, H3, A3, H4, A4, H5, A5, . . . E, G, and H represent experimental repairs, and A represents a control patch. This arrangement allowed for direct comparison of each experimental set with a set of control patches while reducing the number of patches required and the length of pavement, and associated variability, within each comparison unit. Figure 2 shows survival plots over time for one of the comparison units.

On the basis of these survival comparisons, 11 of the 80 total possible comparisons showed a statistically significant difference between the set of experimental patches and the corresponding set of control patches as of the April 1994 performance evaluation. Table 2 summarizes the significant differences for all eight sites. As indicated in Table 2, 4 of the 11 significant differences involve local materials performing worse than the control repairs. In most cases, the failure of the local materials was dramatic and almost immediate. The next most prevalent difference was the performance of the HFMS-2 being poorer than the control in both New Mexico and Ontario.

Preliminary Findings

Several interesting items have come from the pothole repair project to date:

- There has not been a significant improvement in the performance of repairs placed using the semipermanent versus the throw-and-roll procedure when proprietary materials are used.
- Spray injection repairs can be placed as quickly as the throw-and-roll repairs and have been observed to perform as well in most instances. Use of the spray injection procedure requires more effort for the maintenance of the device, and a high skill level for the operator, but can be used effectively by most agencies.
- For situations where patching must be done in adverse climatic conditions, the throw-and-roll and spray injection procedures are recommended to reduce the amount of time crews must spend in traffic and still provide quality repairs.
- Repairs that survived the first month and achieved a higher degree of "set" had a much better chance of surviving as long as the surrounding pavement.

Crack Sealing and Filling

Test Site Installation

Four transverse crack seal and one longitudinal crack fill test sites were installed between March and August 1991. The test site locations are Abilene, Texas; Wichita, Kansas

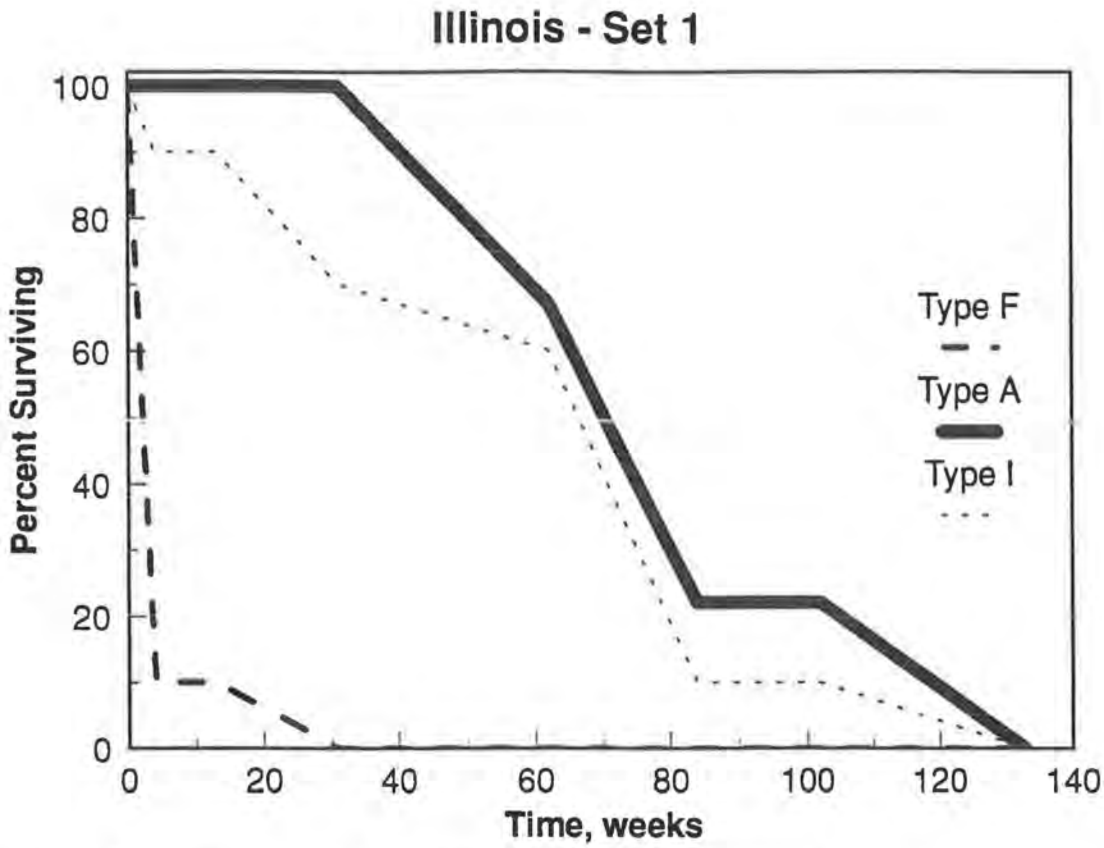

FIGURE 2 Example of various survival plots for pothole repair experiment.

TABLE 2 Summary of Survival Differences

Test Site	Significant Comparisons (at alpha = 0.10)	
	Better Type	Poorer Type (Material/Procedure)
California	Control[1]	Spray Injection
Illinois	Control	Local/Throw-and-roll
	Control	Local/Surface seal[2]
	Control	PennDOT 486/Throw-and-roll
New Mexico	Control	HFMS-2/Throw-and-roll
	UPM/Edge seal	Control
Oregon	Control	Local/Throw-and-roll
Texas	Control	Local/Throw-and-roll
Vermont	Perma-Patch	Control
Ontario	Control	QPR 2000/Throw-and-roll
	Control	HFMS-2/Throw-and-roll

(ideal and adverse conditions); Elma, Washington; Des Moines, Iowa; and Prescott, Ontario (crack fill site).

A total of 15 different materials were placed at the various test sites:

Crack Seal Materials	*Crack Fill Materials*
Meadows Hi-Spec	Hy-Grade Kold Flo
Crafco RoadSaver 515	AC with Hercules Fiber Pave
Crafco RS 211	Witco CRF
Crafco AR+	Crafco AR2
Koch 9030	85–100 Penetration-graded AC
Meadows XLM	
AC 20 with Kapejo Bonifibers	
Dow Corning 890-SL	
Elf CRS-2P	
Koch 9000-S	

The first four of these materials are rubberized asphalt cements, with the Hy-Grade being a rubberized emulsion. The Koch 9030 and Meadows XLM are termed low-modulus rubberized asphalts. Kapejo Bonifibers and Hercules Fiber Pave are two of the brands of fibers available for adding to asphalt cement. The Dow 890-SL is a self-leveling silicone, whereas the Witco CRF and Elf CRS-2P represent emulsified asphalt products. The Crafco AR2 and Koch 9000-S are asphalt rubber materials. Costs for the various repair materials varied from approximately \$2.00/30 m (100 linear ft) of crack for asphalt cement to \$40.00/30 m (100 linear ft) of crack for self-leveling silicone.

Seven different crack preparations were used at the various sites: none; wire brush and compressed air; hot compressed air; compressed air; light sandblast, compressed air, and backer rod; compressed air and backer rod; and light sandblast, compressed air, and backer tape. Each of these procedures had different labor and equipment requirements and production rates. These factors, in conjunction with the performance of the sealants in the field, will be used in calculating the cost-effectiveness of each type of sealant placed.

Eight different configurations of material placement were also included in the experiment and are shown in Figure 3.

At each test site, two replicate sections of the various combinations of material and method (i.e., preparation, procedure, and materials placement configuration) were placed. For each material and method combination, a series of 10 transverse (crack-seal sites) or longitudinal (crack-fill sites) cracks were repaired within each replicate, with the order of seal combinations identical for both replicates. At all test sites, every effort was made to ensure that the cracks treated in the experiment were as uniform as possible. In some instances, this meant that severely deteriorated cracks or partial-lane width cracks were skipped to establish a series of 10 experimentally treated cracks.

Repair Performance Evaluation

Each of the test sites was evaluated periodically to document the survival of the various treatments. Each of the treatments still performing at the time of the evaluation was evaluated for several different distress types: weathering, pull-outs, overband wear, tracking, extrusion, stone intrusion, adhesion loss, cohesion loss (due to either tensile/shear forces or bubbling), and edge deterioration. Also documented were the inches of "failure," defined as locations where the treatment could no longer keep moisture from entering the pavement. Distress information for transverse cracks was recorded along five crack segments: outer edge, outer wheelpath, center of lane, inner wheelpath, and inner edge. These segments provide a method for analyzing the differences in performance that are observed along the crack length. Crack fill treatments were inspected in 1.5-m (5-ft) segments of the longitudinal centerline crack.

Experimental Analysis

Because crack treatment failure has generally been limited, the primary analysis performed has been multivariate analysis of variance (MANOVA) for each of the distress types collected. Tukey analysis, which involved grouping the different treatment types by distress quantities to show where the various treatments performed similarly and where they did not, was also performed. Data were also collected on the amount of movement experienced across a crack to determine which treatments performed better for different ranges of movement.

Tables 3 and 4 give the overall percentages of failure observed for each type of crack-seal and crack-fill treatment, respectively. Failure rates at Elma are consistently much lower than at the other sites. This is due in large part to the moderate climate and lower traffic levels associated with the Elma site.

Figure 4 reinforces this finding and also shows Wichita to be perhaps the most demanding of the sites. Figure 4 shows the average overall survival rates (opposite of failure rates) of sealants placed at all four sites for each site at different periods following installation. Measured horizontal crack movements have generally been the highest at Wichita (ranging between 0.05 and 0.18 in.), and truck traffic on the two-lane facility there is among the highest of the sites.

The primary modes of failure depend largely on the method of application. For instance, full-depth cohesion

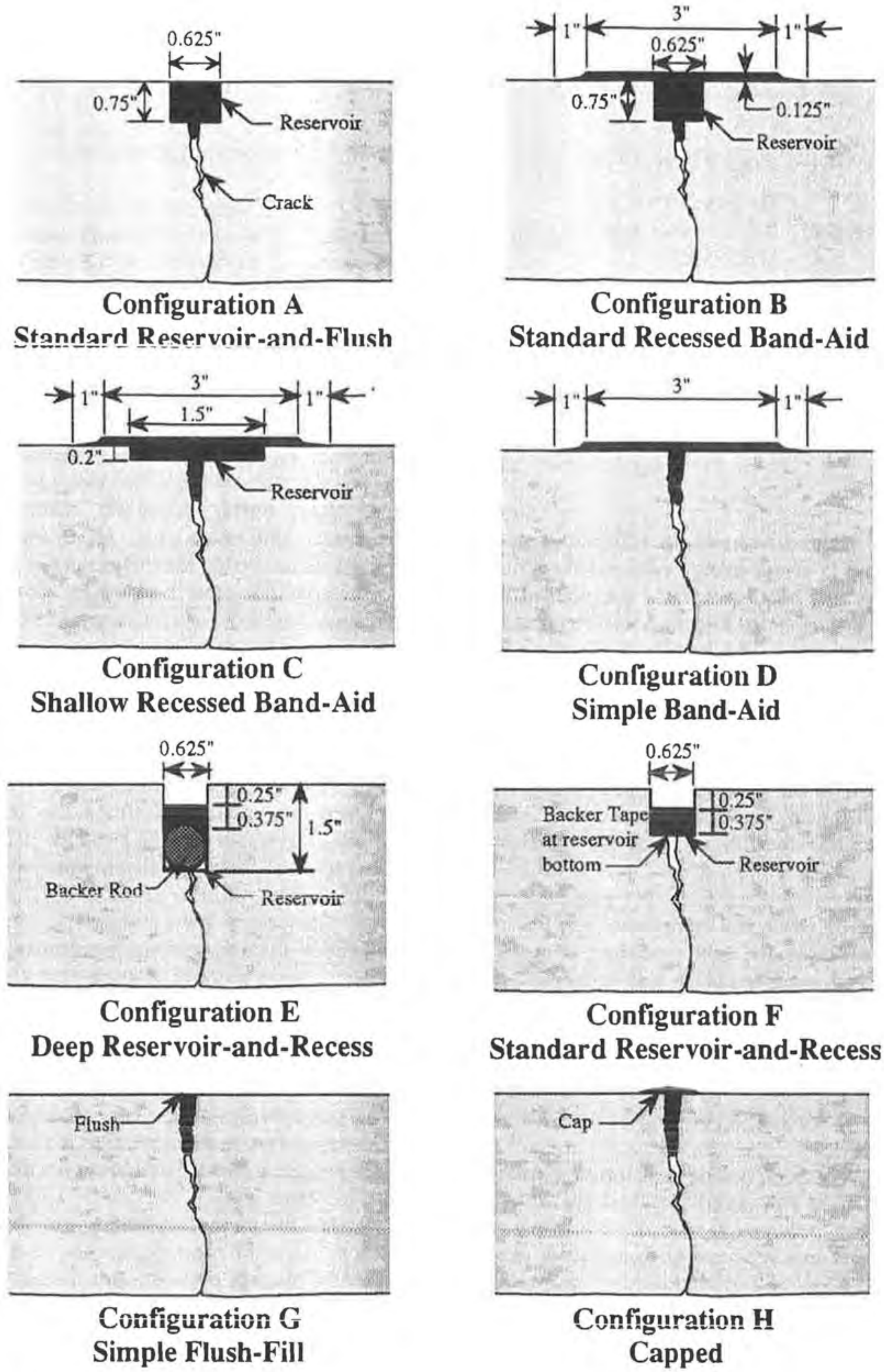

FIGURE 3 Crack seal configurations.

TABLE 3 Percentage of Overall Failure for Various Crack-Seal Treatments at Each Site

Material	Installation Method (Cfg-Prep)	Average Overall Failure, Percent Crack Length				
		Abilene	Wichita (Ideal)*	Wichita (Adverse)*	Elma	Des Moines
Hi-Spec	A-2					6.0
	A-3	2.5	19.9	15.1	0.1	0.6
	B-3	0.1	3.9	1.9	0.0	0.7
	C-3		2.1	2.1		0.3
	D-3	6.5	30.6	21.7	0.0	14.5
	D-4	11.7	27.2	25.7	1.1	7.1
RS 515	B-3	0.3			0.0	0.0
	C-3		1.6	2.3		6.5
	D-3	1.4	22.2	18.8	0.1	12.1
9030	B-3	0.3			0.0	1.4
	C-3		7.7	8.0		0.3
	D-3	11.5	40.6	43.0	0.1	11.2
XLM	B-3	1.8			0.1	0.8
	C-3		10.4	23.6		0.0
	D-3	6.8	26.8	5.8	0.0	1.1
B-Fiber + AC	D-3	53.1	78.6	94.0	0.7	36.9
890-SL	E-5	13.6	18.9		1.8	10.6
	E-6			31.5		
	F-7			NA		
RS 211	B-3				0.0	
AR+	B-3		3.7	2.5		
9000-S	B-3		0.9	1.3		
CRS-2P	G-4					100.0

* Based on data collected from only 1 of 2 replicate sections. NA - Not available.

loss was predominant in the simple band-aid and flush-fill configurations (configurations D and G), whereas full-depth adhesion loss was the main contributor of failure in the reservoir-type configurations (configurations A, B, and C). Self-leveling silicone, placed in reservoir configurations E and F, typically exhibited adhesion failure and edge deterioration failure that stemmed from sawcutting operations.

Results of the MANOVA and Tukey analysis indicated significant differences in fall 1993 performance among the treatments at Des Moines and Abilene. No significant differences, however, were found to exist among the treatments at Elma and Prescott. A summary of the statistically significant differences in overall failure is given in Table 5. Because of incomplete data collected for the two Wichita subsites during the fall 1993 evaluation, the Tukey groupings given in this table represent those formulated for the fall 1992 evaluation. It is believed that only minor changes in performance rankings would have resulted from the fall 1993 evaluation of the Wichita site.

TABLE 4 Percentage of Overall Failure for Various Crack-Fill Treatments at Prescott, Ontario, Site

Material	Installation Method (Cfg-Prep)	Average Overall Failure, Percent Crack Length
RS 211	H-4	0.9
Asphalt Cement	G-1	2.3
	G-4	2.5
CRF	G-4	6.1
AR2	D-4	0.0
	G-4	0.0
FiberPave	D-4	0.9
Kold Flo	G-4	3.6

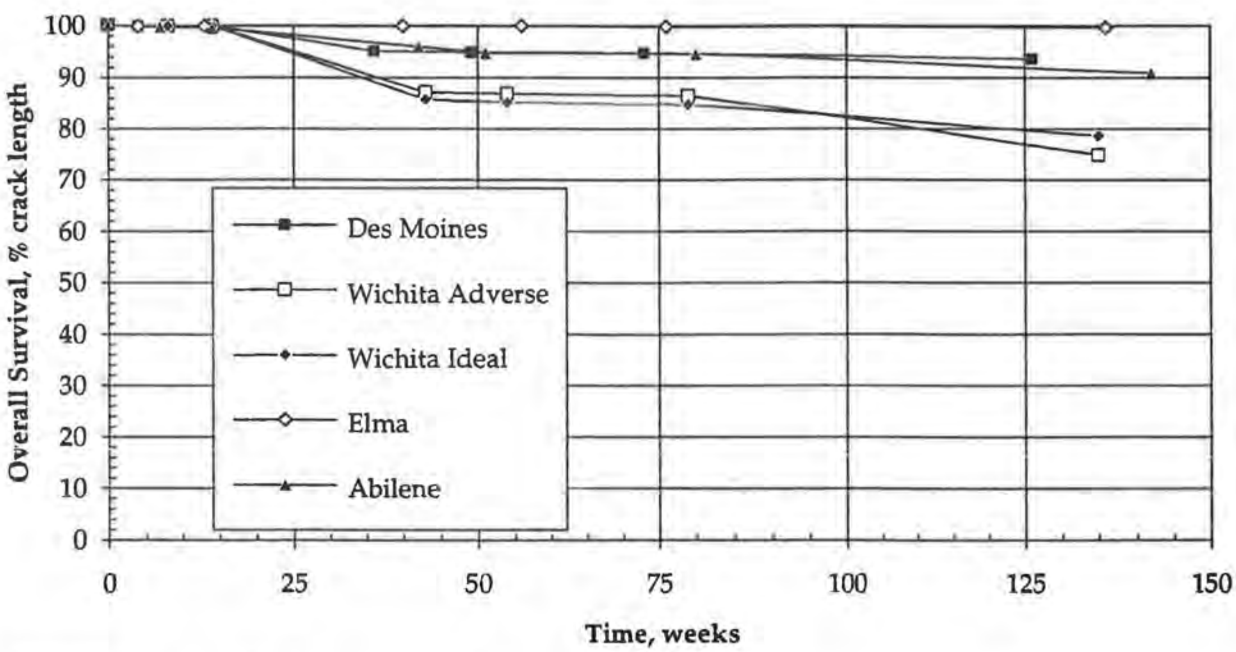

FIGURE 4 Survival of primary crack seal treatments.

In Table 5, treatment performance is categorized by level of performance, with Level 1 representing the best performance, followed by Level 2, Level 3, and so on. On the basis of the results of the Tukey analysis, some treatments were categorized in two or more levels, thereby representing marginal cases. The most notable findings given in this table are the consistently lower performance levels of Bonifiber at each site and the consistently lower performance levels of the simple band-aid material placement configuration (configuration D) for various hot-applied sealants. Also of interest is the low level of performance of CRS-2P emulsion at Des Moines. One may recall from Table 3 that this material has exhibited complete failure.

Preliminary Findings

- In general, good short-term performance can be achieved by both standard and low-modulus rubberized asphalt sealants.
- Barring the creation of secondary cracks during crack-cutting operations, self-leveling silicone can provide

TABLE 5 Tukey Analysis of Overall Failure at Abilene, Wichita, and Des Moines

	Level 1	Level 2	Level 3	Level 4	Level 5
Abilene	Hi-Spec (A-3) Hi-Spec (B-3) Hi-Spec (D-3) Hi-Spec (D-4) RS 515 (B-3) RS 515 (D-3) 9030 (B-3) 9030 (D-3) XLM (B-3) XLM (D-3) 890-SL (E-5)	B-Fiber (D-3)			
Wichita (Ideal Subsite)*	Hi-Spec (A-3) Hi-Spec (B-3) Hi-Spec (C-3) RS 515 (C-3) 9030 (C-3) XLM (C-3) 890-SL (E-5) AR+ (B-3) 9000-S (B-3)	Hi-Spec (A-3) Hi-Spec (D-3) RS 515 (D-3) 9030 (C-3) XLM (D-3) 890-SL (E-5)	Hi-Spec (D-3) Hi-Spec (D-4) RS 515 (D-3) XLM (D-3) 890-SL (E-5)	Hi-Spec (D-3) Hi-Spec (D-4) RS 515 (D-3) 9030 (D-3) XLM (D-3)	B-Fiber (D-3)
Wichita (Adverse Subsite)*	Hi-Spec (A-3) Hi-Spec (B-3) Hi-Spec (C-3) Hi-Spec (D-3) RS 515 (C-3) RS 515 (D-3) 9030 (C-3) XLM (C-3) XLM (D-3) 890-SL (E-6) 890-SL (F-7) AR+ (B-3) 9000-S (B-3)	Hi-Spec (D-3) Hi-Spec (D-4) RS 515 (D-3) XLM (C-3) 890-SL (E-6) 890-SL (F-7)	9030 (D-3)	B-Fiber (D-3)	
Des Moines	Hi-Spec (A-2) Hi-Spec (A-3) Hi-Spec (B-3) Hi-Spec (C-3) Hi-Spec (D-3) Hi-Spec (D-4) RS 515 (B-3) RS 515 (C-3) RS 515 (D-3) 9030 (B-3) 9030 (C-3) 9030 (D-3) XLM (B-3) XLM (C-3) XLM (D-3) 890-SL (E-5)	Hi-Spec (D-3) RS 515 (D-3) 9030 (D-3) B-Fiber (D-3) 890-SL (E-5)	CRS-2P (G-4)		

* Tukey groupings based on performance data collected in Fall 1992.

similar, if not better, shorter-term performance than hot-applied materials.

- The emulsion CRS-2P is inadequate as a sealant for cracks exhibiting moderate to large horizontal movements.
- Bonifiberized asphalt placed in a simple band-aid configuration does not provide good long-term performance in cracks that undergo significant amounts of movement or are exposed to significant levels of traffic.
- Reservoir-type configurations provide better short-term performance than the simple band-aid configuration.
- The standard recessed band-aid configuration shows slightly better short-term performance than the wide recessed band-aid configuration.

JOINT RESEALING

Test Site Installation

The five joint resealing sites were installed between April and June 1991. The test site locations are Phoenix, Arizona; Columbia, South Carolina; Ft. Collins, Colorado; Grinnell, Iowa; and Frankfort, Kentucky. A total of 12 different materials were placed at the various test sites: Crafco RoadSaver 231, Koch 9030, Meadows Sof-Seal, Koch 9005, Crafco RoadSaver 221, Meadows Hi-Spec, Dow Corning 888, Dow Corning 888-SL, Mobay Baysilone 960-SL, Crafco RoadSaver 903-SL, Mobay Baysilone 960, and Koch 9050. The first three materials are low-modulus ASTM D 3405 sealants, whereas the next three are regular ASTM D 3405 materials. The next five materials are all silicones, with the Dow Corning 888 and Mobay Baysilone 960 being the only ones that are not self-leveling. The final material, Koch 9050, is a self-leveling one-part polysulfide.

Four different configurations, or methods of installation, were used for placing the sealant materials, and they are shown in Figure 5.

Two sets of 10 joints were installed at random locations along the test site for each material-configuration combination used at the five test sites. Each of the joints was inspected before installation to ensure a high degree of uniformity among the joints included in the experiment.

Repair Performance Evaluation

All experimental resealed joints have been periodically inspected to check for survival and the development of distress. The distress types that have been documented include partial- and full-depth adhesion loss, partial- and full-depth spall distress, overband wear, stone intrusion, and partial- and full-depth cohesive failure. During each field inspection, distress quantities were recorded at 1-ft increments across the joint, providing a joint position variable that can be used for identifying differences occurring within the wheelpaths or along the lane edges.

Experimental Analysis

Since less than 9 percent of the sealed joint lengths has failed at this time, the primary analysis performed has consisted of multivariate analysis of variance (ANOVA) for each of the distress types collected. Additional analysis was performed involving correlation of field performance with the results of laboratory tests on the sealant materials. Data were also collected on the amount of movement experienced across a joint to determine which repairs performed better for different ranges of movement.

After 30 months, the predominant failure type at all sites is adhesion loss, with spall and cohesive failure also occurring in varying amounts. New spalls are more prevalent at test sites in the colder regions, although adhesive and cohesive failure was observed in both cold and warm regions. The overall seal failure, defined as the percentage of joint length in which moisture and debris can penetrate below the seal material, is given for each material in Table 6. Overall failure includes adhesion, spall, and cohesion failure.

A comparison by state of the primary seals, shown in Figure 6, indicates that the rate of failure has increased now that the seals have passed two winters and three summers. The seals in South Carolina, a wet-nonfreeze region state, are not surviving as well as in other states. This is primarily due to the adhesion failure in the configuration 3 joints, where unfailed silicone sealant was partially removed by the plowing operation. The silicone that remained on the joint walls inhibited bonding of the new sealants and has led to significant adhesion loss.

Preliminary Findings

- The silicone sealants have developed significantly less partial- and full-depth adhesion failure than most rubberized-asphalt sealants. When installed in identically prepared joints using the standard, recessed configuration, the silicone sealants averaged 0.3 percent full-depth adhesion failure, whereas the hot-applied sealants averaged 10.7 percent adhesion failure.
- In states where large amounts of spalling occurred, significantly larger amounts of partial- and full-depth spalls developed in the lane wheelpaths. This verifies the effect of traffic loads on the formation of thin joint-edge spalls.
- The 0.125-in.-thick rubberized asphalt overbanded material remained effective in the pavement wheelpaths

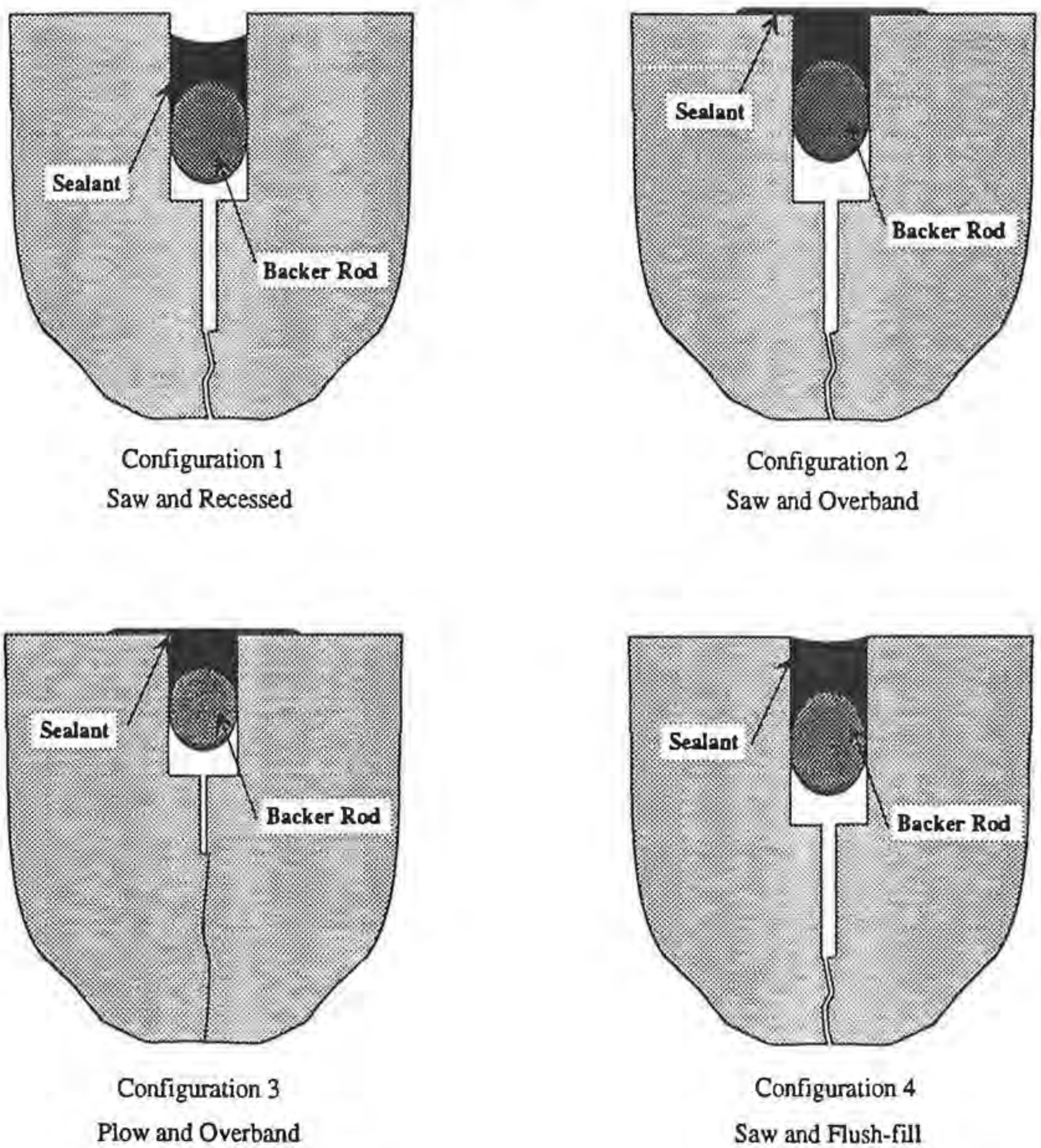

FIGURE 5 Joint seal configurations.

for 9 to 18 months, depending on the material. After 30 months, the overbanded material is completely worn from 90 percent of the joint lengths on all sealants except Crafco RoadSaver 231, where sealant remains along the joint length except in the wheelpath.

- No significant relations ($r^2 = 0.01$ to 0.21) have been observed between adhesive/cohesive failure in each material and the maximum extension experienced by joint seals at the test sites.
- Bubbling has occurred in one of the Mobay 960-SL self-leveling silicone sealants at the Colorado site, which has led to some partial- and full-depth adhesive distress. This material is being reformulated.

Partial-Depth Spall Repair

Test Site Installation

The four partial-depth spall repair sites were installed between March and July 1991. The test site locations are Phoenix, Arizona; Columbia, South Carolina; Ogden, Utah; and Kittanning, Pennsylvania.

A total of 12 different materials were placed at the various test sites (the number or letter in parentheses after the material denotes the symbol used to refer to it in Table 7): Type III PCC (1), Duracal (2), Set-45 (3), Five Star HP (4), SikaPronto 11 (5), Pyrament 505 (6), MC-64

TABLE 6 Summary of Overall Failure for All Joint Reseal Test Sites

Sealant Material	Config.	Total Joints Installed	Overall failure, percent joint length				
			Arizona	South Carolina	Colorado	Iowa	Kentucky
Koch 9005	1	100	6.3	0.1	7.9	5.2	1.0
	2	100	0.1	1.2	3.5	3.0	0.9
	3	60		8.2		1.3	0.5
	4	40	6.4		21.6		
Crafco RoadSaver 231	1	100	26.5	23.2	2.3	1.1	1.9
	2	100	2.7	12.9	4.0	0.6	1.1
	3	60		30.2		2.9	0.3
	4	40	2.2		1.9		
Meadows Sof-Seal	1	80		19.8	9.7	13.5	19.0
	2	80		25.7	8.9	4.3	6.1
	3	60		32.4		8.4	2.6
	4	20			5.9		
Koch 9030	1	80		34.3	19.7	4.2	12.1
	2	80		16.5	19.7	6.6	16.6
	3	60		62.3		13.2	0.7
	4	20			15.5		
Meadows Hi-Spec	1	20	25.9				
	2	20	4.0				
	4	20	1.0				
Crafco RoadSaver 221	1	20	9.1				
	2	20	1.2				
	4	20	8.0				
Dow 888	1	100	0.1	0.3	2.0	1.4	6.5
Dow 888-SL	1	100	0.2	1.0	2.7	2.0	0.3
Mobay 960-SL	1	100	0.1	0.9	4.3	6.4	2.3
Mobay 960	1	20				0.4	
Crafco 903-SL	1	20	0.4				
Koch 9050	1	30			47.4		0.1
Dow 888 w/ Primer	1	10				1.3	
Dow 888-SL w/ Primer	1	10				1.0	
Koch 9005 w/ Primer	1	10					0.8

(7), Percol FL (8), UPM High-Performance Cold Mix (9), Rosco (A), Penetron (B), and AMZ (C). The first six of these materials are rigid repair materials; the remainder represent flexible repair materials. The UPM is the same proprietary cold mix used in the pothole repair experiment, whereas the AMZ and Rosco are types of spray injection devices. The Penetron is a two-part polymer material put into the study at the request of the Arizona Department of Transportation.

Five different procedures were used for preparing the spalled areas and placing the repair materials (the number in parentheses after the procedure denotes the symbol used to refer to it in Table 7): saw and patch (1), chip and patch (2), mill and patch (3), clean and patch (adverse conditions only) (4), and waterblast and patch (5).

A minimum of 10 partial-depth spall repairs were placed for various material-procedure combinations to make a single test set. Two replicates of the test sets were

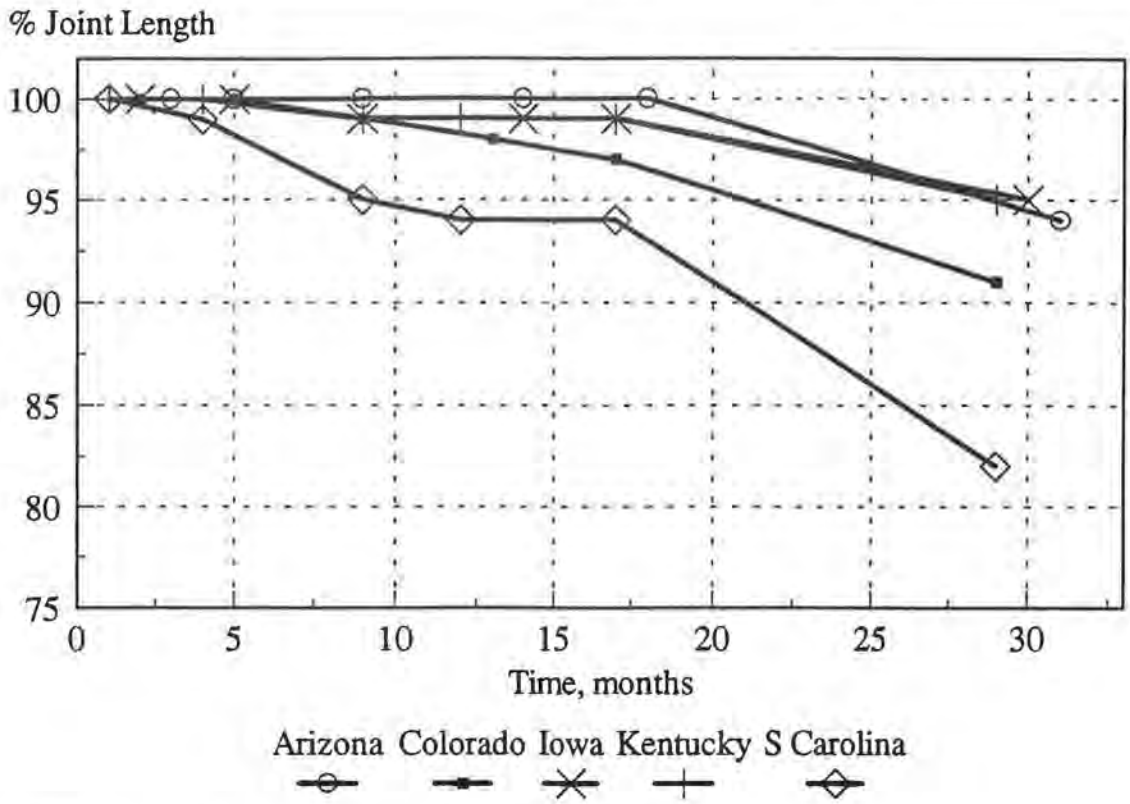

FIGURE 6 Survival of primary joint sealant materials by test site.

placed, with a random order being used to determine each set's position within a replicate.

Repair Performance Evaluation

Each of the partial-depth spall repairs has been evaluated periodically since installation to document its survival and the development of distresses. Distresses that have been documented for the cementitious repairs include spalling, cracking, wearing/ravelling, oxidizing, edge fraying, adjacent pavement deterioration, pavement corner cracking, joint sealant condition, faulting, and patch debonding. Distress types for the bituminous repairs include dishing, raveling, shoving, cracking, bleeding, edge disintegration, and missing patch.

Experimental Analysis

Early analysis efforts for the partial-depth spall repair experiment have concentrated on the distress types and quantities because of the high survival rates that have been observed. Since the failure rates have begun to increase with the latest evaluation, more emphasis has been placed on the survival analysis, similar to that performed for the pothole repair experiment described earlier.

One important difference between the pothole repair and partial-depth spall repair experiments is the lack of a "control" repair for direct comparison with the experimental patches. As a result, a method of comparing each set of material-procedure combinations has been developed that essentially results in the comparison of each set with all other sets of experimental repairs. The result is a series of grouped values similar to the Tukey groupings calculated for the crack seal and joint reseal experiments. Table 7 contains the results of the survival analysis for the partial-depth spall repair experiment. The treatments given in Table 7 use the material and procedure characters given previously in this section to identify the individual treatments.

Findings

Some of the observations and findings which have come from the partial-depth spall repair experiment to date are as follows:

- For the first 2 years, there has been basically no difference in the survival of the Type III PCC repairs and the

TABLE 7 Summary of Partial-Depth Spall Repair Survival Analysis

Test Site	Treatment	Number of Surviving Repairs	Groups with statistically similar survival plots (alpha = 0.10)		
PA	12, 33, 61, 71, 72, 73	20	*		
	31, 41, 51, 62, 92, A2	19	*	*	
	13, 42, 43, 74, 81, 82	18	*	*	*
	11	17		*	*
	32	16		*	*
	84	14			*
SC	11, 12, 21, 41, 42, 51, 71, 92, C2	20	*		
	22, 32, 52, 61	19	*		
	31, 62	18	*	*	
	72	15		*	
AZ	11, 12, 21, 22, 32, 41, 42, 51, 52, 53, 61, 62, 72	20	*		
	B1	17	*	*	
	31	16	*	*	
	73, 92	13		*	*
	71	12			*

NOTE: In the "Treatment" column, the first character of each two-character item indicates the material used from the list of 12 materials applied in the tests. The second character indicates the treatment method from among the five used at the four test sites. No failures had been observed at the Utah test site as of the latest evaluation.

survival of the more expensive proprietary cementitious materials, though some difference began to appear at the Pennsylvania test site.

- The survival of the bituminous patches (cold mix and spray injection) is no different from that of the cementitious and polymer materials, with the exception of the Arizona test site. As with the Type III PCC in Pennsylvania, this difference has only become apparent after the most recent inspection.

Future Efforts

The FHWA-LTPP contract for continued monitoring of the H-106 test sites will continue through 1998, and performance data will continue to be collected and analyzed until that point. In the case of the pothole repair experiment, six of the original eight sites have been lost to overlays by the participating agencies, and in every case the condition of the pavements definitely merited the improvements.

For the six "completed" pothole sites, final analyses of the installation and performance data will be completed and sections for a revised final report will be created. Modifications to the *Manual of Practice for Pothole Repair* will also be made on the basis of the results of the final analyses. Once the remaining two sites are lost to overlay, which should be before spring 1995, a revised final report and manual of practice will be produced, which will encompass all of the findings for the project.

For the remaining three experiments, data collection will continue as long as possible with the cooperation of the participating agencies. Modifications to the final reports and manuals of practice will be made as described for the pothole repair experiment.

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BRIDGE MAINTENANCE

Pennsylvania's Bridge Management Process for Identifying, Priority Ranking, and Completing Bridge Maintenance Activities

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Pennsylvania's Bridge Management System (BMS) stores a wide range of bridge inspection data and analyzes these data using individual subsystems to provide decision-making support for department managers. The subsystems are as follows: Bridge Rehabilitation and Replacement, Bridge Maintenance, Modeling, and Reports. Pennsylvania's BMS operates in a mainframe environment and includes 17 on-line data screens and up to 400 data elements for each bridge. Data on any of the 25,000 state-owned and 6,500 locally owned bridges in the system are retrievable within minutes of inquiry. The system can produce a wide range of reports, including standard menu-driven reports and customized user-generated reports. Besides storing and recording bridge inspection information, BMS can automatically generate improvement costs by bridge for maintenance, rehabilitation, and replacement needs. BMS also can prioritize bridges for capital maintenance improvements. A unique feature of BMS is its modeling capability, which enables the user to predict future bridge needs by programmatically degrading bridge condition and load-carrying capacity over time.

Before the Bridge Maintenance Subsystem is detailed, it is appropriate to give an overview of Pennsylvania's Bridge Management System (BMS). The Pennsylvania Department of Transportation's (PennDOT's) BMS has been operational since December 1986. This system stores a wide range of bridge inspection data and analyzes these data using individual subsystems to provide decision support for department managers. The following subsystems are shown in Figure 1:

- Bridge Rehabilitation and Replacement provides cost estimates and priority ranking of bridge improvement projects to support long-range planning and programming decisions.
- Bridge Maintenance provides cost estimating and priority ranking of bridge maintenance activities for assistance in developing annual maintenance programs.
- Modeling uses deterioration curves for bridge condition and bridge load capacity. It enables department managers to predict future bridge improvement needs using different funding scenarios.
- Reports is available to provide both standardized and customized report generation capabilities for any subset of data in BMS.

Pennsylvania maintains a proactive approach to bridge inspection and bridge management, often implementing new systems or procedural changes before the date set by federal requirements.

The BMS is a powerful management tool that not only records and stores bridge inspection data for Pennsylvania's bridges but also enables department managers to make key decisions concerning bridge inspection, maintenance, rehabilitation, and replacement. Data on any of the 25,000 state-owned and 6,500 locally owned bridges in the system are retrievable within minutes of inquiry. BMS operates in a mainframe environment and includes 17 on-line data screens and up to 400 data elements for every bridge. The system also can produce a wide range of reports, including standard menu-driven reports and customized, user-generated reports. A query language is

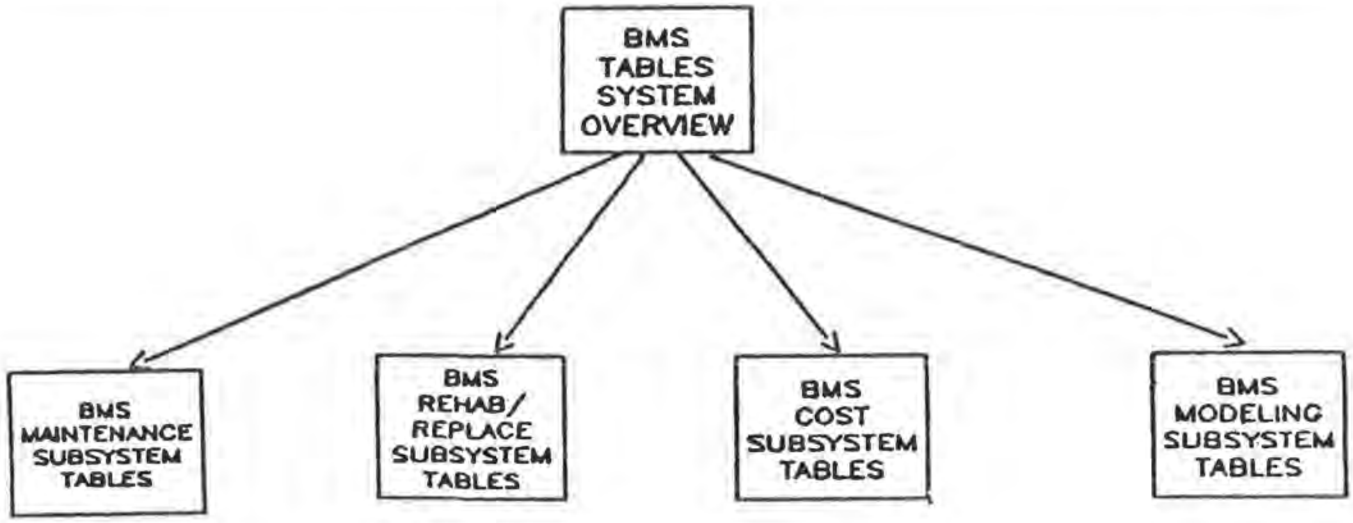

FIGURE 1 BMS tables system overview (*1*).

built into the BMS to allow users to customize reports on any combination of data elements in the system.

Besides storing and recording bridge inspection information, BMS can automatically generate improvement costs by bridge for maintenance, rehabilitation, and replacement needs. BMS also can rank bridges for capital maintenance improvements. A unique feature of BMS is its modeling capability, which enables the user to predict future bridge needs by programmatically degrading bridge condition and load-carrying capacity over time.

Although BMS has been in production since December 1986, improvements and enhancements have occurred continuously. Completed BMS enhancements include new screens for fracture-critical and underwater bridge inspection, sign structure and retaining wall inspection, and system integration with PennDOT's Roadway Management System, Project Inventory System, and Project Management System. All of these screens represent areas of new initiatives since the original BMS was developed.

All data required by the Federal Highway Administration (FHWA) are included in PennDOT's BMS, in addition to data deemed necessary by PennDot. Data are grouped by general data type, and a coding manual provides detailed description and codings for each data item. Table 1 (*2*) gives all data screen names.

Data that reside in BMS can come from any of three sources: direct data entry via keyboard, such as bridge condition ratings; data generated through system calculations, such as improvement costs or priorities; and data imported from other department management systems, such as average daily traffic or program and budget status. BMS also exports bridge data to other department management systems. The exchange of data between department systems occurs automatically at either daily or weekly frequencies depending on data type. All department management systems operate on a mainframe computer platform that simplifies the exchange of data between systems and offers instantaneous data access to all users via computer terminals in all of Pennsylvania's 67 counties. BMS currently exchanges data with the Project Inventory, Project Management, and Roadway Management systems. These mainframe systems can interface because they all use a common link-node location referencing system that uses a 14-digit key to define any point on the network. Therefore, each bridge is uniquely defined by a 14-digit code. BMS also can store inspection data, on line, for the previous five inspections. Beyond that point, the oldest inspection data are archived on magnetic tape. All data are easily retrievable.

The Bridge Maintenance Subsystem of BMS ranks bridges on the basis of needed maintenance activities. It also estimates costs for these activities. A priority-setting procedure has been developed that considers the effect of the most structurally critical maintenance activity need on the bridge and the individual bridge's impact on the road system. A maintenance deficiency rating is calculated by the system for each bridge on a scale of 0 to 100, with higher values suggesting higher maintenance needs. A menu of 76 bridge maintenance activities has been developed in consultation with PennDOT's engineering districts and the Central Office Bureau of Maintenance and stored in the system. These activities cover the full range of maintenance that can be done on a bridge using either department forces or contractors. On the basis of these 76 bridge activities, the Maintenance Needs Reporting Form (Figure 2) was developed for the bridge inspector as a checkoff type listing and as the reporting document. When a reparable deficiency is found, the inspector re-

TABLE 1 Summary of BMS Data (*1*)

Screen	Type of BMS Data
AA	General Data
AB	Features Intersected Data
AC	Structure Data
AD	Utility, Hydrology and Posting Data
AE	Inspection Data
AF	Proposed Improvement Data
AG	Repair and Painting Data
AH	Proposed Maintenance Data
AJ	Fracture Critical Data
AL	Narrative Data
AM	Condition Rating Data
AN	Completed Maintenance Data
AO	Planning, Programming and Budgeting Data
AR	State Roadway Data
AS	Sign Structure Data
AT	Retaining Wall Data
AW	Underwater Inspection Data

views the listing, selects the proper activity, circles the general location, estimates a quantity, and assigns an urgency factor. It reflects the inspector's judgment as to how soon the maintenance activity should be completed. This process occurs at the end of each safety inspection and does not require a significant amount of additional time: approximately 15 min for a typical structure. Also, the inspector estimates the quantity of work needed to facilitate the project planning process. With this additional information, the system can rank bridges on the basis of maintenance needs and can estimate the costs.

The Bridge Maintenance Subsystem provides decision support in the development of the department's Annual Maintenance and Betterment work programs. These programs provide for all noncapital highway and bridge work. The work is done by department forces or contractors. Bridge work includes small bridge replacements and any of the 76 bridge maintenance activities mentioned above. Work programs are developed on an annual basis, and BMS provides support. Besides the various maintenance activities completed each year, about 100 small bridge replacements are included annually in this program.

A thorough field inspection on at least a biennial basis initiates the entire process for bridge management systems and the Bridge Maintenance Subsystem. Bridge inspections

1. Document the bridge and its condition,
2. Become a basis of system data and management information,
3. Ensure the ultimate safety of the traveling public,
4. Form the basis for maintenance planning,
5. Form a portion of the bridge history in the record, and
6. Become a basis for total costing of bridge needs.

The bridge maintenance needs data are collected as a part of the bridge inspection process. Hence, these data are entered into the BMS on-line individual bridge files at the field offices when the inspection data are updated, as soon as the inspection is completed. Once in the computerized system, it can be extracted in any format required by bridge or maintenance staff to satisfy specific planning, programming, or other needs. After each maintenance activity is completed, maintenance information is transferred from the maintenance needs list in BMS to the completed maintenance activities list, where it serves as a historical record of completed work.

The current maintenance work backlog far exceeds what the department can physically and financially handle. Hence, it is important that guidance be provided to the district and the county offices to assist them in selecting the best candidate bridges for maintenance work and which activities to perform first. This helps to ensure that the most critical deficiencies are brought to the attention of management.

A simple ranking procedure has been developed. It considers the effect of the most structurally critical maintenance activity need on the bridge as well as the individual bridge's impact on the road system. The components of the procedure are as follows: activity ranking, activity urgency, bridge criticality, and bridge adequacy.

The bridge maintenance activities themselves vary in their importance to and effect on the structural integrity of the bridge. Activities such as repairing abutment underscour would generally be performed on a priority basis, whereas activities such as applying protective coatings and constructing abutment slopewalls would tend to be less critical and possibly deferred.

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BRIDGE MANAGEMENT SYSTEM

BRIDGE INSPECTION REPORT

MTCE. & MAJOR IMPROV. NEEDS

INSP. DATE: ____________

Inspection Report for:	STRUCTURE IDENTIFICATION NUMBER	STRUCTURE TYPE
Entire Bridge ☐ Main Span(s) only ☐ Approach Span(s) only ☐	A01 ___ ___ ___ ______ over ______	______ ______

		H01 ITEM NO.	H03 LOCATION	UNIT	H05 EST.* QUANTITY	H08 PR	H09 O/C
APPROACH ROADWAY	PAVEMENT (PATCH/RAISE)	RDPAVMT	L N R L F R	S.Y.			
APPROACH ROADWAY	PAVEMENT RELIEF JT. (REP/REPL)	RDRLFJT	L N R L F R	S.Y.			
APPROACH ROADWAY	SHOULDERS (REPAIR/RECONSTR)	RDSHLDR	L N R L F R	S.Y.			
APPROACH ROADWAY	DRAINAGE-OFF BRIDGE (IMPROVE)	RDDRAIN	L N R L F R	EA.			
APPROACH ROADWAY	GUIDE RAIL (CONNECT TO BRIDGE)	RDGDERL	L N R L F R	EA.			
APPROACH ROADWAY	LOAD LIMIT SIGNS (REPLACE)	RDLDSGN	L N R L F R	EA.			
APPROACH ROADWAY	CLEARANCE SIGNS (REPLACE)	RDCLSGN	L N R L F R	EA.			
APPROACH ROADWAY	CUT BRUSH TO CLEAR SIGNS	RDBRUSH	L N R L F R	EA.			
APPROACH ROADWAY	APPROACH SLAB (REPLACE)	A744201	L N R L F R	S.Y.			
CLEAN/FLUSH	DECK	A743101		E.B.			
CLEAN/FLUSH	SCUPPER/DOWNSPOUTING	B743101	1 2 3 4 5 O	E.B.			
CLEAN/FLUSH	BEARING/BEARING SEAT	C743102	1 2 3 4 5 O	E.B.			
CLEAN/FLUSH	STEEL-HORIZONTAL SURFACES	D743102	1 2 3 4 5 O	E.B.			
DECK	BITUM. DECK W. SURF (REP/REPL)	BITWRGS	1 2 3 4 5 O	S.Y.			
DECK	TIMBER DECK (REP/REPL)	B744301	1 2 3 4 5 O	S.Y.			
DECK	OPEN STEEL GRID (REP/REPL)	C744302	1 2 3 4 5 O	S.Y.			
DECK	CONCRETE DECK (REPAIR)	D744303	1 2 3 4 5 O	S.Y.			
DECK	CONCRETE SIDEWALK (REPAIR)	E744303	1 2 3 4 5 O	S.Y.			
DECK	CONCRETE CURB/PARAPET (REP)	F744303	1 2 3 4 5 O	S.Y.			
DECK JOINTS	RESEAL	A743301	N 1 2 3 O F	L.F.			
DECK JOINTS	REPAIR/RESEAL	A744101	N 1 2 3 O F	L.F.			
DECK JOINTS	COMPRESSION SEAL (REP/REHAB)	B744102	N 1 2 3 O F	L.F.			
DECK JOINTS	MODULAR DAM (REP/REHAB)	C744102	N 1 2 3 O F	L.F.			
DECK JOINTS	STEEL DAMS (REP/REHAB)	D744102	N 1 2 3 O F	L.F.			
DECK JOINTS	OTHER TYPES (REP/REHAB)	E744102	N 1 2 3 O F	L.F.			
RAILING	BRIDGE/PARAPET (REP/REPL)	RLGBRPR	N 1 2 3 O F	L.F.			
RAILING	STRUCT MOUNT (REP/REPL)	RLGSTRM	N 1 2 3 O F	L.F.			
RAILING	PEDESTRIAN (REP/REPL)	RLGPEDN	N 1 2 3 O F	L.F.			
RAILING	MEDIAN BARRIER (REP/REPL)	RLGMEDB	1 2 3 4 5 O	L.F.			
DK. DRAIN	SCUPPER GRATE (REPLACE)	DRNGRAT	1 2 3 4 5 O	EA.			
DK. DRAIN	DRAIN/SCUPPER (INSTALL)	B744401	1 2 3 4 5 O	EA.			
DK. DRAIN	DOWNSPOUTING (REP/REPL)	C744402	N 1 2 3 F O	EA.			
BEARINGS	LUBRICATE	A743501	N 1 2 3 F O	EA.			
BEARINGS	STEEL (REP/REHAB)	A744501	N 1 2 3 F O	EA.			
BEARINGS	STEEL (REPLACE)	B744501	N 1 2 3 F O	EA.			
BEARINGS	EXPANSION (RESET)	C744502	N 1 2 3 F O	EA.			
BEARINGS	PEDESTAL/SEAT (RECONSTRUCT)	D744503	N 1 2 3 F O	EA.			
TIMBER	STRINGER (REP/REPL)	A744601	1 2 3 4 5 O	EA.			
TIMBER	OTHER MEMBERS (REP/REPL)	B744601	1 2 3 4 5 O	EA.			
STEEL	STRINGER (REP/REPL)	A744602	1 2 3 4 5 O	EA.			
STEEL	FLOORBEAM (REP/REPL)	B744602	1 2 3 4 5 O	EA.			
STEEL	GIRDER (REPAIR)	C744602	1 2 3 4 5 O	EA.			
STEEL	DIAPH/LAT. BRACING (REP/REPL)	D744602	1 2 3 4 5 O	EA.			
RC/PS	STRINGER (REP/REPL)	A744603	1 2 3 4 5 O	EA.			
RC/PS	DIAPHRAGM (REP/REPL)	B744603	1 2 3 4 5 O	EA.			
RC/PS	OTHER MEMBERS (REP/REPL)	C744603	1 2 3 4 5 O	EA.			
TRUSS	MEMBER (STRENGTHEN/REP/REPL)	A744701	1 2 3 4 5 O	EA.			
TRUSS	PORTAL (MODIFY)	B744701	1 2 3 4 5 O	EA.			
TRUSS	MEMBER (TIGHTEN/FLAMESHORTEN)	C744702	1 2 3 4 5 O	EA.			

		H01 ITEM NO.	H03 LOCATION	UNIT	H05 EST.* QUANTITY	H08 PR	H09 O/C
PAINTING	SUPERSTRUCTURE - SPOT	A743201	1 2 3 4 5 O	E.B.			
PAINTING	SUBSTRUCTURE - SPOT	B743201	N 1 2 3 O F	E.B.			
PAINTING	SUPERSTRUCTURE - FULL	C743201	1 2 3 4 5 O	E.B.			
PAINTING	SUBSTRUCTURE - FULL	D743201	N 1 2 3 O F	E.B.			
ABUTMENT - WING - PIER, ETC.	BACKWALL (REP/REPL)	A744801	L N R L F R	C.Y.			
ABUTMENT - WING - PIER, ETC.	ABUTMENTS (REPAIR)	B744802	L N R L F R	C.Y.			
ABUTMENT - WING - PIER, ETC.	WING (REP/REPL)	C744802	L N R L F R	C.Y.			
ABUTMENT - WING - PIER, ETC.	PIERS (REPAIR)	D744802	1 2 3 4 5 O	C.Y.			
ABUTMENT - WING - PIER, ETC.	FOOTING (UNDERPIN)	E744803	N 1 2 3 O F	C.Y.			
ABUTMENT - WING - PIER, ETC.	MASONRY (REPOINT)	F744804	N 1 2 3 O F	L.F.			
ABUTMENT - WING - PIER, ETC.	ABUT. SLOPEWALL (REP/REPL)	A745101	L N R L F R	S.Y.			
ABUTMENT - WING - PIER, ETC.	ABUT. SLOPEWALL (CONSTRUCT NEW)	B745102	L N R L F R	C.Y.			
ABUTMENT - WING - PIER, ETC.	PILE REPAIR	A745901	N 1 2 3 O F	EA.			
EROSION CONTOL	STREAM BED PAVING (REP/CONSTR)	A745301	UP UN DN	C.Y.			
EROSION CONTOL	ROCK PROTECTION	B745301	UP UN DN	C.Y.			
EROSION CONTOL	SCOUR HOLE (BACKFILL)	C745301	UP UN DN	C.Y.			
EROSION CONTOL	STREAM DEFLECTOR (REP/CONSTR)	D745302	UP UN DN	C.Y.			
EROSION CONTOL	VEGETATION/DEBRIS (REMOVE)	ECREMVG	UP UN DN	C.Y.			
EROSION CONTOL	DEPOSITION (REMOVE)	ECREMDP	UP UN DN	C.Y.			
CULVERT	HEADWALL/WINGS (REP/REPL)	A745201	IN OUT	S.Y.			
CULVERT	APRON/CUTOFF WALL (REP/REPL)	B745202	IN OUT	S.Y.			
CULVERT	BARREL (REPAIR)	C745203	———	S.Y.			

FOR COMPLETION BY REVIEW ENGINEER

APPLY PROTECTIVE COATING						
DECK/PARAPETS/SIDEWALK	A743401	O P S	S.Y.			
SUBSTRUCTURE	B743401	N 1 2 3 O F	S.Y.			
CONSTRUCT TEMPORARY						
SUPPORT BENT	A745401	N 1 2 3 O F	EA.			
PIPES	B745401	LT ℄ RT	E.B.			
BRIDGE	C745401	LT ℄ RT	E.B.			

LEGEND

N .... NEAR	UP .... UPSTREAM
F .... FAR	UN .... UNDER
1, 2, 3, ETC. ..... SPAN OR PIER NUMBER	DN .... DOWNSTREAM
O .... OTHER	IN .... INLET
LNR .... NEAR LEFT OR RIGHT	OUT .... OUTLET
LFR .... FAR LEFT OR RIGHT	E.B. .... EACH BRIDGE (SITE)
* .... IN WHOLE UNITS	XXX .... BMS. DATA ITEM ID.

PR - PRIORITY CODE

0 - PROMPT ACTION REQUIRED (INSPECTOR TO INFORM THE BRIDGE ENGINEER BEFORE UPDATING BMS).
1 - HIGH PRIORITY, AS SOON AS WORK CAN BE SCHEDULED.
2 - PRIORITY, REVIEW WORK PLAN, ADJUST SCHEDULE IF NEEDED.
3 - ADD TO SCHEDULED WORK.
4 - ROUTINE STRUCTURAL, CAN BE DELAYED UNTIL FUNDS ARE AVAILABLE.
5 - ROUTINE NON-STRUCTURAL, CAN BE DELAYED UNTIL PROGRAMMED.

MAJOR IMPROVEMENT NEEDS

F01 YEAR NEEDED ___ ___ ___ ___ F02 TYPE WORK ___ ___ ___

F04 IMPROV LGTH ___ ___ ___ ___ ___ ___

FIGURE 2 Bridge inspection report (2).

As a general rule, activities that most directly, immediately, and positively affect the continued safety and structural adequacy of the bridge would be performed first. Those with minimal immediate impacts would be performed later. The activities have been divided into five groups (A through E) on the basis of their generalized relative importance to the current structural stability of the bridge. In addition, the activities "repair/replace: steel stringers, floorbeams, girders or truss members" could be related to existing or potential fatigue damage. If the needs are indeed fatigue related, they are more important and are given the highest ranking, A. The fatigue relationship is made by comparing these maintenance activity needs with the type of fatigue-prone member that controls the inventory load rating. If the activity is fatigued related, it is given higher priority.

The severity of a deficiency can be a reason to increase its priority for repair. The urgency factor for each activity need is coded by the district bridge inspection unit. Although subjective, it yields an informed, somewhat standardized assessment of how soon the work needs to be completed. It is also a measure of the severity of the deficiency. The rater can rate one of six priority codes, from 0 (prompt action required) to 5 (can be delayed until programmed).

The importance of a bridge to the road network and the impact of the loss of bridge service to traffic are other factors that must be considered in deciding the order in which bridges are to be maintained or repaired. It is readily apparent that the road system hierarchy realistically defines importance. That is, if a bridge on the Interstate and a bridge on the local access system have similar deficiencies, it is prudent that the Interstate highway bridge be repaired first. However, the impact of a bridge's closure also needs to be weighed. If the detour length is excessive and intolerable, the bridge priority for repair should be raised.

The assessment of the importance of the bridge is based on the classification of the highway, its traffic level (ADT), and the detour length that will be imposed on traffic if the bridge were closed. Multiplying the ADT by the detour length results in a partial relative measure of this importance.

The capability of the bridge to safely carry the loads that traverse the route will weigh in a manager's decision of whether to implement repairs. The load capacity rating indicates the current strength of the bridge. It does not indicate what can be expected in the future. The condition rating of the most critical component of the bridge can be used to generally assess degradation. It is based on the summation of the condition ratings for the deck, the superstructure, and the substructure. If any rating is 4 or less, it individually establishes the remaining life. By considering both the current load of capacity and the lowest condition rating of the structure's components, a measure of the deficiency of the bridge is obtained.

Having defined the major parameters that are considered, the relative weights assigned to them and their elements were established in the BMS. To be consistent with the general philosophy of the rehabilitation/replacement prioritization system, a deficiency-point concept was used for ranking maintenance activity. However, the factors and methodology used in each system are quite different. Although it is numerically possible for a single bridge to be assigned in excess of 100 deficiency points, the deficiency point assignment is limited to a maximum of 100. The higher a bridge's point assignment, the higher its deficiency and its priority. (Total deficiency is represented by 100 points; no deficiency is represented by 0 points.)

Table 2 summarizes the four major components of the prioritization system, defines the elements in their makeup, and indicates the initial weights assigned to each. As the procedure is used, evaluated, and refined, the weight assignments may change.

The maintenance deficiency point assignment for a specific bridge is based on the bridge maintenance activity with the largest sum of deficiency points for activity ranking and urgency. The bridge's deficiency point assignment and the bridge's county ranking for maintenance based on the deficiency point assignment will be recorded on the bridge maintenance activity needs screen. Hence, a manager viewing the subject screen for an individual bridge has an immediate indication of the relative priority of the most critical repair need on that bridge and the need compared with the worst possible case (100 deficiency points).

With a deficiency point assignment being stored in BMS for every bridge, prioritized listings can be easily generated using the particular parameters desired. To facilitate this reporting, user-friendly standard report generators with user-defined variables have been developed.

A prioritized listing of bridges to be repaired can be generated for various geographical areas (statewide, district, or county) for use in developing the annual bridge repair work programs. Once programmed, the activity needs screen can be updated to reflect whether each activity is to be done by department force or contract and the year of the program that includes the work.

The department has implemented a mainframe-based Maintenance Operations and Resources Information System (MORIS) to assist the maintenance organization in planning, implementing, and effectively managing all maintenance activities. The system combined previous material, equipment, manpower, and planning subsystems and further enhanced their capabilities.

MORIS can plan and schedule all maintenance activities in advance of field work, including bridge work. It then tracks expenditures of labor, materials, and equipment

TABLE 2 Maintenance Deficiency Points Assignment (*1*)

Maximum Deficiency Pts	Component	Element	Deficiency Point Assignment
40	Bridge Maintenance Activity Rank	Group AF	40
		A	25
		B	20
	Note AF = Group A	C	15
	Activity that is fatigue	D	10
	prone and controls the inventory rating.)	E	5
25	Activity Urgency Factor		
		Code 0	25
		1	20
		2	15
		3	10
		4	5
		5	0
25	Bridge Criticality		
	Part A:	Interstate	5
		U.S. Numbered Highway	4
		State Highway	3
		County Highway	2
		City, Borough St. or Twp. Rd	1
	Part B:	PCN	5
		PCN/Coal Haul	5
		Agri. Access	3
		Industrial Access	3
	Part C:	ADT x Detour Length ≥ 30,000	15
		≥ 15,000 but < 30,000	10
		≥ 3,000 but < 15,000	5
		< 3,000	0
25	Bridge Adequacy		
	Part A:	Lowest Condition Rtg ≤ 3	15
		> 3 but ≤ 4	10
		> 4 but ≤ 5	5
		> 5	0
	Part B:	Load Capacity (Inv. Rtg.)	
		(H configuration) ≤ 12 tons	10
		(H configuration) > 12-19	7
		(ML 80 configuration) > 19 to 30	4
		(ML 80 configuration) > 30	0

daily and provides the necessary data for management to analyze performance, including productivity.

When the BMS is told that certain activities on specific bridges are programmed for implementation by department forces, a copy of the data is transmitted to the planning file in MORIS. The maintenance manager then reviews and transfers the data to the annual and periodic work plans within the MORIS system.

The MORIS system generates the daily crew payroll form, filling in the bridge location identifier plus the activity numbers related to the 76 activities discussed previously. When the work is satisfactorily completed, the bridge engineer signs off and the completed work order goes back to the BMS to update the file and remove the priority maintenance need.

A detailed manual (*3*) is used as a technical planning aid and construction guide for the bridge foremen and their supervisors. They also provide management with a means of measuring both productivity and work quality. These standards include the following components:

- A complete description of the activity in narrative form;
- Crew makeup;
- Specific equipment and material requirements;
- Rate of production; and

04/21/93 COMMONWEALTH OF PENNSYLVANIA PAGE NO: 9
PROGRAM ID: P4575130 DEPARTMENT OF TRANSPORTATION REPORT ID: BMSI5220
SCREEN: "AM" BRIDGE MANAGEMENT SYSTEM

BMS PROPOSED MAINTENANCE ACTIVITIES

SR ID: 22008106520000

FHWA FEATURE INTERSECTED: SR 3009;SUS.RIV;CONRAIL

INSPECTION DATE	MAINT DEF PTS	CO RANK	MAJ IMPROV PROJ STATUS
122292	040.0	0184	2

ACTIVITY ID	ACTIVITY DESC	LOC	UNIT	EST QTY	EST COST	OV RD	PR	PRG D/C	INSP DATE	MTE PG CD	YR
A743101	CLEAN/FLUSH DK.	ALL	E.B.	00001	0000400		5	D	122292		
A743301	RESEAL DK.JOINT	N1230F	L.F.	00360	0003600		5	D	122292		
B743101	FLUSH SCUP/DNSPTG.		E.B.	00001	0000275		5	D	122292		
C743201	PAINT SUPERSTRUCTURE		E.B.	00001	0007000		4	C	122292		
RDPAVMT	PATCH/RAISE PAVEMENT	N	S.Y.	00003	0000120		5	D	122292		
RDRLFJT	RPR/RPL PAVRELIEF JT	N	S.Y.	00027	0006750		5	D	122292		

FIGURE 3 BMS proposed maintenance activities.

04/21/93 COMMONWEALTH OF PENNSYLVANIA PAGE NO: 15
PROGRAM ID: P4575130 DEPARTMENT OF TRANSPORTATION REPORT ID: BMSI5300
SCREEN: "AN" BRIDGE MANAGEMENT SYSTEM

BMS COMPLETED MAINTENANCE INFORMATION

SR ID: 22008106520000

DATE	MAINT ACTIV	ACTIVITY DESCRIPTION	UNIT	ACTL QNTY	ACTL COST	PRG D/C	PI NO
042489	A743101	CLEAN/FLUSH DK.	E.B.	00001	0000252	D	
042690	A743101	CLEAN/FLUSH DK.	E.B.	00001	0000336	D	
121291	B743101	FLUSH SCUP/DNSPTG.	E.B.	00001	0001739	D	

FIGURE 4 BMS completed maintenance information.

Roadside Litter and Current Maintenance Waste Management Practices: Are We Making Any Progress?

Dorothy L. Andres and Chester J. Andres, *Andres Consultants*

The recurrence of litter along highways and roadsides presents problems for state maintenance engineers across the nation. Not only is collection a labor-intensive effort with significant impact on the scheduling of higher-priority tasks, but the disposal of unsorted mixtures of debris presents unique problems. State environmental regulations control waste disposal sites, which are becoming scarcer each year. Recycling and reuse requirements are becoming more common nationwide. Waste products generated from material purchases for routine maintenance operations add to the byproducts for disposal at state maintenance facilities. Most roadside litter is now being removed by low-fee "private partnership" arrangements, heavily supplemented by volunteer and inmate participation programs in many states. In spite of these efforts, costs continue to grow and now exceed $130 million per year for state highways alone. To deal with the changing requirements of ever-expanding environmental regulations, the state maintenance engineer faces a future of managing operations in a proactive environmental role. Maintenance materials are being purchased with prior consideration for waste disposal; roadside debris is being sorted and recycled; and maintenance materials produced from recycled materials and packaged in nondisposable, returnable containers are encouraged in the procurement process. Formal plans for waste management in maintenance operations are necessary to meet growing environmental requirements. The state maintenance engineer is now an active and responsible participant, innovator, and educator in an environmentally conscious society.

Thousands of tons of litter are removed from this nation's highways and roadsides each year. Valuable time and resources of state maintenance programs are being diverted from repairing and maintaining a deteriorating highway infrastructure to litter removal. The state of the practice with respect to the magnitude and character of the roadside litter collection and disposal process, as experienced in state maintenance agencies, is described in a publication of the National Cooperative Highway Research Program (NCHRP), *NCHRP Synthesis of Highway Practice 184: Disposal of Roadside Litter Mixture*. Costs to state maintenance operations alone, as found in a follow-up 1993 survey, were reported to exceed $131 million each year compared with $120 million reported in the 1990–1991 survey, even though volunteerism for litter collection increased significantly.

Some of the findings of the earlier survey conducted for *Synthesis 184* were as follows:

- Litter is viewed by highway maintenance engineers and the public as a major problem along Interstate highways, ramps and interchanges, and primary and secondary roads in urban areas.
- The cost of litter collection exceeds $120 million annually.
- An average of 3.3 percent of each state maintenance budget is spent on roadside litter and debris programs annually.
- Litter collection and disposal requires intensive use of maintenance forces at the expense of other activities.
- Formal waste management practices for maintenance operations are not in general use.

- Automated collection equipment for roadside litter is not generally used by state maintenance crews.
- Equipment manufacturers have not yet developed the necessary high-capacity equipment for automated litter collection on highways.
- Current and potential limits to landfill areas are not recognized by some highway maintenance organizations.
- The maintenance unit's role in solving disposal problems is not universally acknowledged except in dealing with specific incidents that affect operations.
- Few states sort roadside litter mixtures or recycle collected material, and no identifiable trend toward those practices was noted.
- Disposal of road sweepings has been identified as a current or potential problem in most states.
- Safety practices of personnel involved in litter collection and disposal activities are part of maintenance safety training for hazardous materials or are assumed to be common sense measures within general safety practices.
- Police enforcement is not generally recognized as an effective deterrent to littering.
- State beverage container deposit laws are considered very effective as roadside litter deterrents, as reported by state maintenance and environmental agencies.
- Volunteerism is increasing as an assistance option for roadside litter collection activities.
- Adopt-a-Highway programs are generally recognized nationally as the most effective volunteer program benefiting road maintenance operations.
- Costs of highway litter removal activities remain high despite assistance from volunteer groups.
- Antilitter education programs and public media campaigns, such as Keep America Beautiful, were identified as successful approaches to deterring litter.
- No federal funding is available to assist with the problem of highway litter and its disposal, specifically for antilitter education or waste reduction programs.
- A general lack of communication between highway maintenance and environmental agencies impedes cooperation and progress in addressing litter problems.
- The costs of disposing of litter mixtures to comply with environmental requirements are not usually considered when regulations are promulgated.
- Highway maintenance disposal problems require that obstacles to cooperation between environmental agencies and highway maintenance staff be overcome.

The findings indicate that environmental issues related to roadside activities will continue to challenge maintenance engineers. A significant problem was also reported, involving disposables generated within maintenance operations. In the future, maintenance engineers will have to take a more proactive role in dealing with problems of roadside pollution and maintenance wastes disposal. Pollution prevention techniques should be identified, and cleaner technologies should be applied to maintenance operations. Several recommendations and alternative strategies were proposed. Among these is the development of an environmental action plan for waste management specific to road maintenance operations and including alternatives to landfill disposal. Another recommendation was the establishment of waste abatement practices through cautious purchasing of maintenance materials, such as specifying purchases in reusable containers and giving economic incentives to suppliers using recycled materials in their products.

The report also pointed out that public and private partnerships instill a sense of ownership at a grass roots level. Encouraging volunteerism with civic, educational, and corporate groups assists in the control and collection of litter. Transportation agencies share a responsibility for participation in and promotion of educational programs on litter prevention and solid waste disposal.

And finally, in recognition of the millions of dollars spent on the disposal of roadside litter and subsequent costs for compliance with environmental regulations, it was proposed that the highway maintenance and environmental communities work toward communicating and solving the shared problem.

In late 1993, a follow-up questionnaire was sent to each state maintenance engineer to focus on key problems and elements identified in the original survey in early 1991. The purpose was to update selective portions of the earlier information on costs and private participation in roadside programs and also to determine the extent to which more formal, proactive waste reduction programs were being implemented. There was an 88 percent return of questionnaires. This presentation deals with the responses received in the two surveys relative to budgetary impacts and changes in disposal programs as a result of environmental regulations. Any significant impacts of private participation programs on litter pickup operations are noted, as well as any recent changes in state procurement practices for products manufactured from recycled materials. Waste reduction through packaging revisions is discussed.

Costs for Removal of Roadside Litter and Debris

Annual cost figures were made available for this study by 93 percent of the 45 responding states in the 1990–1991 survey years and by 90 percent of the responding states in the 1993 survey. The accuracy of the costs is directly dependent on the cost collection procedures in each of the states. In general the information was reported from the state's maintenance management system. The total cost reported in the more recent survey exceeded \$131 million, representing an average budget impact on maintenance operations of 2.4 percent. In the earlier survey, the

TABLE 1 State Maintenance Litter Programs: Ranking of Annual Costs Versus Budget Impacts for FY 1993

State	1993 Costs in Millions	% of Maintenance Budget
California*	$28.0	5.6%
Illinois	7.5	4.0%
Texas	5.5	1.5%
Florida	5.5	2.5%
Washington	5.4	5.0%
Kentucky	5.6	4.3%
Pennsylvania*	5.0	4.7%
Virginia	4.8	1.0%
Maryland	4.75	4.5%
New Jersey	4.7	8.8%
Oklahoma	3.6	5.0%
Ohio	3.3	3.1%
Missouri	3.0	1.0%
West Virginia	3.0	1.0%
New York	2.8	1.5%
Nevada	2.75	6.8%
Colorado	2.5	5.0%
Connecticut	2.5	2.0%
Michigan	2.5	1.5%
Wisconsin	2.3	2.0%
South Carolina	2.1	1.7%
Minnesota	2.0	1.5%

* Indicates 1991 Data reported

TOTAL - 42 STATES = $131.6 Million

December 1993

figure was $120 million, representing an average budget impact of 2.6 percent. The cost figures, while higher, do not consider the increased assistance to maintenance staff from Adopt-a-Highway and other volunteer programs, the deployment of public aid recipients to collect litter, or prison/labor alternative sentencing programs that include roadside cleanup activities. The cost information is given in Table 1.

Table 1 indicates that New Jersey (one of the most densely populated states, with only 2,455 centerline mi in its state maintenance inventory) and Nevada (one of the least populated states, with 5,500 centerline mi are each spending significant portions of their annual maintenance allocation on the litter problem. Whereas states are reportedly spending more, there is no evidence that they are doing a better job.

Reasons for High Costs for Disposal for State Maintenance Operations

In the original survey, a lengthy questionnaire was sent to each state maintenance engineer and the responsible office for waste management in each state environmental agency. From the original survey, a list of causes for high costs in the collection and disposal of roadside debris was developed:

1. The number and types of permitted disposal sites (state maintenance properties, public landfills, and roadfill), are decreasing nationwide, which results in long hauling distances and high tipping fees.
2. Environmental constraints also contribute to high costs because of the need to sort items from the litter mixture, to recycle, and to temporarily stockpile and store litter.
3. Collection practices rely on labor-intensive manual efforts, with limited automated equipment for highway-scale operations and, again, the need for temporary storage stockpiles.
4. Finally, formal waste disposal strategies are lacking.

Approved disposal sites are diminishing in availability in many states as existing landfills reach capacity or are forced to close because they do not meet environmental

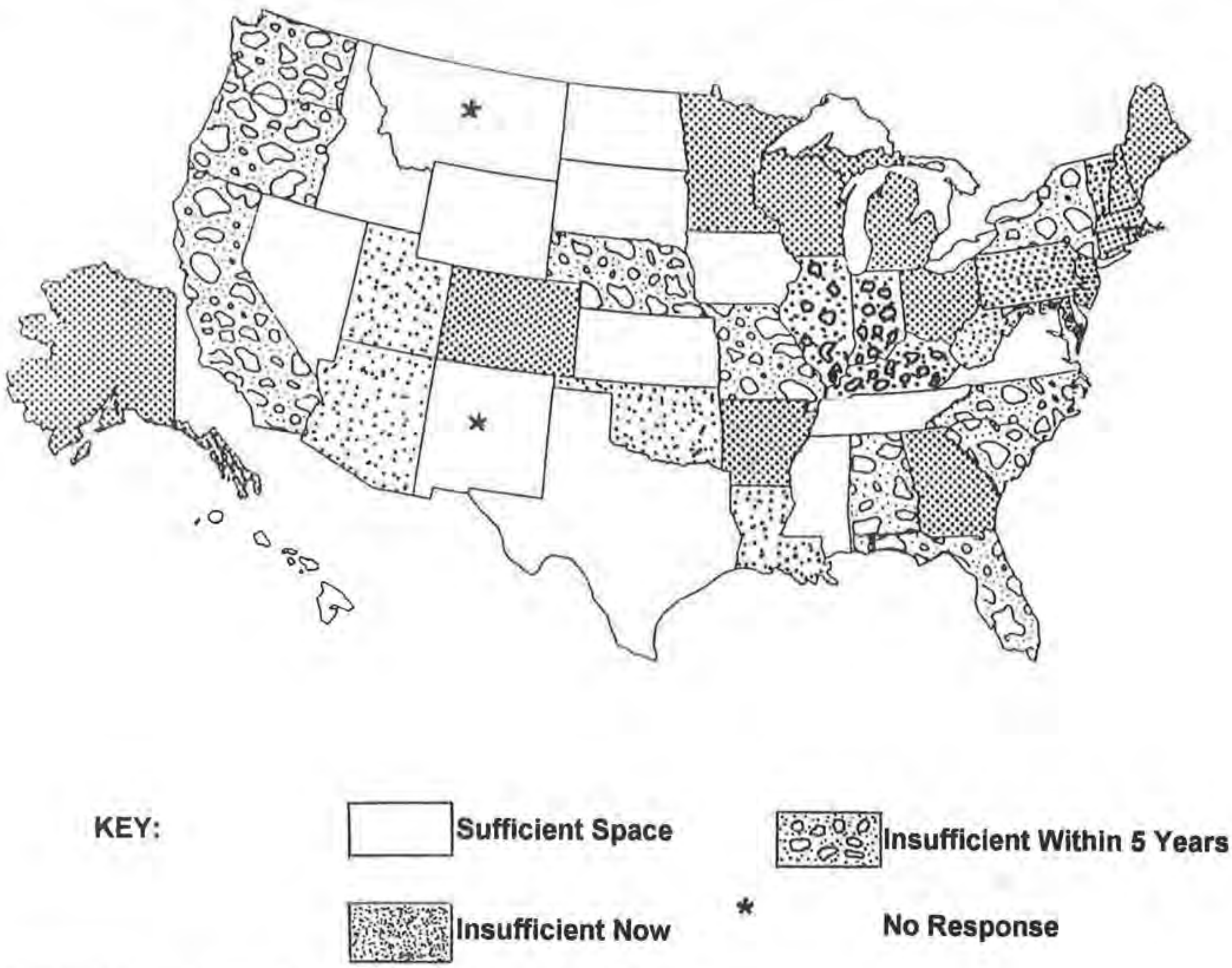

FIGURE 1 States reporting landfill space problems (December 1993).

standards. Development of others is stymied by local opposition or the NIMBY syndrome ("not in my back yard"). State maintenance engineers were questioned about their awareness of the shortage of landfills in their state and its effects on continuing the practice of disposing of unsorted roadside debris in their areas. The estimated years of available landfill capacity, specifically for roadside debris disposal as determined by state maintenance staff, are shown in Figure 1.

During the past 3 years, several of the western states have become concerned with either the lack of landfill space or rising disposal costs as current landfills close. What was essentially a Northeastern and North-Central tier problem is spreading as environmental restrictions or zoning regulations cause potential landfill sites to be eliminated. The 1990 survey results are presented in Figure 1, with several additions from the 1993 survey.

The most common materials presenting collection problems are given in Table 2.

What is Being Done to Reduce High Costs to Maintenance Operations

Staffing Support—Volunteerism

The collection of roadside litter and debris is a labor intensive task, and the people involved in collection along state highways vary among the states. In the early survey of 1990–1991, the majority of states reported that almost all road maintenance personnel (75 to 100 percent) were needed when a cleanup operation was implemented, usually twice per year in the spring and again in the fall. However, maintenance forces were supplemented with

TABLE 2 Ranking of Debris-Causing Problems

Litter Item	% States Identifying Collection As A Problem
Rubber Tires	65%
Glass	54%
Paper/ Cardboard	51%
Plastics	51%
Newspaper	40%
Aluminum Cans	40%
Metal Cans	40%
Other Metal Items	38%
Lumber/Wood	38%
Miscellaneous Household & Yard Trash	3%

outside staffing support from various areas: maintenance contracts for litter collection and disposal, Adopt-a-Highway groups, civic volunteer activities such as Keep America Beautiful, prison labor, alternative sentencing, public welfare recipients, and so forth. By far the most acclaimed by DOT maintenance forces was the Adopt-a-Highway program. Among the 45 states that reported in the early survey, 38 had formal Adopt-a-Highway programs in place and a number of those states reported that more than 50 percent of their roadside litter programs were dependent on Adopt-a-Highway. In the follow-up survey in 1993, all states reported some participation by Adopt-a-Highway groups. Fifty-four percent of the states reported they now do less than 50 percent of roadside pickup with maintenance forces. Figure 2 shows the trend in maintenance dependency for litter collection assistance from outside forces.

Indiana and Wisconsin have agreements with city or county maintenance forces to provide litter pickup or sweeping. Oregon relies on summer youth programs to pick up 75 percent of its roadside litter. Indiana, Maryland, Georgia, Massachusetts, New Jersey, North Carolina, and Oklahoma use convict labor for 30 to 80 percent of this activity. Of all responding states, only Colorado, New Hampshire, Nevada, and Vermont report that 90 percent of roadside litter is being collected by state maintenance forces. There is no explanation for state maintenance costs remaining high in spite of increased volunteer efforts.

Automated Equipment Improvements

Specialty equipment for automated collection of debris from roadsides, excluding sweepers, remains significantly unavailable. In the 1993 survey, among those who responded to a question on the use of automated pickup equipment, the most frequently mentioned were sweeper-type or self-propelled brooms for use along curbsides and ramps. Several mentioned the high incidence of breakdowns experienced with this equipment proposed for use in litter pickup operations. Since the early survey, there has been little to report of positive value. Most equipment purchased and distributed to field operations appears not to have survived the maintenance supervisor's field testing and appears to have been lost or buried as obsolete or unusable in maintenance yards around the United States. New equipment was to be marketed in 1994 to assist with road debris collection process, based on the success of private contracting equipment in several cities in Arizona. The Arizona DOT has used a "truck-mounted mechanical retrieval device" for metals and rubber along paved shoulders and curb areas. The machine is being used primarily in metropolitan areas at speeds up to 35 mph. However, as of this date, it has not yet reached the market. A recent demonstration in fall 1993 was provided to a group of highway maintenance engineers, who generally agreed that such a machine "could be useful within its limited capabilities."

Recycling of Roadside Litter

In the early survey of state environmental agencies, a number of environmental units responded that although there were no specific regulations placed on state maintenance agencies for disposal of roadside litter, specific discarded items found in roadside trash were controlled by solid waste regulations. Many of these states had implemented recycling and source reduction regulations, although not many had passed these on to state maintenance operations. Voluntary participation was encouraged. States engaged in recycling roadside debris or affected by recycling regulations are indicated in Table 3. Whereas recycling may not be mandated for highway cleanup operations, many state Adopt-a-Highway groups separate aluminum cans and bottles from other trash. No states indicated that they had dedicated forces engaged in separating recyclable materials. Only Florida, Oregon, and Pennsylvania reported that income was derived from recycling efforts put forth by maintenance forces. In these pilot programs, the income was returned to state maintenance operating funds in Florida and Pennsylvania, but a very minimal sum was realized. The most successful areas for these programs are in rest areas, but funds realized belong to rest area operators unless specific agreements are worked out to return these funds. PennDOT was one such state working out arrangements to return such funds to maintenance operating accounts. In most states, rubber and tire scraps must be separated from roadside debris sent to landfills. Some states reported on specific litter/waste materials that they recycle. For example, Connecticut reuses rubber tire scraps for manhole covers and rings. Missouri recycles tires, batteries, and yard waste. Vermont indicates that it

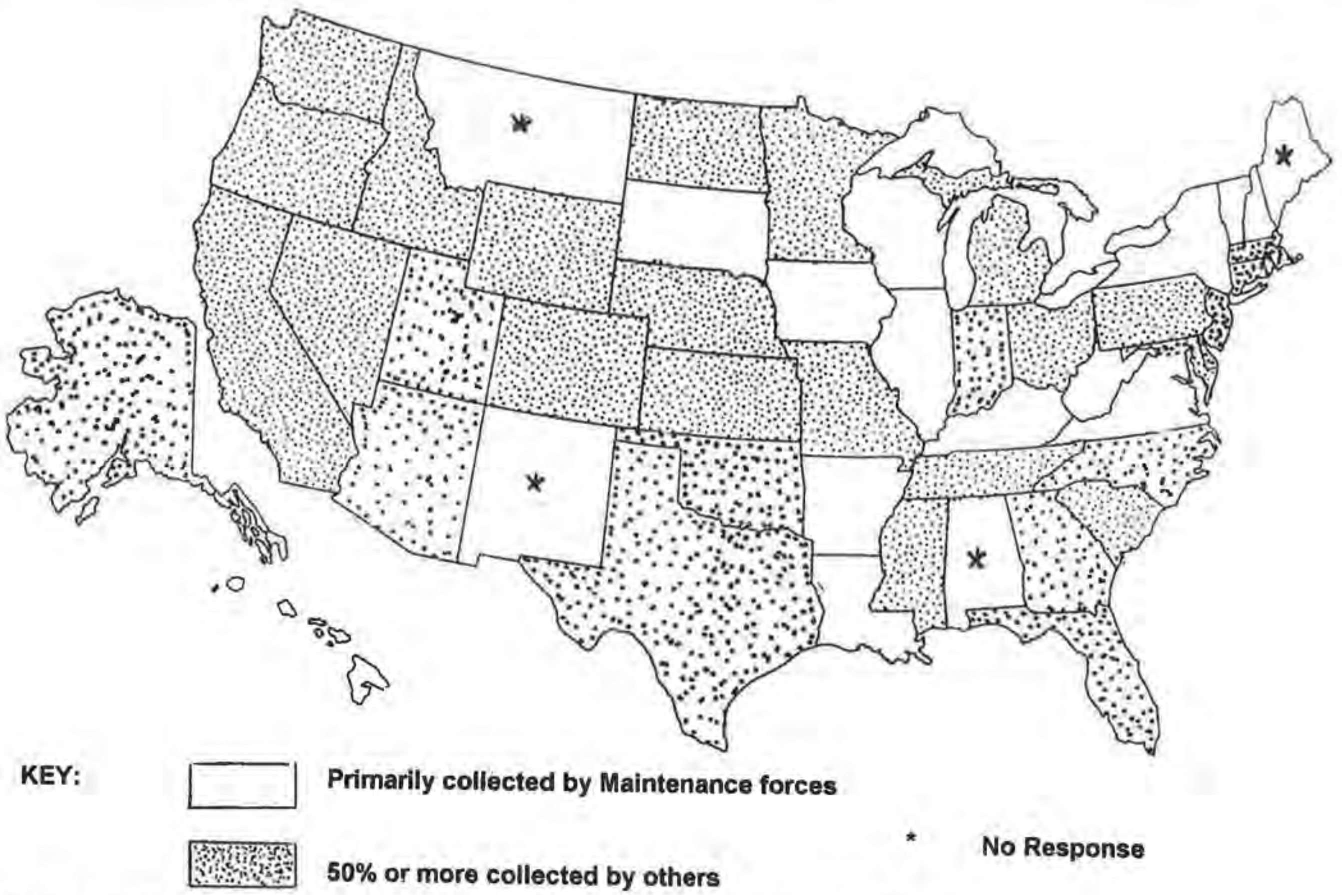

FIGURE 2 Litter collection assistance in state maintenance operations (December 1993).

may soon be required to recycle most litter and waste materials.

Many states reported reusing sweepings as fill materials, and a few are using them for winter abrasives. Several states reported the use of ditch and catch basin clean-out as slope dressing. The chopping of tree cuttings on site for use as mulches is increasing. However, composting practices for vegetative materials and the use of these products from landscape operations were not included in this study.

Environmental Regulations and Maintenance Programs

One of the major concerns raised in the 1990 survey was the claimed lack of communication between environmental agencies and highway agencies, particularly the lack of dialogue between these agencies before regulations are promulgated. There was an indication of a strong need for coordination within environmental units regarding the impacts of one state regulatory program on another state agency operation. In some cases, the responder for a state environmental agency saw no need at the present time for compliance with existing solid waste regulations or clean water requirements. The survey indicated a lack of experience in the "world" the agency regulated and, unfortunately, a future problem to be encountered if regulations are promoted without dialogue.

Several environmental agencies, among them California, Washington, Florida, and Massachusetts, noted that they have worked closely with the state DOT for the reuse and recycling of highway construction materials. In general, environmental agencies saw the solving and handling of roadside litter as a concern of state maintenance organizations requiring a variety of approaches:

- More enforcement,
- More recycling programs,
- More volunteerism,
- More signage along roadsides supporting Adopt-a-Highway and volunteer groups, and
- More use of convict labor and alternative sentencing.

The implementation of many of these alternatives during the 4 years since the study was initiated is evident. An

TABLE 3 Recycling of Roadside Litter

State	Recycling	Re-Use of Debris
Arkansas	X Tires	
Colorado	X	
Connecticut	X Tires	X
Delaware	X Voluntary	
Florida	X By County	
Illinois	X Rest Areas	
Indiana	X Rest Areas	
Iowa	X Not Statewide	X
Maryland	X	
Massachusetts	X	X
Michigan		X
Minnesota	X	X
Missouri	X	
Nebraska	X Rest Areas	
New Hampshire		X
New Jersey	X	X
New York	X	
Ohio	X	
Oregon	X	
Pennsylvania	X	
South Dakota		X
Utah		X
Virginia	X AAH	
Washington		X
West Virginia	X Voluntary	
Wisconsin	X By County	

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improvement in interagency liaison and communications was reported by 20 state maintenance offices. New lines of communication and more willingness to assist as well as regulate have been reported by several states in the latest survey. Some maintenance engineers said that there was a greater willingness in their agencies to listen to and try out environmental suggestions, and others reported there was more communication, but not necessarily more interagency cooperation. It is hoped that an open dialogue trend will continue nationally. These positive indicators were reported in 20 states: Arkansas, Florida, Iowa, Kentucky, Louisiana, Minnesota, Mississippi, Nebraska, New Hampshire, New Jersey, New York, Nevada, South Carolina, Ohio, South Carolina, Tennessee, Virginia, Washington, West Virginia, and Wisconsin.

Revised State Maintenance Purchasing Practices

The preferred strategy of today's environmental leaders and the trend of the 1990s is for source reduction of pollutants and waste stream components. The Office of Public Affairs in the federal Environmental Protection Agency stated that the agency is moving its mission from a regulatory and remedial action role toward a role of prevention. Source reduction involves minimizing the volume or toxicity of materials used in products that wind up in the waste stream. State waste management strategies include legislated reductions in solid waste. In maintenance operations, these strategies could be implemented voluntarily to include waste abatement through the following practices:

- Reducing wastes by minimizing packaging of materials before purchasing,
- Encouraging the delivery of materials in returnable and reusable containers and thereby eliminating one-way refuse,
- Encouraging bidders to deliver products made of recyclable or recycled materials,

TABLE 4 Waste Reduction Activities for Maintenance Operations Procurement/Packaging of Materials for Maintenance Use

STATES	PROCUREMENT REQUIREMENTS	PACKAGING REQUIREMENTS
Florida	X	
Indiana	X	X
Iowa	X	X
Kentucky	X	X
Nebraska	X	
New Jersey	X	
North Dakota	X	
Oklahoma	X	
Oregon	X	
South Carolina	X	
South Dakota	X	
Tennessee	X	
Texas	X	X
Utah	X	
Vermont	X	
Washington		X
Wisconsin	X	

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- Providing economic incentives to purchase from suppliers that comply with mandated waste reduction requirements, and
- Providing disincentives such as including costs for removal and disposal of one-way packaging materials.

A number of states are involved in waste reduction practices through purchasing requirements regarding the use of recycled materials or through specifying packaging requirements stipulating minimal or returnable/reusable containers. Federal procurement guidelines were included in the most recent regulations for compliance with the Resources Conservation and Recovery Act, which are beginning to involve state maintenance operations. According to the latest survey, significant compliance is being practiced in those states noted in Table 4. Iowa and Kentucky are reusing paint containers and totes. Washington is receiving shipment of traffic paint directly into paint holding tanks for loading directly into traffic stripers. Several states including Indiana reuse aluminum sign blanks and reface them, a practice highly supported for economic reasons when aluminum blanks were expensive in the 1980s. Both New Jersey and Texas provide a price advantage to suppliers who bid recyclable packaging.

Research is being conducted by the U.S. Army Cold Regions Research and Engineering Laboratory and the Federal Highway Administration blending plastic waste, collected through recycling programs, with sawdust to produce a plastic composite for use as signposts, guardrail posts, and blocks. The work is aimed at reducing waste materials going into landfills and promoting the use of recycled products in the highway construction industry. The Army Corps of Engineers has begun demonstration projects with a number of construction products fabricated from plastic composites.

FORMAL WASTE MANAGEMENT PROGRAMS FOR MAINTENANCE OPERATIONS

Although more than 50 percent of the states responding to the earlier survey indicated that roadside litter was a planned activity, and many indicated it was a major work generator, only nine states responded affirmatively regarding the existence of a formal policy and program on disposal within their departments. This response did not change in the follow-up survey. The nine states that have or will soon implement a formal waste management program for maintenance operations are Iowa, Kentucky, New Jersey, Ohio, Pennsylvania, Texas, Utah, Vermont, and Wyoming.

Follow-up discussions with those claiming to have formal programs revealed that several were, in fact, no more than an understanding that the collected debris was the responsibility of the district engineer or individual crew supervisor, and disposal was to be done in accordance with local governing regulations. One of the major recommendations made in *Synthesis 184* was that an environmental plan for waste management and waste reduction be developed by each highway agency with the participation and input of state maintenance and environmental agencies. Such a plan could include the following:

- All federal and environmental regulations affecting typical maintenance operations that involve disposal of materials collected by or generated within maintenance activities should be identified. Where applicable, local regulations should be identified for the appropriate units involved.
- All state property disposal sites should be identified, ensuring approval for use and compliance with environmental wetlands requirements. These should be site specific. The anticipated useful life of these locations should be estimated.
- Alternative strategies to landfills should be planned. An example is separation of collected trash components that are not contaminated and can be recycled in accordance with solid waste regulations, voluntarily recycled as a salvageable scrap, or reused in maintenance or construction activities. Some states have used sweepings, ditch, and inlet materials as winter abrasives, clean fill, and fertile surface covers.
- Waste abatement practices should be promoted through cautious purchasing of maintenance materials, encouraging reusable containers, and incorporating economic incentives to suppliers who use recycled materials in their products.

Conclusions

The costs for collecting and disposing of highway litter have risen more than 9 percent during the period between 1990 and 1993. However, when expressed as a percentage of the total maintenance operations budget, the figure appears to have dropped slightly. Contributing to this decline is the increase in the use of volunteer organizations to perform what heretofore has been a routine maintenance function. As the cost to maintain the highway infrastructure rises, funds have been shifted from lower-priority functions, such as litter pickup and landscaping, to repaving, structural rehabilitations, and major pavement/safety improvements. Thus, alternatives such as Adopt-a-Highway, youth programs, "workfare," and contracted services are supplementing traditional maintenance litter collection and waste removal activities.

Problems with litter and its removal as expressed in the 1990 survey continue to be found in 1993 survey responses. Environmental restrictions on disposal will continue and will further limit options available to the maintenance manager. Less populous states with much open land are beginning to experience landfill closures and restricted new openings, as has been the experience in more urbanized regions.

Waste abatement policies have been put into practices in some states. There is a need for extension of these policies to positively affect maintenance operations through maintenance materials procurement contracts. Recycling of maintenance materials and reusable litter products can reduce the load on landfills.

Maintenance operations involving litter, roadside waste, and its disposal are beginning to move from a reactive mode to a planned program. There is much to be gained from in-place maintenance plans for waste abatement and an acceptance of the necessity of environmental compliance, even if at a voluntary level.

Coordination of efforts between transportation and environmental agencies, particularly concerning litter/roadside waste disposal, has continued to improve as indicated by current survey responses. However, there remains room for more interagency cooperation at the highest department levels.

As derived from both the 1990 and 1993 surveys of state maintenance organizations, there is a need for research addressing the reuse of materials, recycling of materials, and development of reliable, high-capacity, automated litter collection equipment. Funding of such research and increased support from the federal level are needed. And, as stated by several maintenance engineers in the survey, it continues to be most important that education on antilitter programs be provided at a grass roots level, through specially developed public information programs for children and adults.

Impacts of Environmental, Health, and Safety Regulations on Highway Maintenance

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Transportation agencies throughout the United States face dilemmas due to the ever-increasing number of environmental, health, and safety regulations being issued at the federal, state, and local levels. These regulations are often issued without complete familiarity with or comprehension of their effects on highway maintenance resources and activities. As a result, compliance with the new regulations has serious impacts on agencies' activities and allocation of resources. Compliance with environmental regulations reportedly cost state highway agencies an estimated $99 billion in 1990, and this figure is expected to rise significantly in coming years. Technical, operational, and economic impacts of these regulations on 17 key areas of maintenance, including herbicide use, road deicing, fuel and asphalt storage, wetland areas, storm water runoff, bridge painting, and roadside litter, are identified. Some highway departments have used innovative methods to help budget resources for transportation maintenance operations; make essential alterations regarding personnel, equipment, and operating procedures; and respond to needs in areas such as inter- and intradepartmental communications, staffing, and training. Legislative decision makers must understand the implications of their actions with regard to environmental regulations.

Regulatory compliance is forcing personnel to change long-standing maintenance practices and spend more money to implement new maintenance methods and equipment. One noted researcher has estimated that the total cost for departments to comply with environmental regulations in 1990 was $99 billion, compared with $41 billion in 1977. He estimated that the amount would rise to approximately $167 billion by 2000. The federal acts requiring regulations pertaining to environmental compliance with identification of administering agencies, is given in Table 1.

The aim of this study, conducted during 1991 and 1992 for the Transportation Research Board, was to identify and highlight the technical, operational, and economic impacts of environmental, health, and safety regulations on highway maintenance programs and to provide information for transportation agencies and legislative personnel on the cost consequences of regulatory compliance. It is hoped that this information will provide greater insight for making appropriate decisions regarding highway maintenance operations.

Information was acquired through questionnaires submitted by maintenance personnel throughout the country, by studying various maintenance programs and the specific problems they face, and by conducting interviews with maintenance personnel. Through these efforts, the research team identified 17 crucial areas of concern to highway maintenance personnel:

1. Herbicides,
2. Deicing,
3. Wetlands,
4. 404 permits,
5. Structural painting,
6. Fuel storage,
7. Roadside litter,
8. Storm water runoff,
9. Hazardous waste,
10. Hazardous substance spills,

TABLE 1 Federal Regulations and Administering Agencies

Act or Executive Order	Acronym	Administering Agency
Archaeological Resources Protection Act	ARPA	National Park Service
Clean Air Act	CAA	Environmental Protection Agency
Coastal Barrier Resource Act	CBRA	National Oceanic and Atmospheric Administration
Comprehensive Environmental Response, Compensation, and Liability Act	CERCLA	Environmental Protection Agency
Clean Water Act	CWA	Environmental Protection Agency
Clean Water Act, Sec. 402(p), Storm Water	CWA 402(p)	Environmental Protection Agency
Coastal Zone Management Act	CZMA	Army Corps of Engineers (Department of Defense)
Executive Order 11988, Flood Plain Management	EO 11988	Not applicable
Executive Order 11990, Protection of Wetlands	EO 11990	Not applicable
Endangered Species Act	ESA	Fish and Wildlife Service (Department of the Interior)
Federal Food, Drug and Cosmetic Act	FFDCA	Food and Drug Administration
Federal Insecticide, Fungicide and Rodenticide Act	FIFRA	Environmental Protection Agency
Farmland Protection Policy Act	FPPA	Farmers Home Administration (Department of Agriculture)
Fish and Wildlife Coordination Act	FWCA	Fish and Wildlife Service (Department of the Interior)
Federal Water Pollution Control Act	FWPCA	Environmental Protection Agency
Hazardous Materials Transportation Act	HMTA	Office of Hazardous Materials Transportation (Department of Transportation)
Land and Water Conservation Fund Act	LWCFA	Bureau of Land Management (Department of the Interior)
National Environmental Policy Act	NEPA	Environmental Protection Agency
National Historic Preservation Act	NHPA	National Park Service
Occupational Safety and Health Act	OSHA	Occupational Safety and Health Administration
Preservation of Historical and Archaeological Data Act	PHADA	National Park Service
Resource Conservation and Recovery Act	RCRA	Environmental Protection Agency
Superfund Amendments and Reauthorization Act	SARA	Environmental Protection Agency
Safe Drinking Water Act	SDWA	Environmental Protection Agency
Solid Waste Disposal Act	SWDA	Environmental Protection Agency
Toxic Substance Control Act	TSCA	Environmental Protection Agency
Wild and Scenic Rivers Act	WSRA	National Park Service

11. Nonhazardous materials disposal,
12. Wastewater disposal,
13. Asphalt storage and use,
14. Traffic painting,
15. Air quality,
16. Water quality, and
17. Erosion control.

ISSUES OF CONCERN

The following is a brief overview of some critical problems from the list just cited and methods currently used to address these problems.

Herbicides

Right-of-way vegetation management programs help ensure the safety and continual operation of public highway transport by offering sound, economical maintenance practices for controlling and managing right-of-way vegetation. Methods used to control vegetation include biological (animals, birds, insects, and competing plants), physical (cultivating, trimming, and mowing), and chemical applications. The latter method is widely considered the most effective, economical method of vegetation control; however, growing public concerns and regulatory restrictions have prevented or seriously limited the use of some herbicides.

Herbicide use has been affected most by water quality and health standards, which have caused departments to modify how they apply chemicals; and by hazardous materials regulations, which have limited the ways departments of transportation (DOTs) can dispose of herbicides. These and other regulations have forced states to initiate changes in personnel, equipment, materials, and work methods. Foremost among these changes are the training for handling materials, and the special clothing that departments must now provide to their workers. These new provisions are costly to the DOTs: Pennsylvania annually spends approximately $100 to $150 per person for certification and update training. In New Jersey, annual costs of clothing and training are $5,000 to $6,000 per person; California spends $1,000 per year to train each pesticide applicator; and Vermont spends $4,500 per person annually for clothing and training. Influence from environmental groups has also contributed to reduced herbicide use and has helped shape public opinion.

Tests on areas where chemicals have not been used for 2 years have shown that they are impossible to maintain by physical methods only. Maintenance costs in these areas have increased by 400 percent, and vegetation is still not adequately controlled. A study by the University of Florida found that mowing as often as once every 2 weeks would be required to maintain proper weed control in certain areas of that state; the Florida DOT presently mows its rights-of-way five to seven times a year. Improper weed control could endanger the traveling public and workers who perform the mowing, but increasing the number of mowings per year would drastically increase departmental costs. Other DOTs have experienced similar problems. In conclusion, it would be practically infeasible to maintain the same quality of service with mowing as is now possible with herbicide control.

In Iowa, both herbicide application and mowing have been affected by a new regulation that requires the department not to spray noxious weeds if it is practical to mow instead. The regulation has resulted in an increase of $250,000 in mowing costs. In Oregon, regulations prohibiting the use of pesticides on lands controlled by the U.S. Forest Service and the Bureau of Land Management (approximately 50 percent of Oregon is federally owned land) have resulted in difficult maintenance procedures and soaring labor, equipment, materials, and disposal costs. In Maryland, Occupational Safety and Health Administration standards for noise and chemical exposure and personal protective equipment have affected vegetation control procedures and resulted in additional costs.

The debate among federal lawmakers, lobbying organizations, and environmentalists over the fate of pesticide use is having profound effects elsewhere. Manufacturers, distributors, retailers, and applicators all must deal with new laws and regulations on agricultural chemicals. The National AgriChemical Retailers Association has estimated that distributors will annually spend $77,000 each over the next 10 years to comply with environmental rules, up from $23,000 in 1990.

Deicing Chemicals

Approximately $1.5 billion is spent each year on highway snow and ice removal programs in the United States. Apart from plowing, the most important element of these programs is chemical deicing, which represents about one-third of winter maintenance expenditures. Chemical deicing helps ensure public mobility and safety by quickly and efficiently reducing hazardous road conditions. Sodium chloride (salt) for snow and ice control is the primary agent used by highway departments to chemically deice roads and bridges. If improperly applied, salt can have adverse side effects, including motor vehicle damage, structural and roadside (soil and plant) degradation, and infiltration of water tables. Financial assessments indicate that total nationwide costs for salt-related mitigation far exceed (by approximately 14 times) the national cost of salt purchase and application.

Not all states are required to clean up salt-contaminated sites, but those that are often spend millions of dollars each year on remediation cleanup and salt stockpile management, including facility renovation and construction. Most agencies have not found any environmentally acceptable product options for deicers or new methods of bulk storage. Some states collect discharge water from washing salt application trucks in detention basins or settling ponds, from which the salt can be reclaimed. Some agencies are constructing covered storage areas on impervious concrete loading pads, and some are considering reclamation and reuse of sand used on decks and bridges.

Several states have made significant expenditures in this area:

- Virginia spends approximately $1 million annually on storage facilities and hundreds of thousands more to ensure chemical containment.
- Tennessee purchased five new salt separators at a cost of $20,000 per unit to meet groundwater pollution laws.
- Colorado has built and renovated facilities for snow removal at a cost of $120,000.
- North Carolina has built and renovated facilities to meet groundwater regulations at a cost $1.65 million.
- Pennsylvania has built and renovated several facilities for ice and snow control and truck washing. Costs have ranged from $20,000 to $250,000 per building.
- Massachusetts spent $2.5 million between 1983 and 1990 to investigate and remediate complaints of salt contamination of water supplies.

New chemicals are being tested as possible deicers, and one, calcium magnesium acetate, has shown promising results. Its cost, however, is 25 times that of salt, thus making it an infeasible option for many agencies. Although alternatives to salt use are expensive, many communities are willing to consider those methods in light of the environmental effects of deicing salt.

Wetlands

The government's primary means of protecting wetlands is through the issuance of permits of proposed developments and alterations. This is carried out under the guidance of the U.S. Army Corps of Engineers and the Environmental Protection Agency (EPA). A permit from the Corps of Engineers is required for an individual or group to excavate, locate a structure, or discharge dredged or fill material in U.S. waters. Several federal agencies may be involved in the permitting process, depending on the nature and location of the activity.

The wetland permitting process can add delays and expense to construction and maintenance activities. Permits can take 60 to 90 days to be issued, and both time delays and costs may significantly increase if mitigation is involved. DOT operations may also be affected by regulations designed to protect endangered plant and animal species and historical sites. Permits can be denied by a reviewing agency, which could mean having to choose an alternative method of maintenance; other permits are issued under the condition that the state reestablish wetland areas and their natural components in a safe, ecologically sound environment. These changes usually mean huge expenditures and delays for the affected highway departments.

Section 404 of the Clean Water Act excludes "normal" maintenance activities as nonregulated actions. The Corps of Engineers in most states recognizes this exclusion, although some local offices in the West do not.

Personnel from many highway departments have indicated that an exemption, as in a minimum acreage of wetland use for highway purposes, would help resolve many permitting problems. They have also suggested that more general and nationwide permits would help alleviate some permitting costs and problems.

Many states are facing difficulties in establishing and maintaining wetlands. Florida must carefully control certain invader weed populations while maintaining wetlands on a 2:1 or more replacement basis. North Carolina has a federal mandate to establish a hardwood "bank" and reestablish wetlands near many maintenance and construction projects. Oregon has experienced a $150,000 rise in biennial costs to manage wetland mitigation sites in accordance with federal regulations and permits. In all, the 37 states examined in this study have spent approximately $100 million on wetland mitigation.

Many government representatives and private landowners believe that federal agencies should delegate their authority to issue wetland permits to the state agencies; the reasoning is that this would make the permitting process more efficient.

Erosion Control

Regulations pertaining to soil erosion and sedimentation are designed to avert environmental damage to rivers, lakes, and reservoirs. Preventing this damage can also mean avoiding expensive maintenance such as dredging and soil restoration. Nonetheless, agencies are incurring major expenses in this area due to mounting regulations.

In California, the situation is sometimes confusing. Nine state agencies are involved in defining and establishing regulations. Certain agencies are more involved in different parts of the state (which widely vary in geographic formation) and have various priorities. Each concern must be addressed uniquely, so flexibility on the part of the California DOT is necessary in confronting these issues.

The problem is also a costly one: it costs $12 million to dredge a Contra Costa County reservoir, $25 million over 10 years for sediment cleanup in Alameda County, and $30 million annually to remove sediment from San Francisco Bay area lakes and reservoirs (not counting the bay itself).

In North Carolina, sediment control accounts for 10 percent of that department's construction budget on secondary roads. Erosion regulations have been greatly reinforced by the state's Department of Environmental Health and Natural Resources. Under the regulations, disturbances of less than 1 acre can require installation of a temporary rock dam, seeding and mulching, drainage and stabilization, and monitoring. Even on a small scale, these procedures can cost a great deal; when the activities are large bridge or highway projects, the costs can be enormous.

Underground Storage Tanks

EPA presently regulates approximately 2 million underground storage tanks (USTs) at 750,000 facilities across the United States; another 3 million tanks, most containing home heating oil, are exempt from federal regulations. Of these 5 million USTs, an estimated 80 percent are made of bare, unprotected steel, which is susceptible to corrosion and subsequent leakage. EPA has identified 175,000 confirmed tank releases that are potential threats to public health and the environment. This number is expected to rise to almost 400,000 over the next few years.

State UST regulations, many of which are derived from federal regulations, have significantly increased operating costs. For instance, all new tanks and piping must have leak and corrosion protection and spill/overfill prevention systems, which can push the cost of a new tank to the $40,000 to $60,000 range. Existing tanks, meanwhile, had to have leak detection systems as of December 1993 and must have corrosion protection and spill/overfill prevention systems by December 1998 or, in some states, earlier. Cost information gathered from around the country indicates that upgrading a single tank can run from $25,000 to $45,000.

In many states, funds intended for tank cleanups are running short, forcing agencies to expand their funding bases to include revenue sources such as gasoline fees and taxes. For example, Florida was forced to enact new taxes to raise an additional $160 million annually when the state found that its original $50 million cleanup would not cover the cost of treating USTs. California, with more than 10 percent of its 200,000 tanks reported as leaking, created a similar cleanup fund that was to raise $180 million by the end of 1992. The increased costs of complying with regulations have clearly proven expensive to state maintenance departments, businesses, and taxpayers.

Strict UST regulations and subsequent costs have forced many small businesses with storage tanks to close in recent years. The Petroleum Marketers Association of America, with more than 11,000 members, reports that more than one-third of its members have closed stations in the past several years mostly because of expenses arising from environmental compliance. The average marketer owns 8 to 10 stations and in 1991 spent nearly $96,000 for tank upgrades. For larger operations such as state DOTs, expenses are certain to be higher.

In addition to regulations pertaining directly to tank maintenance, regulations in 40 CFR Part 280 Subpart H require that owners/operators demonstrate financial responsibility by taking corrective actions and compensating third parties for injuries and damages caused by accidental releases. Facilities not involved in petroleum production (such as DOTs) but having a monthly throughput of 10,000 gal or more are required to carry coverage of $1 million per occurrence; lesser amounts are applicable for smaller throughputs.

Storm Water Runoff

The major difficulty in discussing the impacts of storm water runoff regulations is their relative newness: storm water runoff regulations have only been in effect since October 1, 1992. For this reason, no one knows exactly how these regulations will affect operations at state DOTs. On the basis of past experience, however, many expect that they will result in significant increases in operating costs.

EPA estimates that approximately 100,000 facilities, including state DOTs, are covered by the regulatory definition of "storm water discharges associated with industrial activity." This estimate may be low, however; one environmental representative from Alabama has conservatively estimated that there may be 10,000 permit applications in that state alone. The impact of the new regulations appears to be wide-ranging.

Organizations applying for industrial permit coverage for storm water discharges can apply for either individual or general permits. General permits cover several facilities engaged in similar operations, whereas individual permits are tailored to specific facilities.

Applying for an individual permit can be complex; a sizeable amount of material, including site maps, quantitative testing data, and other detailed documents must be submitted. Along with the application fee, the total cost of an individual permit application is approximately $10,000. In Alabama, with an estimated 10,000 applications expected, the total cost may soar to $100 million.

In contrast, the initial cost of a general permit is considerably less than for an individual one, though it still may run several thousand dollars. The requirements to maintain a general permit include implementation of a Spill Prevention, Control, and Countermeasures Plan, which can cost $3,000 to $4,000 and must be updated and recertified by a professional engineer every 3 years; Best Management Practices (BMP), which may require purchasing new equipment at a cost of several thousand dollars; and monitoring and reporting of storm water discharges and annual certification that all discharges meet permit standards, which can add up to between $300 and $400 per month in testing costs. Obviously, the costs of maintaining a general permit can also be quite high.

Lead Paint

The environmental regulation that has had the greatest impact on maintenance organizations and their use of lead-based paints over the past few years is the Resource Conservation and Recovery Act (RCRA). The newness of regulations pertaining to lead-based paints has resulted in some confusion and other problems in the maintenance and painting industries. For example, bids for painting contracts involving the removal of lead paint from bridges or other structures have varied by as much as a factor of 10. Bids from contractors who are knowledgeable of regulations usually run about three times higher than those for projects not involving removal of lead-based paints.

An excellent example of the effect increasing regulation is having on DOTs and the industry recently occurred in Alabama. A company that was unaware of the new regulations submitted a bid for a project involving lead paint removal that totaled $132,500; a second company, aware of the regulations, submitted a bid of $397,325, approximately three times higher. This and other examples demonstrates the impact of increased environmental regulations on state DOTs.

Bridge painting is significantly affected by federal environmental regulations, and many examples support this claim. For example, Georgia DOT personnel have stated that capturing lead paint residue after it has been blasted from a structure has become so costly that they have been forced to reduce the number of bridges they maintain each year from 210 to 50. Similarly, in Idaho, containment and disposal costs have risen to as much as $1 million per project. And recently in Connecticut, two-thirds of the cost of a bridge-painting and rehabilitation project, which cost more than $10 million, went toward environmental protection. Ironically, many states have found that it is sometimes more economical to replace an entire bridge than to strip and repaint the existing structure. Obviously, federal environmental regulations are affecting maintenance operations in this area.

Because of high disposal costs and safety considerations, transportation agencies have chosen to use nonleaded paint on all steel-structure bridges. The Missouri DOT recently attempted to use nonleaded paint on some bridges, with unsatisfactory results. The lead-free paint cost three times more and lasted only half as long, and disposal costs for residue were twice as much as before. However, states now have no alternative but to use the lead-free paints. Clearly, federal regulations regarding lead-based paints are having an enormous financial impact on state DOT budgets. The total financial impact is estimated to be in the hundreds of millions of dollars nationwide.

Hazardous Materials and Wastes

Since 1976, the RCRA has served to protect public health and the environment from improper hazardous waste management practices by determining guidelines for shipping hazardous waste off site, storing it on site, and other practices. Dozens of products used by highway departments are considered to be hazardous, including products for cleaning, operating, and maintaining equipment and vehicles. Not surprisingly, regulation of these types of materials is become stricter. One major concern addressed in the regulations is proper storage of hazardous materials; improperly stored materials can pose a significant threat to the environment, particularly groundwater. Many states are having to meet regulatory compliance by constructing new storage facilities at significant costs. For example, the Florida DOT spent nearly $1 million during fiscal year 1992 to build hazardous materials storage facilities. Similar expenditures are expected in many states.

Hazardous waste disposal also requires large expenditures; for example, Florida pays $200 to $400 to dispose of each 55-gal drum of waste. Even when a portion of waste has been properly disposed of, it remains the property of the company or state that generated it. Florida recently received an unwanted surprise when a site was discovered at which approximately 1,000 drums of hazardous waste had been improperly disposed of by another party more than a decade before. Cleanup and remediation of the site initially cost $4 million, and the department continues to invest nearly $1 million annually for ongoing cleanup.

Finally, there are also steep costs involved in transporting hazardous wastes; these costs can include insurance and waste materials testing. Each laboratory test can cost several hundred dollars, and several tests must be performed monthly. Transportation costs depend on the amount of waste shipped and the distance to the landfill; insurance coverage of $1 million or more is often required. Some states have addressed this problem in part by attempting to recycle wastes such as used oil and solvents into useful products.

Waste Management

An effective waste management strategy ensures that DOT programs and policies remain in compliance with changing requirements.

Program analyses and interviews have uncovered several important aspects of a successful waste management program. They include a standardized reporting system, comprehensive employee training and contingency plans, shrewd purchasing, regular environmental compliance audits of current operations, and a great deal of commitment by top-level management to carrying out these objectives. This sort of program will ensure an economically smart and efficiently run waste management program. Nonetheless, application of these beneficial principles will not fully offset the consequences resulting from the rapid promulgation of regulatory laws.

The increased number of federal environmental regulations has greatly affected state DOT operations. Millions of dollars are being spent to comply with these regulations. Often, one type of compliance must be neglected at the expense of another if regulations affecting that sector of compliance seem more important at the time. The consequence can be deferred maintenance whose effect is difficult to measure. Costs due to the increased number of federal environmental regulations are already significant and will increase in the future. The question is how much more they will increase; only time will provide the answer.

INTERNAL ACTIVITIES

Departments of transportation have responded to environmental, health, and safety laws and regulations using such tactics as internal communications, staffing changes, research, and training. Even though DOTs have developed specific staffing procedures and methods for responding to new or existing regulations, apparently no formal response programs exist.

Several states have developed specific procedures for responding to regulatory laws. Some of those procedures are explained below.

The Michigan DOT (MDOT) has established an environmental task force, composed of top management and chaired by the chief deputy director, primarily to set policy and evaluate compliance regarding environmental issues. Under this task force is an environmental compliance team, made up of representatives from different divisions within the DOT. The team's main functions are (*a*) to identify and discuss MDOT environmental compliance issues dealing with possible air, ground, or surface and groundwater contaminations; (*b*) to develop and implement action plans to resolve environmental compliance issues; (*c*) to develop and evaluate environmental policy for environmental task force approval; and (*d*) to implement environmental task force policy.

Also within MDOT is an environmental unit in the Materials and Technology Division that provides technical assistance to other divisions of MDOT to investigate and resolve environmental issues as they relate to possible air, ground, or water contamination. The Planning Division has responsibility for storm water discharge and wetlands. Each of the department's nine districts has an environmental compliance manager. MDOT has a full-time maintenance environmental engineer in the Maintenance Division who concentrates entirely on maintenance activities, including training and inspections in the area of environmental concerns. This person also serves as a member of the environmental compliance team. The Maintenance Division of MDOT regularly holds formal classes on environmental issues for its workers and assists them in environmental audits.

Environmental audits are the responsibility of the Division of Transportation and Planning. Two-thirds of these audits are related to maintenance facilities and involve visiting different MDOT facilities and determining the violations, risks, and environmental situations that eventually could become violations. The auditor, whose role is to train and direct personnel to help achieve regulatory compliance, is well regarded by other divisions of MDOT. As one representative noted, the auditor serves more as a "coach" than as an "umpire." The Department of Natural Resources, which has environmental responsibility on a statewide basis, would be more of an "umpire" entity.

In MDOT, the manager of health and safety is assigned to the Division of Personnel. The State Department of Labor is responsible for safety statewide, whereas the State Department of Health is responsible for health statewide.

Oregon has experienced significant success in litter control. This success can be attributed to four aspects of the state program: (*a*) revenue acquired through the sale of special license plates; (*b*) instigation of an Adopt-a-Highway Program for trash pickup; (*c*) strong enforcement of antilitter laws; and (*d*) recycling and reuse of some waste materials. For example, old tires are shredded for mixing in asphalt material; also, the department is required by law to use grass clippings to make mulch and compost.

One of the California DOT's (CalTrans) most successful management programs is in herbicide use, which is not a serious problem because the CalTrans has in place an exceptional training and procedures program. A well-conceived, comprehensive, preparatory program that addresses all major issues has been enacted, and detailed explanations of CalTrans's needs and requirements have been quantified in reports such as the Environmental Impact Study, so that substantial documentation has been readily available for hearings on the subject and for advertisements to the public. According to DOT representatives, money spent in this area has been well invested, and the strategy of introducing BMP has worked well. Most environmental organizations in the state have also been pleased with it.

A member of DOT summarized the view of the department that a commitment is being made to regard environmental thinking as a way of life, from the top officials down through the entire organization.

In North Carolina, a recent fire at a chicken-processing plant has greatly increased awareness of worker safety on all fronts. The state is attempting to increase the number of state on-site safety inspectors, and the North Carolina DOT is increasing worker safety training.

The Virginia DOT budget is greatly affected by safety, health, and environmental training. The training is closely tied to worker right-to-know laws. Virginia's concern for its employees is reflected in a number of policies. For example, (*a*) at least one person in each work crew must be trained in CPR, (*b*) health tests must be run on employees exposed to certain chemicals, and (*c*) employees who use chemicals for vegetation control must be certified applicators. The Virginia DOT spent $2.95 million on worker training during the 1990–1991 fiscal year.

The Indiana DOT is conducting an environmental assessment of its facilities and how environmental and worker safety laws and regulations apply to the agency. The research effort, *Development of a Strategy for Compliance with EPA and OSHA Regulations Applicable to INDOT Facilities*, is Joint Highway Research Project HPR-2040-(027). The research consultant is the School of Civil Engineering, Purdue University.

The Center for Hazardous Materials Research and Triline Associates of Pittsburgh, Pennsylvania, has completed a research effort for the Pennsylvania Department of Transportation entitled *Waste Management Strategies*.

Interorganizational Efforts

A major hurdle transportation agencies face in responding to environmental, health, and safety laws and regulations is the development of rapport with various regulatory agencies. Several factors can affect these relationships: performance and regulatory cross-purposes, conflicting personalities, lack of communication, previous experience, financial considerations, and political opinions.

Several departments of transportation have made significant efforts to enhance coordination and cooperation with regulatory agencies. In Michigan, for example, the Department of Natural Resources (DNR) is responsible for developing and enforcing environmental regulations. One problem for MDOT has been that, at times, different geographic regions and divisions of the central office of DNR have inadvertently offered conflicting responses to regulatory questions. In environmental impact statements for project development, wetland mitigation, and so forth, this problem has been addressed by placing a DOT liaison in the Bureau of Transportation Planning. This employee handles all official communications between MDOT and DNR, attends DNR monthly briefings about new and existing regulations, and keeps MDOT informed of any pending regulations. The liaison serves as the single spokesperson for MDOT in the areas of project development, wetland mitigation, and so forth.

There is no liaison in the area of hazardous and polluting materials, although the agency is considering one. In this area, interagency cooperation has consisted of task groups with representatives from MDOT, DNR, and other state agencies identifying and resolving regulatory concerns on specific issues.

The Oregon DOT is looking into funding a position for an employee who would work on DOT business but be based within the Department of Environmental Quality. This individual would serve as a liaison and a project facilitator between the DOT and the regulatory agency. Agency personnel realize that funding this position would affect their budget, but they also understand that a liaison could help prevent delays in conducting DOT business, which could be far more costly in the long run.

According to CalTrans representatives, preparation is the key when introducing maintenance-related problems to governing agencies, legislative officials, or other departments. A key to their success in this respect has been the development of relationships with personnel in such areas as the Fish and Wildlife Department.

CalTrans has attempted to identify best management practices for use when dealing with legislative and other decision-making bodies in state government. This is obtained by a task force that determines mutual goals and a framework for achieving these goals. As one DOT representative explained, if the department leaves an impression that it is working in good faith, the legislature is less likely to "come down on them," and the DOT is likely to have more flexibility in carrying out its activities.

Whenever possible, the department prepares well-documented, quantified information to build its case before state decision makers. This is one way the department has attempted to shift from being a reactive organization to a proactive one.

The DOT has joined with other state departments, such as Fish and Wildlife and Natural Resources, to participate in joint training sessions so that various mutual concerns can be heard and understood and interaction facilitated. These administrative and communication activities are just some of the ways departments are attempting to confront the problems of regulatory compliance from an organizational perspective.

Conclusion

Highway maintenance personnel in all regions of the country will face increasingly difficult times and situations in the future. The dual problems of constantly changing and proliferating regulatory laws and the costly modifications they dictate, coupled with the ever-tightening budgets confronting most departments, are seriously hampering departments' ability to perform standard maintenance activities without diminishing the quantity or quality of work. Millions of dollars are being spent on efforts to comply with regulations. One area of departmental responsibility must often be neglected to meet the more urgent regulatory demands of another area. The effect of this practice, known as "deferred maintenance," is yet to be fully determined. However, it is safe to assume that costs of regulatory compliance will only continue to mount in the future; the only questions are how high and how rapidly the costs will climb, and how the citizens of affected states will in turn be affected, either as taxpayers or as travelers.

Environmental Training for Hazardous Materials Management

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Departments of transportation are today, more than ever before, affected by a staggering load of rules and regulations designed to control and manage hazardous waste. Federal and state environmental protection agencies, the federal Occupational Safety and Health Administration, and local environmental regulators all promulgate rules and regulations that can create a nightmare for transportation managers. In 1989, the Ohio Environmental Protection Agency issued findings and orders to the Ohio Department of Transportation (ODOT) concerning mismanagement of hazardous waste in five separate locations. The lack of required training was the item most cited as causing ODOT's management problems with hazardous waste. The best way for departments of transportation to minimize hazardous waste management problems is to have a well-trained staff. With that in mind, ODOT developed hazardous waste training courses for all employees whose job requires hazardous waste management. If ODOT's training program had been in place during the mid-1980s, there is a good chance that the agency would not have been found in violation of environmental regulations. The $12 million to $15 million now being spent to remediate these sites could be spent on new county facilities or other capital improvement programs. Transportation officials must place priority on employee training in order to decrease environmental liability.

Departments of transportation are today, more than ever before, affected by a staggering load of rules and regulations designed to control and manage hazardous waste. Federal and state environmental protection agencies (EPAs), the federal Occupational Safety and Health Administration (OSHA), and local environmental regulators all promulgate law, rules, and regulations that can create a nightmare for transportation managers. The Ohio Department of Transportation (ODOT) became painfully aware of the consequences of its failure to properly manage hazardous waste in the late 1980s. Apathy, poor training, and fear all contributed to enforcement action taken against ODOT by the Ohio EPA.

Federal and Ohio laws provide for "cradle to grave" regulation of hazardous wastes. The federal hazardous waste law is known as the Resource, Conservation and Recovery Act of 1976 (RCRA). It is under this act that the Ohio EPA found that ODOT mismanaged its hazardous waste.

In 1989, the Ohio EPA issued findings and orders to ODOT concerning violations of environmental law at the following locations:

1. District 4 headquarters at Ravenna,
2. District 5 old garage site at Newark,
3. District 6 headquarters at Delaware,
4. District 11 headquarters at New Philadelphia, and
5. Traffic sign shop at West Broad Street.

All of the citations are similar. The findings and orders cite mishandling, improper storage, and improper disposal of hazardous waste. In addition, ODOT was found to be in noncompliance with employee training requirements and was fined $124,000, which was ordered spent on an employee training program.

The Division of Operations is responsible for carrying out EPA's findings and orders at ODOT. The Division of Administration, Bureau of Health, Safety and Claims, is responsible for establishing a training program and providing technical assistance to the Division of Operations.

The Division of Operations proceeded with the first step in compliance with EPA's order by hiring consultants to prepare closure plans. The plans were completed and submitted to EPA for approval in 1990. The second and final step of the process required the development of bidding specifications and subsequent advertisement of the projects. This last prework phase will be completed in 1994 for all five projects.

The complexity and unknown variables of RCRA projects add to the difficulty in completing a closure plan. This paper will use the District 5 project, located in Newark, Ohio, as an example of how an RCRA closure is accomplished.

ODOT is currently in the project or remediation phase of its RCRA closures. Since the ODOT has little or no experience in this type of work, it chose to complete the projects one at a time instead of doing all the work at once, in order to gain experience and perhaps reduce costs. The District 5 project, is typical of all the other violations. The constituents of concern are very similar from site to site. Generally, the department conducts work at the areas for a number of years. The garage at Newark opened for business in the late 1920s and remained an active facility until the early 1980s.

The site consists of five closure units located on approximately 3 acres of land. Area A was used by the ODOT Traffic Section to house pavement marking operations. The primary constituents of concern were lead and solvents, such as xylene and toluene. Area B was a storage building for new products associated with ODOT's testing laboratory. The primary constituent of concern is 1,1,1, trichloroethane. Area C was used to store waste testing solvents and also had spills associated with poor handling practices. The primary constituent concern was 1,1,1 trichloroethane. Area D was located next to ODOT's main garage and was used to paint equipment. The primary constituents of concern were lead and solvents, such as xylene. Finally, Area E was used to store waste oil and other petroleum-based products. The primary constituents of concern were lead, benzene, xylene, and other hydrocarbon products.

All of the information, as described, was included in the Findings and Orders issued by the Ohio EPA. Once the Findings and Orders were received by the department, the closure of each project had to follow RCRA guidelines as described below:

1. A closure plan was prepared by a consultant. This plan was then submitted to the Ohio EPA for approval.
2. Once approval was granted, ODOT prepared a bid document, which followed the procedures established by the approved closure plan.
3. The project was advertised for sale.
4. Bids were received and the project awarded.

Once the project became active, it also had to follow RCRA guidelines established in the closure plan. Generally, the work proceeded as follows:

1. Lay out the test sample pattern.
2. Obtain samples by geological drilling.
3. Follow health and safety plans for air monitoring and decontamination procedures (i.e., equipment and staff).
4. Initiate remediation based on the results of the sampling.

The cost of the District 5 RCRA project has been beyond ODOT's highest estimates. To date, ODOT has spent \$4.0 million and is not yet finished with all of the areas. ODOT will have to install a groundwater treatment system, which has not been designed at this time. Final costs could exceed \$7.0 million.

Costs for all of ODOT's RCRA projects, based on the Newark work, could range between \$12 million and \$15 million. As with most DOTs, ODOT has no excess funds for environmental cleanup. The agency has used funding from its capital improvements area, which is for facilities improvements. This has caused a setback for ODOT's long-range program of building new garages and outposts. The agency simply cannot afford to repeat its poor management of hazardous wastes. The best way to minimize future environmental liability is to have a well-trained staff that will follow ODOT's hazardous waste management programs. To accomplish this goal, ODOT has initiated an extensive training program.

Four levels of training classes have been designed on the basis of OSHA and EPA training requirements. ODOT also recognized the need to train the managers in the department to have the level of support and understanding. Without management support, the training and subsequent implementation of policy is very difficult to accomplish. The following is a description of the goals and course agenda for ODOT's hazardous waste management training classes.

Management Course—Regulatory Overview

The goal of this course is to make managers aware of the numerous regulations that affect their operations. This course should provide an overview of the requirements of each regulation as it pertains to ODOT's operations. At a minimum, topics to be covered should include the following:

- RCRA waste generation and disposal requirements,
- 29 CFR 1910.120 Hazardous Waste and Emergency Response,
- OSHA requirements,
- SARA Title III,
- Management liability (civil and criminal), and
- ODOT's Hazardous Materials Program.

Hazardous Waste Supervisor

The goal of this course is to make supervisors aware of the numerous regulations that affect their operations. This course should provide an overview of the requirements of each regulation as it pertains to operations and identify specific areas that need daily supervision to ensure implementation. At a minimum, topics to be covered should include the following:

- RCRA waste generation and disposal requirements,
- Inspections,
- Manifests,
- 29 CFR 1910.120 Hazardous Waste and ER (plans, drills, experience),
- OSHA requirements (general),
- SARA (reporting requirements),
- Spill reporting,
- Labeling requirements,
- 49 CFR Part 172,
- Container management,
- Liability (civil and criminal), and
- ODOT hazardous materials program.

Emergency Response Course

The course must present the basic information as established in 29 CFR 1910.130. The program is to be a combination of classroom/lecture, problem solving, and hands-on exercises. It must also be tailored to ODOT operations by involving problems, scenarios, and examples of the potential operations ODOT employees may encounter as well as some specific chemicals used at the facilities. Each topic must include a discussion of the specific ODOT policies, procedures, and operations (ODOT's hazardous materials program).

The goal of this course is to provide the attendees with the ability to implement a safety plan; classify, identify, and verify known and unknown materials using basic monitoring equipment; function within an assigned role; select and use respiratory protection and personal protective equipment; assess hazards and risks; perform advance hazardous materials control operations within provided capabilities; select and implement appropriate decontamination procedures; complete record-keeping procedures; and understand basic chemical, biological, and radiological terms and behavior. At a minimum, the following topics are to be covered:

- 29 CFR 1910.120 requirements;
- Chemical and physical properties of hazardous materials, both general and specific to operations encountered;
- Recognition, identification, and risk assessment of hazardous materials;
- Toxicology;
- MSDS;
- Respiratory protection;
- PPE—selection, care, and use;
- Medical surveillance—1910.120 requirements;
- Heat/cold stress—symptoms and prevention;
- Response techniques: containment, confinement, and so forth;
- Decontamination;
- Physical hazards;
- Communications;
- Safety issues
- Transportation/disposal;
- Incident command system;
- PUCO requirements 42 CFR;
- Termination procedures and recordkeeping;
- Public community relations issues/plan;
- Labeling;
- Emergency plan;
- Security and control; and
- Container management.

Awareness Course

This course must present the basic information as established in 29 CFR 1910.120. The program is to be a combination of classroom/lecture, problem solving, and hands-on exercises. It must be tailored to ODOT operations by involving problems, scenarios, and examples of the potential operations ODOT employees may encounter as well as some specific chemicals used at the facilities. Each topic must include a discussion of the specific ODOT policies, procedures, and operations.

The goal of the course is to provide those persons who, in the course of their normal duties, may be the first on the scene of a hazardous materials incident with the competency to respond in a safe manner. These personnel are not expected to take any actions other than to recognize that a hazard exists, call for trained personnel, and secure the area. At a minimum, the following topics are to be covered:

- Toxicology;
- Physical and chemical hazards of hazardous materials;
- Recognition and risk assessment of hazardous materials by their labels, placards, shipping papers, and MSDS;
- Potential emergencies that may be encountered;
- Site security and control;
- U.S. Department of Transportation *Emergency Response Guidebook*;
- Site-specific emergency response plan;
- Additional resources available; and
- Expectations of role/actions within the emergency response plan.

Results and Discussion

ODOT has received positive feedback from the people who have taken these courses. The agency trained nearly 700 employees at a total cost of approximately $60,000. The agency cannot relax its training efforts now, even though it has completed a large program. RCRA states that if an agency generates and disposes of hazardous waste, continuous training must be maintained.

The appropriate level of training for staff transfers and new hires must be identified and that training administered on a timely basis.

The benefits to the department from a well-conceived and presented training program quickly manifested themselves in positive management practices. The ODOT Waste Management Program was the basis of training presentations, not a generic program that did not reflect ODOT's operations. This resulted in an increase in employee interest. Instead of studying a lot of regulations from the Code of Federal Regulations, students were able to associate the rules and regulations with actual ODOT work practices.

Hazard communications and hazardous waste manifests, both critical in managing ODOT's hazardous waste program, have been sources of misunderstanding and improper use. The training of the ODOT staff has resulted in a much better application of how MSDS data and hazardous waste manifests tie into proper waste management. Employees now realize what information is important and where to look for it.

Housekeeping is another task that often does not receive due attention. Improper labeling, outdated waste, spills, and leaks all added to problems with proper waste management. The ODOT staff has improved its housekeeping chores and, in some cases, has developed new ways of preventing problems associated with housekeeping.

In one field district, the inventory system has been changed to incorporate a bar code system for product identification and tracking. The bar codes are affixed to each product as it is received and remain in place until the product is used. Additional information concerning the product may also be affixed with the bar code, such as stickers advising of flammability, toxicity, and required safety precautions.

The ODOT training program has resulted in much higher awareness of waste management among employees. They have a much better idea of why proper waste management is so important to the department.

One of the main challenges for the future is to maintain the level of interest shown by employees immediately after receiving training. As with most DOTs, waste management is not ODOT's primary work objective and can quickly be lost in the day-to-day business of building and maintaining highways. The challenge will be met with continuing education and inspections conducted by the department's environmental staff.

Another challenge will be to identify and properly manage all of the waste streams generated by the department. The Division of Operations has 244 garages and outposts, all with the potential of generating hazardous and nonhazardous waste. The need to identify these items and extend training to employees not already trained will be continuous. The training program will also have to address new hires and transfers on a timely basis.

If the department's training programs on waste management had been in place during the mid-1980s, there is a good chance that it would not have violated the RCRA. The $12 million to $15 million now being spent to remediate these sites could be spent instead on new county garages and other capital improvement programs. ODOT must continue to train its employees in an efficient and timely manner to reduce the chances of incurring future liability under environmental law. Transportation officials must place the priority of employee training at a high level to keep liability at a low level. These efforts must succeed because the alternative is unaffordable.

Storm Water Management Strategies To Meet National Pollution Discharge Elimination Systems Requirements

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Storm water runoff from highways and other paved surfaces may contain levels of petroleum, metals, and particulates that could affect the environment. To address potential environmental impacts, the federal National Pollutant Discharge Elimination System (NPDES) regulations were enacted in 1990. The Washington State Department of Ecology (Ecology) is the regulatory authority for the NPDES program. Municipalities with populations exceeding 100,000, as well as transportation departments, are obligated to obtain a municipal NPDES permit, which will provide conditions for storm water management. Ecology issues permits on a watershed basis, and a single municipal permit will be issued for that watershed. Washington State Department of Transportation (WSDOT) staff coordinate with the municipalities to develop a practical storm water management plan for each watershed that places sites in priority order for improvement and that reflects a sharing of costs. Approximately 2,500 storm water outfalls along 1288 km of state highway have been inventoried to characterize the discharge quality and therefore potential impact on surface waters of the state. A prioritization scheme was developed that will be used in selecting areas for highway storm water improvement. WSDOT maintenance facility storm water issues are not covered under the WSDOT municipal permit. However, through the development of the city and county municipal permits, all WSDOT property storm water will have to be managed. The WSDOT has and will continue to recognize quality-of-environment issues in all phases of planning, construction, and operation. The storm water quality impacts of WSDOT facilities and highways must be balanced with other traditional goals of the department.

Washington State, with a population of 5.2 million, is considered by many to be a leader in environmental protection. In 1970 the Washington State Department of Ecology (Ecology) was established, and remediation regulations governing solid waste, hazardous waste, air quality, groundwater protection, and hazardous waste sites were developed. In 1985, under the direction of then-Governor Booth Gardner, the Puget Sound Water Quality Authority was formed to coordinate the development of the Puget Sound Water Quality Management Plan (PSWQMP). The 1980s represented, without a doubt, the renaissance of the environmental movement in the state.

Within the bold framework of the PSWQMP, municipalities within the Puget Sound region were to develop watershed management plans that included practices and programs to protect the aquatic environment. A "highway runoff rule" was enacted by the legislature under the authority of Ecology in 1991. The rule required the Washington State Department of Transportation (WSDOT) to prepare a highway runoff manual to "direct stormwater management for its existing and new facilities and rights of way in the Puget Sound basin." WSDOT opted to develop its own highway runoff manual rather than adopt by reference the Ecology-developed manual. This provided several benefits to WSDOT beyond avoiding the obvious confusion created by interpretation of a complex technical document. Ecology's manual was developed to provide storm water guidance for all land uses, whereas WSDOT's addressed only highway runoff. In addition, WSDOT improved on technical standards to make many of them more workable and efficient. Implementation of the rule, however, was contingent on the availability of appropriated funds. Legislative funding for storm water management and control was very limited, allowing only for the development of a few waste treatment facilities, the preparation of a highway runoff manual, and limited field inventories of drainage outfalls.

Because Washington is a delegated state under the National Pollutant Discharge Elimination System (NPDES), the Department of Ecology coordinated with WSDOT toward the development of a municipal NPDES permit. Essentially the highway system, within certain-sized cities and counties, is considered equivalent to municipalities in the discharge of storm water. The municipal NPDES regulation has three purposes:

- Prohibit nonstorm water discharges into storm sewers,
- Reduce or eliminate discharge of storm water–borne pollutants, and
- Establish a permit system for industrial and municipal storm water discharges.

It is interesting to distinguish between the municipal and industrial NPDES permit programs. In 1992 Ecology promulgated its industrial NPDES permit program (similar to the federal program), which required certain industries and commercial entities to obtain NPDES permits with controls on storm water discharge from these facilities. WSDOT facilities were not included under this permit system.

Development of the Municipal Permits

Ecology's initial efforts were directed toward issuing permits on a jurisdictional basis; for example, to King County, Seattle, and so forth. Then the watershed approach was adopted. This required the coordination and cooperation of major municipalities and WSDOT in the development of one permit per watershed. The first watersheds requiring the municipal permits are the Cedar and Green rivers in King County (see Figure 1). WSDOT, King County, city of Seattle, and METRO (Sewer and Stormwater Authority) are players in developing this permit, which will be issued in mid-1994. Other watersheds and permit issuance dates are

- Tacoma-Pierce County, fall 1994;
- Snohomish County, summer 1995; and
- Vancouver-Clark County, 1996.

In 1993 the Washington State Legislature appropriated $650,000 for WSDOT to characterize these drainage systems and to develop the permit. Six contract interns were hired for 9 months to find, quantify, and characterize the discharge from the WSDOT highway system in these watersheds. All outfalls greater than 30 cm were located and mapped using a global positioning system (GPS).

The field team inspected 438 km of highway in the watersheds of the Green and Cedar rivers, and 1,086 outfalls were characterized. In addition, existing best management practices (BMPs) were located, mapped, and characterized as treatment swails, oil water separators, vaults, and so forth.

Following this inventory, the discharges from the highway system were ranked according to a somewhat complex formula that included these rating factors:

- Highway design features,
- Operation conditions,
- Drainage system characteristics,
- Water quality and aquatic biological data, and
- Surrounding land use characteristics.

Of the 1,086 outfalls, 31 were ranked sufficiently high to require retrofitting. Estimated costs to install the storm water treatment and control features for these outfalls range from $3.1 million to $3.9 million. Total costs to correct all outfalls that contribute particulates and other contaminants to water bodies is estimated at more than $70 million statewide. These funding needs are being addressed as a part of the development of a new environmental funding program.

WSDOT's manual will be used to design the above retrofits and to tailor maintenance practices to improve or correct storm water. In some cases, the simplest and most effective retrofit is enhanced maintenance. As additional BMPs are installed and as WSDOT staff are encouraged to consider water quality during routine maintenance, annual maintenance costs will increase substantially. This redirection of focus and effort is particularly challenging in light of limited maintenance funding. Additional funds are being sought for maintenance of catch basins, grassy swails, detention ponds, and other storm water runoff features.

Increased attention to storm water also places greater demands on environmental staff within the department. As more emphasis is placed on improving storm water quality, more solid waste is created, much of which presents disposal problems. For example, the more frequently that catch-basins are cleaned, the better the storm water leaving the system. More frequent highway sweeping reduces the potential for particulates to enter storm water. Both vactor and road abrasives contain metals and petroleum hydrocarbon, which render them unsuitable for normal solid waste disposal. Additional solid waste treatment/disposal facilities will therefore be necessary and are

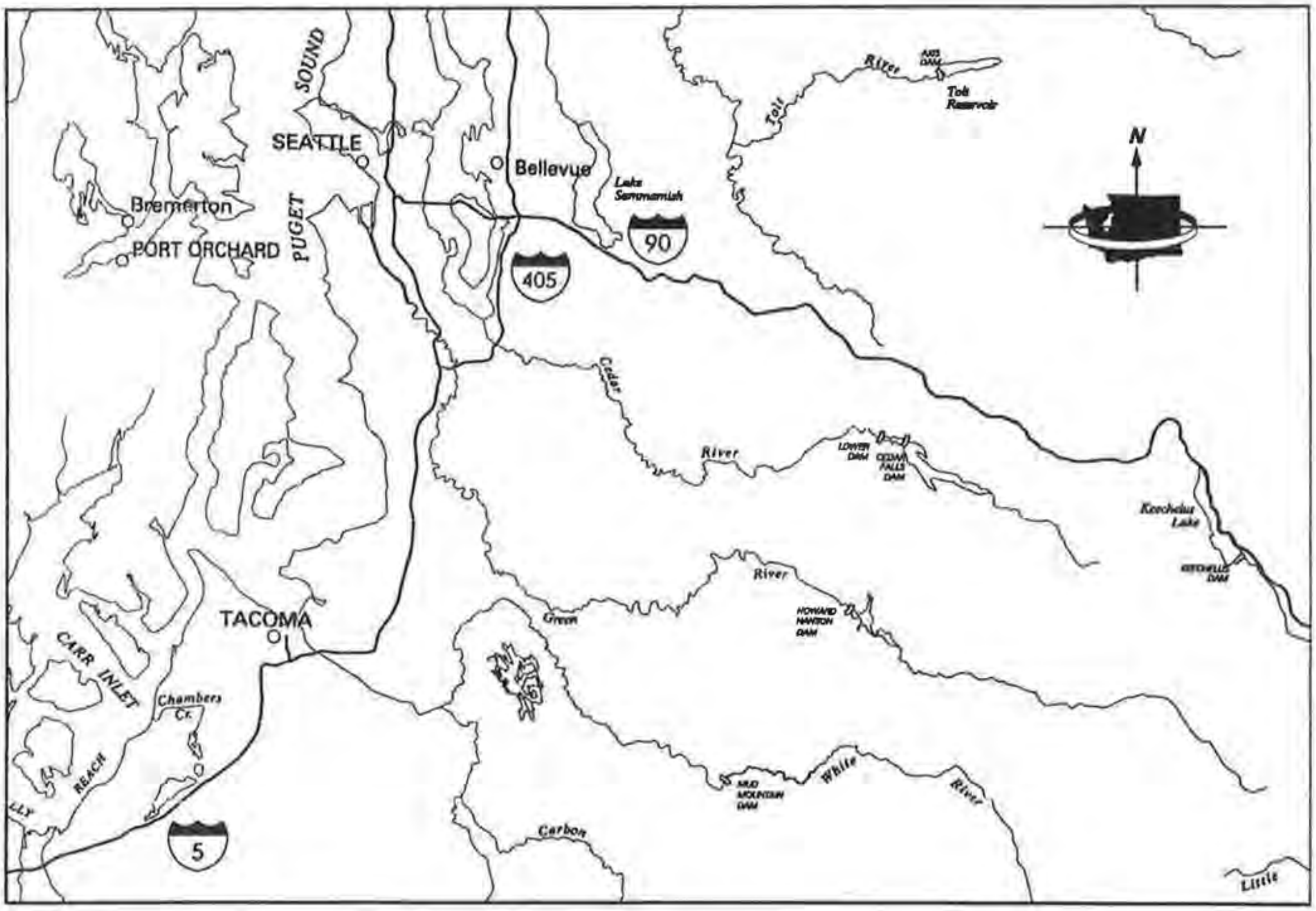

FIGURE 1 Cedar and Green rivers watershed in King County.

being developed as a direct consequence of improving storm water quality.

Maintenance Facility Stormwater Issues

The federal industrial NPDES permit program, as distinguished from the nonindustrial NPDES program, did not include transportation maintenance facilities as entities requiring storm water improvements. Similarly, the jointly developed municipal NPDES permit omitted facilities and focused solely on highway runoff.

Under the authority of the PSWQMP, and the subsequent development by municipalities of storm water manuals, many types of WSDOT activities and facilities are proposed to be regulated. This regulated is intended to improve overall storm water from all sources within municipal jurisdictions.

For the purpose of demonstrating the potential significant impacts of these municipal storm water manuals, the recently developed Tacoma-Pierce County storm water manual is presented. Several practices and capital improvements are discussed:

- Equipment cleaning,
- Vehicle washing,
- Structure pressure washing,
- Bulk shipments,
- Mobile fueling at construction sites,
- Permanent fueling areas,
- Vehicle maintenance,
- Pouring of concrete and asphalt at temporary sites,
- Vegetation management,
- Above-ground storage tanks,
- Storage of barrels,
- Stockpiles,
- Storage of treated wood,
- Petroleum-contaminated soils stockpiles,
- Building maintenance,
- Parking lots, and
- Sidewalks and driveways.

This proposed storm water manual would have significant impacts on facilities and maintenance practices:

- Discharge from the cleaning and washing of equipment cannot enter (directly or indirectly) the storm system;
- No vehicle wash water containing soaps can enter the storm system;
- All vehicle fueling areas must be covered and interceptor drains installed at fuel islands to intercept run-on surface water;
- Floor drains in vehicle maintenance shops are prohibited;
- Stockpile sites require containment berms or downstream filter devices;
- Treated wood must be stored on paved surfaces draining to treatment system; and
- All parking lots, sidewalks, and driveways require monthly sweeping.

WSDOT technical staff have been part of the development of this manual through membership on the advisory committee. Staff have attempted to present arguments of practical limitations and implications of some of the proposed BMPs.

Estimated costs to comply with these proposals would be $2 million initially and $100,000 annually. It is anticipated that this draft manual will be modified as it proceeds through the public review process and adoption by the city and county councils.

Regulatory Climate

The 1994 legislative session is a dramatic example of the change occurring in the environmental movement in Washington State. Whereas the 1980s was the decade of environmental perpetuation, the 1990s is an era of socioeconomic interest. No new regulatory environmental regulations were submitted for legislative review. Business interests, criminal justice interests, and a stale economy weighed heavily among the successful legislation. The voices calling for "no more environmental regulations" and "more jail time" are powerful now in Washington State.

To be realistic, however, attention to water quality as a driving force in local growth management legislation and the severely dwindling salmon resources present strong arguments for water quality protection. It is likely that we will continue to see increased pressures for storm water treatment and control.

Conclusion

WSDOT's primary emphasis has been on building and maintaining a highway system that recognizes mobility and safety. In recent years, environmental considerations and costs associated with project environmental improvements have together created an increased interest in environmental quality at WSDOT.

Storm water regulations and emphasis are the most recent of a series of environmental requirements being addressed by WSDOT. Through legislative funding, the department is developing an inventory and priority ranking of storm water discharges from the highway system. Water quality improvements will be made as funds are reallocated or directed toward storm water features and maintenance. Historically the department has only made environmental improvements as part of construction projects. Now, through the leadership and direction of the Transportation Commission, a service objective has been established that recognizes and funds needed retrofits for storm water improvement.

This refocus on highway runoff has precipitated a review of how and where water quality improvements are made. Instead of small, independent "fixes" by different transportation entities, partnerships are developing to make more comprehensive and therefore more significant water quality improvements. WSDOT has historically coordinated construction projects with cities and counties, and the coordination of water quality improvements blends well with traditional alignments.

Through its participation in advisory committees developing municipal storm water manuals, the department has opportunities to present balanced arguments for achievable goals for storm water improvements, given current funding availability.

Storm water management improvements must be made to protect the Puget Sound water quality and the diminishing fish resources. WSDOT's contribution to this improvement will be significant and challenging. It will be challenging in the sense that traditional behaviors and practices are being questioned and different ways of doing business will be necessary.