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Contents

Foreword

This Record contains 22 papers presented at the Sixth Maintenance Management Workshop, "Innovations for Maintaining the Highway Infrastructure in the 1990s," held in Jackson, Mississippi, July 25–27, 1990. Maintenance management workshops are held at approximately 5-year intervals to provide information on the state of the art to professionals responsible for maintaining highways. The papers in this Record are grouped into four topic areas—maintenance management systems, new tools and techniques for highway maintenance, general maintenance topics, and maintenance personnel issues.

The first topic area, maintenance management systems, includes six papers on transportation agencies' efforts to improve the effectiveness of their management information systems. The common thrust of the improvements is to reduce data entry requirements for field managers while providing them with planning and scheduling capabilities. One system is integrated with the accounting and roadway management systems and provides an automated maintenance planning capability based on roadway deficiencies. Another system provides improved information flow to and from crew supervisors by utilizing microcomputers. One state is converting to a commercially available, personal-computer-based system used by the National Park Service to manage its maintenance activities. One paper describes the Saskatchewan (Canada) system, which provides up-to-date resource usage, accomplishments, and expenditures at all organizational levels.

The second topic area, new tools and techniques for highway maintenance, contains five papers that describe research efforts to evaluate the application of new technologies to improve the efficiency and effectiveness of highway maintenance activities. The new tools include lap-top and hand-held computers, electronic clipboards, bar code technology, voice recognition systems, distance-measuring instruments, telecommunications devices, satellite global-positioning technologies, geographic information systems, and expert computer systems. The applications of these tools are described in the context of maintenance crew card data entry, life-cycle costing for pavement management decisions, real-time pavement weather forecasts to reduce ice and snow control budgets, and a computer-aided maintenance management system.

The third topic area, general maintenance topics, contains seven papers on research efforts to assist maintenance managers in evaluating highway maintenance programs. The efforts include an assessment of timing and level of maintenance and rehabilitation activities on pavement condition, a description of the rating procedures and distress-monitoring approach used in the long-term pavement performance program, the use of an expert computer system to assist pavement engineers in determining maintenance strategies, an evaluation of the engineering characteristics of vegetation to reduce roadside maintenance costs, and an assessment of bridge rehabilitation and maintenance costs. This section also contains a paper on an agency's efforts to implement a maintenance quality evaluation program and one on a new approach in France to enhance productivity and effectiveness of highway maintenance operations.

The maintenance personnel issues topic area contains four papers on educational and motivational developments. The developments include the use of interactive videodisc training to improve roadway maintenance, the results of a survey on the value of motivation among maintenance workers, an assessment of the present and future role of maintenance management training in the nation's colleges, and a discussion of innovative strategies for upgrading personnel in transportation agencies.

Maintenance Operations Resources Information System

Michael M. Ryan and Charles A. Wilson

In 1986 the Pennsylvania Department of Transportation installed an updated maintenance management system. The system includes the payroll, material, and equipment cost-tracking features for each maintenance activity common to most systems. Whereas the previous software was modernized and integrated with the accounting and roadway management systems, automation of maintenance planning was probably the most innovative step in improving maintenance management systems. Department policy requires that maintenance personnel survey the roads for deficiencies that require corrective responses. Maintenance managers then prepare 4-month period plans from the surveys. Weekly plans are developed from the period plans. The final product is a completed daily payroll. The planning subsystem incorporates all this activity into one screen-driven data base. From the time that a road deficiency is inventoried through management review of the history of completed work, all planning processes can be monitored, and a complete roadway history is maintained.

In July 1986 the Pennsylvania Department of Transportation installed a new maintenance management system. The new system incorporated several stand-alone systems into one all-encompassing Maintenance and Operations Resources Information System (MORIS).

A daily payroll system, which tracked foreman cost and was similar to that of many other states, was developed in the early 1970s. Material inventory and equipment management systems were developed separately as stand-alone systems. The rewrite of these systems provided fresh software that integrated several features with the accounting and roadway management systems and included a greatly improved equipment repair work order feature in the equipment subsystem. The highway and materials inventories and equipment data bases have numerous on-line ties to each other.

The highway subsystem incorporates the standard features of a maintenance management system, including performance standards for field foremen and annual work plans. County, district, and central office managers are provided with reports that measure production, productivity, unit cost, and plan adherence. However, the function that best defines MORIS as state-of-the-art is the highway maintenance planning and scheduling module.

Before MORIS, department policy required that county maintenance managers survey their roads and record deficiencies needing maintenance. They were also to prepare 4-month "period plans" that specified the activities to be performed on the routes to be repaired. The benefits of the period plan include projecting material and specialized equipment needs and identifying efficient work flow from one route to the next. A weekly planning meeting, at which the county manager and his assistants scheduled specific workers and equipment for the following week, was also required.

It was realized that this process could be computerized and that the result of the planning could be a preprinted payroll that would feed into the existing daily payroll system.

The first step in the planning and scheduling process is to input information from the road condition survey into the road information (RI) screen (see Figure 1). With this approach the route and maintenance activity numbers that will eventually be used to document the completed work are input into the system up front. An example of a filled-out RI screen is given in Figure 2. In this case the assistant county maintenance manager has observed that cracks need to be sealed or shoulders need to be cut on a particular route.

The process continues as the assistant manager surveys the roads and builds an inventory of work to be completed. The assistant manager can either input the data on a remote mainframe terminal or have the office staff enter the data from the assistant manager's notes.

This example of RI screen entry is self-explanatory with the exception of the route. Pennsylvania has replaced stations with a state route–segment–offset location referencing scheme in roadway data bases. Each state route is divided into approximately ½-mi segments. Signs have been erected at the begin-

ROADWAY INVENTORY

DATE	ACTIVITY	ROUTE	EST. PROD.
____	____	____ ____ ____	____

REMARKS	FOREMAN	PERIOD
____	____	____

FIGURE 1 RI screen.

ROADWAY INVENTORY

DATE	ACTIVITY	ROUTE	EST. PROD.
2/10/90	711-7215-01	1002 10 0 40 1250	4 (MILES)

REMARKS	FOREMAN	PERIOD
HEAVY BUILDUP ON SHOULDERS	31	

FIGURE 2 Filled-out RI screen.

Pennsylvania Department of Transportation, Transportation and Safety Building, Harrisburg, Pa. 17120.

ning of each segment (see Figure 3). The RI screen sample in Figure 2 indicates that shoulder cutting needs to be done on State Route 1002 beginning at Segment 10, Offset 0 and continuing to 1,250 ft beyond the start of Segment 40. Figure 4 shows what the project would look like on a plan drawing.

The second of the four job steps is preparation of the period plan. The only step is to enter the period number on the menu of things to do on the RI screen (see Figure 5). By entering Period 3 the manager indicates an intent to complete the work during March, April, May, or June.

After indicating the work to be included in the period plan, the manager selects the print function. The system sorts the work items by activity and state route and calculates the total crew days planned for each foreman. The guideline is to include enough work on the period plan to account for at least 70 percent of the crew days available. Inclement weather and emergencies are accommodated in the remaining 30 percent of the period plan. The system automatically prints the period plan on the local printer (Figure 6).

FIGURE 3 Sign at beginning of Segment 70.

STATE ROUTE/SEGMENT/OFFSET

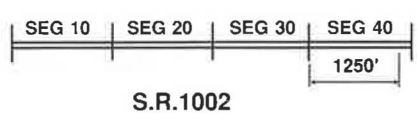

FIGURE 4 Plan drawing of project.

ROADWAY INVENTORY

DATE	ACTIVITY	ROUTE	EST. PROD.
2/10/90	711-7215-01	1002 10 0 40 1250	4 (MILES)

REMARKS	FOREMAN	PERIOD
HEAVY BUILDUP ON SHOULDERS	31	3

FIGURE 5 Entry of Period 3 on RI screen.

FOREMAN 31

CRACK SEALING

S.R. 0364 S.R. 1004 S.R. 4022

SHOULDER CUTTING

S.R. 0322 S.R. 1004 S.R. 2032 S.R. 4032

CRACK SEALING	**2.5 DAYS**
SHOULDER CUTTING	**3.0 DAYS**
	5.5 DAYS

FIGURE 6 Period plan.

The assistant manager then has a plan for the coming 4 months. The calculation of crew days and the typing of the plan have been done by the computer. As the weeks pass the assistant manager will pick items that are listed in activity order on the period plan and organize workers and equipment for the weekly plan. A weekly planning meeting is generally held on Thursday. The assistant manager schedules a project for the next Monday by typing a 1 next to the item on the weekly plan screen, for Tuesday by typing a 2, and so forth (Figure 7). One or two activities per day are normally scheduled. The system retains the crew members and equipment assigned to the foreman for the previous week, so the manager only has to make changes where men or equipment are to change. Usually the remarks section is the only portion of the weekly plan that requires typing.

If the print option is selected again, the system will preprint a daily payroll for each day of the next week, and a weekly plan summary for each foreman will be printed. The assistant manager distributes the weekly plans and payrolls to his foremen (Figure 8). The foremen know what they are to do the

FOREMAN 31

	ROUTE		
MON.	1002	CRACK SEALING	300 GALS
TUE.	2034	SHOULDER CUTTING	4 MILES
⋮			

HARPER	170 40 4066	CREW CAB	017 2024
MYERS	193 30 8486	TAR KETTLE	324 5017
⋮		⋮	

REMARKS: Inclement Weather Plan Will Be Litter Pick Up

FIGURE 7 Weekly plan.

FIGURE 8 Distribution of weekly plans and payrolls to foremen.

following week and have payrolls that contain preprinted coding.

Hours worked and production units to be completed are not preprinted on the payroll. The route, accounting coding, social security numbers, names, and equipment numbers are preprinted. If one crew member is substituted for another, the foreman draws a line through that entry and writes in the correct entry. All valid social security numbers, equipment numbers, and accounting and route numbers are stored in the computer, eliminating errors on the payroll signed by the foreman.

The completed and signed payroll is taken back to the office for entry into the computer. Data entry time has been greatly reduced because there are no errors on the preprinted portion, and generally the only information left to be entered is the production hours and production units.

Figure 9 gives a flowchart that summarizes the MORIS process.

The process requires the field manager to work on a computer, whereas the old manual system did not. The process forces more planning and scheduling, which, it is believed, is an appropriate function for first-level managers.

Department crews perform a variety of maintenance functions, from litter pickup and brushing to seal coats and minor paving. If productivity levels are to be maintained on priority activities, good planning is critical. Management must direct the foreman to perform the priority tasks. Management has the responsibility to ensure that the foreman is supplied with adequate labor, materials, and equipment to complete the task. MORIS facilitates this process.

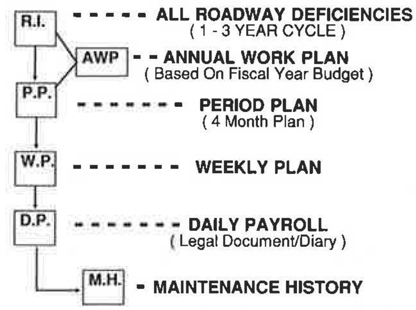

FIGURE 9 MORIS flowchart.

In summary, MORIS is probably better described as a management system than as a computer system. The formalized process supports and reinforces the correct management processes.

Abridgment

Arizona Department of Transportation Highway Maintenance Management System

George R. Russell

The Arizona Department of Transportation has modernized its first-generation highway maintenance management system by utilizing microcomputers at the crew level. Maintenance crews now develop their own annual work plans, which results in much more realistic plans than had been prepared and imposed by the central office. In addition, management reports are available to crew supervisors on a much more timely basis. The new system, the changes made to achieve it, and the advantages obtained are outlined.

The Arizona Department of Transportation, with the assistance of Burke & Associates, Inc., has designed, developed, and implemented a series of major improvements in its first-generation highway maintenance management system, called PeCoS.

Like the initial system, the new system—PeCoS II—is used to plan, budget, and control highway maintenance operations. Some elements, such as activity performance guidelines and highway feature inventories, are the same as or similar to PeCoS, but a number of major improvements are reflected in the new system:

- The new system resides on microcomputers in each maintenance area and most crew offices, which allows field managers direct access to and control over their work programs and other work planning data.
- The responsibility for maintenance work planning and control has been decentralized. Field managers now have greater latitude in defining work needs and in developing work programs.
- The central maintenance office staff, instead of having primary responsibility for work planning, act as technical advisers to the district and area staffs.
- Planning values have become more flexible. Allowances are made for regional variations to reflect legitimate differences in material prices and in how work is performed in various parts of the state.
- The maintenance management computer programs have been rewritten to provide managers at all levels with more convenient and timely access to management information.
- Differences between "PeCoS" dollars and "real" dollars, as they appear on budgets and cost reports, have been minimized through the use of parallel costing methods and a reduction in the number of separate reporting documents. The use of statewide average rates for planning and budgeting was eliminated in favor of rates that more accurately reflect local maintenance costs.

This report provides an overview of the new system and highlights the major benefits of the new system.

OVERVIEW OF SYSTEM IMPROVEMENTS

PeCoS II represents the state of the art in maintenance work management techniques and supporting computer software. Its most significant innovation has been to place maintenance work planning in the hands of the field managers who must make the day-to-day operational decisions regarding specific work needs, priorities, and crew assignments.

System Components

Figure 1 is a schematic diagram of the major system elements. They are grouped into the following categories:

- *Work planning elements* consist of the actions needed to develop appropriate plans and budgets, including definition of service levels, resource needs, and funding requirements for each activity.
- *Work scheduling elements* include monthly work calendars and weekly crew schedules.
- *Work reporting elements* include daily work report entry, processing, and file maintenance.
- *Work control elements* consist of management reports that are available from the local microcomputer as well as the mainframe.

Figure 1 also shows the interfaces with other systems, including pavement management, payroll, equipment management, and materials inventory management.

Arizona Department of Transportation, 206 South Seventeenth Avenue, Phoenix, Ariz. 85007-2630.

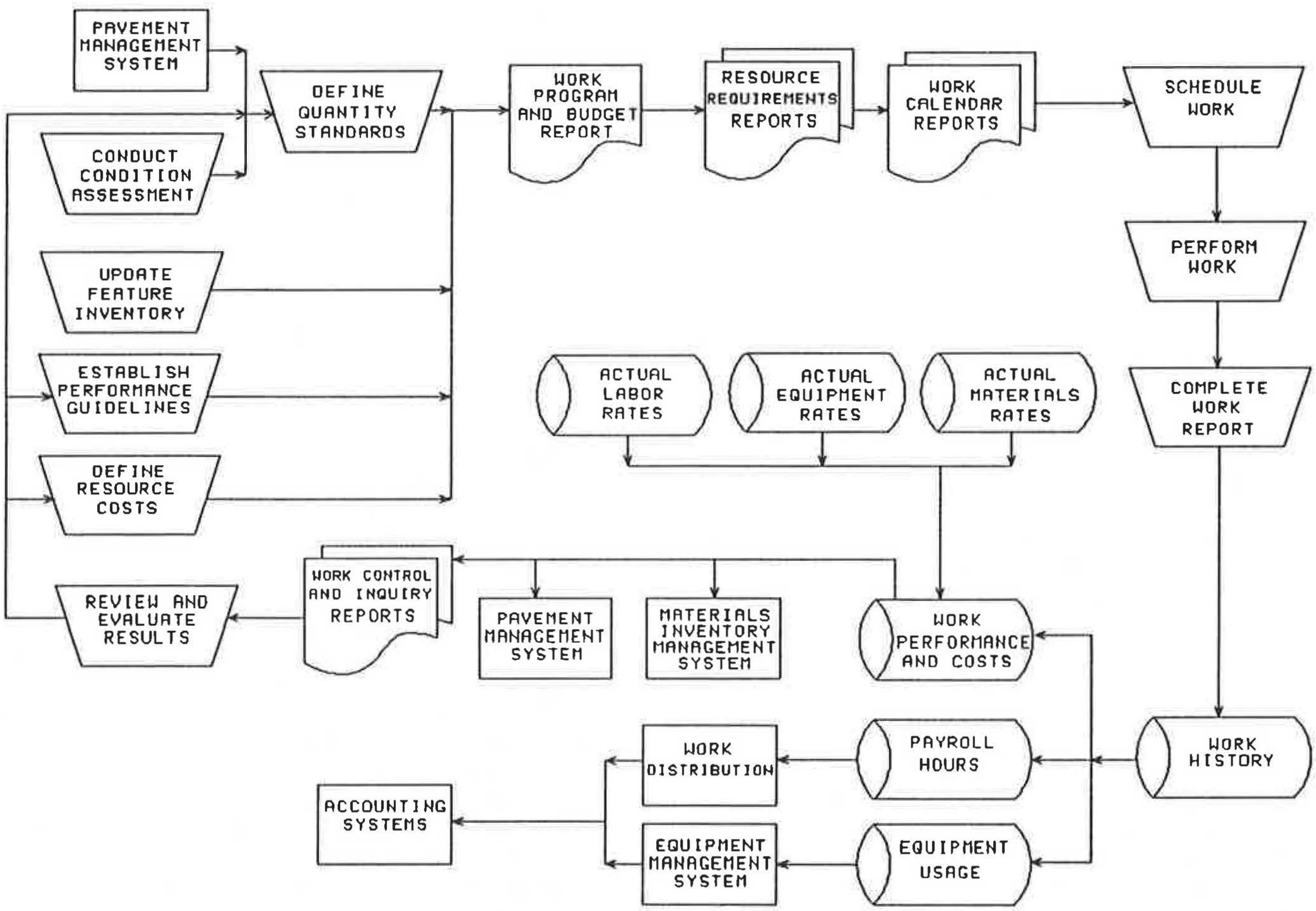

FIGURE 1 Major system elements.

Summary of Modifications

Fourteen major modifications were made to PeCoS:

1. Each area has been assigned responsibility for the development and updating of its own work programs. The central maintenance office now provides statewide maintenance management coordination and technical assistance.
2. A liaison person from the central maintenance office has been assigned to each district to provide assistance and technical support.
3. Each maintenance ORG (the lowest organization element) now has access to a microcomputer for developing and maintaining work programs, processing work reporting data, and generating reports.
4. The PeCoS computer software was rewritten in dBASE III and transferred to the microcomputers. The maintenance management system, formerly a centralized mainframe application, now operates on area-level microcomputers, and each area has its own data base. The mainframe is used for district and statewide management information storage and report generation and as a gateway to enter information to the payroll and equipment management systems.
5. The activity planning process has been modified to allow the user to enter most of the planning values for a single activity on one user-friendly, interactive screen that immediately displays the impact of planning decisions on the work program and budget.
6. Crew compositions, average daily production values, and quantity standards can be refined at the area level to reflect local conditions. This reduces the disparity between actual work performance by the various areas and the standards for performance that (in the past) were established on a statewide basis without regard to legitimate regional differences.
7. The differences between PeCoS budget dollars and financial (line item) budget dollars have been reduced by increasing the number of labor, equipment, and materials rate options and adjusting the options for each area. In the past, for example, PeCoS had only two statewide labor rates for work program and budget development; now there is one rate for each employee class—a rate that accurately reflects the planned labor cost.
8. Modifications were made to the PeCoS work program and budget report to make it more readable and useful. Several versions of the report are available.
9. Under the old system, the work program and budget were annual plans; little attempt was made to extend them to a monthly basis. PeCoS II has a labor day distribution and a work calendar to allow the user to create monthly work programs from the annual plan. This ability to plan work on a monthly basis has made it considerably easier for ORG crews to manage their activities in relation to their established work programs.

10. A resource requirements report was developed to document monthly needs for each class of labor, equipment, and materials. The ability to evaluate resource needs on a monthly basis, rather than simply in terms of annual averages, has enabled maintenance field organizations to manage more effectively.

11. Crew scheduling procedures were revised. The scheduling period was reduced from 2 weeks to 1, and the scheduling form was modified to allow for more detailed work assignment planning.

12. The crew day card, which was a work authorization as well as a work reporting document, has been replaced by a new daily work report. The new work report eliminates the need to complete a separate equipment utilization report, and it will eventually eliminate the need for a separate biweekly time sheet.

13. Differences between cost data shown on PeCoS reports and those reflected on fiscal expenditure reports have been reduced by using more accurate and up-to-date rate tables and by modifying the PeCoS costing methodology to more closely resemble those of the payroll and equipment systems. Differences will remain, however, in the materials costing process. (In PeCoS II, materials are expensed as they are used over a period of time. The accounting system, however, expenses the same materials when the vendor's invoice is paid.)

14. In the past, all work control reports were generated from the mainframe. It took some time for the work report data to come in from the field and for the reports to be produced and distributed. Under PeCoS II, almost all work control reports are available from the local microcomputer as soon as the latest work reports are entered. Many of these reports are also available on the screen. This allows field managers much better access to timely activity cost and work performance information. It also is a major benefit when work programs need to be updated.

PROJECT BENEFITS

The modifications and improvements that were made to PeCoS will result in a number of significant benefits:

- Improved work planning: The system incorporates decentralized work planning. Both the authority and the means to do their own work planning—in the form of computer hardware and software—have been provided to area and ORG managers. Maintenance planning is far more realistic than was possible under the former centralized planning. Also, the monthly work calendars allow ORG supervisors to plan crew activities in greater detail than was possible under an annual work program. The result is maintenance work programs that are consistently employed by field crews.
- Better management information: The use of microcomputers with local data bases allows managers and staff at all levels a much greater access to timely and accurate management and cost information. The single source document (the new daily work report) consolidates reporting paperwork for the various management and accounting systems, thus improving the consistency of the data among these systems. The result is an enhanced ability to monitor and evaluate work performance and costs and to update work programs.
- Reduced paperwork: The single source document will reduce the paperwork burden on the crews and the area staffs, thus freeing their time for other work.
- More effective resource utilization: The improved crew scheduling procedures, as well as the new resource requirements report, allow managers to improve resource needs planning and specific labor and equipment assignments, thus making better use of limited resources.
- Cost savings: The more accurate and timely cost and work performance data enable the staff to better manage the work of crews and thereby to achieve greater efficiency at the job site and a more purposeful expenditure of resources and funds.

Indiana's Maintenance Management Information System

JOHN P. BURKHARDT AND LARRY J. GOODE

In 1986 the Indiana Department of Transportation (INDOT) realized that its computerized maintenance management system was not meeting the needs of the department. Problems included a cumbersome mainframe system that necessitated sequential running of programs, an inordinate amount of paperwork, and, most important, lack of meaningful feedback to district and subdistrict managers and foremen. INDOT's Maintenance Management Section studied several alternatives to eliminate or reduce the problems. The alternatives included the development of a new system using INDOT's data processing resources, the use of existing systems in operation in other states and agencies, and a contract with a vendor-consultant for a product already in use in a public agency. The Pennsylvania Department of Transportation's Maintenance Operations Resources Information System (MORIS) was reviewed as part of the evaluation. A team consisting of specialists in maintenance management, equipment and inventory management, and data processing was sent to Pennsylvania for 2 days. Although the team was impressed with the highly integrated nature of MORIS, the team eventually rejected its use for Indiana. The use of MORIS in Indiana would have required a major upgrade to the department's mainframe computer, a major reworking of the software to fit Indiana's legal and financial requirements, and some departure from existing well-accepted maintenance management practices. The Maintenance Management Section selected a commercially available product that matched, in theory, the existing maintenance management system. The product is generic, operates on a personal computer, and permits data to be uploaded to the department's data base for use by other functions. The selected product is used by the National Park Service to manage maintenance activities.

The Indiana Department of Transportation (INDOT) is responsible for roadways classified as Interstate routes, federal routes, or state highways, including toll facilities but not county roads or city streets. Of the 28,250 lane-mi for which INDOT is responsible, 16.9 percent is in the Interstate system.

INDOT is organized into 6 districts, 37 subdistricts, and 122 maintenance units. Cities and counties do not contract with INDOT to provide maintenance or snow removal. A force of approximately 2,000 maintenance workers is responsible for road maintenance activities. The department contracts for a considerable amount of work each year, including mowing, herbicide application, sweeping, guardrail maintenance, resurfacing, and wedge and level. Excluding toll facilities, approximately $16 million supports work program materials and another $16 million supports work performed by commercial contractors.

Indiana's maintenance management system has been used since the mid-1970s to control the state's roadway maintenance program. The system was developed by Roy Jorgensen Associates, Inc., to operate on the department's mainframe computer.

Because it was one of the last systems of its type to be implemented, INDOT's system benefited from the development work done for other state systems. Since its installation, new programs have been written, and the system has evolved to take advantage of new computer technologies. Still, the improvements could not overcome some major problems, including excessive paperwork, sequential program runs, and lack of information for district and subdistrict managers and foremen. Most managers viewed the system as belonging to the central office even though the system was well accepted at the foreman and crew leader levels. The theory behind the system became an integral part of how maintenance operations were accomplished in Indiana. However, the department needed to provide more support for all managers and to simplify the data processing to make it responsive to current and projected needs.

In 1986, the department's Maintenance Management Section began to study ways to provide better data processing without seriously changing the accepted theory of maintenance management. Three options were considered:

- Use the department's data processing section to write software for a new system to reside on the mainframe computer (Option A),
- Find a state or other large public agency with a system that would fit projected needs (Option B), and
- Find a vendor-consultant with a maintenance management system in production and in use at a large public agency (Option C).

OPTION A

Option A was found to involve several problems. The data processing staff believed that the department should retain the existing package as a nucleus for the new system. A number of enhancements would be designed cooperatively by the Data Processing and Maintenance Management sections. The Maintenance Management Section was not in favor of this option because many problems with the old system might carry over to the new system.

The maintenance management staff also believed that the section lacked the knowledge of data processing required to properly instruct the Data Processing Section in its desires for the new system. After extensive discussion, the department's Data Processing Management Committee, which had oversight responsibility, rejected Option A.

Division of Operations Support, Indiana Department of Transportation, 100 North Senate Avenue, Indianapolis, Ind. 46204–2249.

OPTION B

Of the state department of transportation management systems evaluated, Pennsylvania's Maintenance Operations Resources Information System (MORIS) was the most highly recommended because of its integration of personnel, equipment, and materials information. A three-member team from Indiana spent 2 days as guests of the Pennsylvania Department of Transportation.

The team represented the Maintenance Management Section, the Division of Information Services, and the task force working to develop a new equipment and inventory management system. MORIS was viewed at Harrisburg and at a district office to see the system from two perspectives. After the demonstration of its capabilities, the team was certain that MORIS was a state-of-the-art system.

From Indiana's viewpoint, several obstacles would have to be overcome to use MORIS. They would be inherent in any system developed to meet the needs of an individual state and included the following:

- MORIS was designed with Pennsylvania's legal and financial requirements in mind. Major modifications would be required to tailor the programs to Indiana's needs.
- MORIS had not only maintenance, equipment, and inventory management modules, but also pavement management and payroll modules and others that Indiana was not prepared to accept. The integration of programs that made MORIS so appealing prohibited the selection of specific modules by Indiana unless the whole system were adopted.
- MORIS required computer resources in excess of those available to INDOT.
- MORIS uses a theory of maintenance management different from INDOT's. Indiana's system is essentially the original resource management concept developed by Roy Jorgensen Associates, Inc. Maintenance requirements, resources, and unit costs are identified; performance standards that guide crew size and equipment needs are provided; work is planned; schedules are generated; work is performed; and work accomplishment and resources used are measured and reported. The evaluation team believed that a number of accounting features had been added to MORIS. They satisfied the equipment and inventory task force member. The member representing maintenance management believed the changes to be too great a departure from Indiana's existing system. In addition to operational training in MORIS, theoretical training would be required to prepare field staff if MORIS were adopted.

Indiana was forced to abandon this option and look for a system that would meet its needs without a large financial expenditure for software modification, training, documentation, or hardware.

OPTION C

After reviewing several software packages and proposals, Indiana selected a package developed by De Leuw, Cather & Company and applied in the National Park Service. The following is a description of the system as it will be applied at INDOT.

A maintenance management system is intended for use by front-line managers as daily, weekly, and yearly management decisions are made. The vendor-consultant and INDOT share a concept of maintenance management. Central to this con-

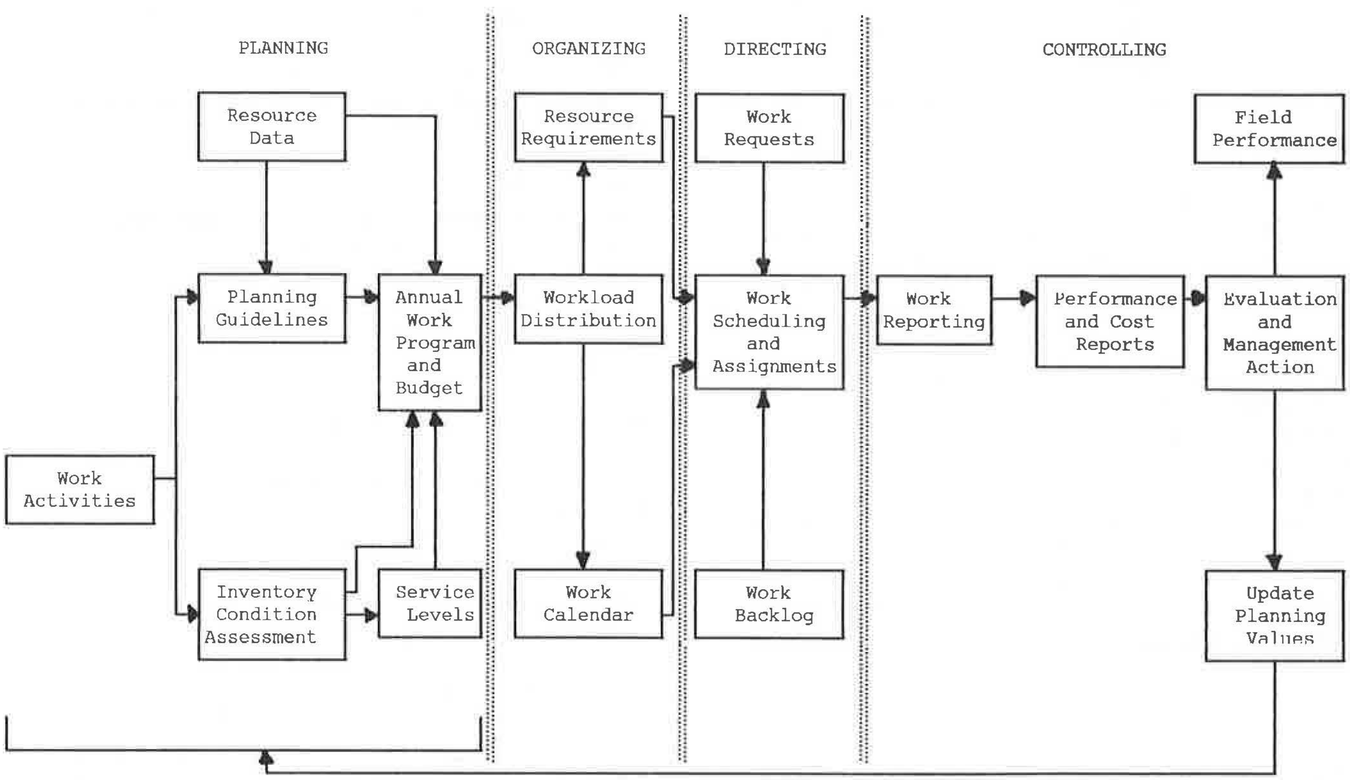

FIGURE 1 Maintenance management information flow.

cept are inventories, quantity standards, performance standards, identified resources, unit costs, work programs, schedules, budgets, work reporting, productivity, and reports of accomplishment and deviation (Figure 1). The software applied in the National Park Service used these concepts and structures and was compatible with Indiana's existing system. Though operational training in system use would be required, little theoretical training would be required to familiarize field personnel with the concepts behind the system.

The system is generic. It is not bound by the legal and financial requirements of any end user. In Indiana the software will replace the system used for management of field maintenance activities. In addition, it will be used to control work activities, prepare budgets, and track work performed by traffic operations and by the buildings and grounds function. The Division of Toll Roads, whose financial and data processing operations are independent of the rest of the department, will also use the software. Finally, the Indianapolis Department of Transportation will use the software, as modified for INDOT, as its maintenance management system.

The software operates on a personal computer (PC). This is both an advantage and a disadvantage. From the standpoint of the end user, the field manager, operation on a PC is an advantage over a mainframe system. The user has direct control of input and output, giving a feeling of ownership. The feeling that the field only supported a system that belonged to the central office would be eliminated. All resource files, work programs, budgets, work schedules, and a variety of reports would be available to the field manager at any time (Figure 2), including weekends, when the mainframe computer in Indianapolis is turned off.

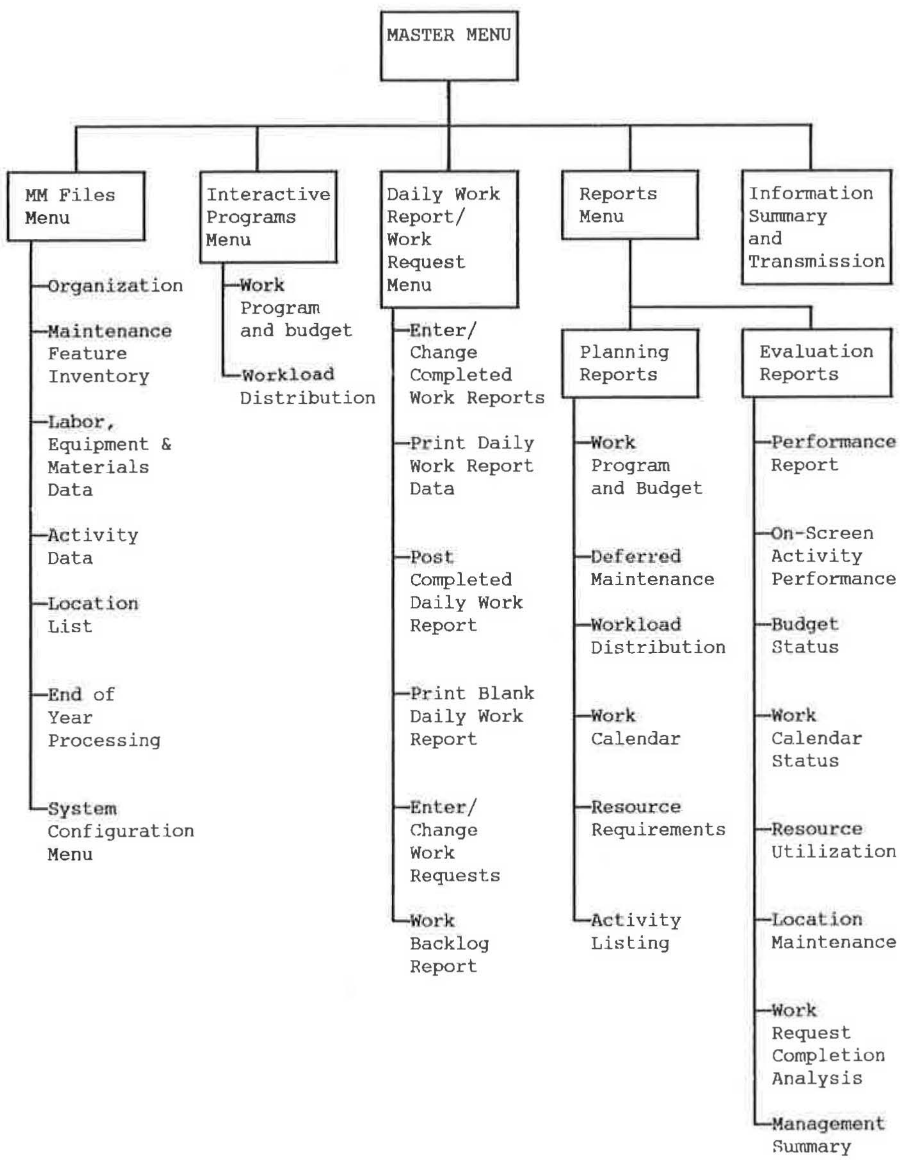

FIGURE 2 Menu of screens and reports available from the De Leuw, Cather & Company maintenance management system.

The software, residing locally in the PC, allows users to

- Keep track of inventories, resource tables, unit costs, and performance standards;
- Prepare jointly (subdistrict, district, and central office) annual work activities and quantity standards, resulting in a completed budget, work program, work calendar, and resource requirement listing;
- Record work performance on crew day cards prepared locally and enter the results into the local PC, where edits are performed; and
- Obtain results from various reports showing accomplishment, deviations from the program, cost per unit of production, and other items (Figure 2).

The PC is also a disadvantage. Although the system's primary function is to support field managers in maintenance subdistricts, the information from the system is needed to support decision making at the district and central office levels. In addition, by mandate of the department, the system must support the pavement and bridge management function and other users needing information from the system. The major problem is the transfer of data from 37 subdistrict maintenance PCs and 6 district traffic PCs to the department's central computer system. Local responsibility for system maintenance, including file backup, is also a potential disadvantage.

The department and the vendor-consultant worked together to solve the data transfer problem. The PC software places data into an ASCII file. The data can then be imported into a PC data base or transferred to the central mainframe computer. At the subdistrict PC the data will be entered and checked for accuracy. At regular intervals subdistrict personnel will use the PC software to prepare and transmit summary files to the central mainframe. Some detail records will also be transmitted. The department's Division of Information Services, which is responsible for data processing, will provide the communication software, file storage, and interface with the department's central data base. This data transfer process would have been facilitated by a centralized system operating on the department's mainframe computer. Under the new system, district and central office personnel will obtain maintenance management information by using on-line query capabilities on the central data base after files have been transferred from the PCs to the mainframe (Figure 3).

INDOT determined that the cost of modifying the software to meet departmental needs was reasonable. The contract cost for software modification, training, and documentation was $418,979. This includes $55,000 for work done for the Indianapolis Department of Transportation. In addition, approx-

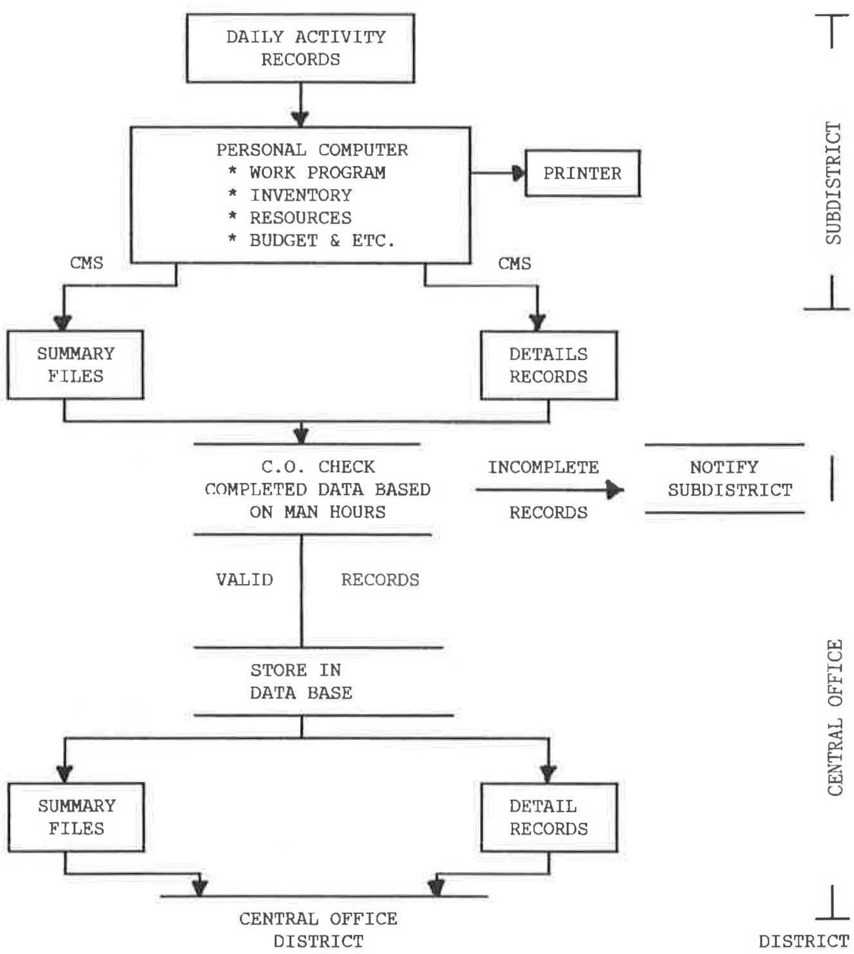

FIGURE 3 Flow diagram of data transfer.

imately $250,000 was spent for IBM PS/2 Model 60 PCs for districts and subdistricts. These PCs were the first placed by the department in the subdistricts. They support other software besides the maintenance management system.

An additional $55,000 is anticipated in labor and data processing development costs within the department to fully implement the new system. The total cost for the system will be approximately $724,000. The Maintenance Management Section estimated potential savings of between 5 and 10 percent in better utilization of labor, materials, and equipment, either as reduced costs or as increased productivity. These are estimates, but it is certain that, compared with the total cost of the system, benefits will be realized as payback within the first calendar year of operation.

CONCLUSION

Though the option INDOT selected does not give the complete integration of multiple systems that MORIS does, Indiana is confident that ease of use, familiarity with the system, local ownership, reduced paperwork, and transfer of data to central users will provide a dramatic improvement for a reasonable cost, and that the system will provide for INDOT's needs for some time to come.

Abridgment

Integration of Personal Computers with Mainframe Computer Maintenance Management Systems

Gabriel J. Choquette and Ernest N. Herrick

Maintenance management systems have been in existence for 20 years. Connecticut's is old technology developed in 1972. At a low cost, Connecticut integrated personal computers with the existing mainframe system. This has helped Connecticut gain greater independence and flexibility in the field and has significantly reduced data entry errors.

Connecticut is one of the smallest states in the nation, ranking 48th in area. However, the state ranks fourth in population density. Approximately 3.1 million persons occupy 5,009 mi^2. Connecticut has 169 towns and 8 counties.

The Connecticut Department of Transportation maintains approximately 4,900 two-lane mi of roadway, of which approximately 900 mi is Interstate. To maintain these roads, the state is divided into four districts, each district being administered by a district maintenance manager. The districts are further divided into three sections; each section is administered by an operational superintendent. Three districts have their sections divided into four areas (a maintenance garage and associated area of responsibility), and one district has its sections divided into five areas. Two operational superintendents of each district are responsible for one of two specialty crews (signs and markings and electrical) for that district. In addition, two operational superintendents are responsible for maintenance of bridges, each superintendent being responsible for two districts. The total complement of personnel, staff, and field is approximately 2,200.

Maintenance management consists of planning, scheduling, and controlling work on the basis of desired levels of service. Maintenance management systems are comprehensive approaches to effect maintenance management. The objectives of Connecticut's maintenance management system are to

- Define work activities and measurement units in terms that are significant for planning work and measuring performance;
- Establish desired levels of maintenance service;
- Provide an objective basis for establishing annual work programs;
- Use labor, equipment, material, and financial resources in the most efficient and economical manner; and
- Provide the means for management to evaluate performance in terms of performance standards and work programs.

Connecticut Department of Transportation, 24 Wolcott Hill Road, Wethersfield, Conn. 06109.

To accomplish the objectives, maintenance activities were divided into 10 functional categories: pavement and shoulders, drainage, structures, traffic services (signs, markings, illumination, etc.), extraordinary maintenance (accident, storm damage, etc.), work for other state agencies, snow and ice control, roadside (mowing, etc.), betterments, and overhead (training, vacation, sick leave, etc.). Work activities associated with each category were identified and described. To date Connecticut has defined 154 maintenance work activities.

For each work activity, standards were developed for performance, quantity, and quality. Actual work performance can be compared with the performance standards to monitor productivity and efficiency. Both planned and actual maintenance activities are developed and evaluated within the defined levels of service.

Connecticut's maintenance management system is a mainframe computer application and was developed in 1972. Although Connecticut's maintenance management system can be considered old technology, Connecticut integrated personal computers with the mainframe computers to increase efficiency, accessibility, and independence inexpensively.

The original information flow and data entry procedures consisted of field personnel completing code sheets on planned activities and work accomplished. The code sheets were forwarded to the district office and district personnel keypunched cards and entered the data by means of the cards. These procedures were prone to error and delay and were not responsive to users. On receipt, the report was reviewed for coding and keypunch errors. Errors were recorded, the data were reprocessed, and another report was generated. The recycling continued until the information for the month was correct. On the average, final reports were 2 to 3 months late.

To reduce dependence on this process, the Office of Maintenance developed a turnkey system using personal computers to enter data and generate reports. The system consists of three elements: data entry and validation, uploading information to the mainframe, and report generation.

For the first element, a user-friendly application was developed to check the validity of information being entered into the personal computer. The personal computer program was developed to identify data that violated the parameters of the maintenance management system master file in the mainframe and correct the data at the time of entry into the personal computer. During the input phase, a data entry person fills in the blanks on a screen (see Figure 1). The program will not accept invalid data.

The second element is a menu option for uploading records to the mainframe (see Figure 2). All that is required of the user is to enter the option letter. When the user selects the option to upload records, the system first checks to see if there is a floppy disk in drive A. If there is no disk, the system prompts the user to insert one. If there is one, the system compares the size of the file on the hard disk with the amount of space available on the floppy disk. If there is sufficient space, the system proceeds to the next phase; otherwise, the system prompts the user to insert a new floppy disk. Next, the system converts the dBase III data file on the C drive to an ASCII file and transfers program control to the Sperry Terminal Emulator Program (STEP). The STEP program logs onto the mainframe, copies the records from the personal computer to the mainframe maintenance management system master file, logs off the mainframe, and returns program control to the personal computer. The personal computer application then asks the user if the uploading was successful. If

```
                 MAINT. MANAGEMENT SYSTEM
     START RECORD #: 2023   ADDING RECORD #: 2023
-----------------------------------------------------------
   ACTIVITY             9999 To exit

   CREW SIZE

   DATE

   AREA CODE

   R/T HOURS

   O/T HOURS

   ACCOMP.

-----------------------------------------------------------
```

FIGURE 1 Input phase.

```
                 MAINT. MANAGEMENT SYSTEM
-----------------------------------------------------------
          =========== MAINT.10 ============
                 A->    INPUT
                 B->    PRINT
                 C->    UPDATE
                 D->    DELETE
                 E->    UPLOAD
          ============ PLANNED ============
                 F->    INPUT
                 G->    PRINT
                 H->    UPDATE
                 I->    DELETE
                 J->    UPLOAD
          =================================
                 K->    REPORT
                 X->    EXIT
-----------------------------------------------------------
                INPUT WEEKLY MAINT. 10
```

FIGURE 2 Menu option for uploading to mainframe.

the answer is affirmative, the system copies the file from the hard disk to the floppy disk and then erases the file on the hard disk. This ensures a backup copy of the records. If the answer is negative, the system asks the user if the user wishes to try again.

The third element consists of generating reports. The user selects the option for reports, and the system then prompts the user to enter the report parameters (beginning and ending dates of the report requested). The interfacing with the mainframe is similar to that for uploading.

By integrating personal computers with the mainframe, the Office of Maintenance has gained significant independence and flexibility in the field. District personnel now have more control over data entry and generation of needed reports.

The cost to accomplish the interfacing was minimal. Each district office had personal computers (NCR PC6s, which had been purchased previously for $3,220). The only hardware expense was the purchase of four Sperry STEP boards at a cost of $150 each. The programming was done by maintenance personnel and took approximately 1 month.

The major features of Connecticut's current stand-alone maintenance management system are the documentation of work hours and accomplishments annually and the ability to compare performance for each maintenance activity against a standard. The shortcomings of the system are as follows: it is not flexible; it is not integrated with equipment, budget, or material data; it does not provide information at a low-enough level to be used in the field; and it does not provide equipment or manpower scheduling capabilities.

Pennsylvania's Maintenance Operations Resources Information System (MORIS) is more sophisticated than the system used in Connecticut. Pennsylvania has integrated several systems with its maintenance management system, and the scheduling module as described appears to be most beneficial. Connecticut currently uses manual methods for scheduling similar to those Pennsylvania used before MORIS. Deficiencies are identified in the field, and work, materials, and equipment are scheduled at biweekly meetings.

The advantages in MORIS's scheduling module are apparent, and it was the next logical step in the evolution of Pennsylvania's maintenance management system. The integration of financial, equipment, material, and scheduling functions can relieve administrators of many hours of monitoring and controlling maintenance functions. However, in Connecticut the technological development of the maintenance management system has not progressed beyond the stand-alone system developed in 1972.

In summary, Pennsylvania should be commended for furthering the development of maintenance management system concepts. As are most technical advances, its advance was built on the merging of previous experience, a need for improvement, and innovation.

Overview of Saskatchewan's Maintenance Management Information System

DENNIS S. DAY AND BARRY D. MARTIN

Saskatchewan Highways and Transportation operates a maintenance management information system that provides up-to-date resource usage, accomplishments, and expenditures at any organizational level. The system captures data for the department's equipment management information, expenditure distribution, and pavement management information systems. Currently, the system operates on a mainframe computer located in the provincial capital. Data are entered daily at each area office on a microcomputer and communicated in batch mode to the mainframe. After the data pass certain validation tests, the system's year-to-date file is updated and a report is immediately returned to the area office. The system contains some unique features, including holding accounts that provide up-to-date expenditures even though payroll is processed biweekly and equipment nightly. Saskatchewan's approach to data entry and the philosophy used in designing the system are described. The type of data captured, the level at which the data are captured, hardware and software used, interfaces with other systems, and how the system itself is managed are reviewed. It is concluded that the system's success is due to its design philosophy of meeting the needs of the frontline maintenance manager.

Saskatchewan is set in the Great Plains region in the interior of Canada. Agriculture and resource industries such as petroleum, uranium, potash, and timber are the mainstays of the provincial economy. The province has an area of 653 000 km² (252,000 mi²) and a population of approximately 1 million. Nearly all reside in the southern half of the province, dispersed among 63,400 farms and 1,000 communities. The resulting population density is only three persons per square kilometer and only a few hundred per community. The largest centers are Regina and Saskatoon, with populations of 170,000 and 180,000, respectively.

Saskatchewan has a surveyed rural road network of 200 000 km (124,000 mi), which gives it the largest road network per capita in Canada and one of the largest in the world. Much of this network consists of graded and graveled roadways serving the agricultural regions of the province. Seventy-six percent of rural travel is carried by the 25 639 km (15,931 mi) of provincial highways maintained by Saskatchewan Highways and Transportation.

Building, maintaining, and rehabilitating this large highway network within the limits of a small tax base have been a constant challenge. Saskatchewan has met the challenge by constructing a variety of pavement standards that vary in design life to meet the needs of the varying classes of highways. These standards range from standard pavements with a 15-year design life to thin (40-mm) cold-mix surface treatments requiring extensive annual maintenance. Table 1 lists the length of the various pavement standards, typical construction costs, and average annual surface maintenance costs.

Saskatchewan Highways and Transportation, 1855 Victoria Avenue, Regina, Saskatchewan, Canada S4P 3V5.

Another important aspect of this challenge has been to develop a system to provide managers timely information necessary for maintaining the highway system as efficiently as possible.

The department's maintenance operations are managed through six district offices. Each district is divided into 3 to 6 maintenance areas for a total of 28 area offices located in 25 cities or towns throughout the province. Each area supervises up to 6 sections for a total of 164 section crews.

A section is the first level of management organization involved in the delivery of the maintenance program. It is essentially a discrete crew of one to five persons with an established equipment fleet and is responsible for an assigned portion of the highway system. Each asphalt section handles an average of 192 km (119 mi), whereas gravel sections (generally remote northern locations) maintain an average of 111 km (69 mi).

Saskatchewan manages the maintenance of its diverse mix of pavement structures by setting measurable objectives in terms of a riding comfort index (RCI). Traffic, weather, subgrade quality, and age are the major factors that determine performance of road surfaces. Saskatchewan has found that weather is often the most significant factor determining the performance of old or thin pavements. Because of the degree of variation encountered, standards for funding surface repair have been established on a basis of per kilometer dollar allotments adjusted for surface type and region of the province. Over the years, the department has determined that its RCI objectives will be achieved, on the average, with the standard allotments. This method of managing surface maintenance increases the need for maintenance supervisors to have accurate and timely information on their input costs.

HISTORY OF SASKATCHEWAN'S MAINTENANCE MANAGEMENT SYSTEM

Saskatchewan's first maintenance management information system (MMIS) was developed in-house in 1977 and implemented in 1978. The system was plagued with several problems from its inception, the most significant being that constraints originating in other systems precluded a design that provided timely information for the field. The system failed to provide adequate editing procedures and report formats and required a laborious hard copy data input from the field to the district office. District clerical staff, who were unfamiliar with the data because they were not directly involved with the maintenance organization, did the final keying.

TABLE 1 SASKATCHEWAN'S PAVEMENT STANDARDS, APRIL 1989

Pavement Standard	Length (km)	Estimated Life (years)	Typical Construction Cost ($/km)	Annual Surface Maintenance ($/km)
Standard Pavement	5 448	22	164,000	1,453
A Pavement	2 302	17	100,000	1,433
B Pavement	2 394	8	75,000 [1]	1,742
C Pavement	1 674	N/A	47,000	2,113
Oil Treatment	7 993	N/A	32,000 [1]	3,155 [2]
Gravel	5 828	N/A	2,000	1,823
Total	25 639	N/A	N/A	2,136

1. Estimated, standard no longer constructed.
2. Includes an annualized cost for seal coating.

The lack of timely and accurate reports coming back from the system resulted in most field managers relying on their own manual ledgers. The quality of data being entered into the system eroded as field managers viewed the system as uncompensated extra work. The needs of the most important users were not being met.

In 1983 a committee of the system's users was mandated to review the system and those with which it interacted to produce an effective MMIS. The committee conducted interviews at all levels of the maintenance organization to uncover the basic problems and lack of support. It concluded that the primary user of the system was the lowest level in the management chain. It determined that all senior management's needs could be met by consolidating information of the lower levels and that the organizational level responsible for entering data had the most right to satisfaction with the system.

Some of the committee's recommendations were considered fairly radical at the time. The recommendation to use microcomputers located in the area offices for data entry was not easily accepted by the department's mainframe-oriented data processing unit. However, after a successful pilot project the committee's recommendations for a revised system were implemented beginning in the summer of 1984, and full integration with other systems was completed by the spring of 1985.

OVERVIEW OF CURRENT SYSTEM

The primary purpose of the MMIS is to provide the information required by all levels of maintenance management for effective, responsible decisions. The objective of the system is to provide timely, accurate information that is collected as efficiently as possible.

The system is a resource management system that tracks four primary resource inputs: labor, equipment, materials, and external costs. Physical accomplishments are entered to provide measures of cost-effectiveness. The system records resource usage and accomplishments for each maintenance activity. Saskatchewan has limited the number of maintenance activities it uses to 47. They are grouped into 18 work classes (the lowest level used for budget control) and 5 main program components. For most work classes the information is captured for each surface type on each segment of highway within a maintenance section. The resulting provincewide total possible combinations of activity, management unit, highway segment, and surface type is more than 11,200. The maintenance activities used and their associated data elements are listed in Table 2.

Using these data, the system can provide the three types of management information required: costs (accounts, equipment, and labor), resource usage and inventory, and accomplishments.

The information is available in reports for any combination of organizational grouping, highway network classification, or pavement type. Valid combinations of these elements are reviewed annually by head office and district staff. Once made final, this chart of accounts becomes a key element of the edit checking routines.

SYSTEM ARCHITECTURE

Hardware and Software

The core of the system is operated on an IBM Model 3090 mainframe located in the provincial capital. The master file and inventory files are updated on verification of daily transaction files, after which the transaction files are discarded. The master files are kept on disk and backed up nightly.

Remote data entry is done on four types of terminals: IBM-compatible personal computers, DEC Rainbow personal computers, Northern Telecom terminals, and Mohawk terminals. Several software packages and languages are used throughout the system. Data are entered through a data base package called DataStar on the Rainbows and through a dedicated data entry package called Entry Point 90 on the IBM PC compatibles.

Data are verified on the mainframe using a number of custom procedures written in COBOL. Similarly, interaction with data files in other systems is accomplished using COBOL source code.

All standard reports are produced with Mark IV. Recently, SAS (Statistical Analysis System) has been introduced to the maintenance organization and is now being used extensively to produce custom reports at the head office and district level. Both of these software packages lend themselves well to summarizing and reporting the many possible combinations of data.

TABLE 2 CHART OF ACCOUNTS

Work Class	Activity	M_Unit	Control Section	Type	Liq	Agg	Mix	Stockpile Used	Stockpile Prod	Sq, m	Hrs
Section Surface Repair	Other	DAMU	#	12-17	*	*	*	*			*
	Spot Sealing	DAMU	#	13-17	*	*		*		*	*
	Machine Patching	DAMU	#	13-17	*	*	*	*			*
	Hand Patching	DAMU	#	13-17	*		*	*			*
	Crack Sealing	DAMU	#	14-17	*	*		*			*
	Gravel Blading	DAMU	#	12-17						#	*
	Spot Regravel	DAMU	#	12-17		#		#			*
	Sand Sulphur Patching	DAMU	#	15-17			*	*			*
	Flushing	DAMU	#	13-17	*					*	*
	Thin Overlays	DAMU	#	13-17			*			*	*
Stockpile Aggregate		DA				*			*		*
Stockpile Asphalt Mix		DA			*	*	*	*	*		*
Seal Coat on Oil Treatments		DA	#	13	*	*		*		*	*
Dust Treatment		DAMU	#	12	*	*		*			*
Subgrade Stabilization		DAMU	#	12		*		*		*	*
Railway Crossing Maintenance		DAMU	#	12-17	*	*	*	*			*
Deep Patching		DAMU	#	13-17	*	*	*	*		*	*
Snow and Ice Control		DAMU	#	12-17	*	*	*	*	*		*
Mowing		DAMU	#							*	*
Pavement Marking		DAMU			*			*	*	*	*
Sign Rehabilitation		D									*
Sign & Guardrail Preservation		DAMU	#								*
Highway Illumination		D									*
District General Services	Hotline	D									*
	Non-Expendable Items	D									*
	Supplemental Pay	D									*
	Communications	D									*
	Training Programs	D									*
	Staff Travel	D									*
	Other	D									*
	Eqpmt. Repair Tptn.	D									*
Holding Accounts	Labour	D									
	Asphalt	D			#						
	Salt	D									
	Calcium Chloride	D			#						
	Beaded Paint	DA			#						
Area General Services	Area Administration	DA									*
	Non-Expendable Items	DA									*
	Communications	DA									*
	Electrical Power	DA									*
	Training Programs	DA									*
	Other	DA									*
Tourist Facilities		DAMU			*						*
Airports		DAMU									*

* indicates data items which may be entered for a particular activity
# indicates required data items

Operation

Each of the 164 regular section crews telephones or radios its area office each day and provides the area office clerk with all the data pertaining to the work that the crew accomplished the day before. The information is collected and summarized by the 28 area clerks on data entry forms similar to the sample shown in Figure 1.

After data are collected for the previous day's work, they are entered at the area terminal and transmitted to the mainframe for processing. If the data contain errors, processing stops and an error listing is sent back to the area terminal for correction and resubmission to the mainframe. When the data are error free, processing automatically takes place. On completion of processing, a daily work report is automatically sent to the terminal that submitted the data, the provincial year-

Record 1 Expenditure Distribution

Date YY MM DD	Vote	Management Unit	Control Section	Project I.D.	Type	Activity	Accounts Costs	Hours of Work	
								Service	Salaried

Record 2 Material Quantities

Litres of Asphalt		Tonnes of Aggregate -Sand		Tonnes of Asphalt Mix - Salt		Stockpile Production	m^2 of any Measurable Work
	Stockpile		Stockpile		Stockpile		

Record 3 Equipment Usage

Unit No.	Assigned Management Unit	Usage Hours / km	Down Hours	End Meter Reading

FIGURE 1 MMIS-EMIS data entry forms.

to-date file is updated, and inventories are adjusted. The daily work report is reviewed, certified correct, and then filed chronologically for audit purposes at the area office. Although these duties are normally performed by the area clerk, the area maintenance supervisor can enter the data and will take over this duty if the clerk is on sick or vacation leave.

The six district maintenance planning supervisors are responsible for supplying and updating material unit costs for items such as asphalt, salt, and calcium chloride. Major contracted items such as seal coats and crushing and stockpiling aggregates and thin overlays are entered at the district level in the same manner as in the areas. The district maintenance planning supervisor is also responsible for the general supervision of the system at the district level and represents the district on the user's support committee.

In keeping with the philosophy that the system belongs to the frontline maintenance managers, data entry from the head office is not permitted. Even data from operations such as pavement marking that are managed from the head office must be entered through regional headquarters. All adjustments that may be required are performed at the area or district level. This reinforces the concept that the areas are responsible for their own data.

INTERACTION WITH OTHER SYSTEMS

Figure 2 diagrams the relationship between MMIS and other systems.

Equipment Management Information System

Data from the department's equipment management information system (EMIS) is used to validate equipment identification as part of the edit-checking process. Invalid unit numbers are trapped at this step. After the edit-checking process, EMIS provides equipment rental rates to MMIS so that equipment costs can be calculated and used in MMIS. In turn, the equipment usage entered through MMIS is passed on to EMIS to update equipment usage logs and standard transaction documents.

Expenditure Distribution System

This is the official accounting system of the department. It records all expenditures by the organizational unit responsible for the expenditure and the highway segment on which the expenditure was made. The system contains a table of allowable distributions against which MMIS data are validated as part of the edit-checking process.

Expenditures by the payroll system are distributed in the expenditure distribution system on the basis of the labor hours reported through MMIS. This process is discussed in greater detail later in this paper.

Pavement Management Information System

Annual maintenance effort is one of the key factors considered in the department's pavement management information system (PMIS). MMIS provides annual quantitative measures of deep patching, spot sealing, hand patching and thin overlays, and total costs of other maintenance items. This information, along with ride, surface condition, and traffic data, is used to model pavement performance.

Geographic Information System

Links are being developed to report maintenance information using the department's geographic information system. Main-

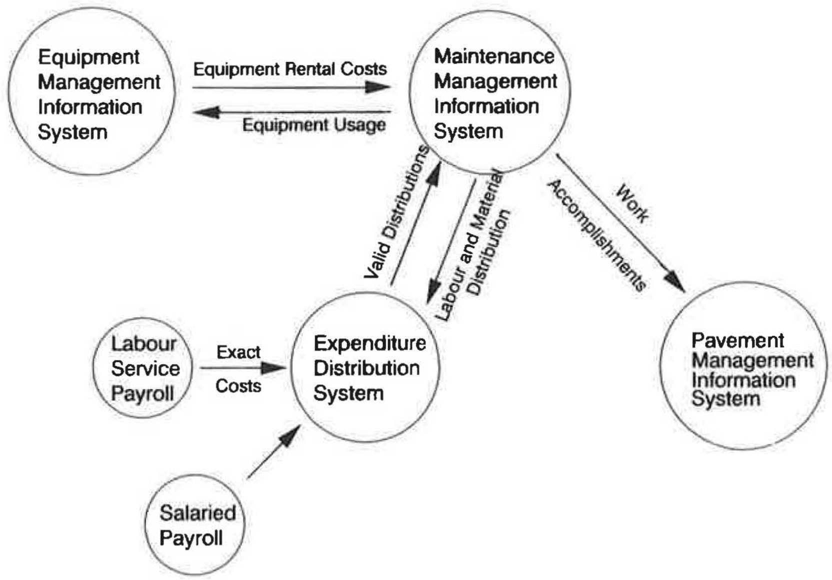

FIGURE 2 Interfaces with other systems.

tenance area and section boundaries have been digitized and preliminary reports produced.

UNIQUE FEATURES

Providing timely and accurate information required several unique solutions and compromises in system design. Although some of these may appear to reduce accuracy, it was determined that timeliness and an acceptable degree of accuracy were more important to the end users than absolute precision. An example of this can be found in the processing of accounts. An area office will record an invoice in MMIS to the nearest dollar before it is passed on to the district and eventually the head office, where it is processed through the accounting systems to the nearest cent. It is more important for the area supervisor to know costs today to the nearest dollar than two weeks hence to the nearest cent.

Other innovative solutions are found in the methods of estimating labor costs and material usage.

Labor

A major problem of the original system was that labor expenditures were obtained from the payroll system. This had two serious drawbacks:

1. It required a detailed breakdown of activities on each employee's time sheet. These were most often hastily prepared at the end of the pay period and consequently inaccurate.
2. It caused a serious lag in labor cost entries into the system.

The revised system addressed this issue by introducing a labor holding account. All time sheets are now charged to a single holding account through the payroll system. MMIS captures daily hours of productive work and charges them to the appropriate distribution at an average labor rate for each district. This method offers an immediate estimate of labor costs in MMIS. "Productive" means that only time worked is entered; costs associated with sick leave and statutory holidays are assimilated through the average labor rate.

The department's expenditure distribution system requires an accounting of actual labor costs. This is accomplished by redistributing the balance of the labor holding account using the hours and estimated labor expenditures contained in MMIS. Reports of undistributed balances between the two systems go to each district, where necessary adjustments are made to the average labor rate. The two systems must balance at the end of the fiscal year.

The concept of charging an average labor rate is difficult for persons outside the maintenance organization to understand. Use of this method and productive hours simplifies accounting for items such as sick leave, overtime, and different earning rates because of seniority. In addition, the concept of productive hours gives the true labor requirement for performing activities regardless of the pay schedules for the particular employees who did the work. This method has significantly reduced the paperwork required to allocate labor costs.

Materials

Costs to purchase materials such as asphalt, salt, calcium chloride, and beaded paint are also charged to holding accounts. These transactions are passed to the distribution system holding accounts and accumulated throughout the year as new material is purchased or produced.

Usage of materials is charged to the various distributions on the basis of a stockpile price and the estimated quantity used. Both of these are recorded in the MMIS year-to-date master file.

At the end of the fiscal year, the total purchase cost of each material in each district as reported in the distribution system is divided by the total quantity used that has been recorded in the MMIS system. This district average price is then applied to the quantities used for each highway segment. The result is debited to that distribution in the distribution system and credited to the material holding account.

MANAGEMENT OF THE SYSTEM

The system is managed by a committee of users. The committee is composed of one representative from each district, two from Operations Services Branch and one each from Maintenance Branch and the department's data processing unit. Currently the committee is chaired by Operations Branch. The committee identifies problems with the system, recommends enhancements and revisions and determines their priority, and coordinates annual year-end and start-up procedures. The committee's role in training and encouraging uniformity of procedures may be its most important, because training of new staff is accomplished solely through job experience.

Total costs (after volume discount) for central processing and data storage for the 1989–1990 fiscal year were $62,543. Estimated communications costs, including modem rental, were $58,100, for a total estimated annual operating cost of $120,643. This amount is categorized in the following table.

Category	*Percentage*
Communications	48.1
Processing	33.6
Tape and disk storage	14.4
On-line connect time	2.0
Maintenance and development	1.9

FUTURE ENHANCEMENTS

Saskatchewan has come a long way in gaining the support of the field staff that is necessary for meaningful data input to its MMIS. Unfortunately, many area supervisors are now manually reentering data from MMIS reports into their own personal computers to track various trends and obtain summary reports. This is counterproductive and indicates that the system is not fulfilling a need. The next challenge will be to make the data more accessible so that a manager with a personal computer can tap into the system and analyze or generate custom reports.

There is considerable room to improve the accuracy of the data collected. A recent study found asphalt application rates for spot sealing to be exactly the prescribed rate of 1.50 L/m^2 in a number of maintenance areas. This was because most sections were calculating the square meters of accomplishment by multiplying the metered asphalt quantities by the application rate to determine the number of square meters of work completed.

Senior managers also want the ability to record the location of maintenance activities within a control section. The current proposal is to record the start and end kilometer locations of each day's work. Field personnel view this negatively as more, and unnecessary, data for them to collect. The trade-off for data entry would be the elimination of management unit, highway classification, and pavement type codes. The advantage would be more accurate matching of information for PMIS and the department's geographic information system.

SUMMARY AND CONCLUSIONS

Saskatchewan's strategy has been to enable its area maintenance supervisors to do their jobs effectively by providing them with the necessary information and tools. They are given clear guidance in the form of manuals containing department policies, standards, practices, procedures, and budget guidelines. They are given qualitative objectives such as ride, and finally, they are given an information management tool that enables them to manage their area efficiently.

The movement of the data entry and editing processes to area offices has made frontline supervisors responsible for their data. The system has gained their support by providing them with timely information that they need to do their jobs. The quality of information collected by the system has improved by forgoing precise data in favor of timely information.

ACKNOWLEDGMENTS

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The views expressed in this paper are those of the authors and do not necessarily reflect the policies of Saskatchewan Highways and Transportation.

Makings of an Effective Maintenance Management System

Ronald B. Hamilton and William C. Grenke

Maintenance management systems (MMSs) have existed for 20 years. Nearly every highway agency has a system in operation. It is appropriate to examine the experience to determine what is being done right and where improvements are needed. An effective MMS results in improved service and efficiency and reduced costs through preparing work programs that are based on prevailing field conditions and budget constraints, staffing at optimum levels, scheduling and directing maintenance crews for maximum productivity, and assuring that work programs are followed. The introduction of microcomputers has profoundly affected maintenance operations. Use of the computer often falls at two extremes. Some believe that the computer is a nuisance and a generator of paper. They would rather not have to apply it. At the other end of the scale, there is a tendency to equate management systems with the software. Some are mesmerized by the technology and lose sight of the objective of the computer systems. Use of computers in highway maintenance operations is examined. Issues discussed include determination of management functions that are most effectively automated and some pitfalls to avoid in system design.

The first maintenance management systems (MMSs) were implemented in the 1960s and 1970s. Although the basic concepts have changed little, recent technological changes have affected the way MMSs are used and viewed. With 20 years of experience, it is appropriate to assess the level of success that has been achieved.

The current state of MMSs in state highway agencies is addressed. The observations were developed from a survey of state highway agencies and personal experience in highway maintenance. The survey was conducted by submitting to all 50 states a questionnaire to identify the current technology and computer applications used in MMSs as well as the degree to which MMSs have provided an effective management approach to maintenance operations. The results of the survey are tabulated in a separate document and are available on request from the authors.

The following topics are discussed:

- A basis for measuring maintenance effectiveness,
- The MMS elements common to most state systems and how effectively they are used, and
- The current state of automation and technology.

BASIS FOR MEASURING PERFORMANCE

A number of indicators measure maintenance effectiveness. All lead to answering two basic questions:

- Is the work being performed in a cost-effective manner?
- Has a higher level of service been achieved?

It is inappropriate to speak of "cost savings" in a maintenance operation. No agency would voluntarily turn back money saved; instead, more work would be performed. Cost-effectiveness, then, should be measured by the unit cost of the work performed, which is normally directly related to crew production.

A higher level of service goes hand in hand with cost-effectiveness. If work is done at a lower unit cost, then more work can be performed, and it would appear that a higher level of service is being achieved. But this is not always the case. One must look at where the efficiency dividends are being spent. There is no greater waste of money than spending it efficiently on the wrong thing. Achieving a higher level of service means doing the right work—developing and executing a maintenance work program geared to the prevailing road conditions within the constraints of available funds.

Five indicators are adequate for measuring maintenance effectiveness: activity unit cost, average daily production, amount of work performed, compliance with the annual plan, and quality of work.

Measures such as personnel or equipment utilization should be reflected in the annual plan. It could be argued that there are other measures of effectiveness, such as safety and aesthetics. However, if the maintenance program is the right one, then those activities that promote motorist safety, comfort, aesthetics, and preservation of infrastructure are balanced within the available funds. Obviously, higher service levels should be possible with more money; however, this is more a measure of funding availability than a measure of how effectively maintenance operations are performed.

It might also be argued that the only true measure of effectiveness is the condition and performance (e.g., safety record) of the highway system over time. Although this might be true overall, funding availability probably plays the largest role here as well.

The effectiveness measures addressed in this paper deal with the operations over which maintenance managers have control. That is, given a budget, how can maintenance managers, at all levels, effectively plan and execute a maintenance program? Assuming that maintenance effectiveness can be measured by the indicators described above, management decisions and actions should be executed with the primary objective of increasing performance as measured by these indicators. (There are exceptions, such as personnel matters dealing with worker safety and rights and actions dictated by

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external sources such as the Occupational Safety and Health Administration, but these are not addressed in this paper.)

The MMS is no exception. The MMS should be designed and implemented for the primary purpose of improving performance—working more cost-effectively or increasing service levels, or both.

ELEMENTS OF AN EFFECTIVE MMS

Of the 42 state highway agencies that responded to the survey questionnaire, 37, or 88 percent, indicated that they have implemented an MMS. Whereas the basic elements of the systems are similar, no two states have precisely the same type of MMS. Given that numerous states report that the MMS has aided in improving services and reducing costs, there is no set definition of how a system should be structured. The structure and application of the MMS vary with organizational structure, management style, data processing capabilities, and general operating environment.

Certain elements are present in most systems. The most common elements are described below. An assessment of how effectively the elements have been implemented is provided on the basis of the measures outlined above.

Performance Standards

Performance standards are the most basic of the system elements. They are used to establish standard crew sizes, equipment, work methods, and production rates, and they provide the basis for planning work and assessing results. All but two of the states (92 percent) indicated that they use performance standards. The two that did not use standards use the MMS as a reporting system.

To be effective, the standards must be established as basic policy and as procedural guides for executing specific activities. Managers at all levels must be persuaded that the standards represent the best approach to performing work and that, if they are followed, they will lead to increased production, lower unit costs, and higher-quality work. Some pitfalls in the use of performance standards include the following:

- Field organizations are not provided with standard equipment. The performance standards should be based on the most efficient method of achieving quality results and should specify the most efficient equipment. However, equipment-purchasing practices do not always allow for providing the right equipment. Too often the maintenance work plan, developed on the basis of the standards, is not used as the primary input to determining fleet size and makeup. Only 15 percent of the survey respondents indicated that the MMS had a "very significant" impact on fleet size. Thirty-one percent said that the MMS had no impact at all on fleet makeup.

When the MMS is not used to determine fleet makeup, it is difficult to implement standard work methods and crew makeup. One highway district might use a backhoe on an activity while another district uses an excavator, or one might use single-axle trucks while another uses tandems. Variances in quality and unit costs will result. When unit costs are different, it is sometimes believed that the standards are wrong and are therefore useless. To correct this, management must use the standards and the annual work plan as the basis for determining fleet requirements. If this has not been standard practice, a transition period will be required during which it should be recognized that unit cost will naturally vary.

- Field managers are not convinced that standards are applicable in a maintenance operation. In a highway agency, the daily maintenance operations are the responsibility of dozens of field managers around the state. The managers often have their own opinions of how best to perform work. The opinions might be based on the availability of equipment assigned to the organization, the availability of a highly qualified operator, or comfort with the way work has always been performed. Although good management practice dictates that individual initiative not be inhibited, it is incumbent upon middle management to motivate field managers to use good work methods in line with established standards. This can be achieved by comparing results of field organizations. Managers with low production rates will soon be motivated to achieve higher productivity. However, if the field manager is correct and has a better method for improving productivity and achieving higher-quality work, consideration should be given to redefining the standard. The MMS should include a continuous process of reviewing and updating performance standards.
- Standards may be used for short-term ratings of performance. Compliance with plans and standards can and should be used to measure performance on a long-term basis; however, the performance ratings should be done constructively. The survey indicated that one of the most unpopular effects of the MMS is an aversion by field managers to "being controlled or monitored."

This aversion is natural but should not be a deterrent to work monitoring and evaluation. Because field conditions vary significantly with location, season, and general operating environment, compliance with the standards should be measured over a long period of time, perhaps monthly or quarterly. Crews will naturally do better than the standard on some days and not achieve it on others, so day-to-day comparisons are not very helpful.

- Too many standards may be used. In trying to develop a standard to cover most prevailing conditions, it is easy to fall into the trap of overspecifying standards. As a result, too many standards are developed, and it becomes difficult to measure results. Reporting becomes inaccurate and the information from the MMS is not useful. The best way to correct this is to view the MMS as a tool for managing the significant few activities that consume the bulk of manpower and dollars. A rule of thumb has not been established, and the number of performance standards that should be used varies from state to state; however, in nearly all cases 30 or 40 activities are more than adequate for an effective MMS. Agencies with scores of performance standards should take a critical look at the usefulness of having so many activities.

Annual Work Planning

Annual work planning in a state highway maintenance operation consists of defining the types of activities that should be performed to balance preservation, safety, aesthetics, and comfort within the available funding. All but two of the states responding to the survey indicated that they have an annual planning process.

Planning is most effective when it is done in the context of establishing program objectives. In field maintenance operations, the program is represented by the annual plan of activities to be performed by the field organizations. In planning the amount of work, objectives are established for each activity, for example, the amount of mowing or chip seals. The annual plan should establish the most effective maintenance program, given funding limits and the physical needs of the roadway system.

For each activity, a quantity standard or level of service should be established on the basis of engineering judgment or analysis, agency policy, or historical performance. Recognition should be given to varying topographical and climatic conditions in the state. For example, one corner of a state might experience significantly more rainfall than another, and as a result, mowing might have to be performed more often to achieve the same level of service.

A primary objective in the planning process should be to achieve a consistent maintenance program from district to district. This does not mean that the program will look the same, but it does mean that the infrastructure will be maintained at approximately the same level and that the citizens will receive the same basic services. If this is achieved, a higher level of service will result.

Common pitfalls in maintenance planning are as follows:

- The program is not established as an objective. Too often the planning process becomes an exercise in budgeting—justifying current or increased funding levels and personnel quotas. Once the plan is developed, the commitment to achieving it no longer exists. To complete the management cycle, the work plan must be viewed as an objective at all levels, especially in the field. Natural catastrophes such as floods or exceptional snowfall will alter the plan but should not be a deterrent. Obtaining commitment to the annual work plan requires (*a*) that upper management be committed to planning the maintenance program and executing the plan, (*b*) that this commitment and the plan be communicated to field managers, and (*c*) that field managers be involved in the planning process using the MMS quantity standards and performance standards.
- Resources are not organized in line with the annual plan. Fifty-six percent of the state highway agencies responding to the survey indicated that personnel levels are established by agencies external to the maintenance program, such as through legislative or executive mandate. Though this may be inevitable, management should recognize that it damages maintenance operations. Establishing fixed personnel quotas normally means that staffing will be constant throughout the year. When staffing is not adjusted for peaks and valleys in the work load, compliance with the annual plan is nearly impossible and service levels decrease.

To be most effective, personnel quotas should be established on the basis of the annual work calendar. Once the annual plan is established, a work calendar should be developed to depict the work to be accomplished each month. The work calendar will dictate the resource requirements for labor, equipment, and materials. In nearly all cases, there will be significant peaks and valleys in the work load. Staffing levels should be established on the basis of needs generated from the work calendar, making use of temporary help or private contracting during periods of peak work load.

In the same fashion, leasing equipment during such periods will avoid keeping the unit in the fleet beyond the short periods of need. If rental units are commercially available, equipment ownership costs can be reduced significantly through an effective leasing program.

Correcting the problem of staffing quotas set by external agencies might be difficult. In states where labor quotas are established by legislative mandate, considerable effort is required to make changes. Use of the MMS annual work plan and work calendar can be a valuable tool for managers to convince authorities of the need for change.

Crew Scheduling

Crew scheduling deals with the short-term scheduling and assignment of crews to specific routes and activities. Seventy-five percent of the responding states use some form of short-term scheduling. To be most effective, scheduling should consider three primary inputs: the annual work plan, performance standards, and the prevailing physical condition of the road infrastructure.

If the annual work plan is established as an objective, crew scheduling should follow the work calendar developed from the annual plan. The work calendar specifies the general amount of work for each activity to be accomplished each month. If it is followed closely, the work plan will be accomplished and the maximum level of service will be achieved. Performing the work in accordance with established standards will ensure that the work is accomplished within the available budget and at the least unit cost.

Routine maintenance activities cannot effectively be planned on an annual basis for each route. The work calendar specifies only the total number of units to schedule each month. The routes and locations of the work will depend on where short-term needs arise. Scheduling pothole patching, for example, will depend on where the potholes occur and the routes with the highest priority for patching.

An effective scheduling program requires the field manager to be constantly aware of prevailing conditions through a systematic road inspection process. Some common pitfalls in the scheduling element of the MMS are discussed:

- Not following the annual work plan: Sixty-six percent of the states use the annual work plan "none" or "some" as part of developing short-term work schedules. Thirty-four percent indicated that the annual plan has a "very significant impact" in the scheduling process.

The work plan is achieved by using it as a primary input to the scheduling process. Too often the annual work plan is not followed, and the work performed is left to the discretion of the field supervisor. When the annual plan is not followed, the wrong work is done, and service levels decrease.

- Not following performance standards: When standard crew sizes or equipment complements are not followed, the unit cost of the activity will probably be higher than planned, affecting compliance with budgets. Following performance standards requires that the field manager be committed to the standards and that the proper equipment be available. Good scheduling consumes time, and it is easier for a manager to assign personnel and equipment on the basis of their ready availability than to develop and execute a schedule.

Achieving compliance with standards normally requires (*a*) that the MMS annual plan be used to determine equipment needs and that the agency supply those needs to field organizations and (*b*) that the field manager view the performance standards as policy to be followed unless extenuating circumstances arise. Where the standards are not followed, field managers must be motivated to understand how they can help achieve quality work at a lower unit cost.

- Not using a systematic process of field inspections: Because the annual plan cannot specify the timing of work on particular routes, the field manager must ensure that crew schedules are aimed at the most critical needs. This requires routine inspection of roads by the field manager or foreman. Without a clear definition of needs, work is normally scheduled on routes where the most external pressure is applied. This results in inefficiencies and high unit costs because crews jump from one location to another and experience a high proportion of mobilization time. This in turn results in a self-perpetuating "brush fire" approach to maintenance work.

To correct this, the manager must be convinced that a systematic approach to crew scheduling will be beneficial. Good scheduling requires a great deal of management time to inspect roads, develop schedules, communicate the schedules to crew foremen, and coordinate the logistics of equipment and materials. The time spent in these management actions, however, is repaid many times over in improved crew efficiency and reduced unit costs.

A number of state highway agencies—40 percent—have implemented a work order system as part of the scheduling process. With a work order system, the field manager can maintain a backlog of maintenance needs by location. The backlog can be generated from routine road inspections, citizens' requests for assistance, and directives from superiors. The work in the backlog can be ordered by priority and becomes a good input to the scheduling process and an aid in carrying out the annual work plan. Maintaining a perpetual backlog of maintenance needs through the work order system can also be helpful in developing the annual work plan.

Work Reporting and Monitoring

Work reporting and monitoring are essential in an MMS. They complete the management cycle and provide the information needed to monitor work progress and assess work performance. All of the states indicated that they have a reporting process for maintenance work. Eighty-three percent have some form of performance monitoring through the MMS.

Work reporting procedures vary significantly from state to state. The variance generally depends on the level of automation. Some states continue to use a batch process, submitting reports to the central office through field computer terminals. Some states have on-line reporting and report generation capabilities. And some have recently implemented microcomputers in field operations with selected uploading of data to central office mainframes.

The types of management reports produced by the MMS are generally a function of the data processing environment and management style. States with on-line systems have information readily available, whereas batch systems normally result in less timely management reports. States with data base management systems are able to produce reports better suited to the needs of each manager.

More important than the data processing aspect, however, is management's commitment to the principle of work monitoring and evaluation. Surprisingly, a number of high-level managers do not use the MMS. The proportions of state highway engineers, state maintenance engineers, and district engineers who "never" or "seldom" use the MMS are 84, 45, and 71 percent, respectively.

Although managers in these positions are not involved in the daily maintenance operations, the MMS can be extremely valuable for them in planning and monitoring the maintenance program. Obviously, the varying responsibilities of each position require that information from the MMS be presented in formats that meet individual needs.

Some of the pitfalls in the reporting and monitoring element of the MMS are discussed below. All can be corrected by getting the necessary information to the right manager in a timely fashion and in the proper format.

- Lateness of management information was cited in the survey as the most unpopular element of the MMS. Management information is not fed back to the manager in a timely enough fashion for effective decision making.
- Reports are filled with too much data, and managers do not have enough time to pore over all the information.
- If too much time is required for work reporting, it is likely that the reporting will not be done with a great deal of enthusiasm, and accuracy will suffer.
- Most systems have a standard set of management reports. The format and content of the reports are fixed, and all managers who receive the reports get the same information in the same format. However, because responsibilities vary, managers at different levels might need different information.

Correcting these pitfalls requires a practical, management-oriented approach. It must be recognized that most individuals do not like the paperwork associated with reporting work, no matter how little time it might take, and that most managers do not enjoy studying reports to find answers and do not have the time.

This has not changed in the 20 or more years that MMSs have existed and in all likelihood will not change in the future. This must be recognized in the design of management reports. An effective MMS reporting and monitoring element requires that reporting be as simple as possible and that management reports be designed to be used.

Making reporting simple starts with performance standards. There is a direct correlation between reporting accuracy and the number of activities that must be reported. If only two activities (for example, work and leave) had to be reported, accuracy would probably be high. On the other hand, setting program objectives with just these two activities would not be possible. The number of activities must be balanced so that there are enough to achieve good planning and monitoring but not so many that reporting becomes unwieldy and the information useless.

To be useful, management information must be timely, accurate, and presented in the right format.

Timeliness generally requires that management reports be automated. But automation does not guarantee timely information, and it should not be considered a substitute for manual methods of monitoring. For example, a field manager who reviews daily work reports before they are entered into the computer has instant information. The manager does not have to wait for feedback reports to point out problems. Likewise, a district maintenance engineer does not have to rely solely on automated reports to determine whether a particular field crew is following standards. The engineer who is in the field often will form an opinion of how well the crews follow standards from personal observations.

Management information that is late will not be used. How late will depend on the individual style of the manager.

Although some states have ad hoc reporting capability, a common shortcoming of MMSs is that managers at different levels receive standard reports. For instance, a monthly progress report is likely to contain the same information and be formatted in the same way for the state highway engineer, the state maintenance engineer, the district engineer, and anyone else who receives it. In practice, these individuals have different levels of maintenance responsibility. The management reports they receive should help them make decisions with respect to their specific responsibilities—and no more. This might mean that a special report is prepared just for the state highway engineer or that the district engineer gets a report different from the one received by the maintenance engineer. Management reports must be designed in this manner if they are going to be used. Most important, each manager should be given only the information that manager needs and nothing more.

Management reports are for determining how things are going. They can be designed to convey this with little time required for deciphering the information presented. A state highway engineer who has to spend more than a few minutes looking at a report before coming to any conclusions will probably not use the report.

AUTOMATION

The first MMSs were manual. With the introduction of computers, the systems became automated. As technology has progressed, the use of automation in MMSs has also progressed. The survey of state highway agencies sought to determine the degree of automation. Some of the major findings are shown in Table 1.

Generally, MMSs lag other systems in state-of-the-art automation. In most cases, new technology will first be implemented in payroll and accounting systems because of their importance to the agency. MMSs in most states use computer technology that is one or two generations old. The greatest impact is on reporting. States using older batch systems are not likely to get information timely enough to satisfy most managers' needs.

TABLE 1 STATE OF MMS AUTOMATION

A. System Implementation

A vast majority of the states have implemented MMS and are currently developing maintenance related management systems as illustrated by the following:

	Number of States			
	Have Implemented	Currently Under Development	Future Plans	No Future Plans
Maintenance Management System	37	1	3	1
Pavement Management System	22	17	1	0
Bridge Management System	11	12	9	3
Equipment Management System	26	7	7	0

B. System Update

Exactly half of the states indicated that their MMS has had a major revision since its initial implementation.

C. Hardware Configuration

The most common automation configuration is "dumb" terminals connected to a central office mainframe.

	Number of States
mainframe with terminals	30
microcomputers	6
mainframe with download to micros	4
other	6

TABLE 1 (*continued on next page*)

TABLE 1 (*continued*)

D. Operating Mode

Most MMS currently operate in a batch mode.

	Number of States
batch system	26
on-line	17

E. Reporting Procedures

Reporting procedures vary significantly.

	Number of States
stand-alone, strictly within MMS	18
done through accounting	18
MMS is source to accounting	16
MMS includes location reporting	22

F. System Interfaces

At present, most maintenance management systems do not interface with other systems. Typical interfaces include:

	Number of States
Pavement Management Systems	6
Bridge Management System	9
Equipment Management System	11

Older technology uses computer languages that are not as user friendly as today's fourth-generation languages. The older languages are harder to maintain, and changes are more time consuming to make.

The trend for MMSs is continued automation, primarily in reporting and interfacing with other systems. New technology will allow reporting with the use of electronic clipboards, hand-held computers, and other state-of-the-art devices. Interfacing with other systems, such as pavement and bridge management systems, is becoming easier as the technology moves toward data base management systems and fourth-generation languages. Better use could be made of computer graphics technology to present management information more effectively.

One strong theme was conveyed by maintenance managers interviewed by telephone after they had completed the survey questionnaire: the computer is only a tool, and the MMS will be effective only if managers are committed to its principles and apply the principles in their daily operations.

The authors' opinion is that too much attention has been given to the data processing aspects of the system. Not enough emphasis is being placed on management concepts. Advancing the technology is important, but technology alone does not achieve greater effectiveness. That is, having an electronic clipboard will not necessarily result in a higher level of service and certainly will not reduce the unit cost of work. States should have a continuous and active management training program, particularly for field supervisors. Top-level managers must have a strong commitment to the management principles of the MMS. The time and effort spent in the management tasks of planning, scheduling, and evaluating will be paid back many times in increased service levels and reduced costs.

Not all elements of the MMS have to be automated. They can be implemented just as effectively in a manual mode. Elements that require a great deal of data manipulation, including planning, work load leveling, projections of resource needs, reporting, and management reports, lend themselves most readily to automation.

Even if these elements are automated, managers still need to become involved in manual calculations. For example, in the equipment requirements area, a manager might want to perform some one-time analyses of the potential for equipment leasing. Although the MMS could provide the manager with information requirements, it would probably not be beneficial to attempt to automate the analysis, because it would be performed infrequently. Another example is assessing performance. It is likely that no management report will answer all the questions on performance that might arise. For questions on performance that require a unique study, manual calculations and analyses are best.

Scheduling is the most difficult element of the MMS to automate. Because so many variables are involved in scheduling decisions, automation might not be attractive. Some states have automated scheduling; the availability of labor and equipment is kept in files and used as input to the schedules. Mixed success has been reported. Because scheduling is done on a short-term basis, up-to-date information is necessary, which requires much data input and maintenance.

Decisions on the assignment of crews and personnel to routes do not lend themselves to automation. However, maintenance work backlogs can be automated, which is helpful in crew assignment decisions.

In general, elements of the MMS with considerable data input and manipulation can be effectively automated. Elements that require decision making or unique analyses are not effectively automated.

New Tools and Techniques for Highway Maintenance Management

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Traditional maintenance management systems have been in place in most state highway agencies for more than two decades. These systems have been primarily concerned with the management of maintenance resources such as labor, materials, and equipment. However, because of an environment in highway agency administration that increasingly emphasizes accountability and funding justification, maintenance managers must define the role of maintenance activities in highway facility management. Answers are being sought for questions such as the following: To what extent does a certain level of routine maintenance extend the life of a pavement? How can an optimal level of maintenance be estimated? How can the delivery cost of such activities as winter emergencies be minimized? How can maintenance decisions be made consistent throughout the state? How can one justify a maintenance budget request? The rapid development in technologies makes it possible to provide appropriate answers to some of these questions. Recent advances, for example, in information systems, decision sciences, and computer technology can be utilized to improve productivity and reduce costs in maintenance activities. Such advances are also useful in improving record-keeping practices and in monitoring performance. Some of the new tools and techniques that offer much potential are geographic information systems, fuzzy set mathematics and expert systems, mathematical programming techniques, and computer-aided management systems. These emerging tools and techniques are examined, and their adaptability to state highway routine maintenance management is discussed.

Highway management can be viewed in terms of a three-dimensional matrix (*1*). The first dimension refers to highway facilities, including pavements, bridges, roadside elements, and traffic control devices. The second dimension represents agency objectives such as the provision of acceptable levels of service, preservation of facility conditions, achievement of a decent level of safety, minimization of costs, minimization of negative socioeconomic impacts, conservation of energy, and minimization of environmental degradation. The third dimension refers to agency functions such as planning, design, construction, maintenance, information gathering and management, condition evaluation, and so on.

Over the years, highway agencies have become more and more interested in cutting costs and obtaining best returns. This interest led to the development of a number of management systems, each focusing on a function, facility, objective, or their combinations. Pavement management systems (PMSs) and bridge management systems have been developed to focus on a facility (e.g., pavements or structures), usually addressing capital spending (rehabilitation and construction). Maintenance management systems (MMSs), on the other hand, focus on a function (i.e., maintenance) and have traditionally aimed at improving productivity and work accomplishments.

The existing management systems suffer from two major drawbacks. First, the various systems have evolved almost independent of each other, with little thought given to compatibility and exchange of information. They may have different orientations, not reflecting the impacts of capital spending on maintenance and vice versa. Second, the systems developed during a long period and were designed to run on different computer systems with varying stages of sophistication.

The highway management environment has significantly changed since the first MMSs were developed more than two decades ago. MMSs must adopt new tools and techniques to cope with the changing environment. The new approaches can make use of recent advances in the fields of information systems, decision sciences, and computer technology.

INTEGRATED DATA BASE

Over the years, some management systems were developed for mainframes, some for minis, and some for micros. Hence, incompatibilities among programs exist. Some data base management programs were commercially developed and others were homemade. Consequently, some of the programs used flat files, some used hierarchical files, and some used relational files. Some have fixed record lengths and others have variable length. Worse still, different location referencing systems were used. Noncompatible computer systems even coexisted within one agency in different management systems. Under these conditions, file matching becomes a nightmare, if not impossible. To cut down increasing computer operation costs, many agencies moved from centrally controlled and supported mainframe operations to decentralized, user-supported microcomputer networking systems. Some agencies still maintain a mainframe for central pooling of regional information but use micros for intermediate processing. Existing management systems are not always capable of accommodating the variety of computer environments. In addition, a major hurdle to integration of maintenance information with other management systems has been the lack of a common referencing system.

In the absence of coordination, expensive routine maintenance activities, such as seal coating, are sometimes applied on sections that have been scheduled for resurfacing in a few months. An effective exchange of information between maintenance and major activity programs is thus essential. Figure 1 shows an example of how information on seven major activities can relate to routine maintenance activities.

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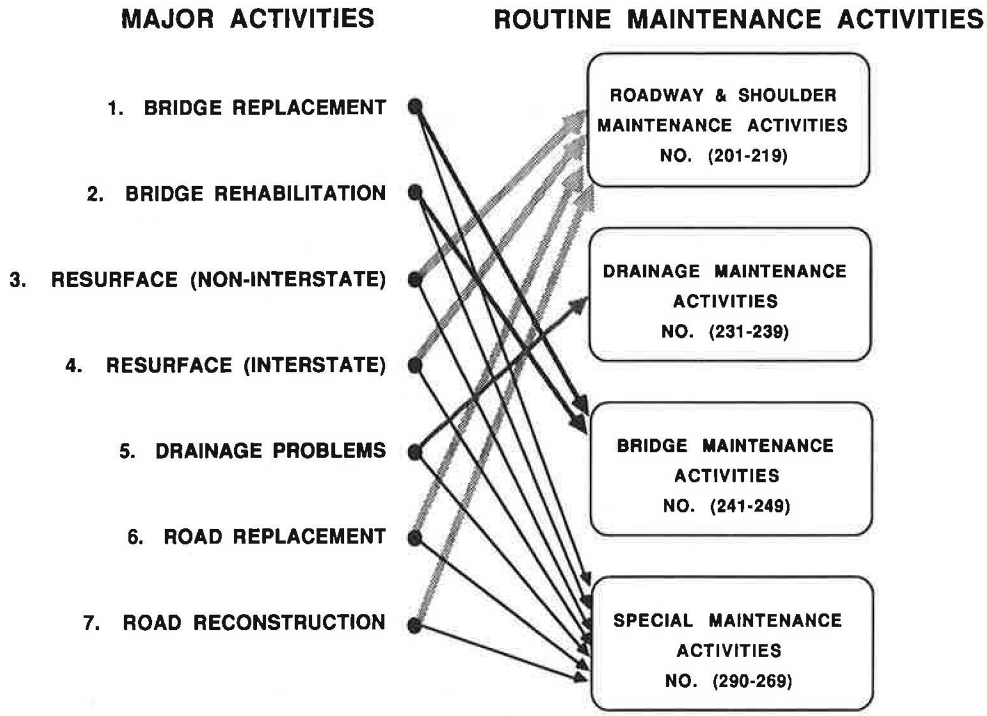


FIGURE 1 Routine maintenance activities as affected by major activities.

Byrd and Sinha (*2*) have discussed data types common to MMSs and PMSs. An example of common data types, involving pavement condition measurements, is given in Figure 2. The data needs of MMSs and other management systems should be carefully examined so that data collection programs can be optimized and individual data bases of different management systems can be integrated for exchange of information as needed.

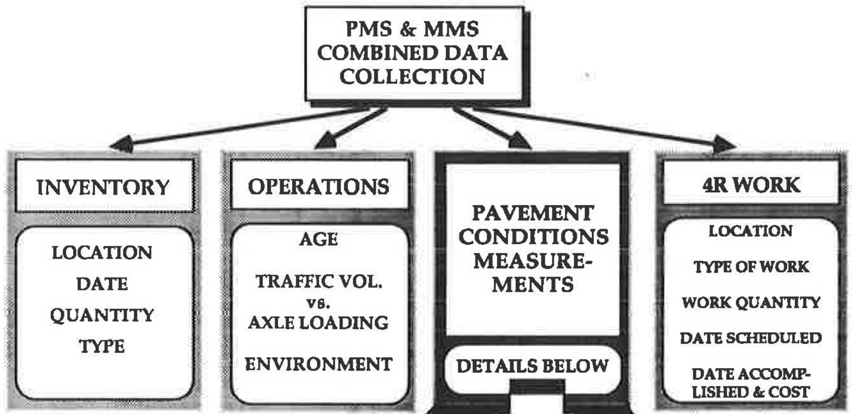
An integrated data base may be sizeable; however, with creativity, data management problems can be overcome. To illustrate, a microcomputer-based routine maintenance data base system was developed for collecting, storing, processing, and retrieving the pavement- and shoulder-related information required in an MMS (*3*). The system can include information on pavement roughness, programmed major activities, traffic, and other data. Because of the largeness of the data file and the relatively slow speed of the personal computer, the indexed sequential technique was used to access information quickly. The information is stored for each of the sections within a subdistrict. To access a specific record in a subdistrict, a search is made in the index file for the subdistrict, and a search for the record is made only in the subfile that includes the records for that specific subdistrict.

The following factors should be considered in developing an integrated data base: type of data to be recorded, frequency of updating, storage and retrieval method, usage of the data by function and line unit, and updating procedures. Special attention should be given to data usage because maintenance information is usually needed at various levels of decision making, such as by top management (for policy purposes) and by the central office (for planning, programming, and budgeting), as well as by the districts, subdistricts, and units (for operations). Standardization will be necessary for the information to be consistent for various uses. For example, "absolute standardization" is required for hierarchical control (through formats) over data storage and retrieval of information, whereas "functional standardization" calls for compatibility of records in allowing the translation of information from one system to another. In all cases, an appropriate common referencing procedure should be used for physical identification of the data.

GEOGRAPHIC INFORMATION SYSTEMS

The need for a common referencing system can be seen from the existence of a critical problem in dealing with maintenance records: the difficulty of identifying the location of maintenance activities undertaken. In many MMSs, maintenance work records are kept by highway section (mostly county line to county line), whereas PMSs use contract sections. Knowing the exact location of both maintenance and capital activities is essential for integrating maintenance with other management systems, if the usefulness of these systems is to be optimized. The rapid development of geographic information systems (GISs) has provided a great opportunity in this area, particularly in combining maintenance information with spatial and other data to produce management information reports.

GISs are simply computerized data base management systems for the storage, retrieval, and display of spatial data (*4*). GISs use two types of data: geocoded spatial data and attribute data. The spatial data are represented by one of two methods, the vector method or the raster method. The vector method represents objects as points, lines, or polygons; the raster method uses the x–y location of the array as an indicator of the spatial location of the point and uses the contents



DATA ITEMS	PMS NTWK	MMS	PMS PROJ	SPECIAL STUDIES OR RES.
SURFACE DISTRESS				
• < Annual		x	x	x
• => Annual	x	x		
ROUGHNESS PROFILE				
• < Annual			x	x
• => Annual	x			
RUTTING/ CROSS SECTIONS				
• < Annual			x	x
• => Annual	x			
SURFACE DISTRESS				
• Random	x			
• Pattern				
• Spot				x
• Continuous		x	x	
SKID RESISTANCE				
• Random	x			
• Pattern				
• Spot				x
• Continuous		x	x	
ROUGHNESS				
• Random	x			
• Pattern				
• Spot				x
• Continuous			x	

DATA ITEMS	PMS NTWK	MMS	PMS PROJ	SPECIAL STUDIES OR RES.
RUTTING				
• Random	x			
• Pattern				
• Spot				x
• Continuous			x	
LOCATION				
• County	x	x	x	
• Route Number	x	x	x	
• Mile Post		x	x	
• Lane		x		
TYPE OF ACTIVITY	x	x	x	
QUANTITY OF WORK	x	x		
COSTS				
• Unit Cost		x		
• Lump Sum		x		
DATE				
• Year	x	x	x	
• Month		x		
• Day		x		
PRODUCTION RATES		x		

FIGURE 2 PMS and MMS combined data collection.

of the array as the attributes of that point. The availability of these two methods gives the GIS two desirable characteristics: flexibility and usefulness. For example, the vector method can present information on road conditions and maintenance performed on a section-by-section basis, whereas the raster representation can be used for preparing and presenting summaries by subdistrict, by district, or for the entire state.

GISs can store and retrieve, analyze, and present data. The ability to store and retrieve data is an advantage because it forces the agency to develop a common referencing system and establish a centralized data base that is accessible by all units. Such a referencing system is required for efficient integration of various files residing with different units of the agency. Traditionally, line units in many agencies viewed a common referencing system as a luxury and never took it seriously. The visual and quick-response enticements of GIS technology improve the likelihood that the subject will be given a higher priority. The staff's ability to respond efficiently to questions from the public or seniors in the agency would be enhanced.

The ability of GISs to analyze data is derived from their ability to link data files to statistical packages, mathematical programs, and plotting software. Consequently, the user can almost instantly extract summary information; statistical results; or graphs about link or system age and condition, classification, priority, scheduled action, and associated key public issues. Summaries of where materials and equipment were used and manpower was tied up can also be extracted from the appropriate files. The user can obtain forecasts about individual sections or the network. For example, the work, materials, and manpower required can all be estimated using mathematical models and displayed graphically or summarized in tables.

The third ability of GISs, presentation of data, allows for preparing quick visual aids for presentation and training and can reduce the work required from drafting staff, such as the preparation of deficiency maps.

Although the benefits are numerous, there are many technical challenges in the development of an effective GIS. Issues that need to be resolved include

- The key questions to answer, or roles the system is to play;
- The referencing system to use;
- The data to include and their structure and design;
- The method to use for portraying information and the information to portray;
- The map scales to use;
- The type of access to allow;
- The type of hardware architecture to use; and
- The protections and securities to put in place.

MAINTENANCE NEEDS ESTIMATION

One of the most important functions of an MMS is to estimate the amount of work to be performed on various highway sections within a maintenance unit during a coming year or season. In most agencies, the budgeting for routine maintenance is established primarily on the basis of historical average quantity standards. Although routine maintenance work loads should be based on road conditions, most current approaches do not provide an assessment of actual needs. A survey procedure was developed for application in Indiana for this purpose (*5*). A condition-based needs assessment and budgeting procedure will provide for a uniformly defined maintenance planning process as well as a tool for checking the maintenance levels of service throughout the network. Such a check is essential for consistency in implementing maintenance policies.

The proposed procedure is to conduct a visual condition survey by unit foremen on a periodic basis. The recommended survey form for asphalt pavements is shown in Figure 3. The approach was tested in the field for validity and accuracy. The surface distresses on highway sections were surveyed by unit foremen. The subjective evaluations of the frequency and severity of distresses were translated to numerical values through a separate analysis. Statistical analyses were then conducted to relate routine maintenance work loads to the subjective evaluation of distresses by unit foremen. For example, it was concluded that the expected work load of shallow patching could be estimated using the following relationship:

DISTRICT ______________ HIGHWAY [SR | US | IS] NO. ______

SUBDISTRICT ______________ FROM ______________

UNIT NO. ______________ TO ______________

DATE ______________ TRAFFIC [LOW | MED | HIGH]

DIRECTION [N | S | E | W]

ASPHALT PAVEMENT				
TRAFFIC LANES & PAVED SHOULDERS				
M	S	N	SLIGHT	POTHOLES
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	CRACKS
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	RAVELING
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	BLOW UPS, BUMPS AND SURFACE FAILURES	
M	S	N	SLIGHT	RUTTINGS, DIPS
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	PATCHED SURFACE
M	S	N	MODERATE	
M	S	N	SEVERE	
UNPAVED SHOULDERS				
M	S	N	SLIGHT	BUILD-UP
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	POTHOLES
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	DROP-OFF
M	S	N	MODERATE	
M	S	N	SEVERE	
DRAINAGE				
P	F	G	DITCHES	

FIGURE 3 Recommended survey form for asphalt pavements.

$$\text{shallow patching} = 0.157 + 0.09253\,(\text{frequency of potholes}) + 0.10865\,(\text{severity of potholes})$$

where shallow patching is measured in tons per lane mile.

The regression equations were converted into charts, some examples of which are shown in Figure 4. The charts can be used by unit foremen to estimate maintenance work loads once the road conditions have been evaluated. To illustrate, if a road section is found to have "many" "slight" potholes, the amount of shallow patching would be 1.20 tons/lane-mi of the section.

Because the procedure allows the estimation of quantities of needed routine maintenance, it can be applied for budget estimation purposes. It can also be employed, when appropriate, as a tool for periodic scheduling of maintenance work load during the year. The significance of this approach is that it would quantitatively link maintenance to road condition, unlike the current historical averages or arbitrary guess-based methods.

CONDITION AND OTHER DATA ACQUISITION TECHNOLOGIES

Two significant technological developments have enhanced the opportunities for improved management effectiveness: automated data gathering and communications technology. Most states determine maintenance needs by visual observations. Advancements in technology, however, are leading to the introduction of devices that can help quantify more rapidly not only items like roughness and deflections, but also distresses like cracks, potholes, raveling, and so on. Photologging went a long way toward enhancing field condition observation. Still, not all conditions could be detected, and it was necessary to examine the photographs and make judgments on the conditions.

Video, ultrasound, and laser technologies (in which images are identified in binary codes and hence are feasible to store on microcomputers) have provided the ability to integrate three processes: observation, identification, and diagnosis. Enhancements in communications technology and decision support systems now allow for the completion of the decision cycle—that is, the analysis of situations and the actions to undertake.

Maintenance managers can now use technology to observe distress, record the observation, and transmit it to the central processing unit. They can apply accumulated expertise (in the form of expert system models) to determine the appropriate action, the amount of effort and resources required, and an optimal schedule for the deployment of the maintenance crews. All they need to do is ensure that the results make sense and meet their objectives. In cases where special decision rules apply, changes may be required.

Advances in computation and the introduction of interactive hierarchical data base systems have also allowed for linkage of various files maintained by different units in an organization. Such linkage can help bring about better synchronization between capital management and maintenance management.

APPLICATION OF FUZZY SETS MATHEMATICS

Fuzzy sets mathematics can be used in assessing road conditions and in areas employing subjective judgments. The

SHALLOW PATCHING (Tons per Lane Mile)

Assessed Pothole Severity \ Assessed Pothole Frequency	N	S	M
Sl	0.20	0.50	1.20
Mo	0.60	1.10	2.10
Se	1.20	1.90	3.10

DEEP PATCHING (Tons per Lane Mile)

Assessed Bumps, Blow ups & Surface Failure Frequency \ Assessed Pothole Frequency	N	S	M
N	0.00	0.04	0.50
S	0.10	0.50	1.30
M	0.90	1.70	3.25

CRACK SEALING (Tons per Lane Mile)

Assessed Severity of Cracks	
Sl	33.23
Mo	103.24
Se	212.73

BLADING SHOULDERS (Shldr Mile per Shldr Mile)

Assessed Frequency of Potholes on Unpaved Shldr	
N	0.10
S	0.30
M	0.90

CLEAN & RESHAPE DITCHES (Ft per Ditch Mile)

Assessed Condition of Roadside Ditch	
P	693.0
F	190.0
G	2.0

FIGURE 4 Proposed present quantity standards.

subjective evaluation of road conditions includes intangible or qualitative information such as wisdom and experience of unit foremen. Fuzzy set theory (*6*), a systematic technique for quantifying imprecise information in the subjective evaluation, can be used to improve the road condition assessment process.

Traditionally, to deal quantitatively with imprecision, the concepts and techniques of probability theory have been employed. Use of probability theory assumes that the imprecision is caused by randomness of variables. However, because the imprecision can be attributed to fuzziness rather than randomness (*6*), the validity of using probability theory to deal with imprecision in decision making is questionable.

Randomness has to do with uncertainty concerning membership or nonmembership of an object in a nonfuzzy set. Fuzziness, on the other hand, has to do with classes in which there may be grades of membership intermediate between full membership and nonmembership. For instance, an ellipse and a square can be drawn side by side. In the concept of randomness of nonfuzzy sets, the answer to the question, Is the shape a circle? is that both shapes are considered "not a circle." However, in the concept of fuzziness, the value of membership belonging to a circle could be 0.0 for a square because a square has no similarity to a circle, and the value of membership for an ellipse could be close to the full membership of 1.0, perhaps 0.90, because an ellipse could well be similar to a circle in shape.

In the road condition evaluation process, a unit foreman must judge the frequency and severity of distresses. For example, the severity of potholes can be slight, moderate, or severe. In a nonfuzzy set approach, the foreman's response can be slight, moderate, or severe. According to the fuzzy sets approach, however, the foreman can quantify a severity level between slight and moderate and between moderate and severe with a numerical rating.

The fuzzy sets approach has been applied in pavement evaluation (*7*), bridge condition rating (*8*), and traffic safety evaluation (*9*). For purposes of illustration, discussion will focus on the use of the approach in rating bridge condition. Bridge condition rating is one of the key indicators in determining the types of repair or maintenance required for a bridge. The usefulness of a bridge maintenance program, therefore, depends on the reliability and accuracy of bridge inspection information. Current bridge inspection practices, however, suffer from three inherent shortcomings (*8*):

1. The parameters in bridge inspections are not completely defined or cannot be precisely measured,
2. Bias and subjectiveness are often included but not systematically accounted for in the evaluation process, and
3. Guidelines for establishing the relationship between the extent of deterioration and the assignment of values of condition rating are lacking.

The purpose of the condition assessment model used as an illustrative example in this paper was to filter the field inspection data of inconsistencies before entering the bridge management system. It was concluded that fuzzy set theory (*6*) was effective in minimizing the bias in judgment and enhancing the overall accuracy of the bridge condition evaluation. One method for combining fuzzy knowledge, the fuzzy weighted average (*10*), was used in the model. The fuzzy weighted average has a simple mathematical form:

$$R = \frac{1}{\Sigma W_i} * \sum (W_i * r_i) \qquad (1)$$

where

R = a fuzzy number denoting a bridge component's resultant rating,
r_i = the fuzzy rating of the *i*th subcomponent, and
W_i = the fuzzy importance factor for the *i*th subcomponent.

The importance factors are generally imprecise quantities and are represented as fuzzy sets. In this model, three bridge components (deck, superstructure, and substructure) were further divided into subcomponents, as shown in Figure 5. Equation 1 represents the fuzzy relationship between the condition of a bridge component and those of its subcomponents. W_i represents the degree of importance of a subcomponent relative to other subcomponents. A detailed discussion of this model and the method of determining fuzzy importance factors can be found elsewhere (*8*).

A microcomputer-based software package for the condition assessment model was developed. The results were in good agreement with the assessment of experienced bridge inspectors. Consequently, the package can be used as an expert system for bridge inspection, particularly for assisting new and inexperienced bridge inspectors.

USE OF EXPERT SYSTEMS

An expert system is defined as a problem-solving computer program for dealing with difficult problems demanding specialized knowledge and skill. It solves real-world, complex

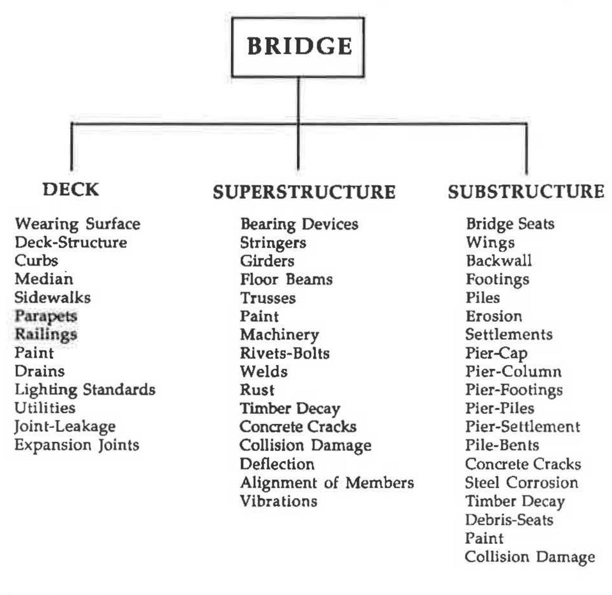


FIGURE 5 Division of bridge components into subcomponents.

problems requiring expert interpretation by using a computer model of expert reasoning. Conclusions are the same as those a human expert would reach if faced with the same problem (*11*). Expert systems are useful when real experts are not available. In addition, expert systems are useful for documenting expert knowledge in a way that is not feasible in books or manuals.

Why are expert systems important? There is a considerable turnover in the ranks of maintenance management; in addition, many experienced personnel are now retiring. Yet many maintenance decisions are made by unit foremen and subdistrict superintendents or field supervisors on the basis of their judgment. If they do not have ample experience, expert systems can help fill the gap. To illustrate, maintenance needs estimation through visual inspection requires foremen not only to correctly assess the road condition, but also to convert the road condition information into work loads. Although the foreman can be trained to assess the road condition, work load estimation demands considerable experience and know-how. There is inherent uncertainty in the unit foreman's translation of distress information into the type and amount of activities to be performed. A knowledge-based expert system could be applied to take care of the uncertainty in the estimation process. It provides a tool for estimating the activities in the absence of an expert. The knowledge base can be tested and altered over time to improve its performance. Because the computer stores the expert system, it can become a part of a larger cost estimation system for the entire road network.

There are several examples of expert systems developed for highway maintenance and rehabilitation management (*12–14*). A discussion of one is presented below.

An expert system was developed for estimating the maintenance work load on asphalt roads and shoulders in the Indiana state highway system (*13*). The maintenance activities related to roadway and shoulder included shallow patching, deep patching, crack sealing, full-width shoulder sealing, seal coating, and leveling. Five types of distresses were considered: potholes; cracks; raveling; blowups, bumps, and surface failures; and rutting and dips.

The collective expertise of 18 randomly selected unit foremen was used for knowledge acquisition. The computer program was written in LISP. There are several advantages of using LISP instead of other languages. The most significant is the flexibility LISP allows for manipulating the knowledge base, which may require change as new information is obtained.

The program is to be used interactively by unit foremen to estimate maintenance work loads on the basis of field observations of pavement and shoulder distresses. The program requires the user to answer questions about the physical characteristics of the highway section, including distress information. The flowchart for the overall program is shown in Figure 6.

The input module fetches all the information from the user. The knowledge base stores all the rules. This is where the expert system applies its own knowledge to the facts provided by the user to develop the conclusions. It has two distinct subdivisions. The first, the conversion module, contains the rules for qualitative values of distresses to be converted into quantitative values through a series of IF-THEN statements. The second part, the rules module, which can also be called the inference engine, includes the rules to estimate the amount of activities and their costs. The output module controls the execution of the entire program and provides outputs in desired formats.

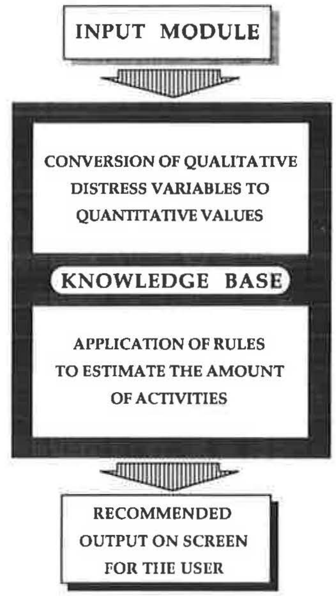


FIGURE 6 Flowchart for expert system.

An example of the input and output information for a 10-mi highway section is given in Figure 7. The work load and costs are expressed as 95 percent confidence ranges.

One of the major causes for the large variation in the estimated work loads is the choice of different activities by foremen for the same type of distress. Some types of distress can trigger different activities, and an activity can correct more than one type of distress. Furthermore, different practices may be expected in different parts of the state. The reasons might be unavailability of materials for a particular activity, one activity being less expensive due to proximity of the site to a mixing plant, and so on. More research is needed so that information about regional practices can be included in the input module before the estimation process.

OPTIMAL PROGRAMMING AND SCHEDULING

Timing, frequency, extent, and type of routine maintenance work have a significant impact on the performance of highway pavements and other elements (*15,16*). An important function of an MMS is therefore to provide maintenance managers with an effective tool for formulating a "good" routine maintenance program one that maintains and preserves the road network under their charge at or above a desired standard.

Unfortunately, many factors make the task of developing a good routine maintenance program difficult:

- Highway maintenance units often have to perform diverse routine maintenance activities on many highway routes over extended areas; these activities have possible consequences of different importance.
- The highways in question may vary from a six-lane Interstate highway to a lightly traveled two-lane road.

INPUT

ROAD SECTION LENGTH (in miles)	: 10
NUMBER OF LANES-- ONE WAY ONLY	: 1
LANE WIDTH (in feet)	: 11.5
INSIDE SHOULDER WIDTH (in feet)	: 3
OUTSIDE SHOULDER WIDTH (in feet)	: 6

CRACKS	SEVERITY	: moderate
	FREQUENCY	: many
POTHOLES	SEVERITY	: slight
	FREQUENCY	: few
RAVELING	SEVERITY	: slight
	FREQUENCY	: none
BLOW UPS, BUMPS AND SURFACE FAILURES	FREQUENCY	: many
RUTTING & DIPS	SEVERITY	: severe
	FREQUENCY	: many

OUTPUT

AMOUNT OF WORK

SHALLOW PATCHING	5.2 - 6.1 tons
CRACK SEALING	1359 - 1584 gallons
FULL WIDTH SHOULDER SEALING	0 - 7 ft-miles
SEAL COATING	0 - 1.7 lane-miles
DEEP PATCHING	8.6 - 9.8 tons
LEVELING	161 - 162 tons

ESTIMATED COSTS

SHALLOW PATCHING	$ 596 - 701
CRACK SEALING	$ 2,827 - 3,294
FULL WIDTH SHOULDER SEALING	$ 0 - 832
SEAL COATING	$ 0 - 2,858
DEEP PATCHING	$ 575 - 655
LEVELING	$ 7,411 - 7,477

FIGURE 7 Example of maintenance work load and cost estimation by expert system.

- Because of resource constraints, not all maintenance needs can be attended to as and when required.
- A routine maintenance program must be planned in coordination with the highway rehabilitation program to obtain the maximum return.

Given this complexity, the most appropriate technique for this situation appears to be optimization. Optimization models are most useful because they define the ideal work mix under a set of prevailing constraints. For example, an integer programming approach was found to provide a good tool for application at the unit, subdistrict, district, or even at the statewide level in Indiana (*17*). The objective function of the model attempts to maximize the preservation of the condition of various highway elements by maximizing the sum of equivalent workday units of routine maintenance activities, each weighted by an appropriate priority factor. The constraints considered include maintenance need requirements; the budget available for the maintenance unit; manpower, material, and equipment availability; and the rehabilitation of the highway sections. The assignment of priority weighting factors considers (*a*) the relative importance of each routine maintenance activity in preserving the highway system at a desired level of service condition, (*b*) the urgency of need for maintenance work in relation to the severity of distress, and (*c*) the type of highway section or highway class.

Such an optimization model can allow for the analysis of shortfalls and surpluses of resources. The benefits of reallocating resources can be examined by performing parameter sensitivity analyses. These analyses are useful because certain parameters might have been a result of managerial policy decisions, and such decisions can be revised after their consequences in terms of what could otherwise be achieved are revealed. The amount of certain resources to be apportioned to a given activity may need adjustment to achieve better results. For instance, the number of temporary laborers to be hired during a given period could be determined by such analyses.

The proposed optimization approach has great potential to enhance the efficiency and effectiveness of MMSs. However, extensive data are needed for successful application of the optimization model. All these data should be readily available in a fully operational MMS. The value and usefulness of the output information depend on the accuracy and exhaustiveness of the acquired data as well as on the skills of the user in interpreting the results obtained from the model. The establishment of an appropriate routine maintenance data base and a good understanding of the operation are prerequisites for a meaningful routine maintenance programming analysis.

Another example of the application of the optimization approach is a model that was developed for use in the reassignment of summer personnel to alternative site locations for winter snow and ice control activities (*18*). The model was developed for application at the district level in Indiana. The model is an integer program that can generate trade-off curves between the objectives of minimizing the total distance that the reassigned workers must travel from their respective homes to one of many site locations and minimizing the maximum distance that any worker must travel. System constraints include demand requirements for workers at each site and the limited availability of state-owned vehicles that may be issued to workers assigned to remote sites. The results indicated that the use of the model could save one district alone about $100,000 during the 1984–1985 snow season.

CONCLUDING REMARKS

With the shift of emphasis from system development to system preservation and maintenance, challenges that demand innovation and creativity face the maintenance managers of state highway agencies. Traditional MMSs, developed more than two decades ago and designed primarily to monitor and control maintenance resources, cannot deal with the changing requirements of maintenance management. Maintenance managers increasingly are being asked to answer questions such as, To what extent does a certain level of routine maintenance extend the life of a pavement? How can an optimal level of maintenance be estimated? How can the cost of such activities as winter emergencies be minimized? How can maintenance decisions be made consistent throughout the state? How can a maintenance budget request be justified? The rapid development in technologies makes it possible to provide appropriate answers to some of these questions. Recent advances in information systems, decision sciences, and computer technology can improve productivity and reduce the cost of maintenance activities. A brief review of some of the emerging tools and techniques that can be used by highway maintenance managers has been presented. These include fuzzy sets mathematics, expert systems, optimization techniques, GISs, and other computer software and hardware technologies.

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Life-Cycle Cost Evaluations of the Effects of Pavement Maintenance

MICHAEL J. MARKOW

Several recent trends in highway programs suggest an increasingly important role for maintenance in future pavement management, operations, data collection, and research. The movement toward life-cycle costing as the economic framework for pavement management decisions will cause managers to consider maintenance as one of a spectrum of options available and to evaluate trade-offs among these alternatives in a more flexible, integrated decision-making process. Furthermore, maintenance is a prime candidate for emerging technologies and research in improved data acquisition and processing, nondestructive testing and evaluation, management of the maintenance function, and materials and equipment needed for maintenance performance. The ways in which the technical, economic, and management aspects of maintenance can be incorporated in life-cycle costing and the results of different assumptions in these areas and their implications for pavement performance and costs are explored. A microcomputer-based procedure for pavement life-cycle costing was employed. The program emphasizes pavement policy at the network level and includes an analytic treatment of routine maintenance that accounts for relative levels of effort and the technological effectiveness of maintenance activities, as well as their scheduling and costs. The benefits of maintenance are expressed as reductions in user costs of vehicle operation as a function of pavement condition; the discounted benefits are compared with the discounted costs of maintenance performance to assess the value of different maintenance options and the technological characteristics of maintenance. The findings affirm the substantial benefits of maintenance relative to costs, the benefits of further improvements in maintenance technology, the long-term benefits of early and frequent maintenance, and the need for management decisions to reinforce the inherent technological capabilities of maintenance in correcting pavement condition.

Recent trends in highway programs suggest that pavement maintenance will occupy an increasingly important role, entailing a more sophisticated treatment, in future pavement management, operations, data collection, and research. The Interstate system and concurrent programs of road construction during the past four decades are ending, resulting in not only more mileage to maintain, but also an inventory of higher-standard, more intensely used roads. Sources of highway financing are continuing to shift from the federal government to state and local governments (historically the providers of road maintenance) and to the private sector (which stands to become more involved in the maintenance and rehabilitation of the maturing road system). Emerging technologies hold several potential applications to both preventive and responsive maintenance and related tasks of highway inspection, ranging from new methods of nondestructive testing and field data collection and analysis to developments in computer hardware and software technology. These and other trends are reflected in new federal policy directives that promise to change the ways in which maintenance and other highway activities are viewed, managed, and evaluated.

Pavement activities in particular are of interest to policy makers because of

- The high visibility of pavements to the motoring public and their close association with perceptions of the highway network overall;
- The strong implications of pavement condition for road structure, operation, and safety;
- The major proportion of highway infrastructure investment represented by pavements;
- The significant trade-offs inherent among options in pavement design, construction, inspection, maintenance, rehabilitation, and reconstruction;
- The need for a long-term perspective in the analysis of pavement strategies; and
- The resulting importance of pavements to management at all levels in federal, state, and local government.

These ideas have been captured in two recent federal pronouncements that will guide future highway transportation policy and, by implication, influence future directions of pavement maintenance management: (*a*) FHWA's new policy on pavement management and eligibility of pavement projects for federal aid and (*b*) the U.S. Department of Transportation's (DOT's) National Transportation Policy.

The FHWA policy on pavements requires states to implement pavement management systems by 1993 and describes the systems' requirements and their proposed applications to specific highway functional classes in the federal-aid system (*1*). An important methodological advance is the recommendation of a life-cycle economic analysis as the framework within which pavement alternatives will be evaluated. The importance of timely, effective pavement maintenance (both preventive and responsive) is clearly recognized. However, because routine maintenance is not eligible for federal aid, the FHWA policy statement does not elaborate on its analysis in pavement management. Nevertheless, the role of maintenance may be inferred from the FHWA guidelines in several areas:

- The requirement for a life-cycle analysis implicitly includes maintenance as one set of actions to be evaluated, complementing pavement design, construction, rehabilitation, and reconstruction.
- Maintenance history is one variable that influences pavement performance (together with traffic, pavement structural

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and materials properties, environment, construction quality, subgrade and drainage, and variability in these parameters)

- Maintenance of the pavement surface (through activities like joint and crack sealing) is critical to retarding water from entering the pavement foundation, which forestalls a primary cause of premature failure.
- Because maintenance is funded differently from capital projects, it is one of the decision variables managers have at their disposal to allocate resources throughout a road network and over time, meet critical road priorities, and remain within budget constraints.

DOT's National Transportation Policy is a much broader, more comprehensive statement of federal objectives, priorities, and strategies in highways and other modes of transportation (*2*). This recently completed report establishes the context for new federal directions in transportation into the next century. Among its many findings and recommendations, several have important implications for pavement maintenance:

- Maintaining existing transportation assets is identified as "the most immediate task for the transportation sector." The national policy envisions this task as a shared responsibility, with the federal government emphasizing capital repairs in its aid programs and state and local governments taking the lead in managing and maintaining facilities.
- The plan adopts a more flexible perspective on aid programs, seeking to encourage a broader range of options and to eliminate "unnecessary or unwise investment."
- The national policy recognizes the potential role of the private sector to join with the public sector in providing needed transportation infrastructure and encourages the elimination or the mitigation of barriers to private-sector participation in planning, owning, financing, building, maintaining, and managing transport facilities and services. Federal policies should also provide better incentives for increased participation by other levels of government and the private sector.
- The importance of early maintenance is emphasized, both to preserve existing assets and to reduce the long-term costs of facility repair. In some cases, "Federal-aid programs have detracted from effective maintenance by tending to encourage new construction at the expense of maintenance."

Taken together, all these trends suggest a number of changes that will affect pavement maintenance in the coming years:

- The role of highway maintenance will continue to evolve in terms of both the increasing demand for maintenance work and the limited supply of increasingly sophisticated maintenance services.
- In allocating highway resources in the future, managers will consider maintenance as one of a spectrum of available options, and will evaluate the trade-offs among the alternatives in a more flexible, integrated decision-making framework. In addition to maintenance, the range of options will include different levels of design and construction quality; various frequencies and levels of inspection, rehabilitation, and reconstruction; and regulatory options governing, for example, vehicle size and weight—all able to be addressed within the life-cycle cost framework proposed by FHWA (*1*).
- Emerging technologies and research dedicated specifically to maintenance will enable much-improved data acquisition and processing, nondestructive testing and evaluation, management of the maintenance function, and performance of maintenance activities.

Ideally, life-cycle costing procedures envisioned for pavement management will anticipate these trends and enable managers to account for them as part of their analyses of pavement options. Indeed, tools are already available to incorporate maintenance in an economic analysis of pavements, as will be described. However, maintenance has suffered from a lack of dedicated research that is only now beginning to be rectified, particularly through the maintenance component of the Strategic Highway Research Program. This research is considering, for example, the effectiveness of different pavement maintenance treatments and the investigation of new methods of nondestructive testing specifically intended for preventive maintenance. The results of these efforts will begin to provide the field validation of how different maintenance activities affect the condition of the pavement and, therefore, what their benefits are in relation to their costs. In the meantime, findings such as those to be described, derived from the results of computer simulations, provide a framework for understanding the life-cycle implications of maintenance for pavement performance and costs. They illustrate the types of relationships that can be expected to result and indicate generally how life-cycle analyses of pavement maintenance need to be structured.

METHODOLOGICAL APPROACH

Historical Perspective

Life-cycle costing of capital assets is not a new concept. It has been applied by industry to plant and equipment for many years. With respect to U.S. highways, basic concepts of engineering economy were formulated more than 100 years ago and began to be applied in studies of highway improvements in the 1920s. More recently, concepts and principles of highway engineering economy in the modern U.S. highway system were compiled, organized, and quantified by Winfrey (*3,4*). This work not only defined a methodological framework, but also focused in detail on the important cost components (e.g., construction and maintenance costs on the agency side and road user consequences on the benefits side) and engineering or technological data affecting these costs (e.g., traffic characteristics, accidents, vehicle power performance, etc.).

These concepts and methods historically have been applied primarily in the context of improvements in the highway system (new construction or major reconstruction and, later, rehabilitation). Routine maintenance, by contrast, was more difficult to incorporate in this framework through the 1960s and early 1970s—not for theoretical reasons, but because of lack of good data in the appropriate form. For example, whereas estimates of annual maintenance costs could be obtained on a systemwide basis, "the desired specific highway maintenance expenses [needed for economic studies of a particular highway link or project] are not available" (*3*). The problem was summarized as follows (*5*):

> There has been much interest over the past decade in the evaluation of highway development, but little has been written on the evaluation of highway maintenance. In practice, maintenance expenditure decisions have continued to be made largely on the traditional and simple grounds that maintenance is necessary to preserve the road assets. While this is frequently true, it is a rough judgement. Moreover, it fails to consider whether the expenditure is justified, for instance, by savings in vehicle operating costs; and it affords no means of quantifying the returns from other expenditures.
>
> This lack of interest in the economics of road maintenance has been due doubtless to its Cinderella image, compared with the more virile image of driving new roads through virgin territory. Perhaps also the lack of interest has been due partly to the feeling that road maintenance would fall away as better roads were built (savings in maintenance are frequently included as a benefit in road construction programmes). Partly, perhaps, it reflected the notion that road maintenance raised no separate problems from those of road construction. While the "Cinderella image" remains a matter of opinion, neither of the other two ideas has turned out to be correct.

At least three factors began to change this situation in the United States in the 1970s: (*a*) the growing realization of the role of maintenance in road preservation, (*b*) the widespread implementation of maintenance management systems in state DOTs, and (*c*) the successful integration of maintenance in an economic decision support framework by international lending agencies like the World Bank. A strong motivation existed to incorporate road maintenance in an analytic framework for projects overseas: particularly in developing countries in tropical climates, low-volume roads that were poorly maintained did not fulfill their design lives. Case studies of these roads illustrated dramatically the trade-offs that existed not only between design standards and maintenance standards, but also between the level of service afforded by the road (a function of design standards, construction quality, and standards of maintenance and rehabilitation) and the consequences to road users. The trade-offs were structured within a life-cycle economic analysis of design, construction, and maintenance standards and technologies as early as 1969 and culminated in the documentation of the World Bank's Highway Design and Maintenance Standards Study and its related computerized procedure, the Highway Design Model (HDM-III) (*6,7*).

Approaches to Pavement Maintenance

The evolution of these techniques in U.S. practice has been summarized with respect to pavement construction, rehabilitation, and maintenance in several sources (*8–10*). Also, applications of life-cycle economic analysis to highways (especially to evaluate construction and rehabilitation alternatives) are described in the pavement management literature and, more recently, in the development of bridge management systems. In focusing on pavement routine maintenance, two approaches to the problem that have been employed in life-cycle cost routines are outlined.

An example of the first approach is given by FHWA's EAROMAR-2 system, a project-level, life-cycle cost procedure for flexible, rigid, and composite pavements (*11*). The specific maintenance-related benefit considered in EAROMAR-2 is the contribution of crack sealing, joint sealing, and patching to the preservation of an impervious pavement surface. When such activities are not performed with sufficient frequency, EAROMAR-2 simulates a progression of events leading from infiltration of water through surface discontinuities to decreases in pavement strength, incremental increases in the rate of deterioration, and resulting increases in life-cycle costs.

The structure of this detailed type of simulation permits an explicit treatment not only of the life-cycle impacts of pavement maintenance, but also of the interactions between maintenance and other factors affecting pavement performance and costs (e.g., the structural and materials properties of the pavement cross section, local environment, and traffic). EAROMAR-2 was applied to a study of the impacts of deferred pavement maintenance. The results indicated that regular and frequent sealing of pavement cracks and other discontinuities could lengthen pavement service life up to about 4 years for both flexible and rigid surfaces (*12*).

The second approach is simpler and more direct. Rather than accounting for the action of maintenance in countering pavement damage mechanisms, it assigns some adjustment due to maintenance directly to the simulation of pavement condition. The adjustment may be in one of two forms: a reduction in the rate of future deterioration or a modest improvement in the measure of current pavement condition. Although this approach lacks the technical sophistication of EAROMAR-2, its simplicity presents the following advantages: a computational economy better suited to network-level pavement analyses; the ability to analyze maintenance activities whose impacts cannot be easily described in more detailed, mechanistic formulations; compatibility with a broader treatment of the technological characteristics of maintenance; and greater ease in implementing on a microcomputer.

Because of these advantages, the second approach was used to develop the findings of this paper. The model used was developed for FHWA (*10*). Pavement condition is measured in terms of a pavement condition index (PCI) on a scale of 0 to 100; the pavement deterioration model predicts the annual reduction in PCI as a function of pavement structure, traffic loads, and an age-related term to reflect nonload causes of damage. The effects of routine maintenance are expressed in terms of limited, positive adjustments in the value of the current PCI. Costs are computed both on the agency side (for pavement construction, rehabilitation, and routine maintenance) and on the road user side (for vehicle operation and travel time, both as affected by current pavement condition).

A complete knowledge of the mathematical functions used in these predictions is not necessary for the purposes of this paper; that information is provided elsewhere (*10*). A more detailed explanation of the models simulating the effects of pavement maintenance itself, however, will be useful. This development is given in the following two sections.

Conceptual Development

Pavement maintenance is modeled as a periodic, limited adjustment in current PCI. Over time, the cumulative effect of these adjustments is to reduce the rate of pavement deterioration. The degree to which maintenance offsets the deterioration trend depends on three aspects of maintenance: the effectiveness of maintenance in counteracting pavement damage, the relative level of maintenance performed, and the variation in the level of maintenance over time.

The concept of effectiveness captures two technological characteristics of maintenance: (*a*) the inherent limitation of maintenance in its ability to affect pavement condition and (*b*) the dependence of this effect on the prior condition of the pavement. The first characteristic is qualitative and helps distinguish maintenance from more intensive activities such as rehabilitation or major repairs. For example, simulation results suggest that the beneficial effects of activities like slurry seals or fog seals of asphalt pavements do not exceed a gain of about 18 PCI points (*10*). The second characteristic derives from the experience that maintenance does not necessarily have the same beneficial effect throughout a pavement's life. For example, a new pavement may receive no benefits from maintenance because there is little or no damage to correct. At the other extreme, a severely deteriorated pavement may also derive little benefit from maintenance because its distress has proceeded too far. Thus, the maximum benefits of maintenance may lie in some midrange of pavement condition, although it is also possible to conceive of maintenance activities whose effectiveness plots are skewed [e.g., analytic studies of pavement patching suggest that maximum effectiveness occurs later in the pavement's life (*13*)].

Maintenance policies do not always call for 100 percent of existing damage to be repaired. Thus, the level of maintenance performed is a variable that must be superimposed on the consideration of effectiveness. The level of maintenance can be expressed conveniently through some relative measure—for example, a percentage or a scaled value. The latter will be used in this study. Level of maintenance will be defined on a scale of 0 to 10, with 0 indicating no maintenance and 10 indicating full maintenance. However, the level of maintenance is a potential value, because maintenance effectiveness also controls the degree of adjustment actually accomplished in pavement condition. Therefore, maintenance has little effect, regardless of the level specified, when the pavement is new or when it has deteriorated significantly.

The third effect represented in the maintenance model is the variation in the level of maintenance over time. It represents management decisions on when in the pavement life cycle to adjust the level of maintenance performed. Furthermore, it recognizes that pavement maintenance is not a one-time event, but rather comprises a series of periodic activities during some interval of the pavement's life. In this context, for example, a policy of "excellent maintenance" implies repeated performance of a mix of well-executed maintenance activities during some time, not simply a single instance of a high-quality maintenance treatment.

The second and third effects—the level of maintenance performed and the time variation of these levels—are under the control of management and can therefore be viewed as elements of maintenance policy. Maintenance effectiveness, on the other hand, is a technical matter. Maintenance effectiveness is sensitive to both the characteristics of pavement construction (i.e., how "receptive" the pavement is to maintenance) and the technology of maintenance itself. Improvements in either of these areas can change the degree to which maintenance can influence the condition of a pavement throughout its service life. Both the level of maintenance and its effectiveness can limit the adjustment in pavement condition that is achieved in any given year. The maintenance effectiveness defines the maximum adjustment that is technically possible; the level of maintenance and its scheduling define what percentage of total maintenance benefit available will be realized in the field.

Mathematical Development

These ideas can be reinforced more precisely in the mathematical models used to simulate pavement maintenance in each year t of the pavement life cycle. Assume that a pavement deterioration model is available to compute the annual incremental loss in PCI as a function of pavement structure, materials, traffic, environment, and other relevant factors. The adjustment in pavement condition due to routine maintenance in year t is as follows:

$$\Delta p_t = (L(t)/10)E \qquad \Delta p_t \leq \Delta P_t \tag{1}$$

where

Δp_t = the adjustment in pavement PCI due to routine maintenance in year t;
$L(t)$ = the level of pavement routine maintenance performance in year t on a scale of 0 to 10, as discussed above;
E = the effectiveness of routine maintenance at the current value of PCI, P_t; and
ΔP_t = the incremental loss in PCI due to pavement deterioration in year t.

Equation 1 limits the beneficial impact that maintenance has on pavement condition to that allowed by (*a*) the level of pavement routine maintenance specified by the manager, (*b*) the technological effectiveness of maintenance, and (*c*) the incremental deterioration in pavement condition. The third constraint inhibits maintenance from significantly improving pavement condition (a situation characterizing rehabilitation rather than routine maintenance). Thus, under ideal conditions, it is possible for maintenance to just offset the rate of deterioration, with no decrease or increase in pavement condition during this period. More typically, the limits imposed by either the maintenance level of performance or the maintenance effectiveness in Equation 1 will cause the predicted adjustment Δp_t to be less than the current rate of deterioration, resulting in a long-term decline in pavement condition to the point of rehabilitation or reconstruction.

For purposes of life-cycle costing, routine maintenance costs are modeled as a linear function of maintenance policy:

$$C(t) = \frac{cL(t)}{5} AR(t) \tag{2}$$

where

$C(t)$ = the pavement routine maintenance cost in year t, in dollars;
c = the unit maintenance cost, in constant dollars per lane mile per year, input as part of the description

of maintenance activities, and geared to average maintenance performance [i.e., maintenance level $L(t) = 5$];

$L(t)$ = the relative level of maintenance performance in year t;

A = the lane miles of pavement being maintained; and

$R(t)$ = the ratio of the following quantities: the actual adjustment due to routine maintenance and the total adjustment theoretically possible in year t, as computed by Equation 3.

$$R(t) = \frac{\Delta p_t}{EL(t)/10} \quad (3)$$

A comparison of Equations 1 and 3 shows that the ratio $R(t)$ will be less than 1.0 when Δp_t is limited by ΔP_t (i.e., when the incremental pavement damage bounds the incremental maintenance that can be performed). Therefore, the maintenance ratio term $R(t)$ acts as a proportional adjustment to the costs calculated in Equation 2 to account for this effective cap on the amount of maintenance that can actually be performed.

EXAMPLE ANALYSES

A series of examples using the models in Equations 1 through 3 will illustrate the application of life-cycle costing techniques to pavement maintenance. Different cases will be illustrated by varying, in turn, the technological effectiveness of maintenance, E, and the levels of maintenance effort, $L(t)$. The implications of the results for the technical, managerial, financial, and research aspects of maintenance management will then be explained.

Problem Description

The case study employs the pavement life-cycle cost model (*10*). To provide a basis for comparison, a zero-maintenance pavement deterioration curve was defined as shown in Figure 1. (The PCI at the end of 20 years is predicted to be 34.) The shape of the curve is characteristic of the deterioration model (*10*) and approximates an S-shaped deterioration trend. Any other pavement damage model could have been used as well, and the implications of other model choices will be discussed below. The focus will be on the relative changes in the deterioration trend as a function of different levels and effectiveness of routine maintenance.

The effectiveness of routine maintenance is characterized by the maximum effectiveness possible and the distribution of effectiveness values as a function of pavement condition. Values of effectiveness are measured by the potential adjustment in PCI points due to maintenance (sometimes called add points). Four distributions of effectiveness were tested:

- Early effectiveness, with maintenance providing the maximum benefit when the pavement is in good to excellent condition;
- Midrange effectiveness, with maintenance providing the maximum benefit when the pavement condition is in the middle of the PCI scale, between 40 and 60;
- Delayed effectiveness, with maintenance providing the maximum benefit when the pavement condition is between 30 and 40 on the PCI scale; and
- Late effectiveness, with maintenance providing the maximum benefit when the pavement condition is poor.

For each of these distributions, three levels of maximum effectiveness were tested: 10, 25, and 40 add points. Figures 2 and 3 show two of the effectiveness distributions for a maximum potential adjustment of 25 PCI add points.

Three facts should be noted regarding the definitions of effectiveness. First, the distributions of effectiveness respond to pavement condition, not to time. The labels such as "early" or "late" characterize the maximum potential impact of maintenance with respect to PCI, not age. (PCI may be correlated with age when a pavement first enters service, because the rate of PCI deterioration includes an age-related term. Once

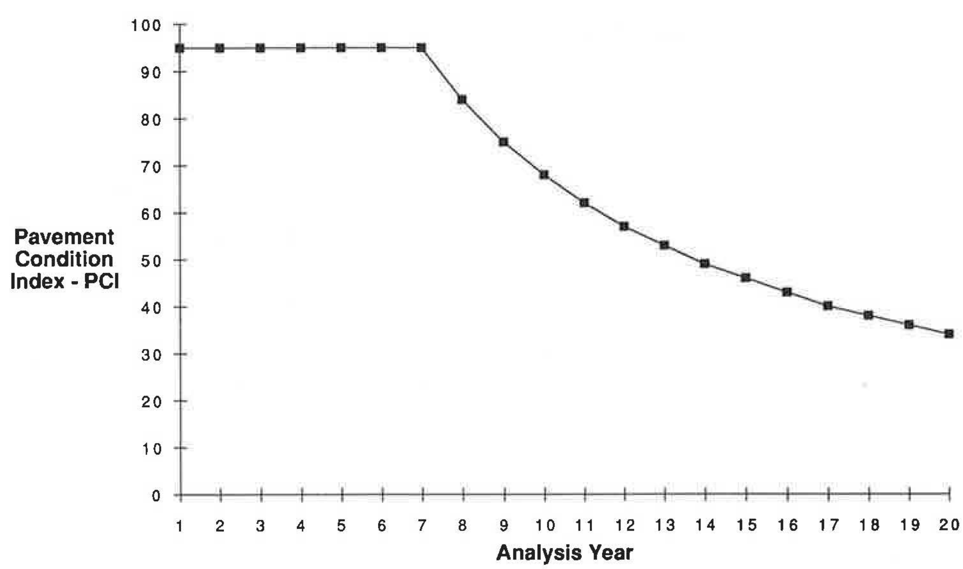

FIGURE 1 Pavement deterioration curve—no maintenance.

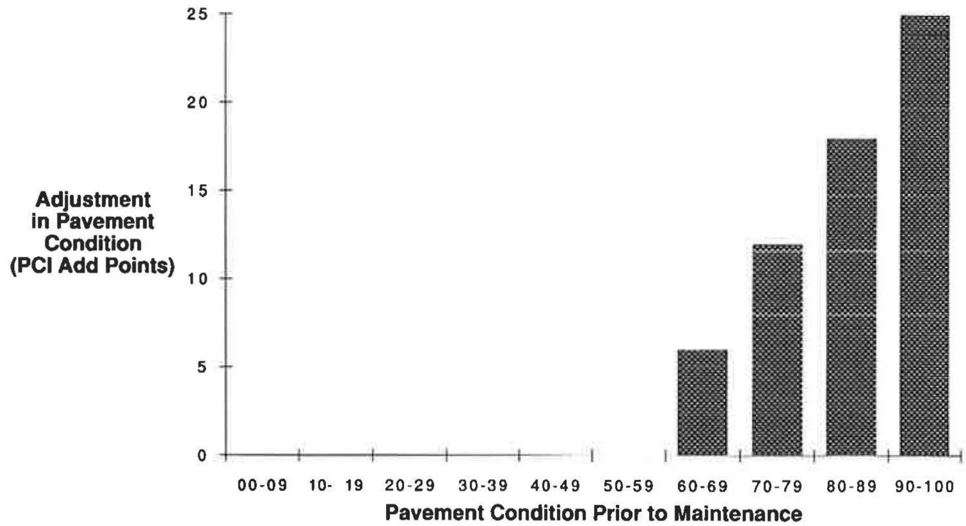

FIGURE 2 Example of early effectiveness (maximum effectiveness = 25 PCI points).

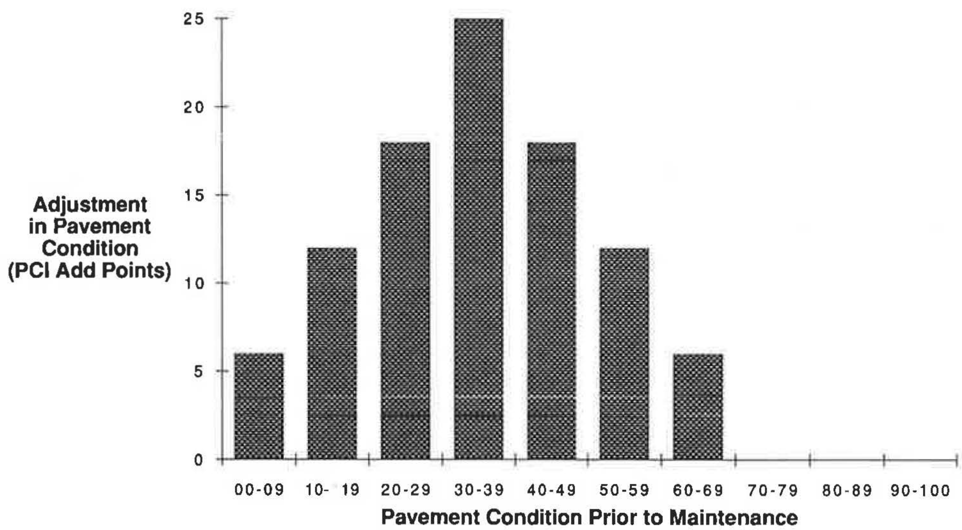

FIGURE 3 Example of delayed effectiveness (maximum effectiveness = 25 PCI points).

maintenance begins to be performed, however, the resulting increments of PCI improvement offset deterioration at least in part, and the relationship between PCI and age weakens.) Second, both the deterioration and the maintenance of the pavement are described in general terms, without distinction of pavement type or maintenance activity. This device is intentional and focuses the discussion on the broader consequences of maintenance policy and technology. Third, the definitions are intended to test a broad range of maintenance possibilities, not all realistic by today's technology. For example, an improvement of 40 PCI points would be a substantial adjustment for routine maintenance to achieve; that level of repair is more typical of rehabilitation. Nevertheless, the purpose of the case study is to probe the implications of different maintenance characteristics for life-cycle costing and to identify parameters for further research. Testing maintenance possibilities at the limits is part of this process.

The PCI add points described by the effectiveness distributions were referred to as potential adjustments, because they may be limited by management decisions on the level of maintenance to be performed. Two levels of maintenance are illustrated extensively in the case study: an average level of 5.0 and a "perfect" level of 10.0. The opposite extreme, zero maintenance, has already been established in Figure 1. An additional level of 2.5 will be introduced in the discussion of economic results. The exploration of this wide range of values will indicate important trends in the relationship of maintenance to pavement performance and costs.

An analysis period of 20 years was selected for this example. The discount rate used was 7 percent. The problem could be analyzed with other combinations of analysis period and discount rate, but the decision was made to focus more on the variation in the maintenance parameters themselves.

Technical Implications: The Role of Effectiveness

The twelve combinations of maintenance effectiveness (four distributions and three maximum values) were imposed on the pavement deterioration curve in Figure 1. To allow the full mobilization of technological effectiveness, the maintenance level was set at 10.0 for this set of runs. An example of the results obtained is shown in Figure 4 for effectiveness distributions limited by maximum potential values of 10 PCI points. (Results for maximum improvements of 25 and 40 points are similar to those shown in Figure 4, but the curves on the right-hand side of the figure are elevated, reflecting the additional improvement due to maintenance.) For each of the four distributions of effectiveness in Figure 4, two curves are drawn: the lower curve (solid symbols) indicates the value of PCI each year before maintenance; the upper curve (hollow symbols), after maintenance.

The results indicate that maintenance effectiveness can influence the long-term trend of pavement condition. Both the distribution of effectiveness and its maximum potential value contribute to this result. For example, maintenance activities with early effectiveness (acting on pavements with PCI of 60 to 100, as shown in Figure 2) maintain pavement condition at a correspondingly high level. Whereas the activities with maximum effectiveness of 10 are able to sustain PCI values in the high 80s (Figure 4), those with a maximum effectiveness of 25 (or 40) are able to sustain a PCI value essentially equal to that of a new pavement. On the other hand, activities with a delayed effectiveness (Figure 3) operate on the pavement in a lower PCI range. For the delayed effectiveness, a maximum adjustment of 10 PCI points will maintain the long-term pavement condition in the high 50s, but a maximum adjustment of 25 (or 40) will maintain pavement condition in the high 60s. Activities with late effectiveness have no influence on the deterioration trend at a maximum value of 10 PCI add points and only a marginal influence at a maximum of 25 add points.

Figure 4 shows pavement condition maintained indefinitely at some level as the result of maintenance—an unrealistic result, particularly over a long period of time. The reason is that the maintenance applications in Figure 4 are idealistic in that their full effectiveness is mobilized (i.e., maintenance level = 10.0). Thus, in these cases the routine maintenance overcomes the incremental deterioration in pavement condition each year. If a realistic maximum effectiveness of 10 PCI is considered, as in Figure 4, but an average level of maintenance of 5.0 is imposed, the result is as shown in Figure 5.

Figure 5 indicates a more realistic trend, particularly for activities with early maintenance effectiveness. There is clearly a benefit of this maintenance, but it does not extend indefinitely. Instead, the curve shows an adjustment of about 8 PCI points above the zero-maintenance trend (which is coincident with the curve for late maintenance effectiveness in Figure 5). This correction translates in Figure 5 into an extension of pavement life of 3 to 4 years, which agrees with other findings (*12*). The midrange and delayed effectiveness curves still show an indefinitely maintained condition in Figure 5, because these activities occur on a more gently sloping part of the deterioration curve and are thus able still to counteract the predicted deterioration each year. This would not be the case, however, if they occurred on a more strongly concave segment of the deterioration function (i.e., where the rate of damage accelerates with time). Thus, the results below may be conservative for activities whose effectiveness occurs later in the pavement's life.

Management Implications: The Role of Maintenance Level

Figure 5 showed the interaction between the technological effectiveness of maintenance and the level of maintenance

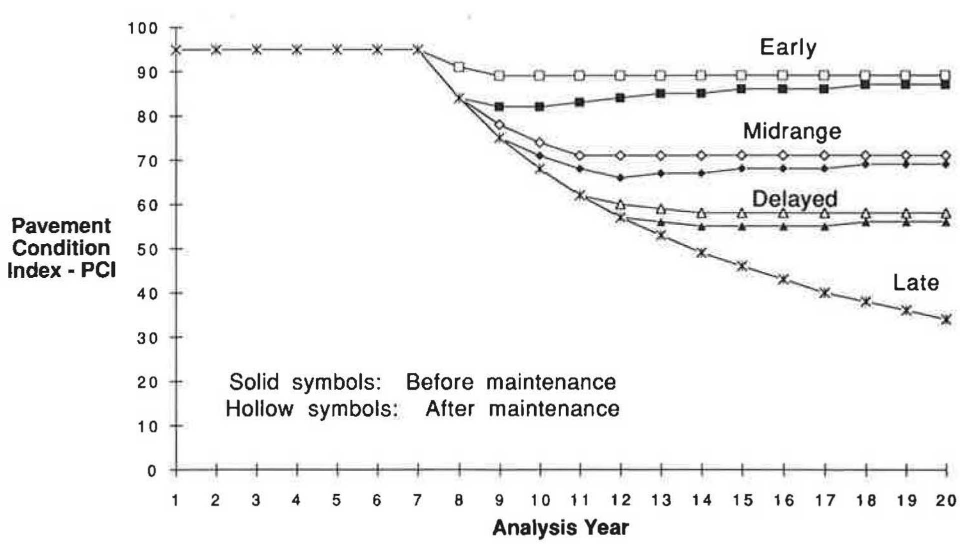

FIGURE 4 Influence of maintenance effectiveness (maximum effectiveness = 10 PCI points, level of maintenance = 10.0).

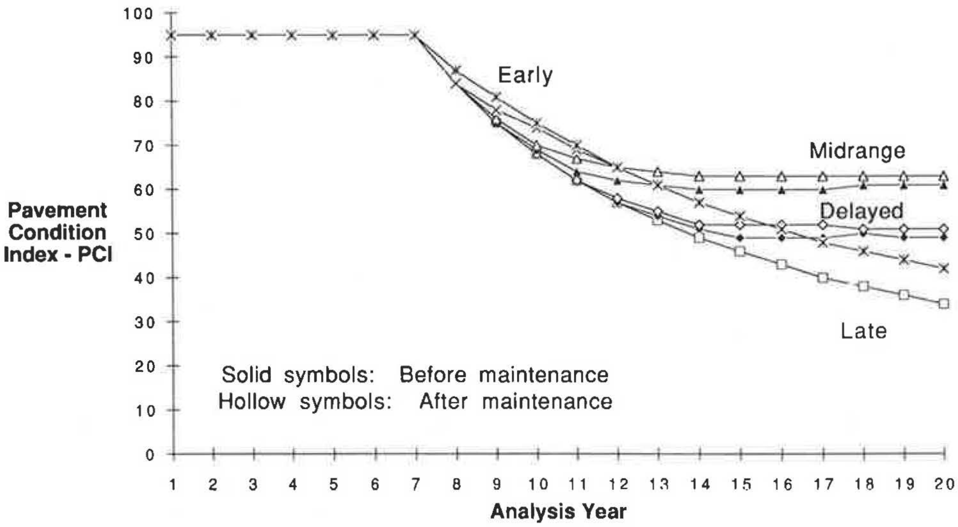

FIGURE 5 Influence of maintenance effectiveness (maximum effectiveness = 10 PCI points, level of maintenance = 5.0).

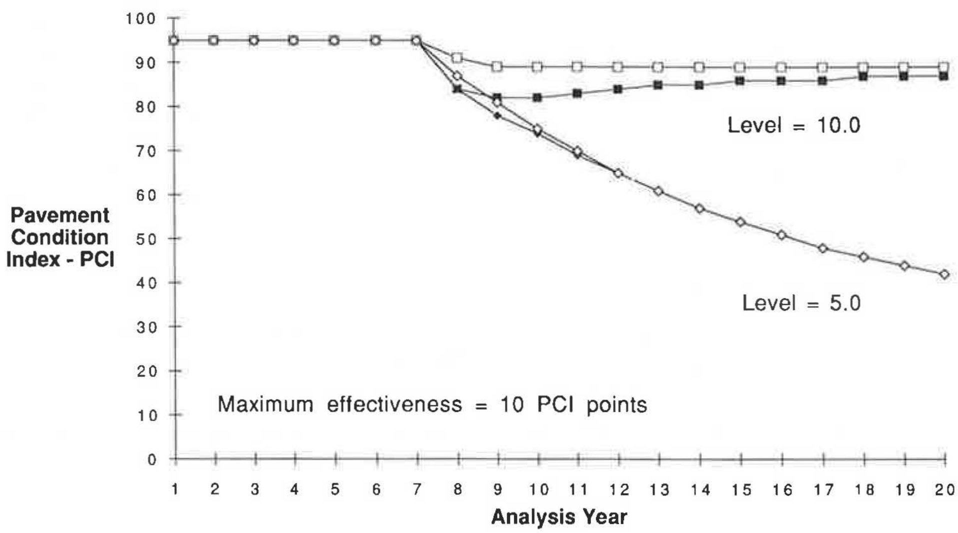

FIGURE 6 Influence of level of maintenance for activities with early effectiveness.

performance specified by management. The interaction is explored further in this section. Figure 6 shows the results of the two levels of maintenance applied to activities of early effectiveness having a maximum adjustment of 10 points. Essentially, it captures the comparison of results between Figures 4 and 5 described above. As before, pairs of curves for each level show, respectively, the PCI values before and after maintenance each year. The divergence in the deterioration trends for the two levels shows dramatically the implications of failing to exploit the full technological benefits of maintenance, especially when the rate of pavement deterioration is rapid. As explained, this type of result occurs not because of the early stage at which this maintenance is performed per se, but rather because in the case under investigation, maintenance with early effectiveness intervenes exactly when the pavement is deteriorating most rapidly. With a different shaped deterioration curve, other examples of maintenance effectiveness would exhibit this type of behavior.

Economic Implications: The Role of Discounted Costs

Discounted cost streams were computed for each case above (and an additional one for a maintenance level of 2.5), tabulating both highway agency costs for routine maintenance and road user costs. The user cost calculations (*10*) include some sensitivity of vehicle operating costs to pavement condition, and it is these differences that were compared among the maintenance alternatives. A total life-cycle cost analysis could have been performed; however, it would have required assumptions for the scheduling of different levels of maintenance over time as well as policy specifications and costs of rehabilitation activities. The additional assumptions would have not only complicated the presentation of results, but also muted the direct relationship between routine maintenance options and their consequent costs and benefits desired in this study.

Therefore, the approach taken was to compute the discounted value (i.e., present value) of the net life-cycle benefits of each alternative as compared with the zero-maintenance case. The net benefits comprise the discounted values of (*a*) savings in vehicle operating costs due to better pavement conditions arising from maintenance alone (no contribution from rehabilitation activities is considered) less (*b*) the costs of the maintenance performed. The total discounted user costs are typically six orders of magnitude (i.e., a million times) larger than the discounted maintenance costs, a result that is not unusual. What is important, however, is how the discounted user costs change due to maintenance. It is the reductions in discounted user costs that are compared with the discounted maintenance costs to calculate net benefits.

The zero-maintenance assumption provides the computational benchmark needed to quantify net benefits across the diverse cases investigated. Application of these results in practice, however, is properly done on an incremental basis by comparing the current, or base case, maintenance policy (which is generally not one of zero maintenance) with a proposed alternative. Incremental net benefits of an alternative to a base case are easily computed from the results presented below by taking the difference between the respective benefit values. For example, assume that one of the cases discussed below (with discounted net benefits of, say, $40 million) approximates the current maintenance policy of a DOT, and an alternative maintenance policy has net discounted benefits of $50 million. The incremental benefits of the alternative to the DOT would equal $10 million ($50 million less $40 million). The large number of possible combinations of cases investigated makes it difficult to organize all results on an incremental basis in an easily understood format. Therefore, the results have been presented as net discounted benefits relative to zero maintenance. Any two maintenance options can be compared by performing the simple subtraction described above.

Examples of discounted net benefit results are illustrated in Figures 7 to 9 for levels of maintenance of 10.0, 5.0, and 2.5, respectively, and for all 12 combinations of maintenance effectiveness. The costs were generated by assuming a 10-mi length of four-lane highway and discounted at 7 percent over the 20-year analysis period. Basic maintenance costs of $500/lane-mi were assumed for a maintenance level of 5.0, with adjustments as indicated in Equation 2 for other maintenance levels. Even allowing for uncertainty in the exact values of the maintenance and user cost models, the following conclusions are warranted:

1. Within each basic distribution of effectiveness, higher magnitudes of effectiveness are desirable. This finding translates into an implied benefit of improved maintenance technology—one that can improve pavement condition to a greater degree or for a longer period. This effect becomes more pronounced when maintenance performed at later stages in the pavement's life (e.g., the midrange, delayed, and late distributions of effectiveness) or the inability to specify full maintenance each year (i.e., maintenance level is less than 10.0 for at least some part of the pavement's life) is considered.

Although the cost of improved maintenance effectiveness is not included in the cost calculations in Equation 2, the results in Figures 7 through 9 indicate the value associated with the improved measures of effectiveness. For example, for a maintenance level of 5.0, the differences between a maximum effectiveness of 10 PCI and one of 25 PCI range from $10 million for the midrange and late distributions to more than $30 million for the early distribution (on an incremental basis). These values far exceed the discounted cost of maintenance over the 20-year period, which is less than $150,000 in all cases.

Finally, there is little beneficial difference among the magnitudes of early effectiveness for a maintenance level of 10.0 (the first three columns in Figure 7). The reason is that all of these maintenance activities contributed to high levels of

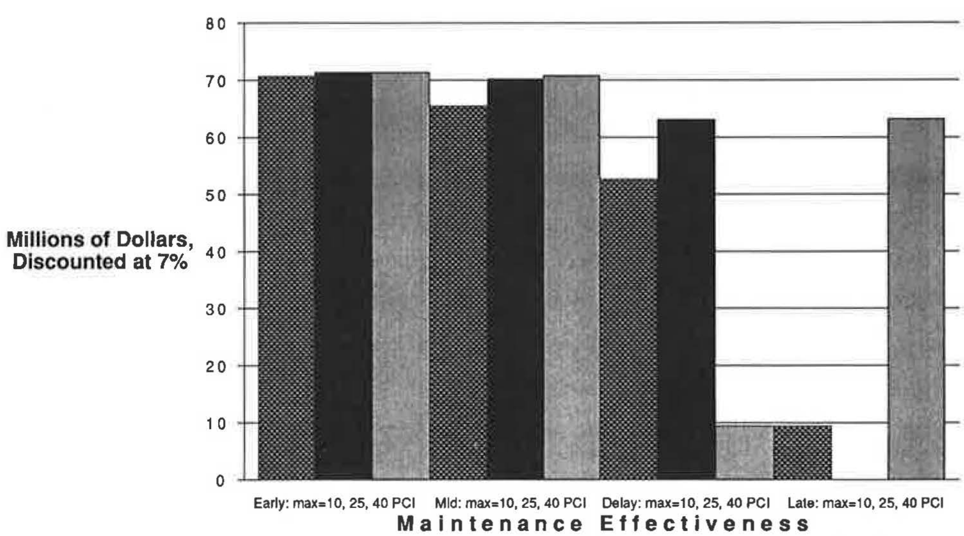

FIGURE 7 Net benefits of maintenance: level = 10.0 for various measures of effectiveness.

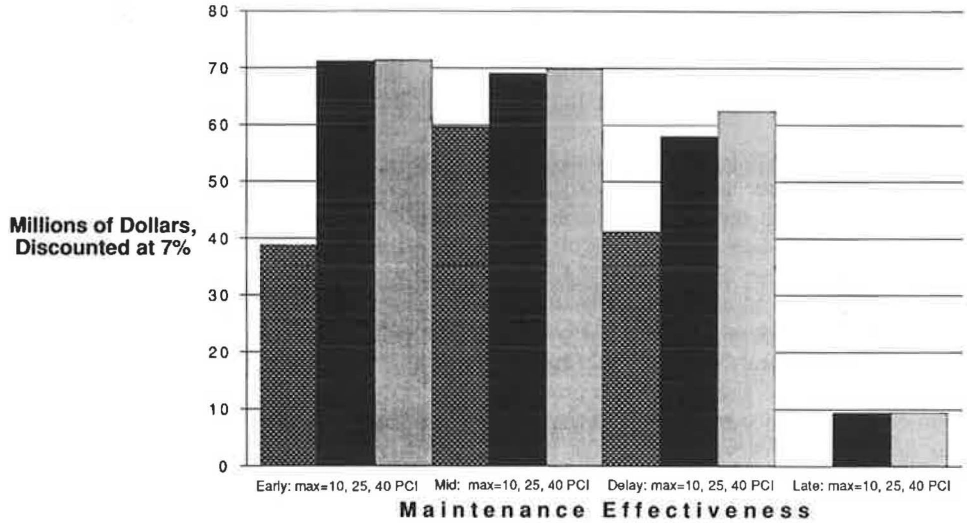

FIGURE 8 Net benefits of maintenance: level = 5.0 for various measures of effectiveness.

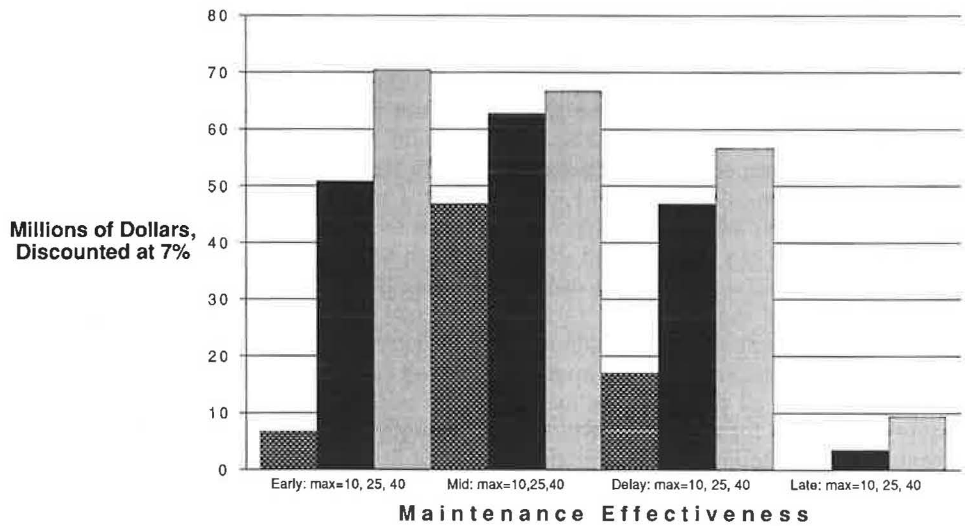

FIGURE 9 Net benefits of maintenance: level = 2.5 for various measures of effectiveness.

pavement performance (e.g., the top curve in Figure 4). This finding highlights the importance of early or preventive maintenance in keeping the condition of the pavement as new as possible for as long as possible.

2. Within the results for any level of maintenance, the net benefits decline for activities with successively later degrees of effectiveness. For example, in Figures 7 to 9, the net benefits decline as one moves from early effectiveness to midrange, delayed, and late effectiveness (basing the comparison on corresponding maximum values: 10, 25, or 40 add points). Furthermore, in the cases studied here, the results are conservative in that (*a*) the predictions for later stages of maintenance effectiveness often assumed indefinite maintenance of pavement condition at some asymptotic level (e.g., as illustrated in Figure 5), resulting in a prolonged period of benefits; and (*b*) the cost calculations do not include any reconciliation of the different terminal conditions of pavements at the end of 20 years. Such corrections (e.g., using a capitalized cost analysis or computation of salvage value and including rehabilitation as well as maintenance) would reduce the net benefits of maintenance in Figures 7 to 9 for the later stages of effectiveness. Somewhat different results are possible for different shapes of deterioration curves. For example, a more concave deterioration trend would derive greater benefits from maintenance with later effectiveness, as noted earlier. This is a point for further research.

3. Both findings are magnified as the level of maintenance is reduced. As the maintenance level is decreased from its maximum of 10.0, one must increasingly depend on (*a*) whatever technological effectiveness maintenance provides and (*b*) exploiting this effectiveness as early as possible to maintain a level of net benefit characterized by higher policies. For example, for the full maintenance policy shown in Figure 7, many of the effectiveness options yield net discounted benefits

between \$50 million and \$70 million. When the maintenance level is reduced to 2.5 as shown in Figure 9, only the higher magnitudes of each distribution of effectiveness attain this level of benefit. (Activities having early effectiveness limited to 10 and 25 add points suffer because of the magnification of the first conclusion above. The limited early effectiveness cannot be mobilized sufficiently in a constrained maintenance policy to forestall the period of rapid pavement deterioration that coincides.)

CONCLUSION

Through life-cycle costing, the effects of pavement maintenance can be compared with other options for pavement management. Some ways in which the characteristics of pavement maintenance can be expressed analytically, and the implications of these characteristics for pavement management and technology, have been explored. Several conclusions have already been discussed. In addition, the following are conclusions of the study:

- The life-cycle benefits of pavement routine maintenance are high in relation to costs.
- The life-cycle benefits of improvements in maintenance are high and justify, on an economic basis, significant expenditures for technological improvements in items like maintenance inspection, materials, equipment, activity performance, and quality control.
- The life-cycle benefits of early and frequent maintenance performance are high. The longer that maintenance keeps the pavement condition like new and forestalls more rapid rates of deterioration, the more significant are the benefits.
- The life-cycle benefits of managing maintenance better are high, particularly in situations where pavement condition, the rate of pavement deterioration, the level of maintenance, and the effectiveness of maintenance are changing over time.

The interplay of economic, management, and technological issues raised in this case study shows that maintenance offers a rich subject in the management of pavements using life-cycle principles. These findings, supplemented by ongoing research in the field, will provide the basis for integrating maintenance with capital projects, regulatory policies, data collection, and other actions in pavement management. Moreover, these findings suggest a basis for evaluating and justifying future improvements in maintenance data collection and performance.

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Abridgment

Solutions To Improve Ice and Snow Control Management on Road, Bridge, and Runway Surfaces

JOE R. KELLEY

An overview of the products and services offered by a full-service commercial weather support company is provided. Solutions are presented to make winter travel safer and to help reduce the billions of dollars spent annually on ice and snow control in North America. The solutions offered come from unique meteorological (pavement- and atmospheric-sensing) instrumentation, data processing units, tailored microcomputer software, a numerical forecasting model that projects pavement and weather conditions, and a specialized weather-forecasting center established to support the transportation industry. Methods to improve the interface between the provider of specialized weather equipment and unique pavement forecasts and the customer who relies on real-time pavement weather information and forecasts to reduce ice and snow control budgets are described.

Significant progress has been achieved in meteorology since Aristotle wrote *Meteorologica* in 340 B.C. and the study of weather became recognized as a science rather than a phenomenon based on superstition, imagination, and acts caused by Greek gods. *Meteorologica* was the "weather bible" for scientific research for almost 2,000 years. Little progress was made until the 16th and 17th centuries, when weather-measuring instruments were introduced, allowing scientists to document and study weather. The greatest growth of meteorology resulted from the birth of the aviation industry after the flight at Kitty Hawk in 1903. Figure 1 gives several historical weather support events.

To support the aviation industry, the U.S. Weather Bureau (now the U.S. National Weather Service) established weather-observing and forecasting facilities at air terminals across the nation. Weather forecasts and predictions can only be as accurate as the information on which they are based. Nearly all weather forecasts are based in part, if not completely, on the surface aviation report, which is taken, recorded, and disseminated from airports around the world. Airport weather observations are generally used by the media as the official weather report, and the official weather forecast for the city, state, and region is based on the surface aviation report. The report is generally available only once per hour. It is accurate and may be timely enough for aviation, but it does not contain surface (pavement) weather information. Not until the mid-1970s were airports in North America introduced to a weather-sensing technology with instrumentation that provided runway-specific temperature, moisture, and information on deicing chemical concentration. In 1982 St. Louis, Missouri, was the first city to purchase and use a street-monitoring system for ice and snow control management. Currently, Road/Runway Weather Information Systems (RRWISs) are operational in 42 states and 6 Canadian provinces. They are installed in more than 90 North American airports and indicate the following (also see Figure 2):

- Surface (pavement) temperatures are obtained from solid-state electronic devices installed in the roadway or runway. The sensors are usually constructed of materials with thermal characteristics similar to those of common pavement materials. Their performance is not degraded by climatic conditions, traffic, or ice-control chemicals. The tested and proven surface sensors are thermally passive and have a stable operating range from −30°C to +50°C.
- Subsurface temperature probes are installed directly below the surface sensor at a depth near 40 cm and provide heat flux information primarily for computer models designed to predict pavement temperature. Frost depth information is also used by highway agencies to regulate truck routing on the basis of the frost level beneath the road surface. The sensor is accurate from −30°C to +50°C.
- The onset and termination of any type of hydrometeors (including precipitation) in the air is detected by sensing interruptions in its infrared optical beam.
- Pavement condition statuses are dry, wet (above 0°C), wet (not frozen at or below 0°C), snow or ice (at or below 0°C), dew, frost, and absorption.
- Chemical factor is a relative indicator of the deicing or anti-icing chemical present in the moisture on the surface sensor.
- Air temperature is measured over a range from −62°C to +70°C.
- Relative humidity generally ranges from 10 to 100 percent.
- Wind direction and speed sensors have an operating range of 360 degrees and record speeds up to 215 km/hr.

The remote processing unit of the RRWIS gathers data from all connected sensors and processes, stores, and transmits these data (surface temperature, subsurface temperature, air temperature, relative humidity, and precipitation).

Surface Systems, Inc., 10420 Baur Boulevard, St. Louis, Mo. 63132.

EVENT	YEAR
* ARISTOTLE wrote 'METEOROLOGICA'........	340 B.C.
* Thermometer/Barometer.................	17TH Century
* U.S. Weather Bureau...................	1870
* 'KITTY HAWK' Flight...................	1903
* Surface Sensors For Runways...........	1970s
* Roadway Surface Sensors (City of Saint Louis, MO)..............	1982
* Pavement Specific Forecasting Center Established (St. Louis, MO).....	1986

FIGURE 1 Historical weather support events.

•Pavement TEMPERATURE At The Surface Head

PAVEMENT STATUSES

•DRY
•WET (Pavement Temperature Above Freezing)
•WET (Not Frozen At Or Below Freezing)
•SNOW - ICE (At Or Below Freezing)
•DEW
•FROST

CHEMICAL DETECTION

•CHEMICAL FACTOR (Deicing Chemical Present)

FIGURE 2 Surface sensor information.

PAVEMENT-SPECIFIC WEATHER FORECASTING

Early in 1986 a new type of meteorological forecasting center was established solely for the prediction of pavement temperatures and pavement weather conditions. This specialized center is staffed by meteorologists who base their forecasts not only on data from pavement weather stations and atmospheric observations but also on weather information provided by federal agencies in the United States and Canada.

Pavement Temperature and Pavement Condition Prediction

Pavement-specific temperature and weather forecasts are generated using site-specific roadway or runway data with forecast input data from meteorologists. Data are processed with a numerical model on the basis of the heat balance equation. Pavement prediction models require site-specific surface and subsurface data for initialization and are based on the heat balance of the pavement surface. The heat balance equation is expressed as follows:

$$\begin{aligned} 0 &= \text{heat in} - \text{heat out} \\ &= (\text{sun's heat} + \text{air's heat} + \text{clouds' heat} \\ &\quad + \text{heat of condensation} \\ &\quad + \text{turbulent heat} + \text{ground heat}) \\ &\quad - \text{heat loss from pavement} \end{aligned}$$

or

$$RN + H + S + LE = 0$$

where

RN = net radiation,
H = heat exchange with the air,
S = heat exchange with the pavement structure, and
LE = latent heat exchange.

Ice and Snow Control Forecast Service Bulletin

Pavement weather bulletins are issued three times per day (early morning, early afternoon, and evening) to subscribers. The prediction bulletin projects pavement and weather parameters that affect ice and snow control procedures over a 24-hr period. Graphically presented information includes the following (also see Figure 3):

1. A pavement temperature forecast: This display shows the temperature profile forecast for the next 24 hr in 20-min intervals. An indicator for a temperature of 32°F (0°C) is displayed when predicted temperatures are near freezing.
2. A freezing-temperature indicator: When forecast pavement temperatures are equal to or less than 32°F, an indicator appears on the line directly below the temperature forecast graph for all times meeting the freezing criteria.
3. A precipitation and surface condition forecast: The forecast graph shows what type of precipitation is expected, the start and finish times, and the length of time that the surface will remain wet.
4. A snow accumulation forecast: This portion of the graph depicts the snow depth forecast (in inches or centimeters) for the valid period of the forecast.
5. A wind speed and direction forecast: This gives the mean wind speed and wind direction forecast for 3-hr intervals during the valid period of the forecast.
6. A mean air temperature and windchill forecast: This gives the mean air temperature and windchill every 3 hr over the valid period of the forecast.
7. A forecaster's discussion: The forecaster who issues the bulletin provides weather decision impact information in plain language.

PAVEMENT-SPECIFIC FORECASTS IN NORTH AMERICA

The decision to establish a facility specifically to provide ice and snow control weather-forecasting support was greatly

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FIGURE 3 Pavement-specific weather forecast bulletin.

influenced by customers with ice detection systems. The Wisconsin Department of Transportation, Division of Highways, which had already installed ice detection systems, submitted a request for proposal (RFP) for the development of an ice- and snow-forecasting model. The RFP stated that the department wanted better tools to perform its tasks and that it needed a greater degree of confidence when it called out the snowplows and deicers. The design of the ice and snow control forecasting center took into account the clearly stated needs defined in the RFP.

The benefits of the Wisconsin Winter Weather System (WWWS) have been acknowledged (*1*). They include reduced personnel overtime costs and decreased use of deicing chemicals and abrasives. The Wisconsin Department of Transportation indicated that if pavement temperature and brine content are known and an accurate pavement temperature forecast is made, savings on overtime costs can be achieved and more precise work schedules planned. Savings of up to 4 hr per individual (a total of approximately $144,000) can be realized for each significant storm. Use of the WWWS during a single storm is now estimated to save about 2,500 tons of salt, or about $75,000. If the WWWS is used statewide for 15 storms, or about 50 percent of the storms, the season savings will be 37,000 tons of salt, or $1,125,000.

The pavement weather forecasting product received the 1988 Award of Excellence in Transportation from the International Winter Cities Corporation (IWCC) in Edmonton, Canada. The IWCC is a nonprofit organization formed to promote the economic advantage of winter.

USING PAVEMENT-SPECIFIC INFORMATION FOR OPERATIONAL DECISIONS

An evaluation of the SCAN 16 EF roadway weather information system installed at four locations in New Jersey stated the following (*2*):

> Utilization of the system leads to reduced deicing chemical usage and a savings in manpower and equipment costs. By monitoring pavement temperatures, Region IV [NJDOT] maintenance personnel were able to delay spreading deicing chemicals by up to three hours. In some cases, these delays resulted in the saving of up to one deicing chemical application per storm. These same delays, combined with delays in crew call-outs and early crew releases, resulted in savings in manpower and equipment costs. The system's greatest potential appears to be a real time statewide roadway weather information system interactively shared with other agencies. Some of the possible benefits: 1) reduced deicing chemical usage (a saving of 54,170 dollars for each spread saved statewide), 2) improved weather forecasts for the state of New Jersey, 3) reduced snow and ice related accidents, 4) other agency interaction (e.g. aeronautics could use the information to assist pilots in developing flight plans, data from the system could be used by the State Police to supplement their Emergency Management System, etc.), 5) savings in manpower and equipment use. A savings (state wide) of 11,500 dollars per hour could be realized for each hour saved by delaying crew call-outs and expediting crew releases. The SCAN System 16 EF works. It is in the best interest of the State of New Jersey and the general public to expand the system to provide statewide coverage.

SUMMARY

Technological advances continue in weather instrumentation, remote pavement sensing, computer design and function, computer software, and communications. Although they are relatively new, roadway and runway weather stations with pavement-specific data provide improved information on which to base ice and snow control management decisions. Numerical weather prediction models are now more accurate and provide the meteorologist with much more information than was previously available to make forecasts.

Pavement weather events directly affect all pavement maintenance decisions. Therefore, pavement weather data and pavement-specific forecasts should be considered by agencies responsible for ice and snow control. Pavement-specific weather reports and forecasts allow ice and snow control officials to be proactive instead of reactive. This can reduce the billions of dollars spent each year on ice and snow control in North America. Making the correct ice and snow decision involves understanding meteorological processes as they affect pavements. When will precipitation start? Will it be rain, snow, mixed, or will rain freeze as it strikes the surface? How much will there be and how long will it last? How cold will the pavement get? What chemicals are effective? Specialized workshops and seminars can improve the use of pavement weather information and weather impact forecasts for ice and snow control on roadways, bridges, and runways. Weather forecasting will not be an exact science in the foreseeable future, but progress is being made. Surface- (pavement-) specific weather information and advances in data collecting and processing and numerical modeling techniques are improving weather support service to ice and snow control managers.

ACKNOWLEDGMENT

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Computer-Aided Maintenance Management

JOHN P. ZANIEWSKI AND MICHAEL J. WILES

A maintenance management system (MMS) allows managers to organize and control maintenance work. A computer-aided maintenance management system (CAMM) is being developed to provide local highway agencies with a tool for developing and implementing an MMS in an economical manner. The CAMM consists of three modules: the MMS development module, the MMS data base module, and the MMS analysis module. The three modules are integrated to function as a unit. The development module allows management to tailor the elements of the MMS, such as maintenance activities, performance standards and quantity standards, and road distresses most likely to be encountered, to the agency's needs. The data base module allows the user to establish and edit the road inventory, pavement condition, personnel, equipment, and material data bases. The analysis module runs the developed MMS. The software will generate performance budgets and schedules for the selected work. CAMM helps managers schedule, budget, and select activities for road maintenance and provides road authorities with the schedule and budget needed to secure political support and funding for adequate road maintenance.

A maintenance management system (MMS) allows managers to organize and control maintenance work. MMSs use information on pavement maintenance needs, available equipment and personnel, and scheduling data to generate work programs and performance budgets for roadway maintenance. MMSs are widely used by state highway agencies and large municipal and county highway agencies. The technology is equally applicable to smaller agencies.

The Federal Highway Administration supports the transfer of technology to local highway agencies through the Rural Technology Assistance Program and technology transfer centers. Under this program, the FHWA sponsors the development and teaching of a 2-day course on MMSs. The workbook for the course provides sufficient detail to allow a small highway agency to establish a manual system (*1*). However, because of the low cost and ready availability of microcomputers, it is believed that a computerized version of the system would be a greater benefit to potential users.

Highway agencies placed several restrictions and conditions on the program, including

1. Use of a DOS-based microcomputer with 640k of RAM and a hard disk,
2. Menu drivers to minimize the need for computer knowledge by the user,
3. Default selections whenever practical (defaults are limited to flexible pavements for the initial development),
4. Maximum flexibility in the options available to the user for defining the needs of the local agency, and
5. Use of a high-level computer language so the program can be released to users without the need to purchase proprietary software (PASCAL was selected for program development).

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Although the program was developed to be as easy to use as possible, it does not relieve the user of understanding maintenance management and its application in a specific case. Hence, the name selected for the program was Computer-Aided Maintenance Management, or CAMM.

Figure 1 shows the organizational structure of CAMM. The maintenance management process is accomplished in three modules for (*a*) development and editing of the system, (*b*) data base development and maintenance, and (*c*) maintenance management analysis.

The development module allows the user to tailor the required elements of the MMS to the needs of the highway agency. The data base module uses the results of the development step to create the data base structure required by the agency and allows the user to enter and edit data elements. Finally, the analysis module performs calculations, including developing budgets and scheduling work.

Figure 1 shows the CAMM menus for module selection. The desired option is highlighted by pressing arrow keys and selected by pressing the return key.

DEVELOPMENT MODULE

There are several approaches to developing and implementing an MMS. The following discusses the elements in MMSs (see Table 1) and the CAMM implementation.

Objective Statement

The objective statement defines the maintenance goals for the management unit. Without clearly stated goals, the management will not know what is expected from the system, and it will be difficult to evaluate and improve the system.

The objective statement section in CAMM allows the user to write an objective statement using a simple line editor. The objective statement contains qualitative information about the goals and limitations of the system. An objective statement is an important part of an MMS, but the objective statement in CAMM does not interact with the other components of the system.

Main Modules	Components
DEVELOP/EDIT	Objective Statement Work Activities Road Class Resources Quantity Standards Performance Standards Inventory Pavement Condition Calculation Units Reports and Forms Matching
DATA BASES	Road Inventory Road Distress Maintenance Needed Maintenance Accomplished
ANALYSIS	Performance Budget Scheduling Crew-Day Cards

FIGURE 1 CAMM menu system.

Work Activity

A work activity describes a specific function that will be performed by the maintenance crews, such as crack sealing, mowing, and pothole patching. Only those activities that require a significant amount of work by the agency should be defined. More than 200 work activities are performed by highway maintenance. The FHWA training course recommends developing an MMS for the 35 to 45 activities that represent approximately 80 percent of the work. Use of a greater number of work activities can create confusion and excessive paperwork. A system that handles the majority of the important activities and is easy to use is preferable to a detailed system that may not be implemented because of its complexity. CAMM is designed to handle 60 work activities.

The work activity section of CAMM allows the user to define the work activities needed. The user is provided with a default list of work activities. The user selects from these or creates others matching the needs of the agency.

CAMM provides several information fields for each work activity. The information required for a work activity consists of the following:

- A numeric code is used to identify the activity. It is preferable to have similar codes for each major work activity (for example, 100 to 199 for roadway surface and 200 to 299 for shoulders). This maintains consistency in the system. Duplicate codes are not allowed by CAMM.
- A unique name describes the activity. Duplicate names are not allowed by CAMM.
- Possible starting day is the earliest time in the year that an activity can be performed.
- Expected starting day is the normal starting date for the activity.
- Expected ending day is the normal ending date for the activity.
- Possible ending day is the latest possible ending date for the activity.
- Frequency is the frequency of the activity. This can be seasonal, routine, when needed, and so forth.

The major work activities defined in CAMM are roadway, shoulders and approaches, roadside, major structures, traffic services, snow and ice control, service functions and overhead, extraordinary maintenance, drainage, and miscellaneous. These activities can be used in the default format, added to, or edited, to customize the system to the user's needs.

The possible starting and ending dates for an activity indicate the earliest and latest dates that the activity can be performed. The expected dates define the normal dates for performing the activity. The difference between them allows flexibility in the scheduling of work.

Road Class

The amount of maintenance required on a road can depend on the classification of the road. The road class screen of CAMM allows the user to define the class of roads used by the agency. The default classes are primary, secondary, and arterial. The classes can be edited by the user.

Resources

Resources consist of labor, equipment, and material. Each type of resource is defined on a separate screen. When scheduling is performed, the resources data base is checked to verify the availability of the resources.

Labor class, number of employees, hourly wage, and employment status are recorded in the labor section (for example, truck driver, 12, $10.00/hr, permanent). Labor includes permanent and temporary employees.

The type of equipment used and the unit cost are recorded in the equipment section [for example, dump truck (5 yd^3),

TABLE 1 ELEMENTS OF MAINTENANCE MANAGEMENT

OBJECTIVE STATEMENT	The objective statement defines the maintenance goals for the management unit.
WORK ACTIVITIES	A work activity describes a specific function that will be performed by the maintenance crews, such as: crack sealing, mowing, pothole patching, etc.
ROAD CLASS	Road classification allows the agency to allocate different levels of work to the various road classes.
QUANTITY STANDARDS	A quantity standard is an average annual value that specifies how often a work activity should be performed in order to maintain the road feature at the desired level of service.
PERFORMANCE STANDARDS	The performance standard is a written procedure for each work activity.
INVENTORY	This is an inventory of the physical characteristics of the road, such as: width, number of lanes, number of gutters, etc.
PAVEMENT CONDITION	Road condition consists of the type, extent, and severity of the distress experienced by the pavement.
CALCULATION UNITS	The units are the units used for all calculations in MMS.
RESOURCES	This is the type of resources used in a MMS. The resources consist of: labor, equipment, and material.
REPORTS AND FORMS	Reports and forms are used by management to monitor and schedule work.

$25.00/hr]. The equipment can be owned by the agency or rented when needed.

Unit costs for the materials are provided in the material section (for example, concrete, $50.00/yd^3.

CAMM compares the available resources with the performance standards. Only the entries in the resources section are allowed in the performance standards. This ensures consistency within the management system.

Quantity Standards

A quantity standard specifies how often a work activity should be performed to maintain the road feature at the desired level of service. The quantity standard is expressed as the number of work units per year. For example, the quantity standard for lawn mowing could be 4.0 mowings per year. For a slurry seal that is performed every 10 years, the quantity standard would be 0.1.

Each road class can have a unique quantity standard for each work activity. For example, the amount of pavement maintenance required on a primary road will usually be more than that required on a secondary road; therefore, the primary road would have a larger value for that particular quantity standard. CAMM requires the user to enter a quantity standard for each work activity. The program compares the quantity standard list with the work activities list and identifies the work activities that need a quantity standard.

Performance Standards

A performance standard defines the method for performing a work activity. Performance standards specify the most efficient combination of crew size, type of equipment, and materials required for a particular activity. The performance standard also includes an estimated average daily production rate for each work activity.

The elements of a performance standard implemented in CAMM include

- Name and code corresponding to the work activity (each work activity has a unique performance standard),
- Description and purpose of the work activity,
- The criteria for performing the work activity,
- The number and skill level of crew required,
- The types and amount of equipment required,
- The types and amount of material required,
- A verbal description of the recommended work method, and
- The average daily work expected to be performed by the crew.

CAMM provides a default list of performance standards corresponding to the default work activities list. The user can edit the default performance standards. New performance standards can be added when the user has defined a new work activity. CAMM checks that each work activity has a performance standard.

Inventory

An effective management system must have a data base consisting of the physical attributes of the road such as section identification, district, area, width, number of lanes, gutters, pavement material, and bridges.

One of the most important requirements of an MMS is the need to uniquely define each pavement section. The default method provided in CAMM is based on the road name, beginning point, and ending point. The beginning and ending points can be mileposts, cross streets, or other physical features. Each road section should have homogeneous features such as width, gutters, pavement type, and so forth.

CAMM provides management with a default list of inventory items. The user is free to select any of these items or to add new items that meet the needs of the agency. The inventory elements defined in this module are used to define the structure of the inventory data base.

Pavement Condition

Pavement condition is defined by the type, extent, and severity of the pavement distress. Whereas average pavement maintenance budgets can be estimated on the basis of historical data, development of work schedules for the repair and maintenance of specific pavement sections requires knowledge of the condition of the pavement sections. This fact was not recognized in the FHWA training course, so the pavement condition feature of CAMM is a new development. Traditionally, pavement condition surveys are associated with pavement management systems. The two systems, however, should be integrated and should operate from common pavement inventory and conditions data bases. In broad terms, the pavement management system could be used for the selection and scheduling of major rehabilitation and overlay projects, and the MMS could focus on the repair of specific pavement distresses and other maintenance activities.

The pavement condition section of CAMM provides the user with a default list of pavement distresses for flexible pavements (*2*) (see Figure 2). The user can select distresses from this list or add new distresses. Descriptions and severity information are provided by CAMM for each of the default distresses. The user can edit the descriptions or add descriptions that meet the needs of the agency. Each pavement distress must have a description of how severity and extent are measured. In addition, a work activity for the repair of the distress is required.

Calculation Units

The calculation units section defines the calculation units for each work activity. For example, the units for pothole patching could be in tons, square yards, and so on. These units will be used for all budget calculations. CAMM provides a default unit for each activity. The user can edit the units or add units for new work activities. All work activities must have calculation units.

Number of Workdays

The number of workdays section provides the user with a default list of the number of available workdays for each month. The user can edit the list if necessary. The number of workdays is required for the planning analysis of work schedules.

Reports and Forms

Reports and forms are used by management to monitor and schedule work. An efficient MMS requires continual updating. The management agency must be aware of daily work progress.

The reports and forms section allows the user to customize reports and forms. The reports and forms are generated in the analysis module. A default list of forms and reports is available. Reports and forms can be selected and edited from this list. If a report or form that does not exist is needed, the agency can create it. The following is a list of the available reports and forms:

- *Crew-day cards* is a report that summarizes the time involved in performing the activity and the amount of material used. Management gives each crew a crew-day card specifying the amount of work to be completed for that day. At the end of the day the crew specifies the amount of work completed and the amount of time and material used for the work activity. Management reviews the crew-day card to determine if

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DISTRESS TYPE

 ALLIGATOR OR FATIGUE CRACKING
 BLEEDING
 BLOCK CRACKING
 CORRUGATION
 DEPRESSION
 JOINT REFLECTION CRACKING FROM PCC SLAB
 LANE/SHOULDER SEPARATION
 LANE/SHOULDER DROPOFF OR HEAVE
 LONGITUDINAL AND TRANSVERSE CRACKING
    (NON-PCC SLAB JOINT REFLECTIVE)
 PATCH DETERIORATION
 POLISHED AGGREGATE
 POTHOLES
 PUMPING AND WATER BLEEDING
 RAVELING AND WEATHERING
 RUTTING
 SLIPPAGE CRACKING
 SWELL
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FIGURE 2 Pavement distresses (2).

the crew is on schedule. This information is used in the analysis module to update the budget and schedule.

- *Work schedules* is the schedule of work planned.
- *Activity summary reports* on monthly, quarterly, and annual bases compare the completed and planned work.
- *Maintenance needed reports* record the location, type of problem, and date reported. This information is entered in the road distress data base and used by the analysis module in budgeting and scheduling work.
- *Condition survey* is a form, filled out by the survey crew, that specifies the distress of the pavement.

Matching

Each pavement distress can have a level of severity ranging from low to high. CAMM allows the user to select the number of severity levels for each pavement distress and to match the work activity for each severity level. For example, alligator cracking with a low severity requires only a skin patch, whereas a high severity requires a full-depth patch.

DATA BASE MODULE

The MMS data base module allows the user to enter inventory and pavement condition data for each road segment and for the resources used. The fields in the data base are defined by the development module. Each road section must be uniquely defined by the section identification fields. The data base module checks the section identification fields to ensure a unique identification for each road section.

User-accessible data bases in CAMM include (*a*) road inventory, which contains information for each road segment, such as length, width, type of asphalt, and so forth; and (*b*) pavement distress, which contains the type of pavement distress found in each road segment.

The data base module allows the user to view or edit one record at time, search or sort the data base on a user-specified field, and scroll or browse through the data base.

The program automatically checks for unique identification of road sections. The road inventory data base establishes the master list of road sections. A section must be defined in the inventory data base before data on maintenance and condition can be entered.

In addition to the user-generated data bases, CAMM generates data bases for needed and accomplished maintenance. The maintenance needs data base is generated on the basis of quantity standards and is used to generate the performance budget. The maintenance accomplished data base is generated when the user enters the data from the crew-day cards. This data base provides historical information about the productivity of the maintenance crews. This data base will be extremely useful for evaluation and revision of the MMS practice of the agency.

ANALYSIS MODULE

The analysis module determines the activities to be performed and calculates the funding required for labor, equipment, and material. The work load is scheduled and balanced. Reports are generated to assign work and to oversee progress.

The analysis module generates the performance budget, schedules work, updates schedule and budget with crew-day cards, and generates reports.

Performance Budget

The performance budget is computed on the basis of the required work. Performance budgets allow management to present a list of work activities and the cost of each activity. This helps management show why the money is needed.

The performance budget uses information provided in the development and data base modules to perform the necessary calculations.

The performance budget module has three parts. The initial performance budget generates the initial budget, the update performance budget is based on feedback from crew-day cards, and the remaining budget generates the remaining cost until the end of the analysis period.

For a user-defined analysis period, the initial performance budget function generates the following reports: needed work for each road section; crew days required for each work activity; total cost for all work; cost for each activity; cost for each activity for each road segment; and labor, equipment, and material requirements.

The update performance budget function (*a*) uses the updated schedule to revise the budget and (*b*) accounts for increases in crew days due to the crew falling behind schedule or the addition of new work activities.

The remaining budget function computes the amount of money required to complete all work activities for a specified analysis period. This is the difference between the updated budget and the amount of work completed.

The results of the performance budget can be categorized into various costs for each activity as follows: total cost to perform a specific work activity, total crew days required, cost of labor per day, cost of equipment per day, cost of material per day, total labor cost for the activity, total equipment cost for the activity, total material cost for the activity, and total cost for each road segment.

Scheduling

CAMM provides the user with a spreadsheet for scheduling and leveling work loads. The user is able to schedule work within the allowable range of months defined in the work activity section of the development module.

The user can override the range of months. For example, if an activity is not normally performed between November and January, the user can override CAMM and schedule within these months if necessary.

Seasonal fluctuations occur in the work load, which result in either an oversupply or an undersupply of resources. For example, a large labor force required in the summer would result in too large a work force for the winter. It would be more efficient to balance the work load throughout the year. Work load leveling is a technique that balances these fluctuations. A range within 5 percent of the work load is adequate for work load leveling.

CAMM totals the work scheduled for each month. The user can level work loads by adding or subtracting crew days for each month.

The initial schedule, which works like a spreadsheet, displays a list of all work activities in a column and all the months in the analysis period in a row. It allows the user to schedule crew days for each month, keeps a running total of the number of crew days that still need to be scheduled, sums the crew days for each month to allow for work load leveling, displays possible and expected starting and stopping months, and prompts the user to save the changes.

The update schedule, which has a column for "additional crew days," will search the road condition data base to see if new work activities are needed. If so, it will add to the schedule, and the required crew days will be added to additional crew days. It allows the user to schedule additional crew days and indicates that a work activity is completed.

Crew-Day Cards

Crew-day cards are issued every day for each activity. The crew-day card informs the crew of the amount of work to be completed for each day. At the end of the day, the crew records the amount of work completed on the crew-day card in terms of the daily productions units specified in the performance standard. For example, the crew would record the number of unpaved road miles that were graded that day.

The data are entered into CAMM, which determines whether the crew is on schedule. If the crew is behind schedule, CAMM calculates the additional crew days required to complete the activity and adds them to the schedule under the heading "additional crew days." Management must then update the schedule to accommodate the additional crew days. Once the schedule has been updated, the performance budget must be updated.

The crew-day card module compares the expected daily work rate with the actual amount of work completed. It adds additional crew days to the schedule if they are required to complete the work activity. It allows the user to indicate when the activity is finished. It updates the schedule to show that a job is finished and updates the Previous Maintenance Data Base.

Generating Reports

The user specifies what reports to print. CAMM searches the appropriate data base and generates the report. The report can be defined in terms of road segment, district, or area.

OPERATING CAMM

CAMM operates on a DOS-based microcomputer with a hard disk. Before running the program, the distribution disk should be copied into a unique path on the hard disk. From the DOS prompt in the program path, execution of the program is initiated by typing CAMM. An initial screen is displayed, followed by the main module selection menu.

CAMM is menu driven. The menus are arranged in the hierarchy given in Figure 1. The user selects an item from the menu with arrow keys and ENTER. The ESC key is used to return up the hierarchy of menus.

A menu is displayed for the selected element. The user either enters data or selects an option from the submenu. When an option in the menu is completed, the title for the option changes from white to magenta. CAMM does several consistency checks in the development module. For example, CAMM checks the performance standard resource requirements to ensure that the needed resources are defined in the resource list. If a performance standard is edited to include a resource that is not on the list, the color of the resource title can change from magenta (complete) to white (incomplete), warning the user that the resource list must also be edited. All elements of the development module must be completed in a coherent fashion before proceeding to the analysis module.

SUMMARY

MMSs are used by state highway agencies for the efficient planning and scheduling of maintenance activities. FHWA is interested in transferring this technology to local highway agencies with limited resources. The Roads and Streets Maintenance Management Systems short course effectively presents MMS concepts, but a microcomputer program of this method is needed for cost-effective implementation.

CAMM's menu-driven approach allows the user to develop an MMS that meets the needs of the agency without having to learn or understand computer programming. Because of CAMM's structure, the user can implement an MMS without using consultants or exhaustively studying MMS methods and procedures. The internal checks built into the development module ensure that all the required elements of the MMS are defined in a consistent manner before an analysis is performed. Coordination between the development and data base modules ensures that the correct structures for the data bases are defined.

The data base module allows the user to create and edit the required data elements. The data bases include both inventory and pavement condition data that are needed for developing maintenance budgets and schedules. The structure of the pavement condition data base promotes interfacing with a pavement management system.

The analysis module generates the usual reports needed by management. A spreadsheet function facilitates the development of a balanced work schedule. Field data from crew-day cards can be entered to update both the data bases and the work schedule.

Development and documentation of CAMM is scheduled to be completed by December 1990. Preliminary alpha testing of the system indicates that CAMM is a powerful yet easy-to-use tool. The next step in the development of the program will be implementation by local highway agencies.

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Abridgment

Summary of Research on Data Collection Systems for Maintenance Management

WILLIAM A. HYMAN, ANCEL DAN HORN, OMAR JENNINGS, FREDERICK HEJL, AND TIMOTHY ALEXANDER

Data acquisition technologies and telecommunications offer maintenance field managers convenient procedures for entering data into the maintenance management system. Many of these technologies offer the potential for daily if not real-time retrieval of information (emergency work orders, equipment availability, and effectiveness of different maintenance methods) and help improve field operations and inventory management and control. Among the technologies are lap-top and hand-held computers, electronic tablets (clipboards), bar coding, voice recognition, and navigational and locational devices such as distance-measuring instruments and satellite global positioning system receivers. This equipment, when combined with telecommunications such as cellular and satellite, can be molded into discrete data acquisition systems for (*a*) daily cost reports (accomplishments, location, labor, equipment, and materials), (*b*) inventory management and control, (*c*) roadway feature inventory updating, (*d*) inputs to short-run scheduling, (*e*) bridge inspection and maintenance reporting, and (*f*) monitoring of snow- and ice-control operations in remote locations and heavy snowstorm conditions.

The objective of NCHRP Project 14-10, *Improvements in Data Acquisition Technology for Maintenance Management Systems*, was to identify the latest technological means to acquire, record, verify, transmit, and receive field-related data for maintenance management systems. The project sought to identify requirements for field data collection and develop system designs for a variety of maintenance data collection activities (*1*). That research is summarized here.

DATA COLLECTION SYSTEMS

A variety of practical, fairly rugged, commercially available data collection technologies can be combined into field systems to enhance the effectiveness of crew leaders and their supervisors. Field systems can be composed of data entry and retrieval equipment [lap-tops, hand-held computers, electronic tablets (clipboards), bar code scanners, and voice recognition] in combination with navigational and locational devices [satellite global positioning system (GPS) receivers and distance-measuring instruments]. Telecommunications, such as regular phone, cellular phone, and low data rate satellite transmissions, can enhance data transfer to and from distant or remote locations.

The following systems are summarized: crew-card data collection, inventory management and control, roadway feature inventory updating, inputs to short-run scheduling, bridge inspection and maintenance, and monitoring snow-removal equipment.

Crew-Card Data

Two field data collection systems for daily work reporting were developed, one for outdoor field use and the other for inside a vehicle. Figure 1 shows a portable field data collection system for outdoor use. A hand-held portable data entry terminal, perhaps with integrated bar code reader, might serve as the data entry device. The feasibility of a bar-coded crew card was tested in equipment demonstrations conducted for field managers. The crew card required no writing or keying of data or performance of calculations, but only the scanning of bar codes. Field managers were receptive. Many also responded favorably to using an electronic clipboard to enter crew-card data. Thus an electronic tablet, lap-top, or some other suitable device might work just as well or better depending on the application.

Location information could be obtained from a GPS receiver. The in-vehicle system that was designed indicates that either a distance-measuring instrument or a GPS receiver could be used to enter the location of the work site. Data could be transferred daily to the host computer by an appropriate method such as removable memory, an RS232 cable, or a docking device for the data collection terminal.

Maintenance field workers could retrieve useful information daily from a terminal located at the staging area where they report to and leave work. Most data collection devices allow data retrieval from the field by using cellular phone.

The types of data a field manager could retrieve from the maintenance management system include comparative efficiency of different maintenance methods, urgent and emergency work orders and related information, availability and location of equipment and materials, budget balances for maintenance activity by management unit, and planned versus actual work.

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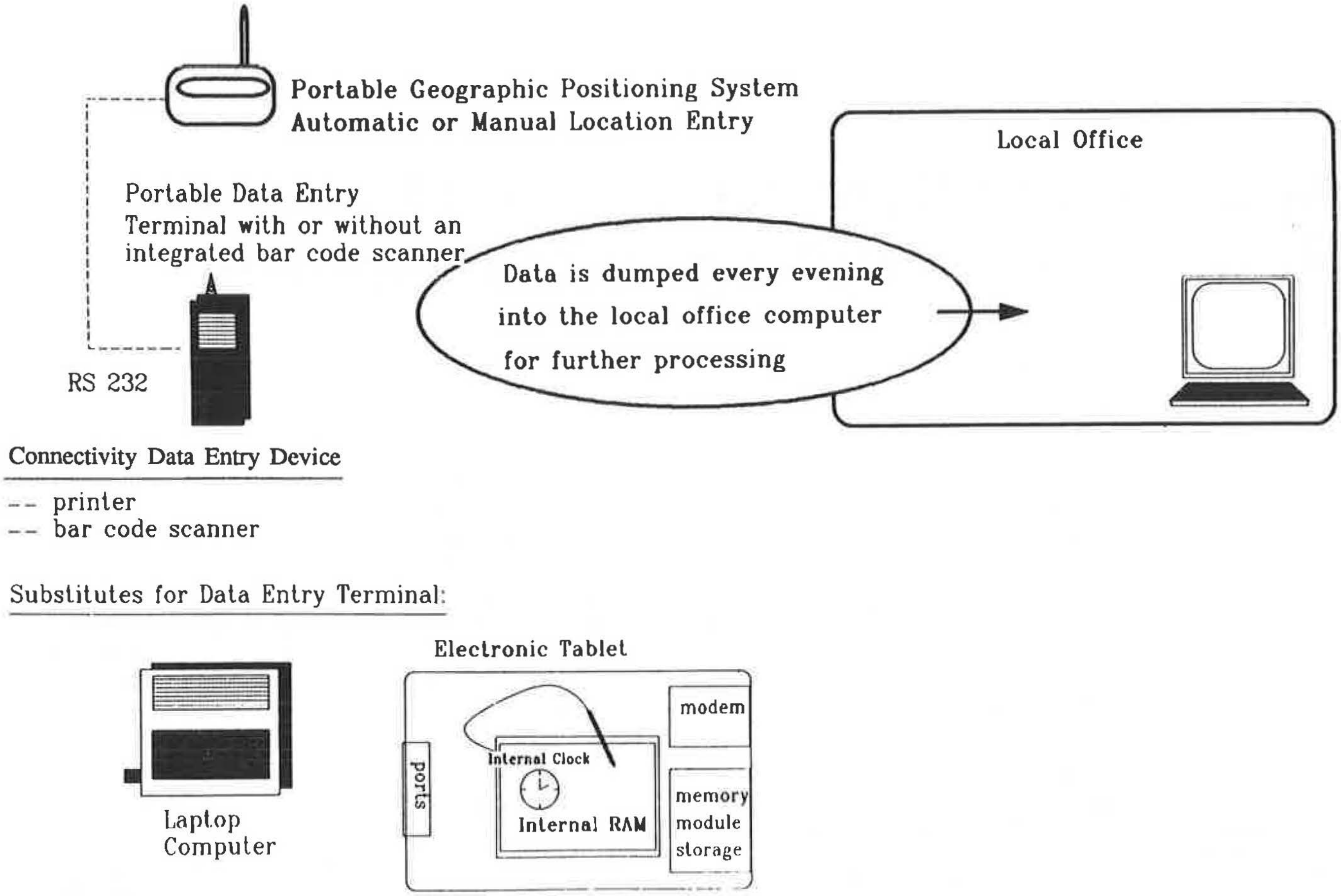

FIGURE 1 Portable field system for crew-card data.

Inventory Management and Control

Given the receptivity of maintenance managers to bar coding, it was concluded that a state or local agency could easily justify implementing a physical asset inventory management system based on bar codes. Among the assets that might be included in this system are vehicles, equipment, office furniture, and selected tools. Maintenance organizations typically use a checkoff list to take inventory and later enter the results into a computer. Use of a hand-held computer with a bar code scanner would greatly speed the process of taking inventory and improve its accuracy. The cost and convenience of applying bar code labels to physical assets would determine the scope of items that could be covered in the inventory system.

Bar codes, and perhaps complementary forms of data acquisition, could be used for a material inventory management system. Material inventory management is much more complex and costly, and may be warranted only in selected circumstances. The rule of thumb in private industry, however, is a payback period of 1 year or less.

In a material inventory management and control system for a large warehouse and maintenance yard, stockkeepers might use a variety of hand-held or fixed terminals with bar code scanners to record inventory transactions. Demand-responsive or serial bar code label printers, or both, could be placed strategically in warehouses to provide labels. Electronic scales could be used to measure odd lots and small parts, which could be labeled with bar codes and scanned once placed in plastic bags. In special situations radio frequency links between portable data entry devices and the host computer may be warranted. Bar-coded personal identification cards might provide access to gasoline and record who withdrew each quantity of fuel. Radio frequency identification tags placed on trucks could help provide access to bulk materials and furnish estimates of usage. In special instances a truck scale might be justifiable for determining the amount of bulk materials removed.

A significantly improved inventory management system would not only serve accounting, financial, and upper management functions, but could also provide rapid, accurate information for maintenance field managers. Information that field managers might desire, besides equipment and material availability and location, includes unit costs, status of materials on order, and repair history of a vehicle.

Roadway Feature Inventory Updating

Maintenance field managers, partly because they know the road so well, frequently have responsibility for updating roadway feature inventories, especially maintainable features. Agencies that rely on measuring elapsed distance from known reference points will continue to use distance-measuring instruments in building roadway feature inventories. An in-vehicle system for updating the inventories would involve some type of data entry device used with a distance-measuring instrument.

If an agency implements a geographic information system (GIS), location information should be expressed in latitude and longitude. This research project identified a prototype system, similar to that being developed under the 38-state GPS/GIS project, for establishing a base inventory including maintainable features. Updating could be accomplished with the same type of data collection system proposed for collecting crew-card data, including the use of a GPS receiver to establish latitude and longitude. More accurate and costly systems would involve differential processing with a second receiver located at a known reference point and a specially designed van for routine feature updating throughout an entire highway district.

Inputs to Short-Run Scheduling

Maintenance field supervisors need to consider a variety of information for short-run scheduling of maintenance operations. Maintenance deficiencies and problems identified while traveling to and from work sites or while patrolling must be combined with citizen complaints, pavement condition and distress surveys, and planned maintenance work based on the annual work program.

A lap-top, hand-held computer, or electronic tablet can potentially be used to combine these data for viewing and consideration by the maintenance field supervisor. The source of location data can be a GPS receiver or a distance-measuring instrument. Software that can assist the field supervisor in setting priorities and determining if needs are being met would be part of the system.

Bridge Inspection and Maintenance

Bridge maintenance work orders are often a direct result of bridge inspection. Also, bridge inspection reports frequently include written reports, sketches, and photographs. To date, pen and paper and a portable camera have proved to be the most suitable tools for recording bridge inspection information.

The recent appearance of electronic tablets capable of handwritten data entry and receiving and transmitting images suggests that there now may be a more efficient approach to bridge data collection. By using an electronic tablet, bridge inspectors could record standard inventory and appraisal information, make sketches, and furnish written comments, including maintenance and repair recommendations. A digital still camera could take photographs, and, potentially, digital images of the bridges could be transmitted and received by means of a cellular telephone. Locational information could be obtained from a map displayed directly on the screen or acquired using a GPS receiver. The internal clock in the clipboard could "date and time stamp" data.

In a data collection system with two-way communication between the field and the headquarters computer, an inspector could retrieve bridge inventory and appraisal data, predicted future condition, repair histories, progress on current work orders, and other useful information.

Monitoring Snow-Removal Operations

Snowplows and blowers operating in heavy snow conditions in remote and many rural locations occasionally collide with cars buried under drifts or slip into a ditch or ravine, sometimes disabling or killing the operator. There is a need to be able to quickly locate snow-removal equipment and injured operators when an accident occurs.

The technology and telecommunications examined in this study suggest a solution to this problem. Inexpensive sensors, a low data rate satellite transmitter, and an omnidirectional antenna can be placed on each snowplow or blower to transmit information on the snow-removal equipment's status to a central monitoring facility. The information that might be transmitted includes location and whether the equipment is moving, the engine is operating, and the snowplow or blower is upright or tipped over.

FURTHER EVALUATION, TESTING, AND IMPLEMENTATION

The technology assessment and the system designs developed in this research represent a first step toward automatic data acquisition and retrieval by maintenance field managers. Although vendor product specifications indicate that equipment is available to withstand rugged, outdoor conditions, practicality and user acceptance must be demonstrated in day-to-day maintenance data collection activities.

Maintenance field workers will welcome improved data collection and work-reporting procedures provided the procedures are simple; result in significantly less paperwork; and provide timely, easily accessible, and valuable information not previously available. To be accepted by maintenance field workers, the new procedures must be perceived as clear benefits to them and not as instruments of increased control and monitoring.

It is not enough that the data collection devices work in the field. They must work as part of a system that provides two-way communication, meets the needs of the field manager, and serves the objectives of maintenance management. Thus the data collection systems as a whole require field testing and evaluation. This research, therefore, calls for further evaluation and testing, including an assessment of the circumstances under which the value of each system and its practical variants exceeds the costs. Further evaluation should lead to the implementation of cost-saving data acquisition systems.

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Pavement Maintenance Effectiveness

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Maintenance and rehabilitation (M&R) activities upgrade pavement condition and foster a new life cycle. Precise prediction of the effectiveness of these activities and how they retard the progression of distresses are key issues in setting priorities in a pavement management system. The extent to which the timing and level of M&R activities influence pavement condition is explored. Employing time series pavement performance data, mechanistic empirical models have been developed to predict the immediate jump in pavement condition, and, following the treatment, the rate of deterioration. Pavement condition rating, an aggregate statistic of both roughness and distress, is used as a measure of serviceability. Parametric studies were undertaken to estimate the timing and to select the most effective level of treatment. The results indicate that the immediate effect of an M&R activity depends on the condition of the underlying structure. The life-cycle analysis of three treatments (surface treatment and thin and thick overlays) applied at various condition levels indicates that if repairs are performed while the pavement is still in the "slow rate of deterioration" phase, life cycles are greatly increased. Similarly, timely maintenance treatment will reduce the equivalent uniform annual cost of the facility.

In recent years the emphasis of highway construction has gradually shifted from new design and construction to maintenance and rehabilitation (M&R) of the existing network. Historically, overlays have been the most common rehabilitation technique. They have often been performed without regard to cost-effectiveness. In many cases it may have been more cost-effective to perform other types of rehabilitation or to do routine maintenance. Maintenance is generally defined as work undertaken to extend the service life of the roadway. Rehabilitation includes placement of additional surface material or other work necessary to return an existing roadway to a condition of structural or functional adequacy. The restoration program could include complete removal and replacement of the pavement structure.

It is easy to visualize the effects of major maintenance, rehabilitation, or renovation on the condition of the pavement. These activities produce a substantial, immediately identifiable correction of deficiencies, represented by abrupt improvements in the condition curve, as shown in Figure 1. The effects of routine maintenance, on the other hand, are harder to detect. It may be that the improvements in pavement condition are so small as to escape measurement, or the maintenance activity may not correct existing damage but rather may prevent future damage or may slow the rate of deterioration.

The effects of M&R must be quantified to make life-cycle cost analyses of alternatives. Several approaches have been used in the past, three of which are described here. The first approach, typical of the EAROMAR-2 (*1*), simulates the mechanism by which routine maintenance purportedly reduces the rate of deterioration. The primary mechanism studied in this way is the reduction in water infiltration due to sealing or patching of joints and cracks. A secondary effect considered is the reduction in roughness, rutting, or spalling due to patching. The second approach, typified by an Austin Research Engineers study (*2*), treats maintenance effectiveness more as a statistical correction to pavement condition or deterioration instead of modeling the specific mechanism involved. A third approach addresses the effect of routine maintenance on the present serviceability index (PSI) (*3*). The effect of routine maintenance on pavement performance is visualized as a shift in the PSI-ESAL loss curve. Not only do the maintenance policy and its effect on pavement performance vary, but so do the annual maintenance expenditures needed to accomplish the maintenance work.

A highway agency can adopt a variety of M&R strategies; each strategy provides a measurable benefit to the system. To provide decision makers with a more definite method for selecting M&R activities, highway agencies are resorting to structured maintenance management principles. Pavement management systems (PMSs) are being instituted to identify and define M&R needs to achieve desired levels of pavement service. These systems compare alternative M&R strategies; the objective is to identify the strategy that will minimize pavement life-cycle costs.

The timing of M&R can be an important factor in maintaining pavements economically. Typical pavement deterioration curves depict pavement life cycles as consisting of two phases (*4*). During the first stage, denoted as "slow deterioration phase," a 40 percent deterioration of pavement condition gradually occurs during 75 percent of the life of the pavement. A sharp decrease in condition occurs during the second phase. An equivalent 40 percent drop in condition takes place during 12 percent of the life of the pavement. Pavement M&R costs at this point are four to six times as high as those at the end of the first phase. If pavement repairs are taken up while the pavement is in the first phase instead of deferring them until the decline to a poor condition, life cycles can be greatly increased.

In identifying cost-effective maintenance strategy, the engineer has to consider the level, type, and timing of M&R action. Life-cycle cost analysis has often been performed to facilitate this procedure. Two performance models are required as a part of life-cycle cost analysis: first, a model to quantify the jump in performance arising from the application of each treatment, and second, a model to detail the rate of deterioration following the treatment. The objective of this paper is to develop the two performance models and to conduct a parametric study elaborating how timing and level of maintenance action affect deterioration rate, pavement life cycle, and, in turn, life-cycle costs of three M&R treatments.

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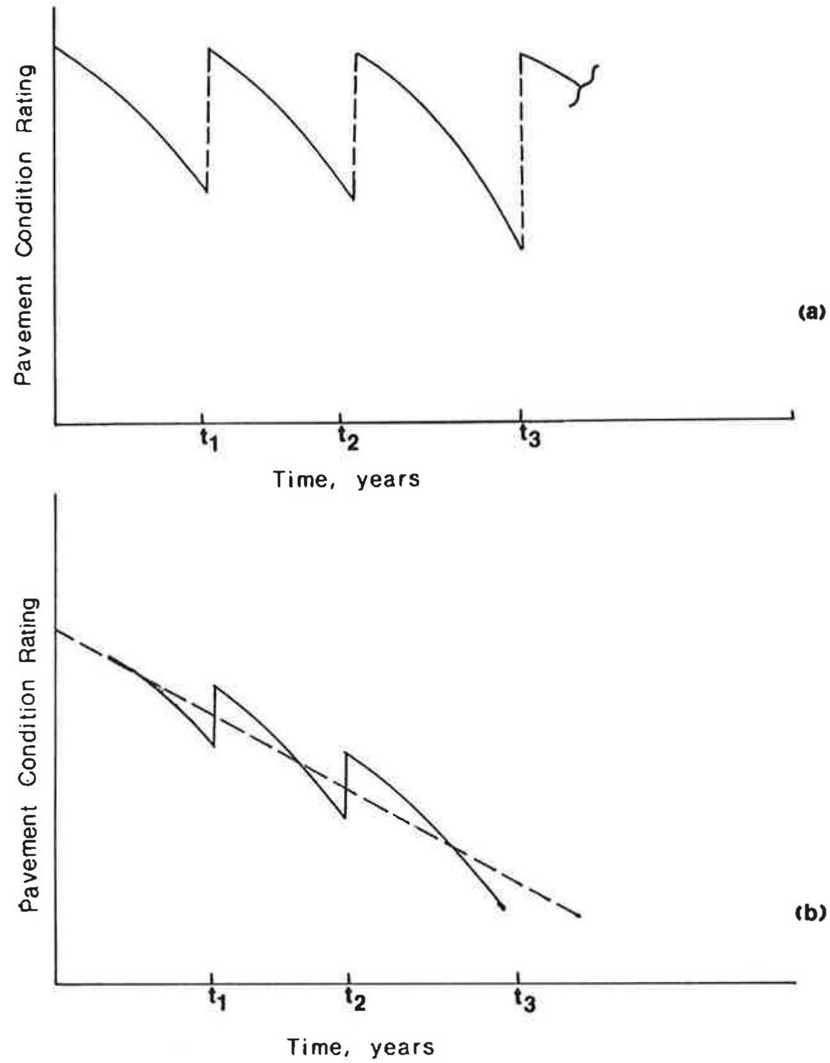


FIGURE 1 Schematic representation of effects of (*a*) rehabilitation and (*b*) routine maintenance.

BACKGROUND

The study includes performance models of flexible pavements with different levels of maintenance treatments. Only three M&R treatments are investigated: (*a*) surface treatment, equivalent thickness of ½ in. of hot mix asphalt concrete (HMAC), (*b*) thin overlay of 1½ in. HMAC, and (*c*) thick overlay of 3½ in. HMAC.

The historical and monitoring data used to derive the models were obtained from a PMS data base of a 2,000 lane-mi road network in north Mississippi. The performance indicator is a pavement condition rating (PCR), which can range from 0 to 100. PCR is an aggregate index derived from monitoring data—pavement roughness rating (RR) and distress rating (DR)—in accordance with the following equation:

$$PCR = RR^{0.6}\ DR^{0.4} \qquad (1)$$

As indicated previously, two models will be developed. The first, which captures the immediate improvement, is based on the PCRs of those sections (30 in all) that received maintenance between 1986 and 1989. The second, a pavement deterioration model, uses the performance history of 600 mi of flexible pavements with overlays. The two models together will be used to compare alternative maintenance actions.

PERFORMANCE MODELS—A REVIEW

Pavement management activities must consider performance of the pavement and the factors that influence costs throughout its service life. Models to predict pavement condition, deterioration, and M&R are included in life-cycle economic analysis for two reasons. First, to estimate the requirements for and the cost of M&R, one must be able to predict the deterioration in pavement condition and when it will occur. Second, the condition of the highway surface affects pavement serviceability and may affect vehicle operating costs and, in turn, user costs.

Most of the current performance or distress prediction models, however, do not consider the influence of preventive,

TABLE 1 FLEXIBLE PAVEMENT DETERIORATION MODELS

Deterministic Models						
Performance Prediction Models	Distress Prediction Models					Probabilistic Models
	Roughness	Fatigue Crack	Transverse Rutting	Thermal Crack	Raveling	
AASHTO, VESYS, Texas FPDS, Mississippi PCR, Washington State, PAVER, Fernando Equation, PARS, PQI, PENNDOT	Arizona, Fwa and Sinha	VESYS, Asphalt Institute, Shell, ARE, World Bank	VESYS, Shell, WATMODE, Ohio State, World Bank	Shahin McCollough	World Bank	Markov chain, survivor curves

corrective, or emergency pavement maintenance activities on the performance of the pavement. This is a serious deficiency, because most highway organizations are faced with a shortage of resources and are being forced to delay pavement maintenance or select among M&R strategies, or both. With appropriate prediction models, the effects as well as the costs of alternative investment policies can be computed.

In making alternative maintenance policy decisions or evaluating maintenance effectiveness, two classes of models are required: pavement performance models and cost models. The current performance models will be briefly reviewed here. The models describe mathematically how pavement condition changes with time and traffic.

Performance in its broadest sense is predicted by deterministic and probabilistic models. The deterministic models include those for predicting structural and functional performance and damage in pavements. The probabilistic models include survivor curves and Markov and semi-Markov transition processes. Damage models are particularly important because they affect M&R activities. Alternatively, pavement performance can be predicted in terms of a single attribute (for example, alligator cracking or roughness) or a combined attribute (for example, AASHO present serviceability rating, which accounts for both roughness and distresses). Table 1 gives some of those models, categorized in accordance with the preceding discussion.

The distress or performance (combined-attribute) models predict the rate of change of condition of new or rehabilitated pavements. To describe the condition after a maintenance activity, however, another model that quantifies the immediate improvements in condition is required. In lieu of this model, a tacit assumption made in several existing PMSs is that the pavement is restored to its original condition—that is, the road becomes smooth and the distresses disappear regardless of the timing of treatment. This assumption might be valid when pavements are rehabilitated with thick overlays.

A maintenance treatment provided to retard distress development (a preventive maintenance program) adds a new dimension because the pavement is not restored to its as-constructed condition. Overlooking this aspect could substantially affect the prediction of the life of the maintenance activity. Accordingly, several recent studies have attempted to model the immediate improvement brought about by a variety of maintenance activities. A life-cycle cost evaluation study (*5*) defined and used a maintenance effectiveness index, which is the ratio of the pavement condition index (PCI) with maintenance and the PCI without maintenance in any given year. The Program Analysis of Rehabilitation Strategies model (*6*) presented a table of immediate jump in PCR as compiled from historical records in Ontario. A 20-section field study in Arizona (*7*) related the roughness improvement to the roughness before treatment. On the basis of roughness data for the Interstate system in Indiana, Colucci-Rios and Sinha (*8*) developed a model for reduction of roughness as follows:

$$RED = 61.35 * T^{0.26} \tag{2}$$

where RED is the percentage reduction in roughness and T is the overlay thickness in inches.

In summary, a cost-effective M&R program must analyze the effect of each activity on pavement performance as well as on life-cycle costs. A study of the effect of maintenance on performance must include models to evaluate the immediate improvement of performance and the rate of change of deterioration after the treatment.

PERFORMANCE MODELS FOR MAINTENANCE EFFECTIVENESS

Quantification of the impact of maintenance on damage rate requires the development and analysis of field performance records and deterioration models. The problem is to modify deterioration functions to reflect the effects of different kinds or levels of maintenance treatments. A pavement data base developed in connection with a PMS for the Mississippi State Highway Department provided the necessary data. The model was formulated in terms of PCR. What treatments and how many levels of each treatment need to be modeled will be discussed later.

The definition and interpretation of routine maintenance will be discussed first. A survey of working definitions of highway maintenance and the relationship between routine maintenance and more capital-intensive rehabilitation works is presented in Coikie and Markow (*9*). Markow et al. (*5*) have adopted an analytic perspective in that routine maintenance comprises activities that can be represented mathematically by corrections to the deterioration function as shown in Figure 1b. This approach provides a general and flexible structure within which different mixes and interpretations of maintenance activities can be simulated. It also distinguishes routine maintenance from rehabilitation by the degree of improvement in pavement condition.

Another issue concerns the classification and summarization of the approximately 20 maintenance activities applicable to flexible pavements. A three-group classification is adopted in this study: (*a*) routine maintenance activities (for example, surface rejuvenation and fog seal) that bring about small changes in the deterioration curve but for modeling purposes cause a small immediate jump in performance soon after application, (*b*) minor rehabilitations (for example, resealing and surface treatment), and (*c*) major rehabilitations (thin overlay less than 2 in. and thick overlays equal to or greater than 2 in.) that result in noticeable improvement in pavement condition. By handling routine maintenance, minor rehabilitations, and major rehabilitations as different levels of a single treatment, their effectiveness can be captured by a single set of models (equations). In this study, the effectiveness of only minor and major rehabilitation treatments are investigated.

Modeling Performance

The research reported in this paper is a part of a program to develop a PMS for the Mississippi State Highway Department. By employing historical information and monitoring data over a 3-year period, mechanistic empirical predictive models are developed, the details of which can be seen elsewhere (*10,11*).

Nonlinear regression models are developed using SAS 5.0 with PCR as the dependent variable. The independent variables are age of the pavement (Age), cumulative equivalent single-axle loads (ESALC), composite structural number (SNC), life cycle before overlay (BEFL), and thickness in inches (T) of the proposed treatment. The best-fit model obtained for performance prediction of flexible pavement with overlays has the following form (the number of data points is 142):

$$PCR(t) = 90 - a\{\exp(Age/T)^b - 1\} \times \log(ESALC)(BEFL/SNC)^c \qquad R^2 = 0.74 \quad (3)$$

where

$PCR(t)$ = pavement condition rating at time t,
a = 0.6632,
b = 0.3558, and
c = 0.1642.

Of the five causal factors recognized by the model in defining the performance of overlay pavements, a parametric study indicates that ESALC and SNC are of only minor importance. Thickness of the overlay and BEFL, in that order, contribute to overlay performance. Age, however, is the most significant predictor.

Condition Adjustment for M&R Action

Routine maintenance is considered to adjust the slope of the deterioration function, as illustrated conceptually in Figure 1b. Within the discrete simulation model proposed in this study, this effect is captured by small increments in current PCR that offset some of the accumulated pavement damage. Minor or major rehabilitations are assumed to repair or restore the pavement condition to some level substantially higher than the pretreatment level. In the extreme case a reconstruction will automatically restore the PCR of the pavement to its as-constructed value. The development of a model to depict the jump in PCR follows.

About 30 overlay projects completed during the 1986–1989 period were analyzed for this purpose. The PCR after the treatment (PCRAF) is the dependent variable, and the PCR before the treatment (PCRBF) and the thickness of the overlay (T) are the independent variables. A multiple regression analysis with SAS Version 5.0 was performed to derive the following functional relationship (the number of data points is 30):

$$PCRAF = A*(PCRBF)^B*(T)^C \qquad R^2 = 0.56 \quad (4)$$

where

A = 23.9984,
B = 0.2883, and
C = 0.0389.

The standard errors of estimate of A, B, and C are 23, 19, and 30 percent, respectively. In Equation 4, PCRAF is a function of thickness as well as the condition of the underlying pavement, a result that agrees with the findings of Colucci-Rios and Sinha (*8*).

Effectiveness of Maintenance

The gain in PCR owing to three levels of treatment (surface treatment, equivalent thickness of ½ in. HMAC; thin overlay of 1½ in. HMAC; and thick overlay of 3½ in. HMAC) is plotted in Figure 2. The thick overlay restores the PCR to just above 85 but falls short of the as-constructed level of 90. Why is the PCR not restored to 90 even with a thick overlay? It is likely that all of the distresses vanish as a result of an overlay emplacement, especially a thick one. By elimination, one may conclude that some roughness will still be present regardless of the overlay thickness. Colucci-Rios and Sinha (*8*) reported that even newly resurfaced pavements exhibit a certain level of roughness, somewhere between 300 and 500 counts/mi as measured by the Portland Cement Association road meter. Life-cycle cost studies at MIT (*5*) indicated similar results—the gain in pavement condition as a result of maintenance activities was 2 to 18 PCI (pavement condition index of PAVER) points, whereas the gain due to rehabilitation action ranged from 25 to 30 points.

Maintenance effectiveness is defined as the change in pavement condition after performing maintenance. The gain in pavement condition due to a 1½-in.-thick overlay ranges from 25 to 13 points for a deteriorated pavement (PCR = 50) to a fair-rated pavement (PCR = 70). The same general trend is observed for surface treatment and thick overlays. With routine maintenance treatments Markow et al. (*5*) obtained a different trend, in that maintenance effectiveness showed a mid-life peak. For patching treatment, Smith et al. (*12*) indicated that maximum maintenance effectiveness occurred early in the pavement's life. One explanation for the disagreement is that the three research studies have investigated different maintenance treatments—Markow et al. investigated routine maintenance, Smith et al. studied the effectiveness of patch-

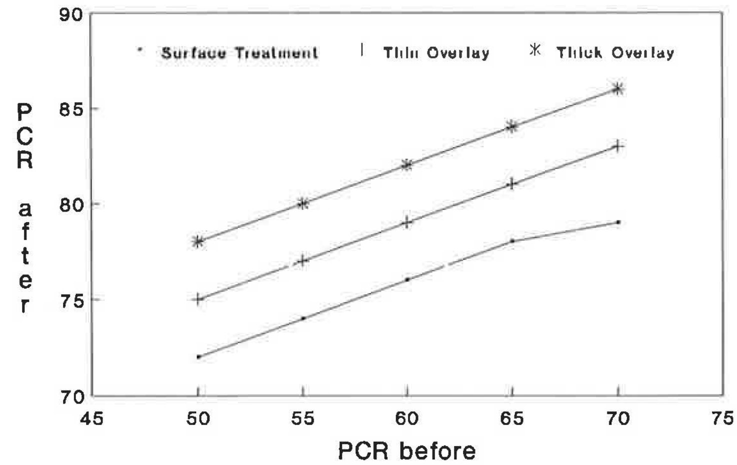


FIGURE 2 Pavement condition after treatment as a function of condition before treatment.

ing, and this research dealt with surface treatments and overlays. Apparently, the treatment level plays a major role in the gain in pavement condition, which, in turn, is affected by the condition before treatment. The three studies used different performance measures, which could be another reason for the contradictory results. Markow et al. and Smith et al. used PCI, which is distress based, whereas the authors used PCR, an aggregate measure of both roughness and distress.

Life Cycle of M&R Actions

Equation 3, with slight modifications, can be used for the life-cycle calculations of each treatment action. The modifications are required because the initial PCR of the road surface immediately after the treatment may not equal 90. Except perhaps for thick overlays, a rehabilitation action seldom restores the pavement condition to the as-constructed value of 90. To account for this difference, a four-step procedure is proposed for life-cycle computation of a specific treatment:

1. Compute the life cycle (L_1) of the maintenance treatment as if the initial PCR were 90 by using Equation 3 (see Path ABC in Figure 3, where the assumed threshold PCR is 50).
2. Locate Point D on Path ABC, where D represents the PCRAF derived from Equation 4.
3. Again using Equation 3, compute the life cycle for a threshold PCR = PCRAF. This life is denoted by L_2 in Figure 3.
4. Compute the life of the treatment as $L_1 - L_2$.

A tacit assumption is that the rate of decline in PCR is a function of the current PCR only.

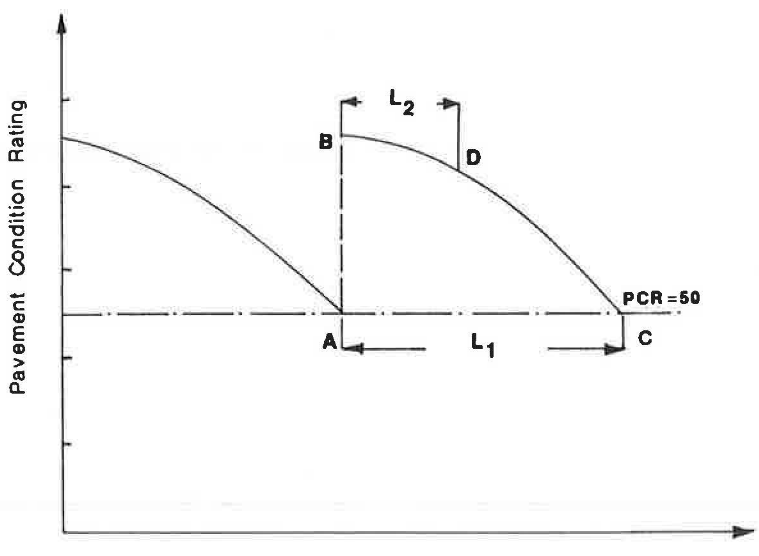


FIGURE 3 Conceptual performance curve for computing life cycle of rehabilitation treatment.

The life cycles of the three maintenance treatments are plotted as functions of PCRBF in Figure 4. As expected, the life cycle lengthens with increasing thickness of the overlay. In addition, the life cycles of all three treatments decrease when the timing is deferred until the PCR drops to the threshold value of 50. This result supports the conventional wisdom that if repairs are performed while the pavement is still in the first phase (defined previously) of deterioration, life cycles are greatly increased. Figure 5 shows two trend curves for each treatment. The first curve is based on the premise that soon after a treatment the condition is restored to the as-constructed value of 90; the second is based on the premise that the condition increases to a value as given by Equation 4. The former approach, which is currently adopted in several PMSs, would overpredict the life of surface treatments and thick overlays by 42 and 12 percent, respectively.

Life-Cycle Costs

The equivalent uniform annual cost (EUAC) of each treatment is calculated (see Figure 6) by using a discount rate of 8 percent and the life cycle as presented in Figure 4. The decrease in EUAC with increase in PCRBF is expected, because EUAC is strongly related to life cycle of the treatment. That is, as the life cycle increases, the EUAC must decrease, because the cost is distributed over a longer period. The benefit for the realistic evaluation of cost-effectiveness with respect to timing should also be included.

CONCLUDING REMARKS

M&R slows pavement deterioration and corrects distresses, prolonging pavement life. Two performance models were

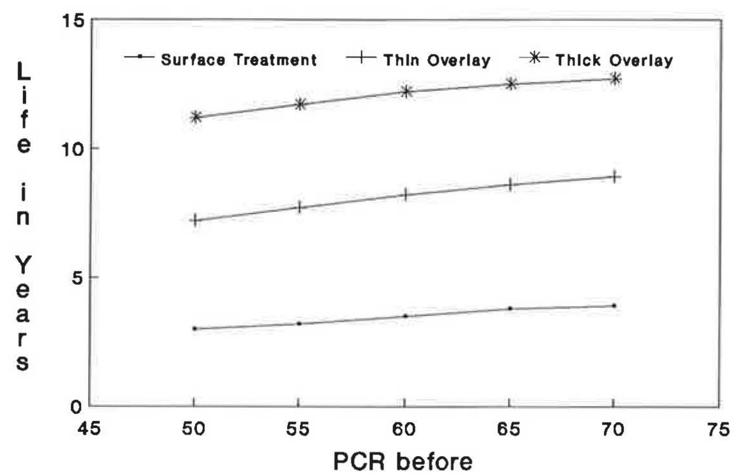
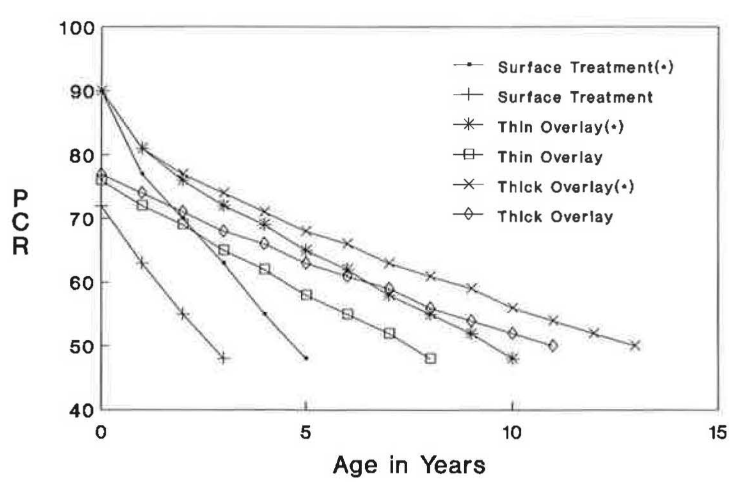


FIGURE 4 Life cycle of pavement as a function of timing of treatment.



(*) indicates PCR prediction with initial boundary constraint = 90

FIGURE 5 Pavement performance curves with and without initial boundary constraint.

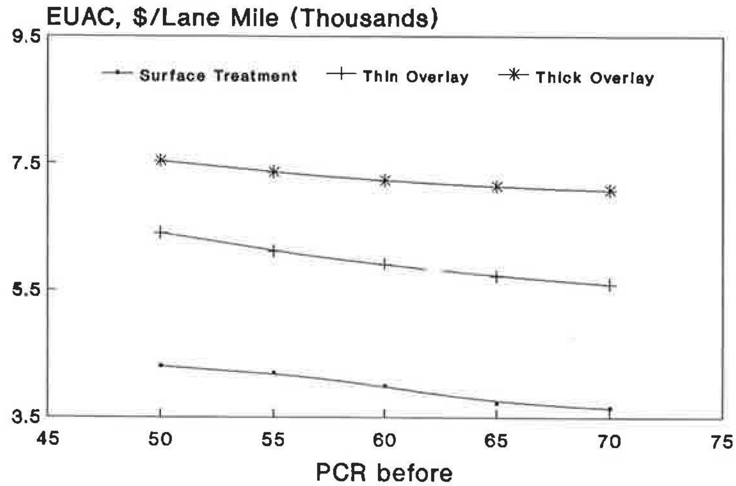


FIGURE 6 Effect of timing and level of action on EUAC.

developed to quantify these results—one to predict the immediate jump in performance and the other for the evolution of deterioration following the treatment. The pavement condition immediately after the treatment is a function of thickness as well as the condition of the underlying pavement. Of the five casual factors affecting deterioration of the rehabilitated pavement, age is the most significant predictor.

The effect of timing and level of maintenance treatment on overall pavement performance was investigated by using these models. The results suggest that pavement condition improves with overlay thickness, but the improvement approaches an asymptotic value that falls short of the as-constructed condition. The life-cycle analysis of treatments applied at various condition levels indicates that if repairs are performed while the pavement is still in the first phase of degradation (slow rate of deterioration), life cycles are greatly increased. By the same token, timely maintenance treatment will reduce the EUAC.

ACKNOWLEDGMENT

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Abridgment

Roadside Vegetation: Player or Pest?

HARLOW C. LANDPHAIR

The relationship of roadside vegetation to common maintenance problems is explored. The focus is on the composition and health of roadside vegetation as an indicator of and participant in the overall cost of highway maintenance. The concept of "plants as engineering materials" is introduced. The concept involves examination of two basic issues: roadside design details and the engineering characteristics of roadside vegetation. It is suggested that a need exists to carefully examine design details that foster problems with vegetation and to consider how to use the engineering characteristics of vegetation to reduce roadside maintenance costs.

As a landscape architect involved in public practice and education for most of my career, I had been involved tangentially in transportation projects for a number of years. In 1987, we were approached by the Texas State Department of Highways and Public Transportation (SDHPT) to assist in the development and execution of a new, broad-based highway beautification program. As part of that contract, SDHPT asked that we focus on beautifying the state's highway system and reducing roadside maintenance costs. These two charges are, if taken together, antithetical. It is not possible to add ornamental plant material to the roadside, regardless of its hardiness, without increasing the maintenance burden to some extent. Yet, we have taken this charge to heart, and it has resulted in the research initiative described here.

For the most part this is not a technical paper. Its purpose is to challenge some of the fundamental beliefs that influence our current approach to roadside maintenance and to initiate a new dialogue about the development and administration of roadside management programs. The emphasis is on the role of roadside vegetation. It is suggested that, of all roadside components, vegetation is the least understood and therefore the most frequently misused and abused. Fundamental questions are raised about the perception and application of vegetation on the roadside, and suggestions are offered as to how views should be changed.

CONTEXT OF ROADSIDE VEGETATION MANAGEMENT PROBLEMS

Roadside vegetation management is universally viewed with mixed emotions. On the one hand it is recognized as the primary material for erosion control and surface stabilization. In other forms, ornamental trees, shrubs, groundcovers, and wildflowers are viewed as "beautification." However, from a maintenance point of view, roadside managers more frequently find themselves locked in mortal combat with the vegetative community of the roadside. Police actions and outright wars are waged annually to remove unwanted vegetation from some parts of the roadside and, in other instances, to get anything to grow at all. Each growing season, roadside managers descend on the roadsides with armies of mowers, grade-alls, front-end loaders, and spray rigs to seek out and destroy the enemy.

It appears that, as roadside managers, we have accepted the inevitability of this seasonal cycle as something akin to the rise and fall of the tides. However, those who accept the inevitability of the vegetation management cycle fail to recognize that plants on the roadside are responding to habitat conditions created by the design of the roadside. The conditions are created by the design of roadside features that make the roadside favorable for plant growth and development. The fact that plants respond to unique microhabitats is seldom recognized in the design of structures and the development of roadside maintenance strategies.

In addition to the design problems associated with unexpected or unwanted plant habitats, there are the characteristics of the plants themselves. Plants, like people, are different in terms of their behavior and their abilities to perform certain tasks. It can be demonstrated, for example, that some plants have decidedly better hydraulic characteristics than others (i.e., some resist flow, whereas others lie down and form a smooth, hydraulically efficient mat that protects the channel and reduces the accumulation of silt). Yet, there is little evidence in the literature that the transportation community has given much thought to these specific vegetation qualities. Herein lie the problems.

Perception of Vegetation as a Maintenance Liability

Except for the redeeming qualities of erosion control and decorative appeal, roadside vegetation is, more often than not, considered a liability. In general the maintenance community accepts this as part of the cost of doing business and proceeds to attack the same old problems with each new growing season. Everyone in the roadside management field has intimate knowledge of these seasonal, vegetation-related headaches. However, for the sake of review, some of the all-time favorites are listed:

- Mowing,
- Brush removal,
- Pavement edge encroachment,

Texas Transportation Institute, Texas A&M University, College Station, Tex. 77843-3137.

- Problems with vegetation and structure interfaces (i.e., signs and poles, guardrails, walls, headwalls and endwalls, and expansion joints in pavement and riprap),
- Obstruction of drainage ways, and
- Blockage of drainage structures.

These problems are not only annual annoyances but also significant drains on manpower and financial resources. It is estimated that Texas spent more than $50 millon on mowing state-maintained rights-of-way in 1988 and an additional $5 million on herbicides for vegetation control. No direct figures were available for the cost of herbicide application, mechanical removal of vegetation, cleaning of ditches and culverts, and other problems directly related to the quality and behavior of roadside vegetation. A conservative estimate is on the order of $250 million. This is not exactly a small sum, yet even at this cost transportation departments across the country watch their budgets escalate and accept the problems as inevitable. It is suggested that this need not be the case.

Vegetation and the Highway Environment

First let us examine the context and environment in which and about which we make daily vegetation management decisions. Three fundamental perceptions influence and cloud decisions about roadside vegetation maintenance:

1. The perception of the roadside: In general the highway design community tends to view the roadside as what is "leftover" after the highway and its appurtenances are accommodated within the available right-of-way. This perception is termed "green scrap syndrome."
2. The perception of the highway landscape: The highway corridor is generally viewed as being the same as or an extension of the landscape by which it is bounded. For example, if a highway passes through a rural setting, it is considered a rural road, and it is generally accorded the attributes of the adjacent agricultural, forest, or range land. This leads to the unrealistic belief that whatever occurs on or adjacent to the original corridor can be regenerated after construction. Let us call this the "green fantasy syndrome."
3. The perception of roadside plant communities: Plant communities are, for the most part, viewed as little "green things" with personalities that are generally at odds with what would be considered acceptable public behavior in good engineering circles. In other words, they display those antisocial types of behavior that obstruct and defy permanent solutions. This perception is characterized as "green belligerence syndrome."

TOWARD NEW PERCEPTIONS OF THE HIGHWAY LANDSCAPE

Although each of these perceptions may have been overstated for dramatic effect, they are real and must be changed to come to grips with roadside maintenance costs. The significance of each perception will be outlined briefly along with examples of how each relates to the cost of maintaining the roadside.

Green Scrap Syndrome

Anyone who has ever tried to compile cost figures for roadside maintenance is familiar with green scrap syndrome. If we look at a typical cross section of maintenance budgets, we will find figures for mowing contracts, purchase of herbicide materials, and in some cases for the cost of spraying. All other maintenance costs are more often associated with the hard structures (i.e., drainage structures, bridges, pavements, signage and delineation, and guardrails and safety hardware). Given the abstract nature of the roadside, it is not difficult to understand why this perception persists, and it is a major deterrent to developing an understanding of the role of vegetation as a highway construction material.

We must recognize that the roadside is not just a collection of green scraps. Consider for a moment the basic functions of the typical highway right-of-way. The immediate shoulder provides information, lighting, emergency stops, runoff, and recovery. The middle zone is usually occupied by drainage channels and structures. The back slope is used to access adjacent properties, provide buffer space between adjacent land use, and provide space for large information standards and lighting apparatus. Seen in this light, the roadside is a far busier place than generally thought. Looking closer, it also becomes apparent that the prevalent material, with the exception of the pavement, is the "green stuff." We also know that if that "green stuff" is in poor health or is not appropriate for the job at hand, unpleasant things occur. Some of the more common problems include accelerated erosion and siltation and blockage of drainage ways and structures, which can also lead to pavement and embankment failures.

Green Fantasy Syndrome

Though the nonpaved portions of the right-of-way closely resemble the adjacent landscape, they are, in fact, quite different. In most cases changes made along the construction corridor realign the microenvironmental conditions to the extent that the right-of-way becomes totally different from its immediate surroundings. Topsoil is disturbed; drainage patterns are changed, which affects overall moisture relationships; slopes and orientations are modified; and the existing vegetation community is effectively destroyed. Ecologists refer to this phenomenon as a catastrophic event. This term is often used by "environmentalists" with great emotional appeal, even though it is out of context with the term's real ecological significance. The net result of a catastrophic event is a new beginning. A new ecological succession begins, in which the forces of nature begin the creation of a new biotic community in harmony with the new conditions. Change is not necessarily bad; it is just different.

The green fantasy syndrome does not recognize the reality of this powerful natural process. We spend untold dollars every year trying to save or fight Mother Nature, and we usually lose in either case. It is important that we, as designers and managers, look more closely at the ecology of the roadside and develop a better understanding of the microenvironmental and successional processes that will occur in the new environment.

Consider for a minute the unique environmental conditions of the roadside. It is hotter and more prone to drought, soils are generally poor and highly compacted, slopes are generally increased perpendicular to the centerline, the air quality is poor due to exhaust emissions, and runoff is generally more polluted in the immediate right-of-way zone. Given the harsh environmental conditions and comparing these conditions to the body of research published on highway vegetation, we find that most of the work has been done using typical agricultural research methods. Most often this means the use of small field plots, 2 to 3 m square, with generally friable, well-drained, and hospitable soils. In most cases the plots are flat, with slopes of 1 percent or less. Temperatures are not influenced by pavement mass, and the air and water are generally clean. Although some generalizations and extrapolations are possible from research using these methods, the aggregate results must be viewed as inconclusive at best because there is no way to realistically duplicate the extreme environmental conditions of the roadside.

On the other hand we know that plant communities do flourish on the roadside, even though we may not completely understand the reasons. Because our attention is usually devoted to the problem areas, we often forget that a much greater percentage of the roadside is all right. This strongly suggests to me that there is a great deal yet to be learned from more careful examination of the conditions and circumstances that lead to this success.

Green Belligerence Syndrome

The earlier "tongue-in-cheek" remark about waging annual war on unwanted roadside vegetation is an appropriate analogy. There can be little doubt that plants like Johnsongrass, varieties of thistle, and other noxious weeds are a headache. However, these are only a fraction of the total roadside plant community. Too often these problem plants draw attention away from a much broader issue of plant suitability.

Different plants have varied preferences for habitat and behave differently depending on the situation. In reviewing a cross section of highway planting specifications it was found that, in almost every case, the roadside is treated as a homogeneous environment, when nothing could be further from the truth. This simple oversight disregards the functional zones of the right-of-way noted earlier. Planting each zone of the roadside with the same plant material is democratic; however, unlike some of today's clothing, "one size does not fit all."

By planting uniformly over the entire cross section of the right-of-way, we essentially surrender the opportunity to design the surface material of the roadside in accordance with the function it is to perform. We would certainly never design a pavement cross section in this way. Yet this is exactly how we design our roadsides. In a majority of the cases we are lucky. The plants sort themselves out through the process of natural selection, and no one thinks too much about it unless problems arise.

If you look closely at the plants growing in older, more established roadside communities, you will see that they have sorted themselves into associations that reflect the microhabitat conditions. Plants with higher moisture requirements will colonize the swales and borrow ditches. Lower-growing species and those most tolerant of frequent mowing will show up on the immediate shoulder. The taller grasses and woody species will colonize the guardrails, walls of drainage structures, fence lines, and any other location that is protected from mowing machinery.

This suggests that we look more closely at the message Mother Nature is trying to send us and begin exercising our design prerogative by establishing plant communities in concert with the function of the particular roadside zone. To do this, we must be better students of how plants perform in the roadside environment. We must recognize that the highway is a demanding environment and that the plants are not being used to produce food, fiber, or red meat. Plants on the roadside are engineering materials and should be understood and used in that frame of reference. The background research we have done to date (reference list available from the author) strongly supports the notion that plants can be developed and used in this way. However, little has been done to develop the information necessary to put these simple principles into practice.

The concept of plants as engineering materials is simple but generally overlooked. In the years ahead we should set a goal to better understand the engineering properties of plant materials so that they can be used more efficiently and effectively to reduce the cost of roadside maintenance. The following principles should govern research in this area:

- The roadside is not just leftover space. It is a necessary and functional part of the highway. It is used to provide safety, drainage, access, and information to the traveling public.
- Each zone of the right-of-way has a different function and should be treated differently with respect to the vegetation that is used in that zone.
- The roadside environment is a structure. By its design and use it is a unique environment. It has nothing in common with agricultural fields, home lawns, forests, or other manifestations of the landscape, and must be understood in terms of its unique ecology.
- Plants are different with respect to their preferences for habitat and the functions they can serve on the roadside. They should be used more effectively as part of the materials selection process.
- Plant-structure relationships contribute to many vegetation management problems and can be corrected by more careful design consideration.

Research in this area will require patience and will take a number of years to reach the objectives outlined. It must be undertaken with the realization that roadside maintenance takes place in an environment of many interconnected systems that cannot be effectively examined out of context. Progress will begin slowly and gain momentum with each new insight. The savings that might accrue from any single discovery or improvement in our maintenance know-how will probably be small. The real benefits will be realized in the aggregation of small discoveries and by continuing the search for simple, common-sense maintenance solutions.

Abridgment

Data Collection and Analysis of Bridge Rehabilitation and Maintenance Costs

MITSURU SAITO AND KUMARES C. SINHA

Analysis of rehabilitation and maintenance work is essential for effective bridge management. Only by correctly understanding costs, timing, and service life of rehabilitation and maintenance work can realistic life-cycle cost analyses of bridges be made. Bridge rehabilitation and maintenance work were evaluated to determine representative cost models that can be used in a bridge management system. Cost and other data needed for the analysis were extracted from the bridge rehabilitation cost file (contract costs), rehabilitation records, rehabilitation design plans, and maintenance records maintained by the Indiana Department of Transportation. Several problems related to the existing rehabilitation and maintenance work recording procedures were identified during the study. A major problem encountered was an inconsistent grouping of rehabilitation activities. Also, unit costs were found to vary substantially within the same rehabilitation category. The difference was partly caused by the wrong classification of rehabilitation activities and partly by the way bridge rehabilitation activities are let for contract. Often, two or more bridges are included in one rehabilitation contract, and only one unit cost per contract is computed despite the differences in the type and amount of work required for individual bridges in the same contract. It was necessary to discount these effects before determining representative unit costs. In addition, a manual inspection of maintenance records indicated the need for a refinement of the bridge maintenance work categories.

Analysis of rehabilitation and maintenance work is essential for effective bridge management. Only by correctly assessing the cost, timing, and service life of rehabilitation and maintenance activities can a realistic life-cycle cost analysis of bridges be made. The number of the types of bridge rehabilitation activities is large. Grouping rehabilitation activities into a manageable number of categories is a necessary step toward developing a practical bridge management program. However, the number of categories should not be too small to maintain the desired level of precision of the estimated costs.

Bridge rehabilitation costs are often estimated using a unit cost calculated for various types of rehabilitation work together. However, a large variation exists among the unit costs of different rehabilitation activities and within each rehabilitation category. There is a danger of overestimating or underestimating future rehabilitation costs if such variations are overlooked. Similar arguments can be made for the estimation of maintenance costs. Bridge maintenance costs are often treated as an annual lump sum amount. But not all maintenance activities are annual events.

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The purpose of this cost analysis was to evaluate the method of record keeping and to determine representative cost estimates that can be incorporated into a network level bridge management system of the Indiana Department of Transportation (INDOT). The results of the assessment and the procedure employed to statistically analyze rehabilitation and maintenance unit costs are summarized. Also discussed are problems that were encountered during the study.

Records of about 440 bridges rehabilitated in 1984, 1985, and 1986 were extracted from INDOT's bridge rehabilitation records. Rehabilitation categories recorded more than once are shown in Table 1. Deck and superstructure work accounted for most of the activities. Substructure rehabilitation accounted for only a small portion of total bridge rehabilitation cost in any year, and there were only a few types of such work.

There were three primary problems in the recording of rehabilitation activities. First, the categorization of rehabilitation activities was often inconsistent, making the task of determining representative costs difficult. Second, there were large variations in unit costs among the different rehabilitation categories and within each category, as shown in Table 1. Third, a large number of rehabilitation contracts contained more than one bridge in one contract, making it difficult to attribute proper expenditures to each bridge.

ANALYSIS OF DECK RECONSTRUCTION AND OVERLAY COSTS

The only category feasible for subsequent statistical analyses was deck reconstruction and overlay. Out of 360 bridges receiving deck reconstruction and overlay, 84 met the data selection criteria: (*a*) one bridge per one contract and (*b*) rehabilitation work that met the definition of the deck reconstruction and overlay category. Unit costs in different years were adjusted to the 1985 level by using the FHWA construction price indices (*1*). Unit costs are expressed in dollars per square foot of deck area. Unit costs shown in this paper are costs of the structure portion of the rehabilitation work. Costs of other miscellaneous items were, on the average, about 110 percent of the structure cost. The analysis of variance (ANOVA) technique was used to determine the effects of various factors on unit costs. ANOVA helps to identify what factors might most affect the values in question (*2*). The SPSS statistical package (*3*) was used for statistical analyses.

TABLE 1 REHABILITATION CATEGORIES USED BY INDOT AND THEIR UNIT COSTS

Rehabilitation Category	Number of Bridges	Unit Cost ($\$/ft^2$)*	
		Min.	Max.
1. Deck Reconstruction & Overlay	360	1.37	32.28
2. Deck Reconstruction & Widening	17	13.93	69.49
3. Deck Reconstruction & Joint Replacement	10	3.18	3.28
4. New Deck	8	14.68	63.21
5. New Deck & Widening	7	6.81	36.28
6. Deck Reconstruction	6	6.49	30.58
7. New Superstructure	5	19.29	65.31
8. Deck Replacement & Widening	4	11.07	72.70
9. Superstructure Replacement	3	23.18	35.23
10. Superstructure Reconstruction & Widening	2	24.73	n.a.
11. Major Reconstruction	2	27.57	n.a.
12. Replacement of Beams	2	3.97	25.68
13. Deck Replacement	2	20.52	30.19
14. All others**	15		

Note: n.a. - Only one unit cost was available.
* - Cost data were obtained for bridges rehabilitated in 1984, 1985, and 1986.
** - Each activity category had only one case.

Remarks: These unit costs are of the structural portion of the total rehabilitation cost.

Factors Used in Cost Analysis

Four classification factors for general bridge management were initially considered: highway system type, traffic volume, climatic region, and bridge type. ANOVA indicated that their effects on the unit costs of this rehabilitation activity were not significant, implying that differences in the unit costs were due to other factors. However, this result does not suggest the complete exclusion of these factors from all other analyses. The test says only that there was no substantial evidence to prove that unit costs were affected by these factor groupings.

Effects of Bridge Attributes on Unit Costs

Bridge attributes that can be readily estimated by inspectors were subsequently evaluated. They included structure length, deck area, and percentage of deck area needing patching. The percentage of deck area needing patching is obtained by dividing the total of shallow patching and full-depth patching by the deck area, both expressed in square feet. This attribute was tested because it is a primary factor in selecting a deck reconstruction and overlay work.

The effects of bridge length and deck area on unit costs were significant at $\alpha = 0.05$ and 0.10, respectively. The deck area needing patching was not significant by itself at these significance levels. Two-way ANOVAs were then performed to see the interaction effect of length and deck area: one for the combination of deck area and percentage of deck area needing patching and the other for the combination of bridge length and percentage of deck area needing patching. The former model provided more distinct unit costs among the factor combinations than the latter. Table 2 shows results of the two-way ANOVA performed on the combination of deck area and percentage of deck area needing patching. The effect of the two attributes (main effects) and their interaction on unit costs were significant at $\alpha = 0.05$. This result implied that unit costs were dependent on both the size of deck area and the percentage of deck area needing patching. Unit costs determined in this manner are more precise than a single mean unit cost.

BRIDGE MAINTENANCE COST ANALYSIS

At the time of the study, five activity types were used to record bridge maintenance work. They were (*a*) hand cleaning of bridges (Activity 241), (*b*) bridge repairs (Activity 243), (*c*) deck flushing (Activity 244), (*d*) patching (Activity 245), and (*e*) other bridge maintenance (Activity 249). The hand cleaning and flushing activities are performed annually on each bridge. The remaining three activities are done whenever the need arises or as recommended by bridge inspectors. Maintenance activities are customarily summarized by highway type (Interstate and Other State Highway) within subdistricts. At the time of the study, maintenance workers were not required to record the specific bridge locations. Hence, the maintenance history for individual bridges was not available. It was necessary to use average values at the subdistrict level to determine representative bridge maintenance costs. An assumption was made on the basis of the result of a previous study (*4*) that each subdistrict follows the same work standards.

TABLE 2 EFFECTS OF DECK AREA AND PERCENTAGE OF DECK AREA NEEDING PATCHING ON UNIT COSTS OF DECK RECONSTRUCTION AND OVERLAY (1985 DOLLARS)

		Deck Area (DA) in Square Yards		
		Small DA<500	Medium 500≤DA<2,000	Large DA≥2,000
Percent of Deck Area Needing Patching (PA)	Low (PA<15%)	N = 6 Mean = 13.74 LL = 9.78 UL = 19.30	N = 37 Mean = 9.09 LL = 7.94 UL = 10.40	N = 6 Mean = 5.73 LL = 4.65 UL = 7.01
	High (PA≥15%)	N = 6 Mean = 16.09 LL = 11.45 UL = 22.60	N = 26 Mean = 10.11 LL = 8.60 UL = 11.88	N = 3 Mean = 8.11 LL = 5.02 UL = 13.12

Definitions: N = Number of samples
Mean = Mean unit cost in $ per square foot
LL = Lower limit of the 95% confidence interval of the mean
UL = Upper limit of the 95% confidence interval of the mean

Remark: The unit costs shown here are of the structural portion of the total rehabilitation cost. Miscellaneous items require an additional 110% of the structure cost.

Data Base and Study Approach

There are 37 subdistricts of INDOT, resulting in 37 data points per year for each activity. The data base for this analysis was prepared using the annual accomplishment and performance summary reports of the past 6 years, from fiscal years 1980–1981 through 1985–1986. Information on the amount of work done, the number of man-hours required, and the number of crew days spent for the five activities was obtained. Cost data were taken from the 1985–1986 reports; hence, computed unit costs were considered to be close to the 1985 price. Cost data consisted of three elements: labor, material, and equipment. Labor was the major portion of the costs for maintenance activities except Activity 243 (bridge repair), for which labor was slightly more than 50 percent of the total cost. All activities were first expressed in terms of man-hours per production unit. At the same time, the total maintenance cost of each activity was converted into cost per man-hour. The cost per man-hour was then multiplied by the number of man-hours required at the work site to determine the unit cost per production unit.

Effects of Management Factors on Work Requirements

The only significant management factor was the highway type (Interstate or Other State Highway), and this was true only for Activities 241 and 243. The difference was moderately significant for Activities 244 and 245. The highway type was not, however, significant for Activity 249. For Activities 241 and 244, the production unit would depend on the size of the deck. Therefore, work requirements would vary considerably for bridges of different deck areas. On the other hand, man-hour requirements of Activities 243 and 249 are the number of man-hours to perform these activities in 1 crew day. Hence, if a repair requires more than 1 crew day, the work requirement for that bridge would have to be adjusted by the number of days. No adjustment is required for Activity 245 (patching), because the unit cost was determined according to the square feet of patching work.

Representative Maintenance Unit Costs

Table 3 shows the unit costs of maintenance activities computed in the manner discussed. The table also shows the 95 percent confidence intervals of the mean unit costs. Deck-cleaning and bridge-flushing costs for particular bridges can be computed by multiplying the unit costs by the ratio of the actual bridge size to the state average deck size as indicated in Table 3.

CONCLUSIONS

The primary goal of this study was to assess the procedures for recording rehabilitation and maintenance activities and to determine representative unit costs. Although the numerical results apply only to Indiana, the analytical procedure followed can be of assistance to other states interested in determining similar unit costs.

The existing grouping of bridge rehabilitation projects was found to be rather inconsistent. Reorganization of rehabilitation categories was recommended to improve the precision of unit costs. A list of suggested categories was prepared on the basis of the literature and opinions of state bridge inspectors.

Bridge rehabilitation is site specific. Therefore, there is a large variability in the amount of work done for each reha-

TABLE 3 UNIT COSTS OF ROUTINE MAINTENANCE ACTIVITIES FOR FISCAL YEAR 1985–1986 (DOLLARS PER PRODUCTION UNIT)

Activity Type	Production Unit	Interstates	Other State Highways
241. Hand Cleaning Bridges *	Per Deck	Mean = 64.87 95%CI = 61.54 to 68.12	Mean = 51.26 95%CI = 49.32 to 53.27
243. Bridge Repair	Per Repair Per Day	Mean = 463.28 95%CI = 413.96 to 512.61	Mean = 455.87 95%CI = 436.19 to 475.43
244. Flushing Bridges**	Per Deck	Mean = 38.67 95%CI = 35.40 to 42.01	Mean = 34.14 95%CI = 32.16 to 36.04
245. Patching Bridge Decks	Per Square Foot	Mean = 12.15 95%CI = 9.64 to 14.66	Mean = 10.34 95%CI = 9.24 to 11.45
249. Other Bridge Maintenance Activities	Per Maintenance Per Day	Mean = 378.90 95%CI = 329.00 to 428.82	Mean = 337.32 95%CI = 311.70 to 362.94

Note: M = Mean value
95%CI = 95% confidence interval of the mean

* Adjustment for Activity 241

- Interstate (INT):

$$\text{Cost per Deck} - \frac{\text{Deck Area } (yd^2)}{1,172.3\ (yd^2)} \times (\$64.87)$$

- Other State Highways (OSH):

$$\text{Cost per Deck} - \frac{\text{Deck Area } (yd^2)}{549.1\ (yd^2)} \times (\$51.26)$$

** Adjustment for Activity 244

- Interstate (INT):

$$\text{Cost per Deck} - \frac{\text{Deck Area } (yd^2)}{1,172.3\ (yd^2)} \times (\$38.67)$$

- Other State Highways (OSH):

$$\text{Cost per Deck} - \frac{\text{Deck area } (yd^2)}{549.1\ (yd^2)} \times (\$34.14)$$

bilitation, and the variability is reflected in unit costs. Statistical principles were applied to analyze rehabilitation alternatives. The ANOVA on unit costs resulted in a list of stratified unit costs for the deck reconstruction and overlay alternative. The stratified unit costs should result in more precise cost estimates.

The maintenance cost analysis required a special procedure to deal with the lack of maintenance history of individual bridges. Recording the specific locations of maintained bridges is essential to collect data for life-cycle analysis. The unit costs presented in this paper reflect the characteristics of maintenance activities in Indiana, and they may not be directly transferable to other states. Nevertheless, the analysis procedure can be useful to other states.

ACKNOWLEDGMENT

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Data Base–Integrated Advisory System for Pavement Management

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Expert (advisory) systems are designed to improve productivity and the quality of decisions by making computers more useful. The objectives are accomplished by providing the user with a better understanding of the program knowledge base through enhanced explanation facilities. An effort at the Pennsylvania Transportation Institute (PTI) of the Pennsylvania State University to develop an advisory system for pavement management activities is described. The knowledge base for the advisory system incorporates the current treatment decision criteria of the Pennsylvania Department of Transportation's roadway management system, the Systematic Technique to Analyze and Manage Pennsylvania's Pavements. PTI researchers emphasized the integration of a data base with the advisory system. If users of this system have access to a data base, they can quickly obtain physical, traffic, and pavement condition information for a particular roadway segment for review and then concentrate their efforts on selecting appropriate maintenance strategies. The application was developed using a commercially available expert system shell. It is currently limited to rigid pavements and provides an interactive environment to assist the user in determining appropriate maintenance strategies, including estimated cost, for a particular roadway segment. The application can also analyze multiple roadway segments to assist an engineer with project development activities.

Expert (advisory) systems are designed to improve productivity and the quality of decisions by making computers more useful. The objectives are accomplished by providing the user with a better understanding of the program knowledge base through enhanced explanation capabilities. In early 1989, Pennsylvania State University's Pennsylvania Transportation Institute (PTI) and International Business Machines (IBM) embarked on a joint study (cosponsored by the Mid-Atlantic Universities Transportation Center) to examine the feasibility of the use of expert systems by highway engineers. Researchers hoped to identify both the positive and negative attributes of expert systems. Furthermore, a demonstration of specific applications within the knowledge domain of the practicing engineer would provide a means for evaluating the usefulness of expert systems.

Expert systems are defined as interactive computer programs that employ a collection of judgment, experience, rules of thumb, intuition, and other experience in a particular field, coupled with inferential methods of applying this knowledge, to provide expert advice on the performance of a variety of tasks (*1*).

Two shortcomings of current highway engineering problem-solving activity are (*a*) the ill-structured nature of solutions and (*b*) the loss of technical expertise. The development and use of expert system applications may hold the answers to these problems.

Solutions to highway engineering problems are typically multidimensional. Human behavior, social considerations, fiscal limitations, and political considerations strongly influence the decision maker. Even the science behind the technical process becomes an art when the decision maker encounters variability in the traffic, materials, climate, and specification input to the process.

Currently, many state highway agencies are facing a shortage of technical personnel (*2,3*). The engineers who designed and built the Interstate highway system are retiring. Often, no mechanism is available to retain their knowledge and relay it to new engineers who will be responsible for maintaining the system. Innovative methods for capturing and transferring this knowledge are needed.

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APPLICATION DEVELOPMENT

The development of an advisory system application consists of the following phases (*4*):

1. Application definition,
2. Knowledge acquisition,
3. Knowledge representation and inference mechanism, and
4. Implementation.

The goal of the project was to create a pavement management advisory system application in 1 year. PTI personnel were provided with a mainframe computer, color graphic terminals, printers, software, maintenance support, and training. PTI supplied the highway engineering personnel (engineers by profession) to develop the application. Although these engineers possess nominal computer programming capabilities, they would not be described as highly computer literate. They received the equivalent of a 1-week training program in expert system development software. The use of engineers for system development was considered vital to the evaluation of the development process.

A literature search was conducted to learn more about artificial intelligence and expert systems in general and to identify previous efforts to develop advisory systems for pavement management (*5*). A standard criteria checklist to evaluate the suitability of an application was organized from the literature search, as shown in Figure 1 (*1,6–8*). It became apparent to the project team that the selected application should have a strong user focus to assist the development and possible future evaluation. In other words, the application

- Is the application focused on a narrow specialty area?
- The application should not be too easy or too difficult for a human to solve.
- The application should be clearly defined.
- Is commitment from an articulate expert or group of experts available?
- Algorithmic solution is impractical because of the complex physical, social, political, or judgmental components.
- Expert is not often physically available to solve the problem.
- Factual elements of the domain knowledge are routinely taught to beginners who can eventually become experts.
- Potential payoffs are high.
- Public knowledge is not sufficient to allow most persons to reach an expert's level.
- Market has potential size to justify development.
- Failure by a faulty human expert cannot be tolerated.
- Faulty or incomplete data will be encountered during the problem-solving analysis.
- Does the application fit well within the corporate environment?

FIGURE 1 Checklist of expert system application criteria.

should not be exotic; it should be based on information and procedures familiar to potential users.

During the second month of the project, representatives of the Pennsylvania Department of Transportation (PennDOT) and PTI met to brainstorm possible application areas. Several areas were reviewed. After additional meetings of the joint study team and of the team and the PennDOT representatives, it was determined that an application based on PennDOT's current pavement management program [Systematic Technique to Analyze and Manage Pennsylvania's Pavements (STAMPP)] would be best suited for advisory system development.

STAMPP OVERVIEW

Developed in 1983 by an eight-member task force, STAMPP provides a systematic process to uniformly rate the condition of the pavement and to recommend appropriate repair strategies (*9*). STAMPP currently provides rating and decision criteria for the following components of the roadway network:

- Rigid pavements,
- Flexible pavements,
- Shoulders,
- Guide rail, and
- Drainage facilities.

Of the approximately 110,000 mi of highway in Pennsylvania, PennDOT manages about 44,000. The highways are divided into segments approximately 0.5 mi in length. Each year, a condition survey of each segment is conducted to document the severity and magnitude of various distress conditions. The results of this survey are entered into a central data base. Recommended maintenance treatments for each segment are generated, and a maintenance and betterment program is established by management, which balances the work recommended by STAMPP with available funding.

The knowledge base, developed and initially field-verified by the task force, is organized in terms of decision matrices. The decision matrix for rigid pavements is shown in Figure 2. STAMPP currently operates as a traditional computer program accessed through the PennDOT mainframe computer system. No interactive user interface is available to provide a conversational environment. In a sense, STAMPP is a rudimentary advisory system, although it lacks the interactive user interface and a separation of the knowledge base and inference engine that satisfy the classical definition of an advisory system. Unfortunately, users throughout Pennsylvania lack confidence in the STAMPP system and therefore will not accept its recommendations. Furthermore, inputs to the decision process, including roughness and truck volume, are not included, causing more resistance to STAMPP's use.

The selection of STAMPP for advisory system development was advantageous for several reasons. First, the knowledge base was readily available. Knowledge acquisition, formally

	Low			Medium			High		
Condition	1	2	3	4	5	6	7	8	9
Joint Seal Failure	X	1	2	1	2	2	1	2	2
Longitudinal Joint Spalling	1	2	3	4	4	4	4	4	4
Transverse Cracking	X	X	X	2	3	3	9	9	9
Transverse Joint Spalling	X	1	3	4	4	4	5	5	5
Faulting	X	6	6	7	8	8	9	9	10
Broken Slab	6	6	6	9	9	9	9	9	9
Bituminous Patching	9	9	9	9	9	9	9	9	9
Surface Defects	4	4	4	9	9	9			
Rutting	10								

No.	Description
X	Routine Maintenance
1.	Spot Joint Seal
2.	Joint Seal
3.	Joint Rehabilitation
4.	Joint Spall Repair
5.	Joint Replacement
6.	Subseal
7.	Subseal and Slabjack
8.	Subseal, Slabjack, and Grind
9.	Slab Replacement
10.	Overlay

Overlay Repair Recommendations:

AADT	Repair
0-1000	3-1/2" Bituminous
1001-2000	6" Bituminous
2001-3000	Concrete Overlay
Above 3000	Reconstruct

FIGURE 2 PennDOT rigid pavement treatment strategies.

referred to as knowledge engineering, can be time-consuming for the application developer and for the expert providing the knowledge. With only 1 year to complete the development, the research team identified an available knowledge base and could then concentrate on other aspects of the study. Second, the application developed would not be viewed as exotic. Instead, it would demonstrate how existing programs and procedures could be presented in a different format. Third, PennDOT representatives expressed the most interest in this application, which indicates that a STAMPP advisory system may offer the greatest payback to the department. Fourth, the PennDOT pavement management central data base is based on the requirements of the STAMPP methodology. This data base would serve as a model for the external data base envisioned for the advisory system. The literature search on advisory system development revealed few attempts to demonstrate data base integration. However, the research team judged that the advisory system's ability to accomplish this integration is essential if the application is to improve a user's productivity.

The criteria shown in Figure 1 were applied to STAMPP to judge its suitability for advisory system development. The STAMPP application fit the criteria well, and development began.

As indicated earlier, the STAMPP methodology has decision criteria applicable to several different components of the roadway network. It was apparent that all components could not be integrated into the advisory system in 1 year. All team members were concerned with promising too much too soon and then not being able to deliver a usable product. The joint study team, in consultation with PennDOT representatives, selected the rigid pavement decision criteria for application development and decided that this would serve as a blueprint for including other STAMPP components at a later date. The objective established by the joint study team was to develop an advisory system application based on the pavement management input and decision criteria for rigid pavements used by PennDOT. It was to have the following attributes:

- For a specific roadway segment, obtain the physical and operating characteristics required for the analysis. This information could be obtained either directly from the user through an interactive interface or from an external data base.
- For a specific roadway segment, obtain the pavement condition survey information required for the analysis. This information could be obtained either directly from the user through an interactive interface or from an external data base.
- Analyze the condition survey information to determine appropriate repair strategies for the roadway segment.
- Provide sufficient explanation facilities throughout the application to give the user access to definitions and descriptions of the required input and to explanations about how the program determined the recommendations (repair strategies).

During the seventh month of development, the application, though still in a formative stage, was demonstrated to several engineers from a PennDOT district office. On the basis of their comments, the following attributes were added:

- Provide the capability to analyze several segments during a single consultation to facilitate a project development initiative.
- Provide estimates of the cost to complete repair strategies recommended by the application.
- Provide a mechanism for the user to perform a sensitivity, or "what if," analysis for a given roadway segment.

APPLICATION STRUCTURE

The expert system shell used to develop the application was the rule-based Expert System Environment (ESE) developed by IBM. ESE consists of two primary components: an expert system development environment (ESDE) and an expert system consultation environment (ESCE).

ESDE is used by the knowledge engineer (application developer) to create the knowledge base. The knowledge base consists of the facts and rules within the application area and information on how the system is to process them. ESDE provides several tools to help the application developer with the development process, including edit, trace, and debug facilities and a graphical representation of the knowledge base. The end user uses ESCE to consult the knowledge base to solve a particular problem. ESCE contains the following interfaces: interactive dialogue, explanation facilities, graphical data representation support, and on-line help systems. ESE may also interact with external routines and external data bases. The relationship between ESDE and ESCE is shown in Figure 3. Currently, the development tool is limited to a mainframe environment. Depending on the size of the knowledge base and its need to interact with external programs, the consultation environment may operate on a personal computer.

The knowledge base consists of facts and rules. A fact in the knowledge base domain can be represented as a parameter. The average annual daily traffic (AADT) for the roadway segment is an example of a parameter. The value assigned to a parameter can have several sources. It may be the result of a rule or come from an end user's input from the terminal, a default value assigned by the developer, or an external source such as a data base. The application developer specifies the source and sequence that the application, during the consultation, will use to obtain the value. Rules represent the relationship between facts. These rules exist as "If <antecedent> - Then <consequence>" statements. The following is an example of a rule:

If transverse cracking is rated at Condition 4, then crack seal the transverse cracking.

The ESE shell allows the developer to structure the application into subproblems through the use of focus control blocks (FCBs). Each FCB contains the rules and parameters of a specific problem area of the application. For this application, the condition survey information is contained in one FCB, the determination of appropriate repair strategies is contained in another, and the estimating algorithms are contained in a third. The FCBs are then arranged in a hierarchical structure of the main problem and its subproblems. The hierarchy is represented as a parent-to-child relationship with one FCB as the root from which the hierarchy is built. The hierarchical structure is shown in Figure 4.

The ESE shell also allows the developer to select either forward- or backward-chaining inference techniques. Both

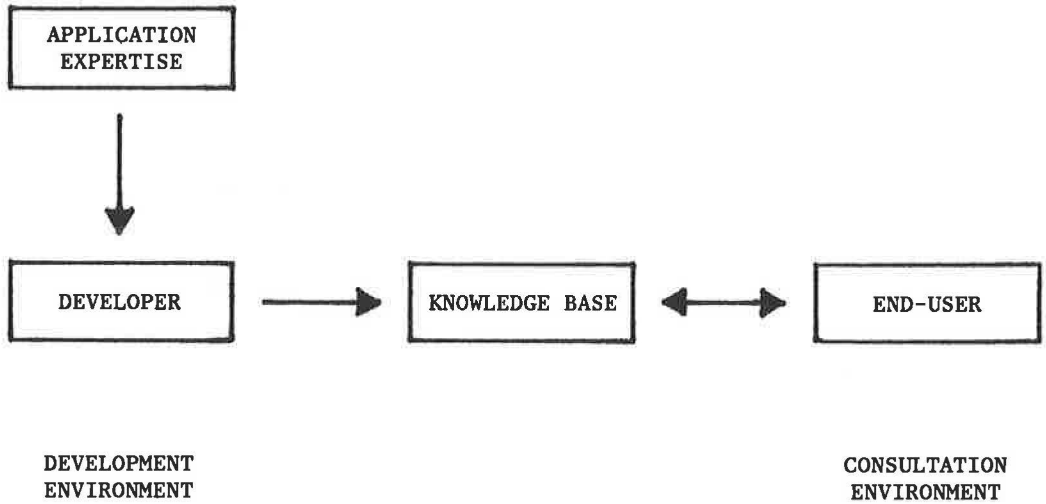

FIGURE 3 Relationship between development and consultation environments of the expert system shell.

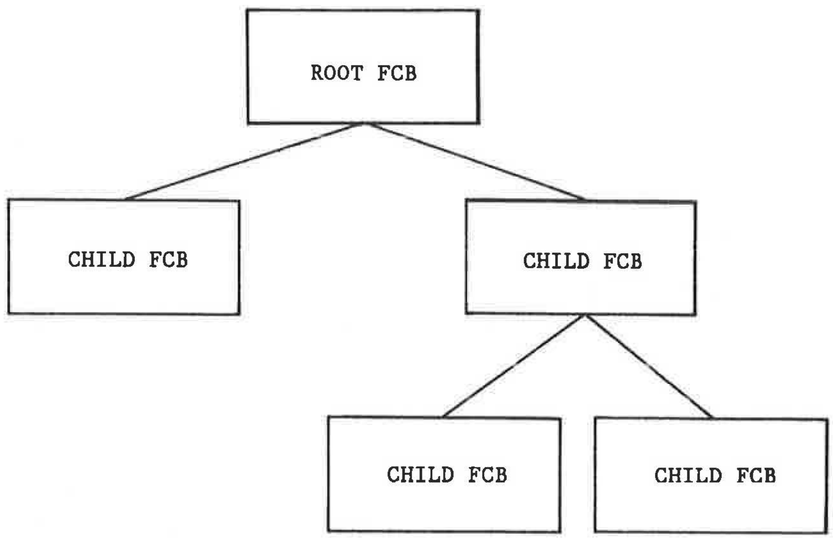

FIGURE 4 Relationship between FCBs.

techniques may be used in the same application through proper design of the FCBs. Forward chaining may be used in one FCB, whereas it may be more appropriate to backward chain the rules and parameters associated with another FCB. Forward chaining is often referred to as a data-driven technique because it works from an initial state of known facts to a goal state. It is most useful in situations where there are many hypotheses and few input data (*7*). However, a drawback of this technique is reduced processing efficiency, because the input of all possible facts for all conditions is required. In forward chaining, the rules within the application are applied to the user-supplied facts to infer new facts. For the rule "if A then B," if Fact A is true, then it is concluded that Fact B is also true. Backward chaining is often referred to as a goal-driven inference technique. Backward chaining assumes that the goal is known, searches the knowledge base, selects rules with conclusions that could satisfy current goals, and then continues to look for facts to satisfy these rules. For example, for the rule "if A then B," if B is established as the goal, the program seeks to determine that Fact A is true for the goal to be true.

EXPERT SYSTEM ANALYSIS OF RIGID PAVEMENTS

As indicated earlier, the knowledge base of this advisory system was limited to the analysis of rigid pavements. PennDOT's decision criteria provided the parameters and rules. For rigid pavements, the STAMPP methodology evaluates nine pavement conditions:

1. Joint seal failure,
2. Longitudinal joint spalling,
3. Transverse cracking,
4. Transverse joint spalling,

5. Faulting,
6. Broken slabs,
7. Bituminous patching,
8. General surface defects, and
9. Rutting.

The pavement is rated on a scale from 0 to 9 to describe the severity and magnitude for each condition except for general surface defects, which is rated on a 0 to 6 scale, and rutting, which is rated on a 0 to 1 scale. Except for rutting, up to two values for each condition may be input for analysis. Rutting is described by a single value.

The advisory system will list recommended repair strategies for a roadway segment given the pavement rating for the conditions listed above. The original decision matrix for rigid pavements as developed by PennDOT (Figure 2) recommends 1 of 12 different repair strategies. As shown in Figure 2, several different pavement conditions could trigger the same repair strategy (*9*). For example, slab stabilization could be triggered by certain levels of severity of faulting or broken slabs. This could be written as a rule in the ESE format as follows:

If faulting is ≥ 2: ≤ 4,

or broken_slab is ≥ 1: ≤ 3,

Then repair_strategy is slab_stabilization.

When the rules were first written into the application knowledge base, the PennDOT decision matrix was interpreted directly, as indicated by the rule above. Although this format was logically correct, it soon presented the application developers with a problem. ESE, as well as any other rule-based shell, interprets the first part of the "IF" statement initially. If faulting was a 2, 3, or 4, the rule would be satisfied and the clause referring to the broken slab would not be evaluated. The consultation would recommend slab stabilization as a repair strategy; however, the reason for the recommendation would not be readily apparent. The ESE-generated explanation facilities, when prompted by the user to explain why slab stabilization was recommended, could only return the rule as written into the knowledge base. It could not explain to the user that slab stabilization was required to correct slab faulting, broken slabs, or possibly both conditions in the same roadway segment. This predicament was unsettling. To the highway engineers on the joint study team, knowing why a particular repair strategy was required was as important as knowing what strategy to use. They recommended further dividing of the rules to provide a uniqueness to the repair strategies on the basis of the pavement conditions. For example, the rule described would be divided into two rules, as follows:

Rule 1. If faulting is ≥ 2: ≤ 4,
Then repair_strategy is slab_stabilization for faulting.
Rule 2. If broken_slab is ≥ 1: ≤ 3,
Then repair_strategy is slab_stabilization for broken slab.

To the computer-oriented joint study team members, the consequences of this recommendation were clear. The number of parameters and rules processed during the consultation would be greatly increased. Therefore, the storage requirements of the application would increase and the consultation speed would be reduced. The engineering viewpoint—the need to know why a recommendation was being made—prevailed. The number of possible recommended repair strategies was increased to 28. The decision matrix was revised to reflect the expanded list of repair strategies as shown in Figure 5. The revised decision matrix formed the basis of the application knowledge base.

HIERARCHICAL STRUCTURE OF FCBs

The application to provide the attributes listed previously required 138 rules, 110 parameters, and 11 FCBs. The hierarchical structure of the FCBs for this knowledge base is shown in Figure 6. The purpose of each FCB is briefly described as follows:

- INTRO is the root FCB of the hierarchical structure. Its purpose is to provide introductory and concluding notes to the consultation. In particular, if a "what if" analysis is to be performed, this FCB provides detailed information on how to save, rerun, and modify the previous consultation to facilitate the analysis.
- ENGINEER's purpose is to access an external data base to obtain information (including name, department, and telephone number) regarding the individual whose user ID accessed the program. Should the information be incorrect, the user can update it, and control is passed to FCB SAVE_INFO to modify the external data base.
- SAVE_INFO is processed only if the user wishes to update the external data base with respect to department, phone number, user ID, and so forth.
- PAVEMENT's purpose is to obtain the state route number, the county in which the roadway is located, and the type of analysis that the user wants to perform. Three types of analysis are possible: single segment; multiple, nonconsecutive segments; and range of consecutive segments. PAVEMENT also determines whether the roadway and condition survey information is to be obtained directly from the user or from the external data base. This FCB also contains a looping function that permits the processing of more than one segment during a single consultation session.
- FIND_RANGE is accessed only if the type of analysis selected is "range of consecutive segments." Only the beginning and ending segments are input during the consultation for this analysis type. The purpose of this FCB is to determine the specific roadway segment numbers to be analyzed.
- SURVEY uses the forward-chaining inference engine to control the interaction between the four "children" FCBs.
- DB_INPUT's purpose is to obtain all pertinent data about the roadway segment from the external data base and to display them to the user. The data include physical and operating characteristics and the most recent condition survey information.
- USER_INPUT obtains all physical, operating, and condition survey information about the roadway segment from the user.

Condition	low 1	low 2	low 3	medium 4	medium 5	medium 6	high 7	high 8	high 9
Joint Seal Failure	2	3	5	3	5	5	3	5	5
Longitudinal Joint Spalling	4	6	8	10	10	10	10	10	10
Transverse Cracking	2	2	2	7	17	17	17	17	17
Transverse Joint Spalling	2	3	9	11	11	11	13	13	13
Faulting	2	14	14	14	16	16	18	18	MR
Broken Slab	15	15	15	19	19	19	19	19	19
Bituminous Patching	20	20	20	20	20	20	20	20	20
Surface Defects	12	12	12	21	21	21			
Rutting	MR								

No.	Description	No.	Description
1	Do Nothing	13	Transverse Joint Replacement
2	Routine Maintenance	14	Slab Stabilization - Faulting
3	Transverse Joint Spot Seal	15	Slab Stabilization - Broken Slab
4	Longitudinal Joint Spot Seal	16	Slab Stabilization & Grinding
5	Transverse Joint Seal	17	Slab Replace - Trans. Cracking
6	Longitudinal Joint Seal	18	Slab Replace - Faulting
7	Transverse Crack Seal	19	Slab Replace - Broken Slab
8	Longitudinal Joint Rehab	20	Slab Replace - Bit. Patching
9	Transverse Joint Rehab	21	Slab Replace - Surface Defects
10	Longitudinal Joint Spall Repair	*MR	Major Rehabilitation
11	Transverse Joint Spall Repair		
12	Slab Spall Repair		* Overlays and Reconstruction are included in this category.

FIGURE 5 Revised rigid pavement treatment strategies.

- TREAT_INFO uses the forward-chaining inference engine to determine the list of recommended treatments for the roadway segment and to display the list to the user.
- DEFAULT_VALUES uses the forward-chaining inference engine to determine the values of the parameters used in the algorithms to calculate the estimated cost for each of the recommended treatments determined during the processing of TREAT_INFO. The values are displayed to the user on two screens for review and modification.
- TREAT_COSTS uses the forward-chaining inference engine to determine the costs for each of the recommended treatments determined during the processing of TREAT_INFO and presents a final summary screen to the user detailing the recommended treatments and the corresponding estimated repair expenses for the specific roadway segment.

As previously discussed, the results of PennDOT's annual condition survey of each roadway segment are entered into

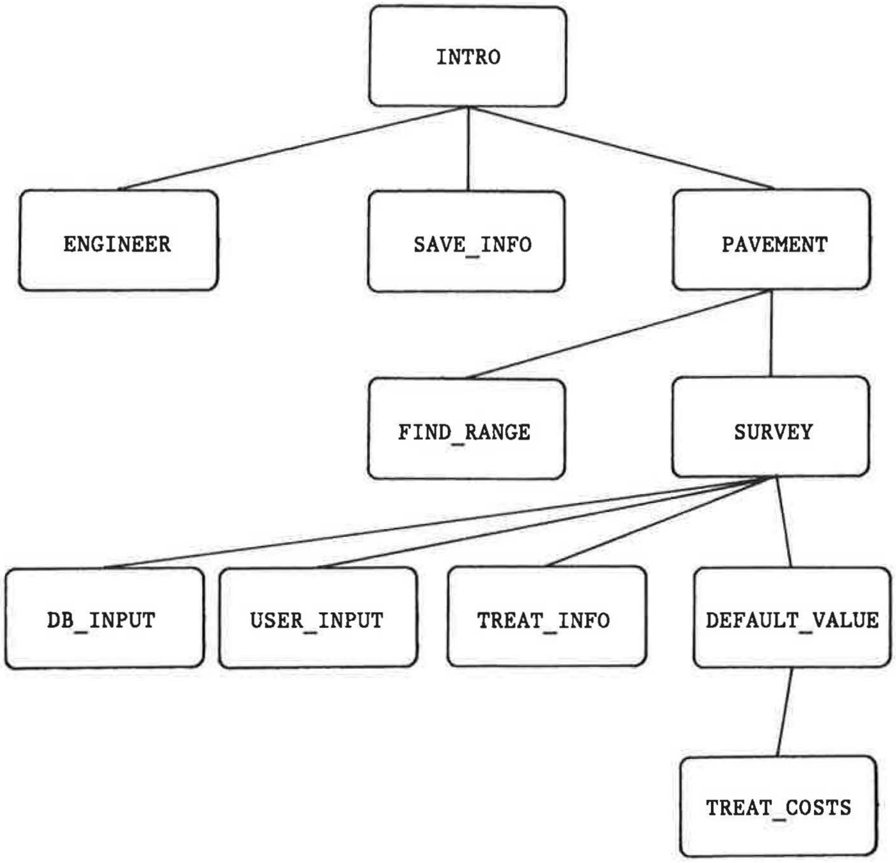

FIGURE 6 Hierarchical structure of advisory system FCBs.

a central data base for analysis. To demonstrate the ability of an expert system to access an external data base, a data table was created for this application. The table contains the pavement condition survey information and segment physical and operating information in the PennDOT data base. The application uses Structured Query Language to access the table. The pavement condition information collected was discussed previously. The physical and operating characteristics contained in the data table are summarized in Figure 7.

An interactive consultation is performed on a color graphics monitor. The application uses 21 screen designs. In addition, the user may access 14 help files at any point during the

Physical Characteristics

- Pavement type
- Roughness index
- Friction index
- Segment width
- Segment length
- Slab length

Operating Characteristics

- Average annual daily traffic (AADT)
- Area code: rural versus urban location
- Percent truck traffic

FIGURE 7 Physical and operating characteristics of the roadway segment included in the data base.

consultation to obtain detailed information about the pavement condition rating system and recommended repair strategies. Several of the more important screens displayed during the consultation are shown in Figures 8 through 13 and discussed below.

Figure 8 shows the default unit costs screen that the program uses to calculate the estimated treatment repair expense. The user may modify any value by moving the cursor to the appropriate cost line and entering the new value. Figure 9 presents the screen in which the user enters the state route number, the county in which the roadway resides, and the type of analysis to be conducted. On the screen shown in Figure 10, the user specifies the source of the roadway and condition survey information—user input or external data base. The physical and operating characteristics of the roadway segment are presented to the user through the screen shown in Figure 11. The screen in Figure 12 shows the format in which the application presents the condition survey information to the user. As discussed previously, except for rutting, up to two ratings per segment can be applied for each condition. The user can press the PF1 key to access the ESE help facility if detailed definitions and descriptions are desired. Pressing the PF4 key provides an abbreviated description of the pavement condition highlighted by the cursor. The application allows the user to modify the condition survey information, which is particularly advantageous in performing "what if" analyses. The final summary screen of recommended treatments and their associated estimated costs is presented in Figure 13. Pressing the PF10 key presents the user with explanations about the logic that the program uses to determine the treatments and costs.

SUMMARY AND CONSIDERATIONS FOR THE FUTURE

The developmental activities for an advisory system for pavement management have been presented. The system is limited to the analysis of rigid pavements and uses the repair strategy decision criteria developed by PennDOT, though it could be used as a blueprint for others interested in advisory system development in this subject area. The advisory system provides an interactive environment for the user to communicate with the knowledge base, demonstrates the ability of advisory systems to use external data bases, and provides a way to perform "what if" analyses.

The program's developmental activities are complete. The final step of the process—implementation, which will be the

UNIT COSTS

The unit costs presented below are the most current available.
Please review and modify if appropriate for this consultation.

DESCRIPTION	UNITS	UNIT COST
Routine Maintenance	Lineal Feet	$ 1.00
Joint Spot Seal	Lineal Feet of Repair	$ 2.00
Joint Seal	Lineal Feet of Joint	$ 1.50
Crack Seal	Lineal Feet of Crack	$ 2.00
Joint Rehabilitation	Lineal Feet of Joint	$ 10.00
Joint Spall Repair	Square Feet of Spall	$ 25.00
Slab Spall Repair	Square Feet of Spall	$ 25.00
Transverse Joint Replacement	Lineal Feet of Joint	$ 11.67
Slab Stabilization	Square Feet of Slab	$ 3.00
Grinding	Square Yards of Grinding	$ 3.00
Slab Replacement	Square Yards	$ 70.00
3 1/2 Inch Bit Overlay	Square Yards	$ 8.00
6 Inch Bit Overlay	Square Yards	$ 10.00
Concrete Overlay	Square Yards	$ 15.00
Major Rehabilitation	Square Yards	$ 30.00

Press ENTER to continue

==>

FIGURE 8 Default unit costs.

What is the State Route No. you wish to analyze?

(Enter a number)

In what county is the roadway located?

(Enter the county name in CAPITALS)
Press PF1 List of Counties

Please select the type of segment analysis you would like to perform for the above State Route:

(Choose one of the following:)

- SINGLE SEGMENT
- MULTIPLE NON-CONSECUTIVE SEGMENTS
- RANGE OF CONSECUTIVE SEGMENTS

When roadway information has been entered, press ENTER to continue.

==>

FIGURE 9 State route, county, and analysis selection.

SYSTEMATIC TECHNIQUE TO ANALYZE AND MANAGE PENNSYLVANIA'S PAVEMENTS

This Advisory System permits the user to either input the pavement's condition survey information directly or to obtain the pavement's condition survey information from the Roadway Management System (RMS) data base for review and analysis.

Do you wish to consult with the condition survey information from the data base or will you enter the condition survey information directly?

(Choose one of the following:)

x RMS DATA BASE
- USER INPUT

PF 1 HELP	PF 2 TOGGLEPF	PF 3 END
PF 4 WHAT	PF 5 QUESTION	PF 6 UNKNOWN
PF 7 UP	PF 8 DOWN	PF 9 TAB
PF10 HOW	PF11 WHY	PF12 COMMAND

==>

FIGURE 10 Processing control.

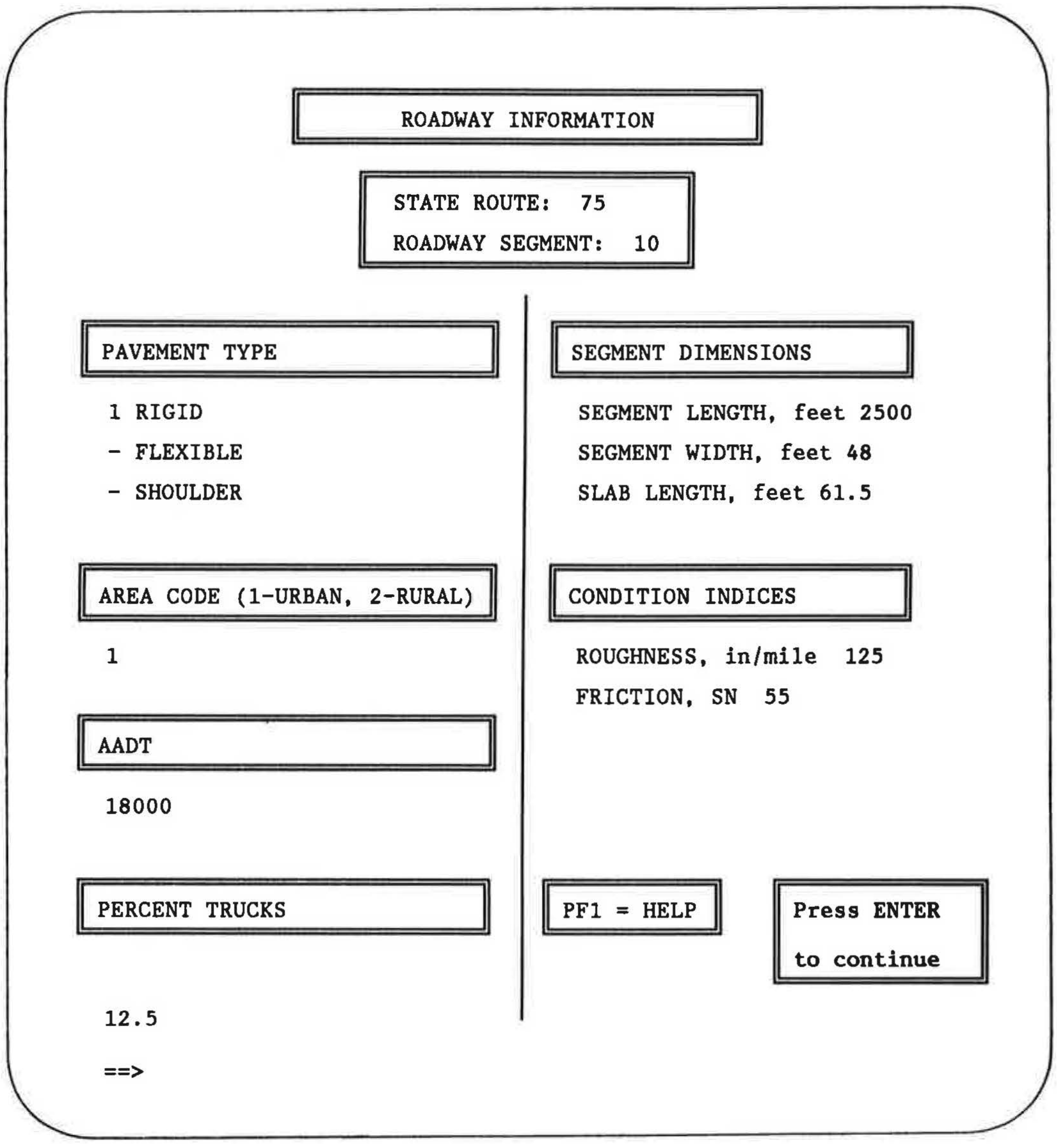

FIGURE 11 Physical and operating characteristics of the roadway segment.

STATE ROUTE 75

CONDITION SURVEY AREA

PAVEMENT TYPE RIGID

ROADWAY SEGMENT 10

AADT 18000

==

These data have been obtained from the Roadway Management System (RMS) data base. Please review and modify if necessary --- Press ENTER to continue.

==

CONDITION	OPTIONS	RATING		
JOINT SEAL FAILURE	(rate 0 through 9)	2	0	
LONGITUDINAL JOINT SPALLING	(rate 0 through 9)	3	0	
TRANSVERSE CRACKING	(rate 0 through 9)	5	1	PF1 HELP
TRANSVERSE JOINT SPALLING	(rate 0 through 9)	2	0	PF4 WHAT
FAULTING	(rate 0 through 9)	3	0	
BROKEN SLAB	(rate 0 through 9)	4	0	
BITUMINOUS PATCHING	(rate 0 through 9)	2	0	
SURFACE DEFECTS	(rate 0 through 6)	4	2	
RUTTING	(rate 0 or 1)	0		

==>

FIGURE 12 Condition survey information.

RECOMMENDED REPAIR STRATEGIES AND ESTIMATED COSTS

STATE ROUTE NO.	75	SEGMENT LENGTH, feet	2500 ft
ROADWAY SEGMENT NO.	10	ROUGHNESS INDEX, in/mi	125
AADT	18000	FRICTION INDEX	55
PERCENT TRUCKS	12.5	LOCAL (1-urban, 2-rural)	1

RECOMMENDED TREATMENTS	ESTIMATED EXPENSE
(2) Routine Maintenance	$ 2,500.00
(3) Spot Joint Seal - Transverse Joints	$ 130.08
(8) Joint Rehabilitation - Longitudinal Joints	$ 3,750.00
(12) Spall Repair - Slab	$ 762.20
(14) Slab Stabilization - Faulting	$ 36,000.00
(17) Slab Replace - Transverse Cracking	$ 46,666.67
(19) Slab Replace - Broken Slab	$ 7,000.00
(20) Slab Replace - Bituminous Patching	$ 23,333.33
(21) Slab Replace - Surface Defects	$ 7,000.00

PF1 HELP FILES   PF10 HOW   Press ENTER to continue

==>

FIGURE 13 Recommended repair strategies and associated estimated costs.

significant test of the application's utility—remains. In addition, it appears that this advisory system should be matched with a geographical information system to provide a mechanism for graphical presentation of the application recommendations.

ACKNOWLEDGMENTS

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Virginia Department of Transportation's Maintenance Quality Evaluation Program

R. D. Kardian and W. W. Woodward, Jr.

On the basis of initiatives to enhance productivity and effectiveness in highway operations, the Virginia Department of Transportation formally implemented a maintenance quality evaluation program on July 1, 1989. The objectives of the program are to monitor the overall quality of maintenance, point out areas of inconsistent performance, and provide a more formal process for ensuring that consistent levels of service are provided statewide. The program provides an evaluative assessment of Virginia's Interstate, primary, and secondary highway systems. It qualitatively assesses the level of maintenance for flexible and rigid pavements, stabilized roadways, roadway shoulders, drainage, traffic control and safety, roadside, and structures. Statistical techniques are used to ensure a random selection of inspection sites and a 95 percent degree of confidence that the results are representative of an entire roadway system. Virginia's quality evaluation program provides comprehensive and systematic reporting of actual maintenance conditions and compares them with approved maintenance levels of service. The program provides the "missing link" in the maintenance planning, budgeting, and evaluation processes.

Quality of work and reliability of data and information have become the hallmarks of a successful organization in recent years. Although the concept of quality assurance is not new to the corporate or governmental worlds, it is increasingly realized that quality is more than a general emphasis in the workplace. It is, in John Naisbitt's phrase, a megatrend—a new direction that transforms lives (*1*).

In a 1987 report to the governor and the General Assembly of Virginia, the Virginia Department of Transportation (VDOT) stated that "efficient, productive, and successful companies exhibit two essential characteristics: (1) they maintain close contact with their customers; and (2) they maintain an environment which promotes constant innovation" (*2*). VDOT's report indicated that the department would initiate a number of proactive measures to place it closer to its citizens and cited numerous innovative cost-saving plans, including the Maintenance Quality Evaluation (MQE) Program. This program was one of several that were developed to help VDOT meet its mission of providing safe, efficient, and effective ground transportation systems now and into the next century.

OBJECTIVES

The main objectives of Virginia's MQE Program are to

- Monitor the overall quality of highway maintenance,
- Point out areas of inconsistent performance, and
- Provide a more formal process for assuring that consistent levels of service are provided statewide.

Virginia Department of Transportation, 1401 E. Broad Street, Richmond, Va. 23219.

LITERATURE SEARCH

The MQE section was formed in the fall of 1987 and staffed in January 1988. A literature search of all the states, FHWA, and TRB was subsequently initiated to determine what analytical programs, processes, or procedures existed that assessed all types of maintenance levels of service. Of particular interest were evaluation programs that assessed major maintenance items, such as the eight for which desired maintenance quality levels were defined in a VDOT document (*3*). These elements included flexible and rigid pavements, stabilized roads, hard and nonhard surface shoulders, drainage, traffic control and safety, roadside, and structures.

It was also important that the MQE Program, when implemented, be able to assess the level of maintenance quality by highway system and to assess rural and urban areas collectively and independently.

The program selected would also provide a confidence level of 95 percent relative to the maintenance quality rating. Ideally, the mechanism utilized during field inspections to identify whether maintenance quality was acceptable would be a simple yes or no designation.

There were 33 responses to the 51 requests for information on formal MQE programs. Five states (California, Florida, Iowa, Mississippi, and Ohio) had formal programs. Four states (Alabama, Maryland, North Carolina, and Texas) had informal programs. Formal programs are defined as those that assess all of the major maintenance elements indicated above on a statewide level and include a systematic numerical rating system, usually on a computer data base.

The literature search also included more than three dozen sources, which were reviewed to determine current practices and methods. A copy of the bibliography is available from the authors.

PROGRAM DEVELOPMENT

Maintenance Characteristics

During initial program development, the eight major maintenance elements represented in the VDOT document (*3*) were divided into 45 subelements or characteristics. For example, traffic control and safety, a major element, was divided into seven maintenance characteristics: signs, pavement markings, signals, luminaires, barriers, delineators, and object markers. The purpose was to allow the ability to determine the reasons for a specific element's quality rating. For example, if traffic control and safety had an unacceptable rating, a review of each of the characteristics composing the element would allow a determination as to which characteristics caused the unsatisfactory rating. This would allow a concentrated effort, if necessary, to improve the quality of maintenance provided within the major element.

Maintenance Condition Standards

Maintenance quality standards or conditions were also designed and developed. The purpose of the conditions was to identify, by maintenance characteristic and highway system, what represented an acceptable level of maintenance quality. In addition, the conditions were intended to be the primary determinant of the inspection team's evaluation of maintenance quality, not only for a specific sample site but also for the entire highway system rating. A summary listing of some of these condition standards for each of the major maintenance elements is given in Table 1.

Preliminary Mapping

During this phase, computer-generated sample sites were identified, highlighted, and routed on state and county maps as well as inventory mileage records. The process was normally completed in the office before the inspection crew left to evaluate the sites, which contributed to efficiency.

Sampling Technique

To ensure the feasibility and validity of the program, it was necessary to use a technique that would determine a representative sample of the total roadway population.

The MQE unit developed a technique that randomly sampled all types of roadway systems on a statewide basis. The unit used the same statistical application as did the Florida Department of Transportation (*4*), which was validated by Florida State University's Statistical Consulting Center, and a sample size formula (*5*) (see Figure 1) that was validated by Virginia Commonwealth University's Institute of Statistics. The sampling plan was reviewed by VDOT's Research Council located in Charlottesville. Under the program, each highway system would be evaluated separately. A pilot sample of 50 randomly selected sites on each highway system was chosen to determine a representative "failure rate." Failure rate was defined as the percentage of sites that did not meet the desired levels of service. The failure rate percentage is a constraint of the sample size formula (Figure 1). The failure rates identified through the pilot sample were 30 percent for the Interstate system and 23 and 25 percent, respectively, for the primary and secondary systems.

On completion of field inspections of the pilot samples, the MQE unit calculated the centerline mileage for each of VDOT's three highway systems. Because each sampled site was 0.1 mi long, the centerline mileage had to be multiplied by 10 to obtain the true size of the population. With these data, plus the desired confidence level of 95 percent and precision rate of 4 percent, the sample size for each highway system could be determined.

The sites to be evaluated were generated through a mainframe computer random-sampling process. Additional sites were normally requested as alternatives if the inspection team encountered maintenance or construction work in progress.

Field Inspections

Through an analysis of the methodologies employed by the field inspection teams of other states, as well as what would be required of Virginia's inspection process, it was determined that an inspection team should consist of two individuals. This size would contribute to objectivity during the comparison of actual with desired quality of maintenance at a given sample site and would enhance the overall safety and productivity of the crew. Safety of the inspection crew and the public was of the utmost importance at all times.

The field inspection was performed by walking along the inside and outside shoulders for the entire 0.1-mi sample site and assessing current maintenance conditions for all inventory items within VDOT's right-of-way. Appropriate measurements of standard criteria were made as well as recording a "yes" if the actual condition met the desired maintenance standard or "no" if it did not.

The ratings were recorded on a form that listed all eight maintenance elements and each of the 45 maintenance characteristics. Lap-top computers were also programmed with these data and used increasingly as the automated capabilities of the MQE Program were enhanced.

PROGRAM VALIDATION AND FIELD TASK FORCE

Validation of a program of this scope and magnitude is extremely important. It is also important that the program be accepted by those who will make strategic decisions from the resulting findings and recommendations and by the field managers whose maintenance effort will be judged relative to quality level. Therefore, a task force was formed consisting of six maintenance field managers with an average of 23 years of highway experience. They had experience at the district and residency office levels and represented five of VDOT's nine highway districts. It was believed that the field managers could provide the MQE unit with valuable insights as to what was normally considered an acceptable level of maintenance. In addition, the quality of the validation of the formula weights assigned to each maintenance element and characteristic would be enhanced.

Before visiting each of the 200 sample locations selected for the validation process, the task force reviewed the proposed MQE Program. This completed the program's development phase.

The task force members were asked to assign a weight from 1 to 100 to each maintenance element and from 1 to 10 to each maintenance characteristic. The scores were averaged to obtain the formula weights used in the calculation of an overall maintenance level-of-service score.

ELEMENTS OF QUALITY STANDARDS FOR TRAVELED WAY, FLEXIBLE - CRACKING, RAVELING, RUTTING, SHOVING/PUSHING, BLEEDING/FLUSHING, RIDE QUALITY, POTHOLES, DISTRESS

EXAMPLES OF CHARACTERISTICS MEETING THE DESIRED CONDITIONS:

CRACKING	95% of the Interstate, 90% of the Primary, and 85% of the Secondary urban and rural pavements are free of severe cracks (i.e., 1/4" or greater in width).
RUTTING	90% of the Interstate, 85% of the Primary, and 75% of the Secondary urban and rural systems are free of severe rutting (i.e., 3/4" or greater in depth).
POTHOLES	The Interstate system is free of potholes, the Primary system has less than three, and the Secondary system has less than five potholes 4 inches in width or greater; 100% of all highway systems are free of potholes that present a tire or safety hazard.

ELEMENTS OF QUALITY STANDARDS FOR TRAVELED WAY, RIGID - CRACKING, SPALLING, FAULTING, JOINT MATERIAL, RIDE QUALITY, POTHOLES

EXAMPLES OF CHARACTERISTICS MEETING THE DESIRED CONDITIONS:

SPALLING	There are no occurrences of severe spalling (i.e., 3" in width or 2 feet in length) on the Interstate, no more than one occurrence on the Primary, and no more than two occurrences on the Secondary urban and rural systems.
FAULTING	100% of all Interstate, Primary, and Secondary urban and rural systems are free of severe faulting (i.e., 1/2" or greater in height) and severe longitudinal joint separation (greater than 1/2" in width).
JOINT MATERIAL	75% of required joint material is present and functioning as intended in each joint on all Interstate, Primary, and Secondary roadway systems.

ELEMENTS OF QUALITY STANDARDS FOR TRAVELED WAY, STABILIZED - DUST CONTROL, RUTTING, POTHOLES, CORRUGATIONS

EXAMPLES OF CHARACTERISTICS MEETING THE DESIRED CONDITIONS:

DUST CONTROL	75% of all Primary and Secondary roads along residential and commercial sections with at least 10 ADT are free of dust clouds that partially obstruct visibility rising above the truck of the vehicle.
RUTTING	All Primary and Secondary roads are free of rutted areas that average 2 inches in depth over a 25 foot section and there are no occurrences that are 3 inches or greater in depth.
CORRUGATIONS	All Primary and Secondary roads are free of corrugations that average 1-1/2 inches in depth over a 25 foot section on the roadway surface area and that are greater than 3 inches in depth.

TABLE 1 (*continued on next page*)

ELEMENTS OF QUALITY STANDARDS FOR SHOULDERS, HARD-SURFACED - DRAINAGE, DISTORTION, JOINT SEPARATION, FAILURE

EXAMPLES OF CHARACTERISTICS MEETING THE DESIRED CONDITIONS:

DRAINAGE	100% of the shoulder is free of any evidence of severe flooding, ponding, pumping, or erosion, and there are no occurrences of a level or greater slope for all highway systems.
DISTORTION	90% of the elevation between the traffic lane and shoulder does not exceed 1/2 inch on the Interstate system or 3/4 inch on the Primary or Secondary system.

ELEMENTS OF QUALITY STANDARDS FOR SHOULDERS, NON-HARDSURFACED - DRAINAGE, DISTORTION, RUTTING

EXAMPLES OF CHARACTERISTICS MEETING THE DESIRED CONDITIONS:

DISTORTION	90% of the edge drop-off or build-up between the traffic lane and shoulder does not exceed 1-1/2 inches on the Interstate or Primary system, or 2-1/2 inches on the Secondary system.
RUTTING	90% of the shoulder on the Interstate system and 80% of the shoulder on the Primary and Secondary systems are free of occurrences of rutting 2 inches or greater in depth.

ELEMENTS OF QUALITY STANDARDS FOR DRAINAGE - DITCHES, CULVERTS, CATCH BASINS/DROP INLETS, CURBS AND GUTTERS

EXAMPLES OF CHARACTERISTICS MEETING THE DESIRED CONDITIONS:

DITCHES	50% or more of roadside and outfall ditches are unobstructed by soil or impermeable material and functioning as intended, and 75% of all paved ditches are structurally functioning as intended on urban and rural roadways for the Interstate, Primary, and Secondary systems.
CULVERTS	50% or more of the culvert is unobstructed and functioning as intended on urban and rural roadways for the Interstate, Primary, and Secondary systems.

ELEMENTS OF QUALITY STANDARDS FOR TRAFFIC CONTROL AND SAFETY - SIGNS, PAVEMENT MARKINGS, SIGNALS, LUMINAIRES, BARRIERS, DELINEATORS, OBJECT MARKERS

EXAMPLES OF CHARACTERISTICS MEETING THE DESIRED CONDITIONS:

SIGNS	90% of roadway signs are functioning as intended and are at least 7 feet in height on all Interstate, urban Primary, and urban Secondary systems, and 5 feet in height from the shoulder on the rural Primary and Secondary systems. Overhead signs should be mounted at a minimum height of 17 feet on structures and 19 feet on cantilevers or double poles from the highest point in the roadway.
PAVEMENT MARKINGS	100% of pavement markings are visible up to 120 feet and functioning as intended on all highway systems. 100% of all roads requiring centerlines and/or edgelines are marked accordingly. Special markings and 70% of raised/recessed pavement markers are functioning as intended.

TABLE 1 (*continued on next page*)

BARRIERS	95% of all wooden fences and 100% of sound/noise barriers are aligned properly and free of missing or broken sections; and 95% of all metal fences/cable guardrails are taut, properly secured to posts and free of protruding metal parts. 90% of each continuous guardrail section does not have missing rails or parts, dents, rust, or interruptions within a section, and is a minimum of 27 inches high.

ELEMENTS OF QUALITY STANDARDS FOR ROADSIDE - MOWING, LITTER & DEBRIS, TREE/BRUSH CONTROL, LANDSCAPING, SIDEWALKS

EXAMPLES OF CHARACTERISTICS MEETING THE DESIRED CONDITIONS:

MOWING	95% of the vegetation on all areas has a (1) minimum height of 6 inches, (2) maximum height of 16 inches on Interstates, high type Primaries, et al., and (3) maximum height of 18 inches on low type Primaries and all type Secondaries. 95% of medians in excess of 50 feet and roadside areas are mowed to the ditch line in cuts and to top of slope in fills. If median is 50 feet in width or less, 95% of the entire median is mowed. For the first mowing after July 1 and the final mowing: 95% of the entire median is mowed and 95% of the roadside is mowed one swath beyond the ditch line and one swath down fill slopes. 100% of the mowing at intersections and curves is adequate to assure safe sight distance for traffic safety. 95% of the urban and rural highway systems are free of weeds in areas around sign posts, guardrail, head walls, and in paved ditches and paved shoulders.
TREE/BRUSH CONTROL	100% of all highway systems has no encroachment of tree limbs within a vertical clearance of 15 feet over the pavement. 100% of the right-of-way has no dead or live leaning trees that present a hazard to pedestrian or vehicular traffic. 100% of all tree and brush encroachment within the right-of-way is controlled at all bridges, curves, intersections and signs to provide adequate sight distance for traffic safety.

ELEMENTS OF QUALITY STANDARDS FOR STRUCTURES - DECK DISTRESS, EXPANSION JOINTS, PARAPETS, BEARING DEVICES

EXAMPLES OF CHARACTERISTICS MEETING THE DESIRED CONDITIONS:

DECK DISTRESS	90% of the deck surface is free of severe pavement failures and 75% of all scuppers are unobstructed and functioning as designed.
EXPANSION JOINTS	100% of all expansion joints are flush with the deck and 75% of the material in each joint is present and functioning as intended.
PARAPETS	100% of the parapets, railings and sidewalks are free of severe spalling, severe cracking, severe faulting, severe misalignment, missing bolts, blunt railing ends, potholes, and voids between the deck and the parapet.

NOTE: A complete listing of maintenance characteristics and associated quality standards is available by request.

SAMPLING FOR QUALITY

-CONCERNED WITH PROPORTIONS (RATIOS) THAT MEET DESIRED LEVELS-OF-SERVICE (LOS)

-RECOMMENDS FIRST PROPORTION BASED ON PILOT SAMPLE

-COMPARES ACTUAL MAINTENANCE CONDITIONS TO APPROVED STANDARDS

-REQUIRES A YES/NO DECISION

SAMPLE SIZE FORMULA:

$$n = \frac{Z^2 \times N \times p\,(1-p)}{(A^2 \times N) + (Z^2 \times p\,(1-p))}$$

n = SAMPLE SIZE

N = POPULATION SIZE (Centerline Mileage X No. of 0.1 mi. Sites/Mile)

p = EXPECTED PROPORTION THAT DOES NOT MEET DESIRED LOS

A = DESIRED PRECISION

Z = CONFIDENCE LEVEL COEFFICIENT (95% = 1.96; 90% = 1.64)

FOR EXAMPLE:

$$n = \frac{(1.96)^2 \times (1{,}027.71 \times 10) \times .30\,(1-.30)}{(.04^2 \times (1{,}027.71 \times 10)) + (1.96^2 \times .30\,(1-.30))} = 8291 \div 17.25 = 481$$

Therefore, a sample size of 481 would be needed for a 95% confidence level and a 4% precision rate to arrive at a statistical conclusion of centerline mileage on the Interstate System Statewide. As the population is stratified (e.g., by highway district), the sample size will increase. The sample size will also increase if "p" increases.

FIGURE 1 Virginia MQE Program sample size formula.

While on site, the field managers were asked to assess whether current roadway conditions were within the department's maintenance policies. "Yes" meant that the field conditions for each maintenance characteristic were within the policy; "no" meant that the characteristic was not within the policy. They were also asked to compare their professional evaluations with the written quality standards and make recommendations for adjustments as necessary. The "yes" or "no" answers were entered into a lap-top computer on site. The task force members were then asked to rate the sample section from 1 to 10, and their answers were compared with a weighted score derived from the lap-top computer's Lotus 1-2-3 programmed formula.

"What if" analyses were made using the lap-top computer to determine an overall numerical value for the site, which would show whether the roadway section was within maintenance policy. If the site was within policy, the task force members were asked to "fail" maintenance characteristics until the site was not within policy. The same "what if" analyses were made if the original weighted score showed that the site was not within policy; that is, the task force members were asked to "pass" some characteristics until the overall section was within policy. In this manner, overall statewide qualitative numerical level-of-service ratings were obtained. It was determined by the task force that the maintenance level of service should be 80 on the Interstate and primary systems and 75 on the secondary system.

PROGRAM IMPLEMENTATION

After an exhaustive program development and validation effort, VDOT's MQE Program was formally implemented on July 1, 1989. From the task force's validation effort, it was determined that only two of Virginia's three highway systems could be evaluated annually with existing staffing levels; however, these systems would be rated twice each year to take into account seasonal influences on maintenance. For example, during fiscal year 1989–1990, the Interstate and primary systems were evaluated.

The Interstate system was rated in the summer and winter, whereas the primary system was rated in the fall and spring. During fiscal year 1990–1991, the Interstate system will be rated in the fall and spring, and the secondary system will be rated in the summer and winter.

This alternating process will continue each year. The evaluation ratings provided through these inspections will provide an accurate assessment of a highway system's overall quality of maintenance on a statewide basis. It is anticipated that increased staffing in the future will allow more specific evaluative assessments down to the individual highway district and residency level.

CONCLUSION

"Quality is measurable," according to Tom Peters, author of a best-selling management book, and "measurement is the heart of any improvement process," according to senior IBM quality manager Jim Harrington (*6*). Virginia's MQE Program will provide comprehensive and systematic reporting of actual maintenance conditions and a comparison of current conditions with approved maintenance levels of service.

It is also anticipated that Virginia's MQE Program will assist the planning process by creating a foundation for systematically determining maintenance resource needs. Analysis of the quantitative data provided by VDOT's maintenance management system and the qualitative data provided by the MQE Program should provide valuable insight into problems that cause inefficient use of personnel, equipment, and materials.

This information will be valuable to the central office and field planning processes by bringing the overall maintenance operation into clearer focus. It should also provide management with better control and accountability relative to maintenance program expenditures and accomplishments.

Although refinements may be necessary, the program in its present form can be an effective tool in management decision making by identifying maintenance needs and helping to standardize the maintenance levels of service throughout the state. VDOT is both excited and confident that the MQE Program will provide the "missing link" in effectively connecting the maintenance planning, budgeting, and evaluation processes.

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Abridgment

Condition Surveys in the Strategic Highway Research Program Long-Term Pavement Performance Study and Pavement Condition Rating for Preoverlay Conditions

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The long-term pavement performance (LTPP) research study, a component of the Strategic Highway Research Program (SHRP), represents a $50 million effort to collect field observations of pavement structures from across the United States and Canada. The procedures to be used for rating the condition of LTPP test sections before overlay are discussed. The methods should be used in classifying the condition of a test section as "good" or "bad"; such information is needed as an input variable to the asphalt concrete overlays on asphalt and concrete pavement factorial experiments. These experiments were defined for recruiting in-service test sections for inclusion in the SHRP LTPP study. The distress-monitoring approach being adopted for the long-term monitoring of in-service SHRP pavement sections is then described. The categories and types of distress data to be collected periodically are described, together with uniform and practical distress definitions and monitoring procedures. Finally, information on the contents of survey forms and maps to be used during the process is provided.

The rapid deterioration of U.S. pavements noted during the last few years underscores a need for developing and conducting comprehensive research on the long-term performance of pavement. In addressing this problem, the Strategic Highway Research Program (SHRP) undertook, in 1987, major research in six primary areas, one of which was the long-term pavement performance (LTPP) study (*1*). The objectives of the study included evaluation of existing design methods; development of improved strategies and design procedures for the rehabilitation of existing pavements; development of improved design equations for new and reconstructed pavements; determination of the effects of loading, environment, material properties and variability, construction quality, and maintenance levels on pavement distress and performance; and establishment of an international long-term pavement data base to support these objectives for both present and future needs. The LTPP data base will include information from more than 1,000 in-service test sections [general pavement studies (GPS)] and from specially constructed pavements [special pavement studies (SPS)] to study the influence of design factors in pavement performance. From the GPS portion of LTPP, 769 projects have been approved. Of these test sections, 48 are planned asphalt concrete overlays of asphalt concrete pavements (GPS 6B), and 22 are planned asphalt concrete overlays of portland cement concrete (PCC) pavements (GPS 7B). The target number of projects to be approved for inclusion in these categories of GPS is 150 and 200, respectively.

The first part of this paper deals with the rating procedures recommended for classifying the preoverlay condition of the LTPP test section included in the GPS factorials 6B and 7B. Because the objective of the rating methods is to characterize preoverlay conditions of GPS 6B and 7B as "good" or "bad" (information needed as input to the previous factorials), and because limited field distress data are collected for this purpose, the proposed methods are modified rating procedures. The second part of the paper deals with long-term pavement distress evaluation, a part of the LTPP monitoring data set. It presents the categories and types of distress data to be collected periodically in both rigid and flexible LTPP test sections using manual or automatic survey procedures.

The Texas Research and Development Foundation (TRDF), with the Center for Transportation Research (CTR) of the University of Texas at Austin as subcontractor, has been selected by SHRP for SHRP LTPP technical support (Project P001). Two pavement distress–related manuals have been completed thus far by the P001 team (*2,3*). The manuals will be used during the periodic monitoring of the LTPP test sections.

FIELD DATA AND RATING PROCEDURES FOR PREOVERLAY CONDITIONS

The GPS 6B and 7B factorials use the pavement condition before overlay as input. Because a limited type of distress data was collected for assessing the pavement condition as good or bad, a rating method for each pavement type (asphalt and PCC) was designed to (*a*) use the maximum possible distress information collected from the LTPP test sections,

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(*b*) examine whether the measurement units used for monitoring the distress extent during the preoverlay condition surveys could be converted with acceptable assumptions to the units defined by the rating methods, and (*c*) compare the relative weights given by each method with each distress type for a specific pavement (asphalt or PCC) with results obtained from previous studies regarding the influence of each distress type in a pavement's performance.

After examining 21 flexible and 17 rigid pavement condition manuals proposed by different highway and other agencies involved in the process of rating pavements, indices based on weighted values of distress types and severity levels were selected (because profile measurement or riding comfort ratings were not available). Distress data from approximately 20 LTPP test sections were used for examining the agreement of the rating method response with the field rater's evaluation. The type of distress data collected for this purpose is reported below.

The following distress information is collected before overlays in GPS 6B. *Alligator and block cracking* and *raveling/weathering* are measured in square feet of affected area for each corresponding severity level (low, medium, and high) noticed in the pavement surface. *Patch deterioration* is recorded as the number of patches and square feet of affected area for each severity level. *Pumping* is included in the survey form but has not yet been reported for any of the LTPP test sections surveyed so far. The number of *transverse cracks* in the pavement test section at each severity level must be monitored. *Bleeding* is considered only when it is extensive enough to cause a reduction in skid resistance and must be recorded in square feet of affected area. *Rutting* must be monitored as the *average rut depth* within the entire section.

The following distress information is collected before overlays in GPS 7B. *Longitudinal and "D" cracking* are measured in linear feet of affected area for each corresponding severity level noticed in the pavement surface. *Joint seal damage* and *transverse cracking* are measured in number within each severity level noticed in the pavement, whereas *patch or slab replacement deterioration* is measured in both number and square feet at each severity level. *Average faulting* is monitored only in severity level, whereas the highest severity of *pumping* is considered. Finally, the number of *corner breaks* present in the test section is monitored. Further details regarding distress types and their corresponding severity levels can be found in the distress identification manual (*2*).

The rating method of the Ohio Department of Transportation and the Pavement Condition Index (PCI) defined by Paver (*4*) were selected for the set of rating procedures evaluated for this purpose—principally because they use the maximum amount of detailed distress data obtained through the condition surveys developed for this part of the LTPP study and because minor assumptions for data conversion are required. The proposed methods are described below.

PAVEMENT CONDITION RATING PROCEDURE FOR GPS 6B FACTORIAL EXPERIMENT

The rating procedure for GPS 6B is based on a simplified version of the PCI of Paver (*4*). It was selected after extensive review of the available literature and after trying various methods with field condition data from approximately 20 LTPP test sections. The results of the analysis indicated that field ratings and the ratings obtained using the method outlined below were the same for most cases available for study. It is recommended that the methodology described be used only for the GPS 6B factorial experiment. The procedure is based on seven of the eight distress types described above. The simplifications, assumptions, and modifications made to the PCI method follow.

Conversion of Field Data from Extent to Density of Distress

The field data must be transformed from extent measurements (square feet, number, linear feet, etc.) to density of distress. In most cases this is straightforward. For example, if there is 110 ft^2 of medium-severity alligator cracking within a section, the density is 110 ft^2/6,000 ft^2 $\times$ 100 percent = 1.83 percent. [The area of the LTPP test section (or sample unit) is 500 ft long $\times$ 12 ft wide, or 6,000 ft^2.] In other cases (transverse cracking, rutting, and pumping), the following assumptions must be made.

Assumptions

Transverse cracking is recorded as the number of cracks at various severity levels. However, the weight value curves for this distress were developed for transverse cracking density, defined as (extent in linear feet)/(test section area in square feet) $\times$ 100 percent. The assumption is that each transverse crack is, on the average, as long as the lane width, that is, 12 ft. The number of transverse cracks is multiplied by 12 ft to calculate the total extent, in linear feet, for each severity level.

Rutting is recorded as average rut depth; the area affected is not given. The assumption is then made that rutting exists in both wheel paths. Each wheel path is 18 in. wide; 18 in. $\times$ 2 wheel paths = 36 in., or 3 ft. It is also assumed that rutting exists along the total length of the test section, that is, 500 ft. Thus, the area affected can be estimated as 3 ft $\times$ 500 ft = 1,500 ft^2 of average rut depth.

Only severity levels are recorded for pumping in the field survey form, and there is no information as to the extent of this distress throughout the test section. For these reasons, it was decided that test sections with pumping will be evaluated on an individual basis (i.e., if a borderline good/bad test section exhibits pumping, it will be placed in the bad category). As mentioned, however, pumping has not been reported for any of the LTPP test sections for which field data are available. In other words, pumping is not a common distress in the asphalt pavements monitored for the LTPP study.

Rating Procedure

Two steps are involved in calculating the final condition index of an asphalt pavement test section: (*a*) the distress information observed on the pavement surface is recorded in the distress survey forms and (*b*) the field data are transformed in distress density and severity levels. The distress density is determined as follows. For distresses measured in square feet,

density = (extent of distress/test unit area) × 100 percent

where extent of distress and test unit area are both measured in square feet. For distresses measured in linear feet (transverse cracking), the same formula is used, but extent of distress is measured in linear feet and test unit area is measured in square feet.

After the density of each distress type–severity level combination is determined, the weight values are obtained from the distress weight curves (*4*). A total weight value is computed by summing all individual distress weight values. Once the total distress weight value is computed, the adjusted weight value can be determined from the corresponding curves. During the determination of the adjusted weight value, if any individual weight value is higher than the adjusted weight value, the adjusted weight value is set equal to the highest individual weight value. The index I is computed using the relation $I = 100 -$ adjusted weight value. The index number that separates between pavement sections in bad or good condition is 55.

PAVEMENT CONDITION RATING PROCEDURE FOR GPS 7B FACTORIAL EXPERIMENT

The rating procedure for GPS 7B is based on a simplified pavement condition rating (PCR) index developed and used by the Ohio Department of Transportation (*5*). It was selected after reviewing the literature and trying various methods using available field condition data from approximately 20 LTPP test sections. The procedure is based on seven of the eight distress types described above. The results indicate that field ratings and the ratings obtained using the method outlined below were the same for most cases. It is recommended that the methodology be used only for the GPS 7B factorial experiment. The simplifications, assumptions, and modifications made to the PCR method follow.

Assumptions

The weight values defined by this method are a function of the density of distresses in percentage of slabs affected or percentage of joints affected. To determine the weight values, the total number of slabs or joints in the test section must be known. The assumption of slabs 25 ft long and 12 ft wide in the 500-ft test section results in 20 slabs (500/25) with 21 joints. As for flexible pavements, it is assumed that the total test section is 500 ft long × 12 ft wide, or 6,000 ft^2. These assumptions hold for continuously reinforced concrete pavements (CRCPs), because most procedures for rating this type of pavement consider imaginary slabs of approximately 25 ft. Faulting is recorded as average faulting with the area affected not given. The assumption is then made that faulting exists in 50 percent of the test section, that is, one slab is level, whereas the following one presents faulting. The extent of pumping in the test section is assumed to be proportional to the severity level observed, because only this information is monitored. For example, when low severity is observed, the extent is assumed to be 10 percent of the section's total length (i.e., occasional); for medium severity the corresponding extent is assumed to be 10 to 25 percent (i.e., frequent); and for high severity, the area affected is extensive (more than 25 percent). The extent weight for the corner break distress is defined differently from that of the original rating method (i.e., occasional = 1 corner break/mi, frequent = 2 or 3 corner breaks/mi, and extensive = more than 3 corner breaks/mi). It is believed that these limits are conservative and, moreover, not practical considering the type and size of the LTPP test sections. The extent for corner breaks is redefined as follows: occasional, < 4 corner breaks/500 ft; frequent, 4 to 8 corner breaks/500 ft; and extensive, > 8 corner breaks/500 ft. Because no information is reported in the preoverlay condition surveys regarding the severity level of this distress, it is assumed that severity level and extent are related as follows: occasional corresponds to low-severity, frequent to medium-severity, and extensive to high-severity distress.

Conversion of Field Data

The field data must be transformed from extent measurements (square feet, number of slabs or joints affected, etc.) to density of distress. For example, if there are 10 joints with seal damage of medium severity on the section, then the density is 10/21 × 100 percent = 47.61 percent, where 21 is the number of joints in each test section. Longitudinal cracking is monitored in linear feet, and the rating procedure uses the percentage of slab affected. To determine the percentage of slabs affected, the number of linear feet observed is divided by the length of each slab (25 ft) to obtain the number of slabs affected. The result is then divided by 20, the number of slabs in the LTPP test section. Patching is reported in number and square feet, whereas the patching density in this method is percentage of slabs affected. However, percentage of slabs affected is the same as the percentage of total area, because

$$\text{Percentage of slabs} = \frac{\text{no. of slabs affected}}{\text{total no. of slabs}}$$

$$= \frac{\text{no. of slabs affected}}{\text{total no. of slabs}} \times \frac{\text{area of each slab}}{\text{area of each slab}}$$

$$= \frac{\text{area affected}}{\text{total test section area}}$$

$$= \text{percentage of area affected}$$

Rating Procedure

Two steps are involved in calculating the final condition index of a PCC pavement test section: (*a*) the distress information observed on the pavement surface is recorded in distress survey forms and (*b*) the field data are then transformed in distress density and severity levels. The distress density is determined as follows:

For distresses measured in square feet,

density = (extent of distress/test unit area) × 100 percent

where extent of distress and test unit area are measured in square feet. For distresses measured in number (e.g., corner breaks),

density = number/500 ft

For distresses measured in the number of joints or slabs affected,

density = (no. of joints or slabs/total no. of joints or slabs) × 100 percent

The density of transverse cracking is defined as average crack spacing (CS) between intermediate transverse cracks as given by the following expression:

$CS = L/(Z + 1)$

where

CS = average crack spacing,
Z = average number of transverse cracks per slab (see example below), and
L = transverse joint spacing (in accordance with previous assumption of slab length of 25 ft).

Example: For a test section with 16 low-severity transverse cracks, the parameters Z and CS are evaluated as follows: $Z = 16/20 = 0.8$, where 20 is the number of slabs in the test section, and $CS = 25/(0.8 + 1) = 25/1.8 = 13.8$. The extent of each distress type used by the rating procedure is shown in Table 1.

After the density of each distress type–severity level combination is determined, the weight value for each distress type is obtained by multiplying the distress weight by the severity and the extent weights (*5*). This PCR procedure permits the addition of weight points when multiple distresses occur in the pavement section. Because the procedure assumes that several distresses will be observed in a given survey, the method tends to overestimate the PCR value when only a few (one or two) distresses are observed. It is unlikely that the condition of a pavement with extensive, high-severity distress of any type would be considered good. Therefore, some adjustments to the PCR method appear necessary when only one or two severe distresses are observed for a pavement section. The suggested adjustment factors for these conditions are as follows:

- If one distress type is observed, multiply the weight value by 2.0.
- If two distresses are observed, multiply the sum of weight values by 1.5.
- If more than two distress types are observed, no adjustment is necessary.

The index I is computed using the relation $I = 100 -$ total weight value. The index number that separates between PCC pavement sections in bad or good condition is 75.

PAVEMENT DISTRESS DATA COLLECTION OF LTPP TEST SECTIONS

The main objective of pavement distress data collection is to provide practical, uniform, comprehensive, and reliable pavement condition information. The characteristics described must be reflected in all pavement data collection steps. The infor-

TABLE 1 EXTENT OF DISTRESS TYPES USED BY RATING PROCEDURE

	Extent			
Distress	Occasional	Frequent	Extensive	Percent of
Patching	<5%	5-20%	>20%	Slabs
Pumping	<10%	10-25%	>25%	Section length
Faulting	<20%	20-50%	>50%	Section length
D-Cracking	<20%	20-50%	>50%	Transverse Joints
Joint Sealant Damage	<20%	20-50%	>50%	Joints
Transverse Cracking	cs>15	10<cs<15	cs<10	-
Longitudinal Cracking	<5%	5-20%	>20%	Slabs
Corner Breaks	<4/500 ft	4-8/500 ft	>8/500 ft	-

mation collected from such surveys should be stored in the LTPP data base, where it can be used to define the pavement's present condition and its condition trend under specific load and environmental conditions to develop pavement performance prediction models. A review of the pavement monitoring literature revealed as many techniques and procedures as there are highway agencies involved in this process. Because the objective of the LTPP study is to produce an international pavement data base, preliminary studies were made by TRDF and CTR to recommend and define a uniform condition survey to be used in the LTPP test sections. The LTPP monitoring data will be collected in the outside lane in one direction of traffic for highways in North America. The data are to be collected on 500-ft-long test sections.

IDENTIFICATION AND DEFINITION OF DISTRESS DATA

Pavement distress represents any undesirable manifestation of defects in the pavement surface capable of affecting pavement serviceability, structural capacity, or appearance. The review of the literature revealed a lack of uniformity in terminology and classification of pavement defects. Because one of the objectives of the LTPP study is to create an international data base for use in all regions of North America and elsewhere, there was a need to

- Standardize defect terminology for defining distress type, severity, and extent to obtain a uniform data base,
- Include distress types that have a significant influence on pavement performance as determined from previous studies,
- Obtain consistency between classification of distresses as well as use detailed measurements to minimize errors, and
- Standardize graphical and visual descriptions of distress types and severity levels to minimize different interpretations between raters.

The distress data to be collected in the LTPP test sections are presented in the *Distress Identification Manual for the Long-Term Pavement Performance Studies* (*2*). Because asphalt concrete pavements, jointed (plain and reinforced) concrete pavements (JCPs), and CRCPs present some noncommon defect manifestations, the distresses for each pavement type are presented separately.

The distresses for pavements with asphalt concrete surfaces have been grouped into the following general categories: cracking, patching and potholes, surface deformation, surface defects, and miscellaneous distresses. Cracking includes alligator (fatigue), block, edge, longitudinal, and transverse cracking, as well as reflection cracking of joints for the overlaid sections. The extent of these distresses must be determined for each severity level using the corresponding measurement units described in the manual (*2*). The extent of the patching and pothole distresses must be monitored within each severity level defined. Rutting and shoving constitute the surface deformation distresses. No severity levels are defined for either, and they must be monitored according to the descriptions in the manual (*2*). Bleeding, polished aggregate, and raveling/weathering constitute the surface defects type. Miscellaneous distresses include water bleeding and pumping (to be recorded in any of the three severity levels) and lane-to-shoulder drop-off, which has no severity levels.

For the JCPs, the following categories of defects have been considered: cracking, joint deficiencies, surface defects, and miscellaneous distresses. Corner breaks and durability "D" cracks, as well as longitudinal and transverse cracks, are included in the cracking category. The extent of these distresses has to be recorded separately for each severity level using measurement units defined in the manual (*2*). The joint deficiencies category includes joint seal damage of transverse joints and spalling of longitudinal and transverse joints. Map-cracking and scaling, polished aggregate, and popouts are included in surface defects. Of these distresses, only map-cracking and scaling must be monitored for each severity level defined. The last category for JCPs, miscellaneous distresses, includes blowups, faulting of transverse joints and cracks, lane-to-shoulder drop-off and separation, patch/patch deterioration, and water bleeding and pumping; only the last two distresses must be monitored by severity levels.

For CRCPs, the last pavement type considered in the LTPP studies, the following distress groups have been included: cracking, surface defects, and miscellaneous distresses. For this type of pavement the following defects are included under cracking: durability "D" cracks and longitudinal and transverse cracks. The surface defects category for CRCPs includes map-cracking and scaling, polished aggregate, and popouts. The considerations related to such distresses are similar to those reported previously for surface defects of JCPs. The last group, miscellaneous distresses, includes blowups, construction joint deterioration, lane-to-shoulder drop-off, lane-to-shoulder separation, patch/patch deterioration, punchouts, spalling of longitudinal joint, and water bleeding and pumping. The extent of these defects in the pavement surface must be monitored using one of the three severity levels available, with the exception of blowouts, lane-to-shoulder drop-off, and lane-to-shoulder separation, for which no severity levels have been defined.

METHODS FOR FIELD SURVEY OF LTPP PAVEMENT SECTIONS

Two pavement distress surveying techniques have been selected for use in the LTPP study: a visual or manual survey procedure and an automatic technique using the PASCO multifunction survey vehicle. The visual surveys are intended for use as a backup when it is not possible to schedule a visit by the PASCO vehicle. If PASCO has surveyed the test section within 3 months before maintenance-rehabilitation work, it is not necessary to perform the visual distress survey, which, however, will be performed in remote areas not directly accessible to PASCO (e.g., Hawaii and Puerto Rico). About 700 GPS test sections have been surveyed to date with the PASCO equipment.

The manual (*2*) should be used as a standard guide for interpretation, identification, and rating of observed pavement distresses. The *Manual for Field Distress Surveys* (*3*) provides instructions, data forms, and maps for use in visual collection of defect information for pavements with asphalt concrete pavements (chapter 2), JCPs (chapter 3), and CRCPs (chapter 4). In the visual pavement distress survey, raters walk along the pavement section and manually draw a map showing the type and exact location of all defects present on the pavement surface—a procedure similar to the one used for the AASHO road test (*6*). The severity level of each distress is identified and recorded on the maps and the data sheets included in the field manual (*3*). The field maps are used to show the exact location of each defect type on the test section. Five sheets are used for mapping; each sheet contains two 50-ft maps that represent 100 ft of the LTPP section. The defects are drawn on the map at the appropriate locations using the various distress symbols defined in the manual (*3*). Once the distress is drawn, it is labeled and numbered using the relative symbols and corresponding severity levels (L, M, or H) if applicable. Any distresses that are not described in either manual should be photographed and videotaped. Their location and extent should be shown and labeled on the map. If bleeding, polished aggregate, or raveling/weathering occur in extended areas over an asphalt-concrete-surfaced pavement test section, the total extent is not mapped. For JCP sections and CRCPs, if map-cracking or scaling, polished aggregate, or popouts occur in large areas over the test section, the total extent must also not be mapped. Instead, the location, extent, and severity level (if applicable) of all these distresses must be noted in the space for comments at the bottom of each map. These distresses should be mapped only if they occur in localized areas. Lane-to-shoulder drop-off for both CRCP and JCP and lane-to-shoulder separation for CRCP are not mapped but are recorded in the corresponding sheets. The data sheets or forms included in the field manual (*3*) provide space for recording the state ID number, the SHRP ID (state code plus SHRP Section ID), the survey date, and the results of distress surveys on different sheets for each pavement type. Except where otherwise indicated, entries have to be made for all distress data elements. If a particular type of distress does not exist, a zero should be entered in the appropriate space. All data sheets and maps are to be completed in the field.

The PASCO multifunction survey vehicle (*7*) was selected for surveying the LTPP test sections. The photographs and other images of the pavement surface collected by this vehicle will be interpreted later in the office. This vehicle is used to speed the field data collection and provide a permanent visual record of the pavement condition. Cracking, patching, and other distresses are recorded using the ROADRECON-70. The vehicle travels at speeds between 3 and 53 mi/hr (5 and 85 km/hr). A continuous photographic record of the pavement surface is made using a 35-mm slit camera. The system synchronizes film feed speed and camera aperture with the speed of the vehicle to equalize image density and photographic reduction. Road widths of up to 16 ft (5 m) can be filmed. Photography is performed at night using on-board lights set at an angle to the road surface so that shadows are produced at cracks and other defects in the surface, making interpretation easier. Interpretations of the distresses are made by a technician viewing the developed 35-mm film enlarged 10 times on the ROADRECON Film Digitizer. A grid pattern is overlaid on the film to aid in qualification of the distress for input into a computer data base.

Rut depth surveys can be carried out at speeds up to 50 mi/hr (80 km/hr) using the ROADRECON-75 system (*7*). A pulse camera mounted on the vehicle photographs hairline optical bars projected onto the road. The camera shutter and hairline projector are synchronized according to the distance covered by the projection vehicle, so that the system is able to create a photographic record of rutting at variable distance intervals. The film is projected onto a digitizing table and traced with a computer "mouse," enabling the wave patterns to be processed into a transverse profile of the pavement surface.

SUMMARY

The simplified rating procedures presented in this paper should be used in defining whether the preoverlay condition of a test section can be classified as "good" or "bad." In the LTPP study this information was used in the GPS experimental factorials 6B and 7B for recruiting in-service test sections for inclusion in the SHRP data base.

The distress surveys conducted as part of this long-term study will be used to quantify the condition of a pavement annually by classifying the amount and extent of distress present. The information to be collected from such a survey has been described, along with the manual and automatic survey procedures. The primary objective of the distress identification and field surveys discussed is the provision of a uniform basis for collecting distress data, and it is expected that the definitions and procedures used in the SHRP-LTPP study will be adopted by highway agencies interested in developing condition surveys.

ACKNOWLEDGMENTS

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New Approach for Improvement of Highway Maintenance in France

PIERRE CHANTEREAU

Highway maintenance policy in France has been completely revised as part of modernization efforts affecting central and local administrations of the Ministry of Civil Engineering. The new policy is based on expanded training for maintenance managers and workers, improved management strategies and organizational structure to provide new levels of service to road users, integration of new tools and techniques to improve efficiency, motivation of workers through participative management, and improved communications among all organizations involved in highway maintenance. Since 1986, 50,000 people have been involved in this effort to improve the maintenance level of service. In the decade to come a new phase will be initiated requiring contractual agreements between all agencies involved in the maintenance of France's roadway system. The contractual agreements were prescribed by the French government in 1989 for all state administrations.

The DDEs—Directions Départementales de l'Equipement—can be likened to local departments of transportation. They belong to the Ministry of Civil Engineering, Housing, Transportation, and the Sea, hereafter referred to as the Ministry of Civil Engineering. As state agencies in all 100 departments (counties), the DDEs are in charge of maintenance for national and local highways. In each DDE, the highway management section has a maintenance equipment department—a logistics and works departmental unit—that provides all the maintenance vehicles necessary. All maintenance actions are carried out by the territorial subdivisions, which are similar to maintenance (or district) centers or local agencies, and by private contractors.

INTRODUCTION

France is the largest country in Western Europe. It has about a fourth as many people as the United States, even though it is only about twice as large as the state of Colorado. France has a diversity of terrain, including the snow-capped Alps on the border with Italy; sunny beaches and steep cliffs stretching along the coast on the Mediterranean Sea; fishing villages along the northwestern Atlantic coast; and colorful apple orchards, dairy farms, vineyards, and many historic castles throughout much of the countryside. Weather conditions are a mixture of oceanic and continental climates.

France is also an industrialized nation with great automobile, chemical, and steel industries. It is a leader in growing wheat, vegetables, and many other crops. France is fifth among the countries of the world in international trade.

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To support its economy, France maintains about 3,600 mi (6000 km) of expressways, 17,000 mi (28 000 km) of national highways, and 200,000 mi (340 000 km) of local highways, in addition to city and town (commune-level) roads and streets.

The basic unit of local government is the commune. France has about 38,000 communes, which vary in size from small villages to large cities. Each commune is governed by an elected council, which selects one of its members as mayor. Mainland France and the island of Corsica are divided into 100 departments (counties). Each department is also governed by an elected council, called the general council, which selects one of its members as president. Since 1982, the presidents of the general councils have been in charge of the 200,000 mi of local highways.

At the departmental (county) level, the national government is represented by the prefect, who is appointed by the national government and is in charge of the expressways and national highways.

The different road systems are maintained and operated by the 100 DDEs. Each DDE contains a highway management section, which has maintenance equipment at its disposal and relies on territorial subdivisions (local agencies) and private contractors to accomplish roadway maintenance.

The DDEs employ close to 50,000 persons in highway maintenance. Whereas highway maintenance work is accomplished under the supervision of the highway management departmental head, maintenance procedures are issued by the Ministry of Civil Engineering's (*a*) Department of Roads and (*b*) Department of Personnel Management. The maintenance cost for national and departmental highways stands at more than $2 billion, of which more than half is for personnel.

At the departmental (county) level, the DDE works for the national government, represented by the prefect, and for the department (county), represented by the president of the department's general council. Working for two distinct authorities has led the DDEs to change gradually to improve performance and efficiency. French highway maintenance policy has been modified as part of these modernization efforts affecting national and local administrations as a whole, and especially the Ministry of Civil Engineering.

THE NEW HIGHWAY MAINTENANCE POLICY

The new policy, drawn up and gradually implemented since 1986, has five main elements: better training, improved management, better equipment, increased worker involvement, and improved communication.

Better Training

Since 1985, significant efforts have been expended to train new and existing staff. Previously, maintenance activities were accomplished using only road construction equipment and techniques. However, users and elected officials have demanded higher standards for road maintenance, reinforcing the need for better training of personnel to meet changing road maintenance requirements.

For example, since 1987 highway management heads have been able to attend three 2-week management training programs developed by the National School of Roads and Bridges (ENPC—Ecole Nationale des Ponts et Chaussées). These programs had been limited to the heads of the DDEs. New personnel entering the subdivisions will be provided with training starting in 1990. The training will consist of solving problems in maintenance task requirements and crew organization. In a similar fashion, subdivision heads are now provided with training. This was already the case with managers of logistics and works departmental units.

During the last 4 years, all personnel in highway maintenance and related departments have been provided with basic training that makes it possible for them to be fully in charge of their activities. This comprehensive training program could not have been implemented without the help provided by the technical schools, the ENPC and the ENTPE (Ecole Nationale des Travaux Publics de l'Etat), which train engineers, and the 10 professional training centers.

The next step will be to assess the impact of this ambitious training policy.

Improved Management

Plan, perform, assess, and correct: these are guiding principles for achieving better results. This new way of conducting highway maintenance not only incorporates the technical aspect of performing highway maintenance but also accounts for new maintenance techniques, better-trained personnel, and the end results as perceived by users. Improving management techniques is a long-term (5- to 10-year) effort, involving planning as well as programming and follow-up on actions carried out within the constraints of human and financial resources.

The new approach, initiated in 1987, emphasizes the following:

- At the departmental level, comprehensive evaluations of all aspects of highway maintenance policy;
- At the subdivision (local) level, evaluation of the cost of highway maintenance tasks using the CORAIL software; and
- At the user service level, evaluation of the level of service provided to road users.

Better Equipment

Previously, construction equipment management was carried out by the logistics and works departmental units that purchased, maintained, and rented equipment to subdivisions. This approach has changed because of pressures from private contractors, equipment manufacturers, and subdivision personnel.

Each logistics and works departmental unit is now more aware of the fact that to become better equipped means accepting technological advancements through

- Experimentation with and understanding of new road construction techniques;
- Use of new data processing applications, such as expert systems (ERASMUS) and data bases (VISAGE);
- Introduction of new equipment units requiring cooperation with private contractors and equipment manufacturers; and
- Promotion of innovations originating with department personnel.

There are two difficulties to this approach to improving daily work productivity: it requires a constant search for new technologies and sensitivity to the impact of the new technologies on personnel. Only if this is realized will each worker become aware of the need to improve efficiency and be a positive agent in the actions to be carried out.

Increased Worker Involvement

Equipment division and subdivision personnel are at the heart of the highway maintenance modernization effort. They must cope with various difficulties stemming from users' demands, increased scrutiny from elected officials and the media, work force reductions, and increased work loads. The maintenance employees represent an important potential. Highly dedicated to the public service, they are capable of improving in their job. To increase maintenance worker involvement, every effort must be made to make it easier for the employees to express their opinions and make proposals. It should also be realized that workers may be directed to accomplish tasks or use methods that may not be to their liking—for example, performing needed maintenance work over a long distance on a given route rather than working in a limited geographic area.

Many experiments aimed at involving the personnel in this process have taken place during the last few years. To help with this effort, engineers must enter into a dialogue with the maintenance workers. The training received by engineers in previous years did not always prepare them for this activity. Therefore, some engineers must be trained in the necessary communication skills before entering into dialogue with the maintenance workers.

Improved Communication

The efficient implementation of the new highway maintenance policy, though impelled by the Department of Roads and by the Department of Personnel Management, depends heavily on the DDEs' efforts. Therefore, it is essential that as much information as possible flow between the different organizations involved.

The Ministry of Civil Engineering has long been encouraging communication between the organizations involved in roadway maintenance, as indicated in the following examples:

- Technical discussions between the Department of Technical Research and Development on Highways and Expressways and the Central Laboratory of Roads and Bridges of the Ministry of Civil Engineering,

- Professional discussions between managers of logistics and works departmental units and the highway management heads (since 1987), and
- Interdepartmental discussions between the Club for Exchanges of Experiments on Departmental Highways and the Task Force on Highway Maintenance (Groupe Permanent de l'Entretien Routier—GPER).

The objective of the third set of discussions, which started in 1986, is to facilitate the horizontal dialogue among the various Ministry of Civil Engineering units and the vertical dialogue among the Ministry of Civil Engineering units, the Department of Roads, and the Department of Personnel Management. To accomplish this, the GPER is organized into four subcommittees that meet three to four times a year. Each subcommittee is made up of 15 to 20 members, who represent different departments. The subcommittees address the following areas: techniques and equipment, human resources, relations with Ministry of Civil Engineering employers, and relations with road users.

The GPER provides a forum for information exchange and makes the results known through a video magazine and a newsletter describing all aspects of the highway maintenance effort.

The approaches described above have made it possible to make outstanding progress in the modernization of highway maintenance during the last 5 years.

CONCLUSIONS

A new policy on highway maintenance has been formulated through dialogue between 1985 and 1990. In the decade to come, a concentrated effort will be made to expand the policy through contractual agreements that will identify results to be achieved. The agreements will assume a variety of forms:

- A 3-year contract between the DDEs and the Ministry's departments for all activities (not just maintenance activities);
- A special 3-year contract with the Department of Roads regarding maintenance of the national highway system, with provision for yearly progress reports; and
- Contracts of two types with department (county) officials in charge of departmental highways: a 5-year contract for maintenance of the departmental road system and a 5-year contract regarding equipment activity within an equipment procurement and renewal policy.

The implementation of these contracts, which is of concern to the 100 DDEs, will require additional progress on two levels: definition of service levels wanted on routes and adjustment of service levels to meet the needs expressed by the road users.

Implementation of road maintenance could then be assessed according to methods prescribed by the government in 1989 for all state administrations. These methods describe the distribution of responsibilities to DDEs through the contractual agreements, the setting up of target objectives and the measurement of results, the satisfaction of citizen and user needs, and the assessment of public policies.

There is no reason to doubt that the results will meet with favorable public response.

APPENDIX

TRAINING

Training problems are important in road maintenance. The Ministry of Civil Engineering must train 50,000 civil servants, consisting of 35,000 employees in the subdivisions, 8,500 employees in the logistics and works departmental units, and 6,000 works surveyors ensuring personnel supervision.

Many of the 8,500 employees in the logistics and works departmental units have highly specialized jobs. Their training is less of a problem because they can be trained in centers existing in the industry.

Until recently, the 35,000 civil servants employed in subdivisions were provided with no training. Two actions have been taken to correct this. The first consists of a 14-day training for new employees. During the training, technical as well as more administrative and organizational topics are developed. The aim is to provide employees with a minimum knowledge of the environment they are entering. The second consists of providing each employee with 5 days/year of professional training. The training must deal with all facets of the trade.

The training is conducted locally by the DDEs. To this end, local training staff have been trained by interregional professional centers relying on teaching materials drawn up at the national level.

It is difficult to assess the results of the training. However, it is believed that it has brought about (*a*) better involvement of employees in their work thanks to the decompartmentalizing that training sessions provide through practical information exchanges between fellow workers and (*b*) a better grasp by employees of their role within the administration as well as their responsibilities to users and elected officials.

The training of nonsupervisory employees must be rapidly implemented in order to modernize road maintenance.

MOTIVATION OF MAINTENANCE WORKERS

Whereas in the past, few experiments were conducted on motivation of nonsupervisory employees, during the last few years such experiments have become more numerous. However, so far no policy has been decided at the central level, except for encouraging this type of incentive.

Actions can be classified into five categories: training actions, quality circle–type actions, study groups, user-oriented actions, and maintenance forums.

Training actions were described in the preceding section.

Quality circle–type actions have been launched in several departments. Results of quality circles are often limited (for instance, change in support for temporary road signs to prevent them from falling down). On the other hand, results are often directly useful. Their modes of operation challenge to a large extent the practices of the personnel hierarchy, as this hierarchy must let initiatives develop, consider proposals, and give effect to selected solutions.

Maintenance study groups have been recently established (less than 2 years ago). They bring together, within every DDE, all the intervening parties (employees working as assistant civil engineers of the State Public Works, subdivision staff, and district engineers). Almost all study groups are centered on technical fields (maintenance of pavements, roadsides, road signs, winter season activities, constructive works, and operation). They are intended to provide further knowledge of the relevant field, to make proposals to be applied in the whole DDE, and to bring about better understanding between all parties.

An example of user-oriented actions is to provide information to the public. Although the primary aim of user-oriented actions is not to motivate employees, they often bring about positive effects thanks to the acknowledgment they grant to nonsupervisory employees.

Maintenance forums have been organized by various departments (departmental bureaus, professional training centers, and the Department of Personnel Management). These events provide employees with opportunities for meeting. They do not all have the same purpose. Thus, the purpose of forums organized by the departmental bureaus is often to make the bureau's activities known at the local level. The purpose of forums organized by training centers and the ministry's Technical Research and Development Centers is to get related departments to know each other better and to make new techniques known. The purpose of forums organized by the Department of Personnel Management is partly to give greater value to innovative approaches.

Whereas these actions are different in character, they all lead to better consideration of the employees' aspirations and contribute to an increase in their motivation.

NEW MAINTENANCE EQUIPMENT

Maintenance spending over the national system and over the departmental systems is divided into three main areas: 40 percent is allocated to general-purpose work that is already highly mechanized (repairs of surface layers, repairs of markings, etc.), 40 percent to standard maintenance work in the production field (pavement reprofiling, mowing, vegetation clearing, localized pavement waterproofing, and winter season activities), and 20 percent to emergency work (pavement palliative maintenance, repositioning of road signs, road survey, etc.).

Efforts during the last few years have been essentially directed toward standard maintenance tasks in the production field because the greatest possibility for gain lies there. As for equipment, the emphasis has been put on two fields: standard pavement maintenance and roadside maintenance.

In the field of pavements, it appeared that major savings could be achieved in surface waterproofing techniques. A new machine called a chips-and-asphalt spreader (see Figure 1) has been designed and distributed nationwide. Compared with previous practices, this equipment provides a saving ranging from 40 to 65 percent depending on the type of repairs. However, this machinery is primarily for use on moderate traffic road systems (2,000 vehicles/day).

For roadside maintenance, several mowing vehicles are in the development stage. Here again costs have sharply decreased. It is difficult to assess gains in productivity because local conditions are highly diverse. Nevertheless, it is believed that, on the average, productivity has more than doubled.

FIGURE 1 RG Secmair.

Until 1985 mowing and clearing of shoulders were performed with farming tractors. A new vehicle has recently been developed in cooperation with a manufacturer. The new vehicle, the PMS Nicolas (see Figure 2), is several times the price of the tractor. Despite its high cost, innovations (hydrostatic transmission, heavy-duty engine, general design, etc.) have made it possible to reduce maintenance costs per square meter by approximately 30 percent. About 20 units of this type are in operation.

Several manufacturers have built prototypes along the same lines—vehicles specifically designed for road maintenance. Four new trucks are currently on trial. Figure 3 shows a vehicle derived from lift trucks. It is provided with hydrostatic transmission and can drive rotor tools. Figure 4 shows a four-wheel drive vehicle, specially built by a small firm, that emphasizes ergonomics. Figure 5 shows a vehicle fitted for mowing and clearing vegetation. The manufacturer is considering using it to perform ditching and verge-leveling work. Figure 6 shows a truck derived from a mountain farming vehicle that is on trial in two departments.

COMMUNICATION

The DDEs must adapt to (*a*) decentralization, which transfers decision-making processes from the national level to the

FIGURE 2 PMS Nicolas.

FIGURE 3 Manitou.

FIGURE 4 Noremat.

FIGURE 5 Secmair.

departments (counties), and (*b*) rapid changes in technology. Communication can assist in the adaptation.

Efforts are being made to (*a*) provide access to basic information for each of the various media and (*b*) use the multimedia concept (newsletters, communication actions, videos, and technical files) to the maximum. Two examples of communication illustrate these efforts:

FIGURE 6 SCM Chapuis.

- The Department of Personnel Management organizes forums at which employees themselves present improvements they have made. The events are organized at the regional level and group together from five to seven departments (counties). They provide opportunities for employees to exchange their experiences and increase their expertise.

  Three or four forums of this type are organized every year in different regions. Innovations presented during these meetings are disseminated through the various information vehicles (newsletters and videos).
- Within the framework of the GPER a video magazine has been created. Its production relies on units belonging to different departments; each unit contributes reports or stories. This tool has made it possible to collect information in two different ways: through the video units that identify and publicize local experiments and through the personnel involved in maintenance, who are beginning to use light video equipment to make their achievements known.

ERASMUS—AN EXPERT SYSTEM FOR ROAD MAINTENANCE

Design work and decision making pertaining to the pavement maintenance of the French road system are spread over about 100 operational sites. At the national level, specialized technical establishments, oriented to testing and research, complete the system of decentralized expertise. These activities involve a few hundred engineers in charge of the decision-making process and a few dozen experts who specialize in one or several facets of pavement techniques. On the whole, this amounts to an annual work expenditure on the order of 5 billion francs. Experience indicates that a share of this spending corresponds to maintenance work, the efficiency of which could be improved by solutions better adapted to technical and economic constraints.

ERASMUS is based on the technology of expert systems. The prime quality of ERASMUS lies in its being a vehicle for propagation of knowledge on road maintenance techniques and economy within the community of users. It contains the whole range of expertise to be found within the professional community and presents it in an easy-to-operate didactic form. Provided with a user-friendly graphic interface, ERASMUS is operated by users with no knowledge of data processing. It is intended to equip every operational decision-making site and is installed on SUN 3/60-type workstations.

ERASMUS assists the user in further specifying the descriptive data of the case to be dealt with: pavement structure, visual condition, results of tests concerning its present state, weather conditions, and traffic conditions. The graphic interface guides the user through the case specification process and allows incomplete definitions.

ERASMUS then draws up one or several diagnoses describing the problems the pavement is experiencing. The diagnosis system performs a nonstraightforward reasoning. It has a feature that enables it to conduct the reasoning further on the basis of "suspicions" (generation of multiple hypotheses), which lead to the possible conclusions "hypothesis proved right" or "hypothesis not matching up with visual condition data." It can issue queries to pavement engineering calculation programs and interpret their results. From elements in the reasoning conducted by ERASMUS, the user can infer the nature of complementary tests that are likely to further specify diagnoses.

The expert system reasons on the basis of the diagnosis or diagnoses derived from the previous stage, considers them simultaneously, and concurrently works out solutions for the diagnosed defects. The reasoning takes into account technical and economic constraints on acceptable solutions presented by the user. Finally, ERASMUS draws up a report on the work and costs involved in the solutions.

ERASMUS has been installed for development and validation at more than 14 sites. Moreover, nine pilot sites have been testing ERASMUS since June 1989 and have handled more than 300 cases. ERASMUS version 1.0 is ready for distribution and the first orders have already been registered. Further developments and improvements are in the design stage.

THE CONTRACTUAL PROCESS IN THE FIELD OF HIGHWAY MAINTENANCE

In the early 1970s the Department of Roads launched an ambitious program for coordinated reinforcement of pavements on national highways. This was accompanied by a preventive maintenance policy whose purpose was to preserve the structural property of pavements. The process for allocating funds was based on centralized procedures. The DDEs appropriated the preventive maintenance concept, and it now appears necessary to give greater autonomy in decision making to local services. Thus the current trend is to implement a policy of contracts regarding financial relations between the headquarters at the Ministry of Civil Engineering and the DDEs.

The new arrangements require putting at the disposal of prime contractors tools ensuring (*a*) a proper technical knowledge of the condition of the property to be maintained, (*b*) a proper financial knowledge of means to be used, and (*c*) a homogeneous approach to service level assessment over the whole territory. At present the tools exist to accomplish the first two functions. As for service levels, documents have been drawn up and issued that make their quantification possible.

A contractual process, however, the main element of which is the quantification of service levels, is difficult to implement quickly. This is why the procedure will first be tried during 1991 in a few departments (counties) before being extended to the whole territory.

The contractual process as applied to relations between the Department of Roads and the DDEs will stand as a methodological basis for negotiations between clients in the departments (counties) and local-level central government agencies as these are put at the disposal of territorial authorities.

Interactive Videodisc Training for Roadway Maintenance

JAMES B. MARTIN

An interactive videodisc system and training program developed for FHWA by the North Carolina Institute for Transportation Research and Education is described. The program includes instruction on various pavement structure repair techniques, including pothole patching, crack sealing, maintenance of gravel roads, ditch maintenance, shoulder maintenance, asphalt chip seals, and basic traffic control. The system hardware has been mounted in a heavy-duty container suitable for shipping. The system is designed to be used with minimal setup. The program is directed toward the highway maintenance worker.

An interactive videodisc training program, "Pavement Structure Repair Techniques," has been developed by the North Carolina Institute for Transportation Research and Education (ITRE). The program was designed for highway maintenance workers in local highway agencies and is intended to instruct the workers in the proper method of performing various pavement maintenance activities. Many millions of dollars are spent annually on the maintenance of roads, streets, and highways across the United States. Performing the maintenance in a proper and cost-effective manner will prolong their lives and benefit the public. It is therefore important that the highway maintenance workers performing these activities be instructed in the proper techniques to be followed. In the past, highway maintenance training has not been a high-priority item in many highway departments.

In January 1988, ITRE was awarded Rural Technical Assistant Project (RTAP) 46A, Pavement Structure Repair Techniques, by FHWA. The original contract required the preparation of seven professional-quality videotapes, each 15 to 20 min in length, for instruction on seven different highway maintenance activities: pothole patching, crack sealing, maintenance of gravel roads, ditch maintenance, shoulder maintenance, asphalt chip seals, and basic traffic control.

FHWA had previously completed an interactive videodisc training program on work zone traffic control. That training program had received a favorable response from FHWA and local highway agencies. Therefore, FHWA was interested in developing other interactive videodisc training programs. It was decided that RTAP 46A was an excellent project to further utilize the interactive videodisc training technique. In addition to producing the seven videotapes, ITRE was responsible for preparing an interactive videodisc training program on the same subject areas. Ultimately, the intent is to compare the effectiveness of the interactive videodisc training with that of videotapes. All seven videotapes have been completed and are being widely distributed. The development of the interactive videodisc program will be described.

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PROGRAM DESIGN

It was desirable to have all seven subject areas included on one side of a single videodisc. Compressed audio was a necessity to achieve the end product. ITRE subcontracted with United States Video Corporation in Vienna, Virginia, to assist in the technical preparation of the videodisc. By using the EECO compressed audio technology, it is possible to place up to 40 sec of audio into one stillframe on the videodisc. This was a key factor in being able to present all seven subject areas on one side of a single videodisc. The final disc contains 864 slides and video stills, 674 character-generated text screens, 100 segments of video totaling 21 min, and 3 hr of linear and compressed audio.

The program also uses the IBM Infowindows touch screen monitor. The touch screen eliminates the need for a keyboard. The target audience consists of highway maintenance workers generally with a high school education or less. Most of the workers are not computer oriented. The touch screen avoids an encounter with a computer keyboard. The intent is to make the student as comfortable as possible with the technology.

The program begins with a brief introduction that familiarizes the students with the methodology of the training program. The students are given a brief explanation of what an interactive videodisc is and are guided through some sample questions and responses.

After viewing the introduction, students must identify themselves by their initials (first, middle, and last) and their birth month. The unique identifier allows the program to track student responses. Software scores the students' responses to questions and reports the scores.

After the student is identified, a main menu is presented. The student can select any of the seven modules—the maintenance activities listed previously—from the menu. Each module is broken into segments. After selecting a module, the student encounters another menu, which allows the student to select a segment.

For example, in the ditch maintenance module the student would select from the following segments:

1. Introduction,
2. Ditch Maintenance Using a Motorgrader,
3. Ditch Maintenance with a Hydraulic Excavator, and
4. How Many Trucks?

The introductory segment briefly describes the purpose of and need for ditch maintenance. Segments 2 and 3 describe the details of two different methods of performing ditch maintenance. Segment 4 describes an easy way to calculate the number of trucks required to perform the ditch maintenance. The menu also contains a selection to exit the module and return to the main menu.

Each module presents instructional material in clearly defined segments. The instruction includes the use of stillframes and motion video to illustrate maintenance procedures. After the instructional material, several questions are presented to the student. A total of 78 questions are included in the entire program, all of which are of the multiple choice or true-or-false type. Many answers are listed on a text screen, whereas others use split screen video images. The student responds to the question by touching the proper answer on the screen. If a correct response is chosen, the student receives congratulations and proceeds to the next question or segment of the module. If an incorrect response is chosen, the student receives remediation, and the correct answer is reinforced. After a review the student moves to the next question or segment of the module.

To make any selection, the student must touch the selection on the screen. The selection is then highlighted by a box. The student then must touch an enter box on the upper right-hand portion of the screen. The student may change the answer any number of times until pressing the enter box. This allows for a change of mind or for making a correction if a wrong answer is selected by mistake.

In addition, an escape box is generated by computer graphics on the lower right-hand portion of the screen. The escape box allows the student to interrupt the program at any point. The student can then exit the system and return at a later time to complete that particular module. The response-tracking program will save the student's responses to questions up to that point. The software will monitor responses to the remaining questions when the student resumes the program.

The program was designed to be used easily by the target audience. For the interactive videodisc system to be effective, highway maintenance workers must not be intimidated by its use. Every effort was made to make the program user friendly.

EQUIPMENT

As previously stated, the interactive videodisc system utilizes the IBM Infowindow touch screen monitor. An IBM PS/2 Model 30 microcomputer was selected because of its size. The EECO P-Cat 300 compressed audio decoder card is installed in the microcomputer to decode the compressed audio from the videodisc. A Pioneer LD-V6010A videodisc player is used. The IMSATT authoring system was used, and the United States Video Corporation did the system programming.

FHWA intends to send this system to various locations throughout the United States. The system is to be tested at several of the 42 RTAP technology transfer centers across the country. The technology transfer centers are jointly funded by FHWA and state highway departments. ITRE is the RTAP technology transfer center for North Carolina. Most of the centers are affiliated with universities and are established to provide technical training and assistance to local highway agencies. Many of the agencies have limited training budgets, and the technology transfer program provides quality training at a minimal cost.

For mobility the equipment is packaged in a heavy-duty shipping crate with dimensions of 27 in. x 45 in. The equipment was mounted inside the shipping crate by staff members in FHWA's electronics lab located in McLean, Virginia. The equipment is mounted on a frame in the crate that is held in position by heavy-duty shock absorbers. The monitor is mounted so that it is at a sitting student's eye level. The crate and equipment weigh approximately 200 lb. Heavy-duty wheels are mounted on the bottom for ease of movement.

All the equipment is wired to a single power strip located in the rear of the shipping crate. The equipment is packaged for use with minimum setup. Once the equipment is received, the front and back doors must be removed from the crate. A power cord from the power strip must be plugged in and the toggle switch flipped on. The system will automatically boot up. The operator can then respond to the touch screen monitor.

Initially, there was concern that the equipment might be damaged in transit. However, the equipment has been shipped several times without damage so far.

TRAINING EFFECTIVENESS

The next step is to compare the effectiveness of the interactive videodisc training with that of videotapes. Test groups will be selected in North Carolina and two other states. Half of the test group will view the videotapes in the more traditional training methodology. They will then be asked to respond to the same questions that are presented in the interactive videodisc program. The other half of the test group will work through the interactive videodisc program. The computer software will keep track of the percentage of correct answers. A direct comparison of the two groups will be analyzed.

FHWA is interested in the effectiveness of the interactive videodisc training technique. It has recently purchased several systems for in-house training use. However, there is some reservation about the effectiveness of interactive videodisc training among highway maintenance workers, who typically have a high school education or less. "Pavement Structure Repair Techniques" was designed to minimize the intimidation factor for these maintenance workers.

It is evident that FHWA recognizes the advantages of interactive videodisc, particularly for maintenance workers. The training is presented on an individual basis, and the student proceeds at his or her own pace. The student is forced to participate in the training activity. When merely viewing videotapes, students may have a tendency to daydream and miss important points in the material being presented. The interactive videodisc does not allow this to happen. In addition, when a student responds incorrectly to a question, interactive videodisc presents an immediate review and remediation. It is believed that this will cause the student to retain more knowledge.

FUTURE

The "Pavement Structure Repair Techniques" interactive videodisc program prepared by ITRE has been reviewed by many highway maintenance engineers. The response to the program has been positive. It must now be tested with highway maintenance workers. FHWA is hopeful that the interactive videodisc will prove effective in training these employees. In the long run, proper and cost-effective highway maintenance procedures will save money and provide a longer life span for the country's roads, streets, and highways.

ACKNOWLEDGMENT

The interactive videodisc training program was developed as a part of RTAP 46A funded by FHWA. FHWA plans to use this along with other videodisc training programs. Related training information is to be available from the RTAP technology transfer centers nationally.

Local Agency Managers' Perceived Value of Motivation Among Maintenance Workers

KENNETH A. BREWER, EDWARD J. KANNEL, AND WILLIAM F. WOODMAN

The results of a limited initial study of manager perceptions of employee motivation in local agency street and highway maintenance organizations are presented. All data are taken from cities and counties in Iowa. The agencies represent organizations generally having professional engineering management at some level in the organization. Managers were found to believe strongly that salary and benefits were prime determinants of employee satisfaction and morale, which is indicative of an organization that subscribes to the "rational-economic man" principle (i.e., tends to see working-level employees as a labor commodity to be bought and used). Conversely, managers were found to believe strongly that their employees were motivated by individual needs, suggestive of an organization with a management philosophy at the opposite extreme—the "complex man" model. The intermediate philosophies of management in the "social man" and "self-actualizing man" models were not found to be significantly subscribed to by local agency maintenance managers in this research. The results suggest that local agencies cannot be expected to be interested in training or programs to enhance employee motivation unless such programs recognize the wide variance of manager perceptions.

Standard works on industrial psychology and motivational behavior in management have presented the generally accepted theories describing a human behavioral approach to encouraging people to perform as the organization wishes (*1–3*). The various reasons for being motivated to work include satisfying different kinds of needs, such as physical and security needs, social needs, and egoistic needs. Physical and security needs are thought to include basic survival aspects of life such as food and water, shelter, and the emotional desire to be relatively secure in these areas. Social needs are thought to include the physical, emotional, and spiritual aspects of a person's life, which can only be met in communication and interaction with other people. Egoistic needs are thought to encompass a desire to be independent and successful on a person's own merit rather than in a social context. Maintenance work can provide opportunities to meet these types of needs, but in different degrees than perhaps other occupations. A maintenance worker who is struggling to make ends meet and satisfy physical needs will be most sensitive to salary scale, amount of overtime work available, and opportunities for advancement to higher pay grades. Workers who lack meaningful social life outside the job and who crave social acceptance will be interested in maintenance positions that permit them to work in groups that provide frequent opportunities to enter discussions. Persons with a strong desire to be recognized as productive are likely to seek individual tasks or supervisor positions to meet egoistic needs. These traditional views of needs suggest that maintenance workers may respond to a wide variety of motivational strategies. However, motivational strategies assuming that people work solely to satisfy some fixed need may not affect the productivity or quality of maintenance personnel.

The traditional views of human behavior in management also contain some fundamental assumptions about the nature of people. One is that at least some people can be described by the principle of the "rational-economic man." Another is that some persons can be described as members of a group classified as "social man." A third is that some persons can be thought of as belonging to "self-actualizing man" groups. A fourth is that some persons belong to a group identified as "complex man." An exhaustive description of these groups will not be presented here [see Schein (*3*)]. However, the implied managerial strategies tending to flow from a manager or an organization that assumes that their people fit into one of the model groups are worth noting here.

An organization following the rational-economic man principle assumes that it is buying the services and obedience of the employees. The organization adopting this approach is not necessarily the maintenance agency. It may be the union that represents the workers. Managers are concerned with planning, organizing, motivating, and controlling.

If productivity is low or morale is sagging, the manager is to change job (task or activity) specifications and organizational relationships among the jobs or change the incentive and control system to motivate employees and increase productivity (increase pay, cut pay, increase quality control standards, etc.). Managers are usually expected to evaluate first the organization itself to see where change may be needed. The manager is then expected to evaluate incentives for motivation and rewards for productivity.

Organizations following the social man assumption expect managers to devote more attention to the needs of the persons working under the manager than to the tasks of those persons. Managers are to be more concerned with the feelings of subordinates and the degree to which they believe that they are "part of the team" than with trying to control the subordinates. Managers are expected to focus more on work team (or crew) incentives than on individual incentives. The manager shifts from planning and controlling to being a go-between for the workers and the higher levels of management. A first-

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level manager in such an organization is seen more as facilitating and supporting the workers than as controlling and motivating them.

Managements that hypothesize the self-actualizing man model assume that worker motives fall into a hierarchy of value. The first level includes simple needs for survival and security, then come social interaction needs, then ego-satisfaction and self-esteem needs, then the needs for independent status, and finally the needs for self-actualization. Such managements also assume that people can and want to grow and mature in their jobs, that people are basically self-motivated, and that there is no conflict between self-actualization and improved agency performance.

This implies a resident management strategy similar to that followed under the social-man theory, but with expanded dimensions. In an agency assuming the self-actualizing man model, a manager will be encouraged to be less concerned about treating employees with consideration and sensitivity and to give more attention to making their work more challenging and meaningful. A manager will be encouraged to delegate as much authority and responsibility as, in the manager's opinion, the subordinate employees can handle. The idea shifts from the agency motivating people to giving the employee the freedom and latitude to dig into the job and become motivated from within. Agencies using this concept pride themselves on being "an organization of self-starters."

The complex man approach to management philosophy recognizes that every model is limited in its ability to describe all conditions. This philosophy accepts the value of the rational-economic man, social man, and self-actualizing man models to describe some people in some situations. However, the complex man concept suggests that people, relations among workers, and relations between workers and the agency are more complicated than do the previous models.

An agency assuming the complex man model is willing to adopt a variety of management strategies depending on the perceived problems and the perceived characteristics of the workers. Agencies thinking this way tend to seek managers who are good at evaluating people as individuals and analyzing situations and who place a high priority on investigating circumstances before acting. Managers in a complex man model organization are flexible.

MERIT OF MOTIVATION SURVEY

In October 1988 an ongoing independent study was undertaken by faculty in the Civil and Construction Engineering Department and the Sociology and Anthropology Department at Iowa State University to investigate the appropriateness of high-level personnel management concepts in local street and highway maintenance agencies. Because it was an unfunded faculty release time effort, it has been a low-cost study restricted to local agencies in Iowa. A brief one-page survey was designed for easy response from maintenance managers in the 99 Iowa county engineering offices and the 71 cities having more than 5,000 persons. All counties in Iowa have registered professional engineers supervising the highway system. Cities with more than 5,000 persons have at least a public works department with a regular street maintenance program and have several employees conducting street maintenance. Even the largest of these organizations would still be classified as small in terms of managerial complexity. All county engineering offices in Iowa are required to have the road system supervised by a registered professional engineer. Some of the counties have only the one supervising engineer, whereas the larger counties may have up to three additional assistant engineers. All except the larger cities will generally have only one engineer responsible for the entire public works operation, so in most of the cities the direct responsibility for managing street maintenance falls on a nonengineer "street superintendent." Cities and counties in Iowa are stable public employers because the state has been in a series of limited-growth or slight decline cycles for the past two decades. Thus, for the sample population, maintenance employee motivation is not affected by sharp growth or decline in agency employment. The Local Systems Office of the Iowa Department of Transportation (DOT) mails to these agencies, on a monthly basis, materials considered essential to coordination by Iowa DOT of local government transportation matters. The Iowa DOT agreed to include the survey form in one of its regular mailings for distribution to the local agencies. Table 1 contains the response results.

It is interesting that, of the city engineering departments responding, almost all thought that more highly motivated maintenance workers would increase the quality of maintenance, but many county engineering departments were somewhat unsure (Question 1). There has been a general assumption that deficiencies in the quality of maintenance are strongly related to employees who do not care about their jobs. Results of the survey suggest that small local agencies generally want more highly motivated employees, but counties expressed some uncertainty about the impact that more highly motivated employees will have on maintenance quality.

Differences of opinion between cities and counties were more pronounced as to whether higher levels of motivation would reduce turnover among maintenance staff (Question 2). County respondents were almost equally divided between positive and negative respondents, and 15 percent were in the "don't know" category. City respondents mostly believed that higher levels of motivation could reduce employee turnover ("definitely" or "maybe"). This suggests that the counties responding to the October 1988 survey are more inclined to regard their employees under a rational-economic man model than either the social man or the self-actualizing man model. If the responding counties have turnover problems among their personnel, this suggests that they think individuals leave for more rational reasons than how they feel about themselves or the job. The more pessimistic response of the counties could be the result of very little turnover among personnel. If no problem exists, then higher levels of motivation cannot be expected to reduce turnover. In fact, for an agency with low turnover and low motivation among workers, stimulating the personnel to higher levels of motivation can increase turnover by encouraging competitive dissatisfaction.

Cities and counties both responded decidedly that higher levels of motivation would contribute to lower absenteeism and higher productivity (Question 3). There was some disagreement between cities and counties over whether motivation would "definitely" or "maybe" have an impact, but the sum of the positive responses was nearly the same for both types of agencies. It is interesting that small-agency managers believed more strongly that higher levels of motivation would

TABLE 1 SURVEY OF IOWA CITIES OF MORE THAN 5,000 PERSONS AND IOWA COUNTIES, 1988

	PERCENT RESPONDING	
	Cities (N = 29 of 71)	Counties (N = 47 of 99)
1. Do you think having more highly motivated maintenance workers would contribute to better quality of maintenance done?		
DEFINITELY	93	57
MAYBE	3	36
DON'T KNOW	0	0
PROBABLY NOT	0	2
NOT AT ALL	0	4
No Answer	3	0
2. Do you think that having more highly motivated maintenance workers would reduce worker turnover among maintenance staff?		
DEFINITELY	41	26
MAYBE	34	13
DON'T KNOW	10	15
PROBABLY NOT	14	38
NOT AT ALL	0	9
3. Do you think that having more highly motivated maintenance workers would contribute to lower absenteeism and higher level of productivity?		
DEFINITELY	76	47
MAYBE	24	40
DON'T KNOW	0	6
PROBABLY NOT	0	2
NOT AT ALL	0	4
4. Do you think that having more highly motivated maintenance workers will enable your staff to accept and adapt to changing work environment or rules changes?		
DEFINITELY	41	40
MAYBE	45	43
DON'T KNOW	10	9
PROBABLY NOT	3	6
NOT AT ALL	0	2
5. Would you be willing to participate in a pilot test of any methods or training created to try to raise the motivation of maintenance workers to evaluate the research results?		
DEFINITELY	24	26
MAYBE	52	49
DON'T KNOW	7	19
PROBABLY NOT	14	6
NOT AT ALL	3	0

NOTE: Percentages do not sum to 100 due to rounding each cell to nearest whole percent.

increase the *quality* of maintenance (Question 1) than that higher levels of motivation would increase *productivity* (Question 3). This suggests a managerial perception that an employee's attitude is more strongly associated with how work is done than with how much work is done. The implication is that management leans toward the rational-economic man model of personnel management.

There was no discernible difference between cities and counties in their perception of the effect higher levels of motivation would have on implementing changes in work rules or work environment. Both types of local agencies thought more highly motivated workers were more amenable to changes in the work environment (Question 4). This suggests a managerial perception more consistent with the self-actualizing man model, in which a person is expected to be most responsive to challenges and stimulation in the type of task assigned. This response also indicates that managers accept some elements of the social man model by assuming that highly motivated persons are responsive to group goals. Because of how the question was asked, it is not possible to distinguish between the two possible managerial assumptions.

Question 5 was intended to measure the sense of commitment to employee motivation as a way to improve street and highway maintenance. Only about one-fourth of the respondents were strongly interested in a chance to implement measures that might increase employee motivation, and about another half were willing to think about it (responded "maybe"). The willingness of three-fourths of the respondents to consider motivational methods to improve maintenance suggests that local agency managers are interested in their employees' relationship to the agency and to their work.

Another inquiry to refine the managerial perceptions under the various behavioral classifications was desired as a follow-up to the initial inquiry. A brief telephone survey with city and county maintenance managers in the same survey population was conducted in 1990.

TELEPHONE SURVEY OF IOWA CITIES AND COUNTIES

The 1988 survey brought to light a difference between the city and county perceptions of the value of employee motivation in reducing turnover. In the telephone survey, the following question was asked:

In your estimate, what proportion of your maintenance personnel have been with your agency less than 5 years? ____ And about what proportion have been with the agency more than 20 years? ____

This was intended to yield an estimate of turnover in a local agency. Any agency for which the percentage of the maintenance staff with 20 or more years of service exceeds the percentage of the staff with less than 5 years of service is considered to be stable and not to have employee turnover problems that could be improved with higher levels of employee motivation. Table 2 shows the results of the telephone survey of cities and counties. Twenty-or-more-year employees outnumbered 5-or-fewer-year employees in almost three times as many counties as those for which the reverse was true. In contrast, the cities were equally split between the two categories. In general, counties have stable maintenance work forces, whereas cities are about as likely to have stable as to have high-turnover work forces.

Seven questions were presented to the respondents regarding their perception of the importance of selected work environment conditions. The questions were designed to estimate the manager's evaluation of work environment characteristics and indicate a level of acceptance of the various behavioral models with respect to maintenance employees. Table 3 indicates how the questions were categorized to support the four behavioral models.

Table 4 contains the results of the telephone survey for the questions indicating acceptance of the rational-economic man behavioral model. For both cities and counties, salary or pay rate is seen as important, but not nearly as important as the benefit package, in attracting and retaining maintenance workers. In the rational-economic man model, management is assumed to be buying the services of the workers. Clearly, the management perception, if a rational-economic man philosophy is applied, is that employee financial security is more important than pay. The questions considered to be secondary indicators of rational-economic man managerial assumptions provided results that were nearly identical to the salary question. Managers responded that these were factors of some importance but indicated a strong measure of uncertainty. Clearly, local agency maintenance managers think that monetary and individual success issues have a bearing on motivating their employees, but they do not regard these factors as the determining issues in building a highly motivated work force.

Table 5 contains the results of the telephone survey for the questions indicating acceptance of the social man behavioral model. The responses to the primary indicator question suggest that local agency maintenance managers do not place much value on the underlying assumption of the social man concept. The secondary indicator questions provided a strongly positive response, but these questions are more indicative of higher personal aspirations associated with other management behavioral models. Thus, the social man model view of maintenance employees is less of a managerial perception than the rational-economic man model.

Table 6 contains the results for the questions indicating acceptance of the self-actualizing man model. A weak positive response was given to the primary indicator questions, whereas a strong positive response was given to several of the secondary indicator questions. Because the secondary indicator questions with strong positive responses are more indicative of other managerial behavioral models, these data indicate that the self-actualizing man model is not seen as a good perceptual model for managing local agency maintenance workers. This was a bit surprising, because the direction of the responses in moving from the rational-economic man model to the social man model implied a more complex managerial attitude. The data indicate that the self-actualizing model is

TABLE 2 TELEPHONE SURVEY RESPONSE ON STAFF TENURE, IOWA, 1990

	PERCENT RESPONDING	
	Cities (N = 20 of 65)	Counties (N = 50 of 99)
0 - 10 percent of employees less than 5 years	20	24
10 - 20 percent of employees less than 5 years	20	42
20 - 30 percent of employees less than 5 years	35	28
30 - 40 percent of employees less than 5 years	10	6
40 - 50 percent of employees less than 5 years	0	0
more than 50 percent of employees less than 5 yrs	15	0
0 - 10 percent of employees more than 20 yrs	15	20
10 - 20 percent of employees more than 20 yrs	45	24
20 - 30 percent of employees more than 20 yrs	20	24
30 - 40 percent of employees more than 20 yrs	5	20
40 - 50 percent of employees more than 20 yrs	0	4
more than 50 percent of employees more than 20 yrs	15	8
more 20 yr employees than 5 yr employees	45	64
more 5 yr employees than 20 yr employees	45	24

TABLE 3 CATEGORIZATION OF IMPORTANCE QUESTIONS FOR TELEPHONE SURVEY

	R-E	Soc	S-A	Cmplx
Importance of salary or pay rate	P	-	S	S
Importance of benefit package	P	-	S	S
Importance of new equipment	S	-	P	S
Importance of group work experience	-	P	S	S
Importance of individual review	S	-	P	S
Importance of public service recognition	-	S	S	P
Importance of supervisor sensitivity	-	S	S	P

R-E = rational-economic man model
Soc = social man model
S-A = self-actualizing man model
Cmplx = complex man model
P = primary measure of adoption of management behavioral model
S = secondary measure of adoption of management behavioral model

TABLE 4 TELEPHONE SURVEY RESPONSES RELATED TO RATIONAL-ECONOMIC MAN

	PERCENT RESPONDING	
	Cities (N= 20 of 65)	Counties (N= 50 of 99)
PRIMARY Questions		
How important do you think the salary or pay rate is to your people in deciding to come to work for you, or in deciding to stay once they join you?		
VERY IMPORTANT	35	38
SOME IMPORTANCE	45	56
ONLY A LITTLE IMPORTANCE	15	4
NOT A FACTOR AT ALL	5	0
DON'T KNOW	0	2
How important do you think the retirement, health insurance, sick leave, vacation, etc. programs are in attracting new employees or keeping good employees?		
VERY IMPORTANT	60	70
SOME IMPORTANCE	35	30
ONLY A LITTLE IMPORTANCE	5	0
NOT A FACTOR AT ALL	0	0
DON'T KNOW	0	0
SECONDARY Questions		
How important do you think it is to your maintenance personnel that your agency provide them with high quality equipment, such as new pickups, buying new graders rather than used equipment, and so on?		
VERY IMPORTANT	25	36
SOME IMPORTANCE	70	50
ONLY A LITTLE IMPORTANCE	5	12
NOT A FACTOR AT ALL	0	2
DON'T KNOW	0	0
How important do you think it is to your maintenance personnel that each employee gets an annual review on his or her performance?		
VERY IMPORTANT	30	8
SOME IMPORTANCE	30	32
ONLY A LITTLE IMPORTANCE	30	28
NOT A FACTOR AT ALL	10	18
DON'T KNOW	0	2
No Answer	0	12

TABLE 5 TELEPHONE SURVEY RESPONSES RELATED TO SOCIAL MAN

	PERCENT RESPONDING	
	Cities (N= 20 of 65)	Counties (N= 50 of 99)
PRIMARY Question		
How important do you think it is to your employees that they get to work in teams or crews or groups where they can share their job efforts with other people?		
VERY IMPORTANT	25	10
SOME IMPORTANCE	50	54
ONLY A LITTLE IMPORTANCE	20	30
NOT A FACTOR AT ALL	0	6
DON'T KNOW	5	0
SECONDARY Questions		
How important do you think it is to your maintenance personnel that the public be made aware of the value of their work to public safety and service?		
VERY IMPORTANT	45	50
SOME IMPORTANCE	45	38
ONLY A LITTLE IMPORTANCE	5	6
NOT A FACTOR AT ALL	5	4
DON'T KNOW	0	2
How important do you think it is for the first-line supervisor (foreman, crew chief) to be sensitive to differences among all the employees under his or her supervision?		
VERY IMPORTANT	65	64
SOME IMPORTANCE	35	30
ONLY A LITTLE IMPORTANCE	0	4
NOT A FACTOR AT ALL	0	0
DON'T KNOW	0	2

TABLE 6 TELEPHONE SURVEY RESPONSES RELATED TO SELF-ACTUALIZING MAN

	PERCENT RESPONDING	
	Cities (N = 20 of 65)	Counties (N = 50 of 99)
PRIMARY Questions		
How important do you think it is to your maintenance personnel that your agency provide them with high quality equipment, such as new pickups, buying new graders rather than used equipment, and so on?		
VERY IMPORTANT	25	36
SOME IMPORTANCE	70	50
ONLY A LITTLE IMPORTANCE	5	12
NOT A FACTOR AT ALL	0	2
DON'T KNOW	0	0
How important do you think it is to your maintenance personnel that each employee gets an annual review on his or her performance?		
VERY IMPORTANT	30	8
SOME IMPORTANCE	30	32
ONLY A LITTLE IMPORTANCE	30	28
NOT A FACTOR AT ALL	10	18
DON'T KNOW	0	2
No Answer	0	12
SECONDARY Questions		
How important do you think the salary or pay rate is to your people in deciding to come to work for you, or in deciding to stay once they join you?		
VERY IMPORTANT	35	38
SOME IMPORTANCE	45	56
ONLY A LITTLE IMPORTANCE	15	4
NOT A FACTOR AT ALL	5	0
DON'T KNOW	0	2
How important do you think the retirement, health insurance, sick leave, vacation, etc., programs are in attracting new employees or keeping good employees?		
VERY IMPORTANT	60	70
SOME IMPORTANCE	35	30
ONLY A LITTLE IMPORTANCE	5	0
NOT A FACTOR AT ALL	0	0
DON'T KNOW	0	0
How important do you think it is to your employees that they get to work in teams or crews or groups where they can share their job efforts with other people?		
VERY IMPORTANT	25	10
SOME IMPORTANCE	50	54
ONLY A LITTLE IMPORTANCE	20	30
NOT A FACTOR AT ALL	0	6
DON'T KNOW	5	0
How important do you think it is to your maintenance personnel that the public be made aware of their work to public safety and service?		
VERY IMPORTANT	45	50
SOME IMPORTANCE	45	38
ONLY A LITTLE IMPORTANCE	5	6
NOT A FACTOR AT ALL	5	4
DON'T KNOW	0	2
How important do you think it is for the first-line supervisor (foreman, crew chief) to be sensitive to differences among all the employees under his or her supervision?		
VERY IMPORTANT	65	64
SOME IMPORTANCE	35	30
ONLY A LITTLE IMPORTANCE	0	4
NOT A FACTOR AT ALL	0	0
DON'T KNOW	0	2

TABLE 7 TELEPHONE SURVEY RESPONSES RELATED TO COMPLEX MAN

	PERCENT RESPONDING Cities (N= 20 of 65)	Counties (N= 50 of 99)
PRIMARY Questions		
How important do you think it is to your maintenance personnel that the public be made aware of their work to public safety and service?		
VERY IMPORTANT	45	50
SOME IMPORTANCE	45	38
ONLY A LITTLE IMPORTANCE	5	6
NOT A FACTOR AT ALL	5	4
DON'T KNOW	0	2
How important do you think it is for the first-line supervisor (foreman, crew chief) to be sensitive to differences among all the employees under his or her supervision?		
VERY IMPORTANT	65	64
SOME IMPORTANCE	35	30
ONLY A LITTLE IMPORTANCE	0	4
NOT A FACTOR AT ALL	0	0
DON'T KNOW	0	2
SECONDARY Questions		
How important do you think the salary or pay rate is to your people in deciding to come to work for you, or in deciding to stay once they join you?		
VERY IMPORTANT	35	38
SOME IMPORTANCE	45	56
ONLY A LITTLE IMPORTANCE	15	4
NOT A FACTOR AT ALL	5	0
DON'T KNOW	0	2
How important do you think the retirement, health insurance, sick leave, vacation, etc., programs are in attracting new employees or keeping good employees?		
VERY IMPORTANT	60	70
SOME IMPORTANCE	35	30
ONLY A LITTLE IMPORTANCE	5	0
NOT A FACTOR AT ALL	0	0
DON'T KNOW	0	0
How important do you think it is to your employees that they get to work in teams or crews or groups where they can share their job efforts with other people?		
VERY IMPORTANT	25	10
SOME IMPORTANCE	50	54
ONLY A LITTLE IMPORTANCE	20	30
NOT A FACTOR AT ALL	0	6
DON'T KNOW	5	0
How important do you think it is to your maintenance personnel that your agency provide them with high quality equipment, such as new pickups, buying new graders rather than used equipment, and so on?		
VERY IMPORTANT	25	36
SOME IMPORTANCE	70	50
ONLY A LITTLE IMPORTANCE	5	12
NOT A FACTOR AT ALL	0	2
DON'T KNOW	0	0
How important do you think it is to your maintenance personnel that each employee gets an annual review on his or her performance?		
VERY IMPORTANT	30	8
SOME IMPORTANCE	30	32
ONLY A LITTLE IMPORTANCE	30	28
NOT A FACTOR AT ALL	10	18
DON'T KNOW	0	2
No Answer	0	12

not perceived as any more applicable than the social man model.

Table 7 contains the results for the questions indicating acceptance of the complex man model. The responses to the primary indicator questions are most positive for this model. The manager perception is, clearly, that people need to be treated as individuals in their particular circumstances, even though the manager regards the workers as sensitive to financial security issues. This is an interesting result because most of the local agencies are unionized, which limits the degree to which workers can be treated in a unique way for any given circumstance. It may be that, because these are small agencies, there is still an opportunity to know the workers intimately despite union contracts and work rules. Workers were not directly questioned in this study, so it is not known whether their perceptions match those of the managers to any significant degree.

SUMMARY

It was concluded that small local agency maintenance managers perceive their workers to be sensitive to financial security issues for employee motivation and that they also support an assumption of the complex man model of behavior. Acceptance of the complex man model indicates that the managers perceive that they must evaluate each employee's situation and respond differently to different people in different circumstances to motivate and lead their workers effectively. Local agency maintenance managers regard improved motivation as helpful in improving the quality of maintenance, achieving less absenteeism, and gaining higher productivity. These findings suggest that street and highway maintenance can be improved by providing local maintenance managers with tools and skills to better motivate employees.

Because the research reported in this paper only addresses the managers' perceptions, further study should be undertaken to examine the perceptions of the workers to determine whether they are similar. Even without data on worker perceptions, it is important to note how managers view the motivation of their employees. If managers do not believe that people-oriented and worker self-esteem incentives are important, study and research on developing methods to create such incentives will never be effectively implemented in local agencies. The results of this limited study suggest that a wide range of manager perceptions exist and, thus, that local agency maintenance managers are open to new ways of enhancing the motivation of their employees if the new ways are consistent with the managers' views of the employees.

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All conclusions and opinions drawn from these data and expressed in this paper are solely those of the authors.

Present and Future Role of Maintenance Management Training in Civil Engineering Higher Education

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Undergraduate (B.S. degree) civil engineers provide the majority of the professionals entering highway maintenance engineering. The continued decline in planning, design, and construction as functional activities in state departments of transportation and the proportional growth in maintenance and operations activity suggest that it is time to examine the degree to which undergraduate civil engineering education is preparing young people for highway maintenance engineering careers. A survey of the 20 largest education programs indicates little overall educational strength suitable for highway maintenance careers. The Accreditation Board for Engineering and Technology criteria were found to be both a hindrance—emphasizing traditional science, the planning-design-construction process, and general education—and a help in providing a mechanism by which TRB and AASHTO can become active in instituting change.

The bulk of the engineers working for state departments of transportation (DOTs) are civil engineers. A 1984 study of personnel found that almost three-fourths of all professionals at DOTs were civil engineers (*1*). Because civil engineering undergraduate programs are the predominant supplier of young professionals to DOTs, the suitability of undergraduate civil engineering programs for the preparation of engineers entering the field of highway maintenance management is explored.

The changing skill requirements for young civil engineers are explored in light of the maturity of the U.S. highway system. Clearly, skill requirements are shifting from those necessary to developing a system to those necessary to efficiently maintaining and operating facilities. Next, the results of a survey of the civil engineering curricula of the 20 U.S. universities that graduate the most civil engineers are presented. Many curricula do not provide ample opportunity for engineers to develop skills in the maintenance management area.

Civil engineering education has traditionally identified its responsibilities for training undergraduate engineers in broadly defined categories of knowledge. The categories usually include structural design, water resources and environmental engineering, materials engineering, surveying, and highway and transportation engineering. Some universities may include further categories such as construction engineering and management and municipal engineering. Each category can be further divided into subtopics. For example, highway and transportation engineering can be divided into subtopics such as pavement design, traffic engineering, and transportation planning.

Although civil engineering undergraduate programs contain diverse areas of knowledge, they all follow the general theme of bringing a civil engineering project through the stages of planning, design, and construction. The plan-design-construct theme is so highly integrated into the traditions of civil engineering education that it is the motto of the civil engineering national honorary society, Chi Epsilon. Chi Epsilon retains the motto of Chi Delta Chi, which stands for conception-design-construction.

The opportunity for engineers in DOTs to participate in the planning, design, and construction of new highways has diminished. The last major highway construction initiative, the Interstate highway system, is virtually finished. In the summer of 1989, the Federal Highway Administration reported that roughly 99 percent of the planned Interstate system had been completed. Of the remainder, 60 percent was under construction and 20 percent was under various stages of preconstruction (*2*).

Aside from a few, and quite remarkable, examples of private-public partnerships and toll-financed facilities, it appears that, in the foreseeable future, no significant national highway building projects will be initiated. As John Hassett, the former Executive Director of the International Bridge, Tunnel and Turnpike Association, stated while reflecting on the end of the Interstate system's construction, "Any future program will be far less dramatic and inspirational; . . . it will be more in the nature of a shoring-up, fix-it-here, fix-it-there type of plan" (*3*).

Furthermore, the financial resources necessary for DOTs to initiate all but a few stopgap construction programs are unavailable. The American Association of State Highway and Transportation Officials has projected that current annual funding levels for highways, at all levels of government, are roughly $14 billion below the expenditures needed simply to maintain highways in their current condition (*4*).

To reduce the gap between financial resources and needs, 47 states (all except Alaska, Georgia, and New York) raised gasoline taxes during the 1980s, and the federal government increased the federal gasoline tax by 5 cents/gal in the Surface Transportation Act of 1982 (*5*). Unfortunately, revenue increases have barely kept pace with inflation. For example, in dollars adjusted for inflation (1984 dollars), the federal government invested $11,112 million in highway-related

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expenditures in 1980 and $11,746 million in 1988 (5). Clearly, the gap between the funding needed to maintain highways in their existing condition and the funding available is widening, making it imprudent to even suggest significant additional highway construction.

In addition to current problems, the specter of growing needs and declining revenue sources looms. Vehicle miles traveled are likely to double in the next 30 years, whereas gasoline taxes (in absolute dollars per mile traveled) are likely to decline because of improved fuel economy (6). Truck traffic, measured in ton-miles, increased at a rate of almost 2.7 percent/year during the 1980s and is likely to continue to increase (7). Furthermore, the American Trucking Association predicts that another 50 billion ton-mi of freight traffic will be carried by trucks and diverted from the rail system if proposals for a national long-combination-vehicle network are adopted (8). All the likely traffic trends paint an even bleaker picture of the ability of available financial resources to meet needs.

The dreary outlook leads to the conclusion that significant new highway construction is unlikely and that DOTs are apt to be preoccupied with stretching their resources to provide for maintenance and restoration. Engineers entering DOTs are more likely to be charged with better managing current activities and more efficiently allocating available resources than with planning, designing, and constructing new facilities. Larson and Haack defined the "shift from transportation system development to transportation system management" as a megatrend that changes the skills that future transportation professionals will need (9). Furthermore, because of public infrastructure funding shortfalls in general, more civil engineers in all subdisciplines (i.e., environmental engineering, structural engineering, geotechnical engineering, etc.) are likely to become increasingly involved in infrastructure maintenance and maintenance management.

CIVIL ENGINEERING CURRICULA CONTENT

Engineering educators recognize the importance of monitoring and adjusting the content of the civil engineering curriculum as needs change. However, a change of emphasis in one area must be continuously balanced by an equally great need in other areas. For example, in the environmental engineering area, an argument could be made to expand curricula beyond traditional water and wastewater treatment to more diverse areas of air pollution, hazardous waste management, and occupational health and safety. Arguments that civil engineers would be well served by more preparation in planning issues, including public administration, law, finance, and economics, have also been made (10).

In considering the arguments, the university must develop a program that meets minimum standards established by the Accreditation Board for Engineering and Technology (ABET) but is not so high in credit hours that the engineering program cannot attract students (11). Several undergraduate programs were reviewed to assess the current position of engineering curricula in providing students with the skills needed to manage maintenance.

The university catalogs of the 20 largest civil engineering programs in the United States, on the basis of total undergraduate and graduate degrees granted, were surveyed for content appropriate to enter the maintenance engineering profession. Table 1 gives the programs surveyed, the number of graduates in 1987–1988, and the credit hours required for the B.S. degree in civil engineering.

TABLE 1 SAMPLE OF CIVIL ENGINEERING PROGRAMS IN THE UNITED STATES, 1987–1988[a]

University	BS Degrees	MS&PhDs Degrees	BS Credits Required
Colorado State Univ.	72	70	130.0s
Georgia Inst. of Tech.	88	56	206.0q
Iowa State University	107	23	133.5s*
Mass. Inst. of Tech.	34	101	133.0s
N. Jersey Inst. of Tech.	57	66	136.0s
No. Carolina St. Univ.	170	42	138.0s
Penn State University	124	34	132.0s
Purdue University	115	101	131.0s
Stanford University	33	111	180.0q
Texas A&M Univ.	209	64	136.0s
Univ. of Cal.-Berkeley	68	204	120.0s
Univ. of Colorado	90	66	128.0s
University of Florida	83	59	143.0s
Univ. of Illinois	98	94	129.0s
Univ. of Maryland	74	58	132.0s
Univ. of Missouri-Rolla	97	29	139.0s
Univ. of Texas-Austin	72	90	131.0s
Univ. of Washington	106	68	183.0q
Univ. of Wisc-Madison	90	48	135.0s
Virginia Poly. Inst.	146	80	136.0s

s=semester credits; q=quarter credits
* estimated equivalent semester credits
a Source: Degree data are from the March, 1989 issue of Engineering Education

There is a significant range in the number of credits required for a B.S. degree in civil engineering. On the basis of equivalent semester credits, the largest credit program is approximately 20 percent greater than the smallest. The curriculum of each school's civil engineering program is examined to determine how it meets accreditation requirements and whether additional credits have provided an opportunity for a student to prepare for a career in maintenance and operations when compared with programs requiring fewer credits.

ABET does not specify the number of credits necessary in a basic B.S. program, but it does specify a breakdown of 3 years of study in areas including mathematics and basic sciences (1 year), engineering sciences (1 year), engineering design (½ year), and humanities and social sciences (½ year). Programs having more than 128 semester credits may consider 16 credits to be ½ year. In addition to these defined areas, universities must demonstrate that students have developed competency in written and oral communications and an understanding of the ethical, social, economic, and safety considerations in engineering practice. The latter requirements may be met by formal course work or, as a minimum, by the faculty including these concepts in regular course work.

Courses from the university programs were reviewed to determine how the credits are divided among the ABET categories and to assess the availability of courses that would allow the student to develop skills in economics, systems analysis, management, or maintenance engineering that would be needed in infrastructure maintenance programs.

Table 2 shows the distribution of credits among the major ABET subareas. Because engineering science and engineering design are difficult to separate in many engineering courses on the basis of the catalog description, these courses could not be specifically identified, and only a range of credit hours is listed. However, it must be recognized that the ABET reviewers examine the entire course content and student transcripts to ensure that minimum requirements are met. A communications section is also shown in the table, even though this is an area for which ABET has a content requirement but no specific credit requirement. As indicated in the table, communication skills in English and technical areas have been combined.

Table 3 shows the breakdown of the curricula credits that are either technical electives, usually from a defined subset of courses, or free electives. Wide ranges occur, which result

TABLE 2 CREDITS BY TOPICAL AREA GROUPING

Humanities & Social Sciences: (ABET requires one-half year or a minimum of 16 semester credits)

16 credits - 4 programs
17 credits - 1 program
18 credits -10 programs
19 credits - 0 programs
20 credits - 1 program
20+ credits -4 programs

Mathematics and Basic Sciences: (ABET requires one year or a minimum of 32 semester credits)

32 credits - 9 programs
33-36 credits - 3 programs
37-39 credits - 5 programs
40+ credits - 3 programs

Engineering Sciences: (ABET requires one year or a minimum of 32 semester credits)

Range is from 10 credits plus portions of shared courses to 32+ credits plus portions of shared courses.

Engineering Design (ABET requires one-half year or a minimum of 16 semester credits)

Range is from 4 credits + portions of shared courses & electives to 16+ credits plus portions of shared courses

Communications: (writing, speech, graphics, presentation seminars)

None required - 2 programs
3 credits - 2 programs
4 to 6 credits - 2 programs
7 to 9 credits - 7 programs
10+ credits - 7 programs

ABET criteria are from 57th Annual Report of the Accreditation Board for Engineering and Technology

TABLE 3 PORTION OF B.S. CIVIL ENGINEERING CURRICULUM AVAILABLE IN TECHNICAL ELECTIVES

Elective technical credits		% of total credits
6 or less	-3 programs	3
7 to 12	-5 programs	9
13 to 18	-3 programs	12
19 to 24	-6 programs	15
25 or more	-3 programs	25

from the philosophy of the departments. Some programs require only introductory courses in two or three of the traditional areas of civil engineering, whereas others may specify at least two courses in each major area of the department.

It should not be assumed that a higher percentage of electives indicates a more flexible program. For example, one school in the group with 19 to 24 credits for electives restricts the choices to a small number of courses, all of which are in the traditional analysis or design categories.

A variety of courses that would be especially useful to a maintenance engineering professional were identified. They include courses in traditional areas such as transportation engineering and pavement design, but also include engineering economy, statistics with decision theory, systems analysis and optimization concepts, construction and management, and maintenance engineering. Table 4 summarizes the availability of these courses.

Four universities do not require any transportation engineering courses, but three of them provide an elective that gives the potential to take one or several transportation courses. A majority of universities also require a basic course in engineering economics. Offerings in the other areas are much more limited. Both undergraduate and graduate courses open to undergraduates are shown, even though some undergraduates may not be eligible because of university policy. Courses in highway engineering and pavement design were identified here even if only a small portion deals with restoration or rehabilitation of infrastructure. As can be seen, only two universities offered a course that emphasized maintenance or management of pavements.

RECOMMENDATIONS

Faculty background and capability may be one of the constraints on the breadth of educational opportunity available for persons interested in highway maintenance engineering. ASCE has changed ABET accreditation criteria for civil engineering programs from requiring that a faculty have persons qualified in at least three specialty areas (subdisciplines) to requiring four specialty areas. Unfortunately, ASCE has not yet defined which civil engineering subdisciplines must be represented. Recognition of the importance of transportation maintenance and operations could be stimulated if AASHTO and TRB cooperate with ASCE to create a subdiscipline list that includes those topics.

As a related matter, the civil engineering programs may examine their content with a view to incorporation of infrastructure rehabilitation in much the same way as an ABET engineering design requirement. A course in the senior year that (*a*) analyzes existing facility quality, reliability, and the economic aspects of various stages of maintenance compared with new facility design and (*b*) develops a maintenance management system would have as much educational value as a design course in a single structural, pavement, or highway design project.

TABLE 4 HIGHWAY MAINTENANCE-RELATED COURSES IN CIVIL ENGINEERING CURRICULA

Subject Area	Number of programs with at least one course: Required	Elective
Transportation	16	3
Engineering Economics	14	3
Systems Analysis	6	8
Statistics	10	(a)
Highway Engineering	-	12
Pavement Design (with limited maintenance)	-	8
Construction and management	(b)	15
Maintenance Engineering	-	2

(a) Statistics courses may be available as electives through other departments

(b) Required courses with CPM or similar emphasis are not shown.

In summary, it is clear that young engineers are not likely to have the same opportunities as prior generations of civil engineers to participate in the planning, design, and construction of new facilities. The shift from system development to system management represents a significant change in direction for the profession. Analysis of curricula at U.S. universities with the largest number of civil engineering graduates suggests that, in general, existing programs lack the breadth and flexibility to develop knowledge in areas that are especially useful to a maintenance engineering professional. Therefore, the academic community is likely to be better able to meet the skill requirements of future civil engineers by amending curricula to include more maintenance management content.

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Abridgment

Innovative Strategies for Upgrading Personnel in State Transportation Departments

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The most crucial problem facing departments of transportation in the next decade will be the shortage of professional employees to create and maintain roadways. Between now and 2000, the work force will grow more slowly, the number of new workers entering the labor force will decline, and the fastest-growing job market will be in professional, technical, and sales fields, which also require the highest educational and skills levels. The challenge to meet staffing needs is compounded by high turnover at senior levels anticipated by state departments of transportation and the fierce competition for entry-level professionals. To explore this human resource situation, AASHTO and FHWA sponsored a study that addressed the shortages and the strategies employed by state departments of transportation to cope with or prevent shortages. An overview of the results of the study and the related activities being undertaken by the Texas State Department of Highways and Public Transportation is presented. Among the strategies the responding states reported are broadening the mix of in-house technical skills; consistent upgrading of skills and knowledge, especially in computer technology; and the development of professional engineers and managers to fill the leadership void. Implementation of the strategies involves recruitment, training, and management development techniques that offer long- and short-term solutions. A common thread running through the survey responses from all states was the priority placed on creating a positive work environment—one born of the knowledge that human resources are both the present and the future of transportation.

More than ever, it is time to look toward the future—the end of this century and beyond. Across the nation, departments of transportation are facing a new decade and new demands. The most crucial demand is focused not on the roadways themselves, but on the engineers and personnel who work to create and maintain them.

Almost all states have predicted shortages of professional employees in their highway departments. Among the reasons are the high rate of retirement, the changing emphasis and growth of programs in the departments, and a shrinking supply of civil engineering graduates. These factors combine to create two challenges for all departments of transportation: to upgrade their existing professional personnel and to attract what new engineers are available. However, the challenges are not mutually exclusive. If training is increased, benefit programs are improved, and incentives for existing engineering personnel are built, not only will those engineers be upgraded and retained, but also working for the highway departments will be made more attractive to new engineering graduates.

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To explore this human resource situation, a study was sponsored by AASHTO and FHWA and conducted in the National Cooperative Highway Research Program. Using a mail-out survey sent to all departments of transportation in the United States and Canada, the study addressed the problems of existing or predicted shortages of qualified professional, technical, and managerial personnel, as well as strategies for coping with or preventing the shortages from occurring. The questions were designed to explore existing public-sector recruitment, training, and management development techniques and to identify innovative techniques employed by particular state departments of transportation. The results of the survey were summarized in *NCHRP Synthesis of Highway Practice 163* (*1*). An overview of the results of the study are presented.

Between now and 2000, the following trends are forecast: the work force will grow more slowly than at any time since the 1930s, the number of new workers entering the labor force will decline, and the fastest-growing job market will be in professional, technical, and sales fields, which also require the highest educational and skills levels. For state departments of transportation in particular, the trends are accentuated by the high turnover rate. For example, up to one-third of all transportation engineers will retire by 1995. Whether the retirements are due to aging, personal financial considerations, or service completed, the high turnover at the senior level creates a leadership vacuum. The vacuum is critical. The pool of experienced professionals to fill the positions vacated above them is shallow. These changes in the departments, combined with the fierce competition for entry-level professionals, create the challenge: to recruit and retain qualified engineering professionals. In response to the challenge, government agencies in general need to invest heavily in the continuing development of their personnel.

Several strategies were identified in the study. First, many agencies' efforts have, with time, shifted from traditional highway construction to rehabilitation, repair of bridges and structures, and a serious commitment to preventive maintenance. Therefore, the mix of in-house technical skills must be broadened to meet the change in focus. Second, advanced technology, especially in computers, requires the consistent upgrading of skills and knowledge to address and fully utilize that state-of-the-art technology. Third, the leadership vacuum mentioned earlier requires the development of professional engineers and managers to fill the vacancies at the top.

State departments of transportation must identify recruitment, training, and management development techniques that offer long- and short-term solutions. Human resources forecasting and planning is one area that offers solutions. Research activities in this area allow management to get the information necessary to formulate and implement effective policies and programs to better prepare for future needs.

In their recruitment programs, it is essential that public agencies offer competitive salaries and benefits throughout their job series and grade structures. If government agencies can combine positive recruitment strategies with increased supervisory discretion during the hiring process, they can begin to overcome some of the traditional handicaps in competing with the private sector.

Training is another area that can yield solutions to the human resource problem. Training of all kinds is recognized to be a necessary investment in the human resource base of organizations. Employee orientation programs; technical training for both new and established employees; and supervisory, management, and executive development training are all efforts that can keep existing personnel fully trained. Besides maintaining their productivity for jobs in which they now serve, the programs also prepare them for jobs in the future. For example, management training and development at the middle level can help prepare individuals of the organization to "step up" into positions that open above them, filling the leadership vacuum.

Human resource management has become increasingly performance oriented. Merit pay plans, performance appraisals, and decentralization of personnel policy for increased adaptability to current demands are but three strategies that, if implemented, can foster better productivity and loyalty.

In fact, many departments of transportation have begun to recognize the importance of people as their most important resource and have begun to revise their organizations, cultures, and training accordingly. A thread running through all the responding states' programs was the priority placed on creating a positive work environment. A second thread is the changing approach to training. Classes, instead of being geared to only one or two positions, are being broadened to include more employees and to encourage them to attend training programs and develop skills outside their present job. Both factors enhance long-term careers in state departments of transportation.

Texas is taking a more developmental approach to performance management. For many years, management by objective (MBO) has been its main management tool. To adapt to the new emphasis on training and on identifying training needs, the MBO was revised to include a more detailed performance appraisal system. The new performance planning and evaluation form involves both supervisor and employee in the setting of job responsibility, training objectives, task design, and career development plans. Although it is too early for hard conclusions, signs indicate that the new form increases communication between management and employees, which is leading to more effective and creative development of the staff. The *Supervisors Handbook* sums it up: "Supervisors are responsible for the effective use of resources, and our people are our most important resource. Thus, performance planning and evaluation is the most important job of the supervisor."

Technical training is another area in which improved strategies can lead to reduced human resource shortages. The trend is toward a recognition of the need to develop integrated training systems and facilities that allow departments of transportation to meet existing skills requirements across functional activities while anticipating future needs. Technical training requires attention to the qualifications, training needs, and opportunities of all employees. Most organizations, therefore, have established technical training planning, delivery, and evaluation systems as elements of their overall human resources management strategies. Ongoing technical training and associated support systems are being recognized as rational investments in the future of all departments of transportation. The expanded use of programmed instruction; interactive computer-based learning technology; in-house training video production; and cooperative training ventures with other state and local agencies, community colleges, and the like are only a few of the ways in which technical training is being developed and utilized as an upgrading tool.

Texas has responded well to the increased need for technical training. In 1981, the Personnel Division changed into the Human Resources Division. It started with a staff of 3 located in the main office and has since grown to a staff of more than 37 with a separate training facility.

Training is not the only area that is growing and developing to meet the human resources challenge. Because of the higher-than-normal retirement rate experienced by and predicted for many departments of transportation, and the ensuing vacancies, many organizations are emphasizing management development programs intended primarily to aid professional engineers in acquiring managerial and supervisory skills. Although highly qualified in their areas of expertise, engineers cannot be expected to be effective in managerial roles without the necessary mix of experience and training in such areas as leadership, decision making, communication, supervision, and administration of personnel procedures. Programs are being developed in many states to provide such training.

Management courses in Texas use an adjunct instructor system to provide students with instructors who have hands-on experience in the specific areas in which they teach. Qualified and experienced individuals in each management area are chosen from the ranks of the department and taken through a train-the-trainer program. The instructors then prepare their own course outlines and materials and teach for 18 months. The system has been found to be effective in the 4 years since its inception. Because of their field experience, the instructors have credibility, and many useful and practical management skills have been taught and learned.

A second area of management development is executive development. To prepare mid-level managers for vacated positions involving executive responsibilities, several states have implemented programs designed to accelerate the acquisition of the administrative skills, knowledge, and abilities required of executive-level personnel.

By now, it should be clear that on the whole, departments of transportation are restructuring and reorganizing training with people in mind, because employees are their most important resource. With that realization has come a new emphasis on career development. Internship and traineeship programs have been designed in several states to accelerate familiarization with the functions, technical activities, and managerial responsibilities inherent in departments of transportation. Internships allow low-cost access to useful skills and are an effective recruiting tool. Traineeships, on the other hand, involve planned rotation of duty assignments of current employees, which broadens their skills base and enhances their career development. Both types of programs are beneficial, because they provide necessary training yet allow each employee to be productive.

State departments of transportation are also recognizing that the development of their human resources cannot be left to the voluntary and largely individual efforts of their employees. The old approach was to neglect the career concept in favor of a position-oriented approach. That approach is being replaced by the concept of a series of career ladders leading from entry-level positions to middle- and higher-level technical and managerial responsibilities. Therefore, programs utilizing career counseling sessions, new employee orientation, formal and informal training, and quality circles (among other things) are being initiated to encourage employees not only to be effective at their current positions but also to think and plan ahead for skills at other levels and areas of interest.

Job rotation and cross training are two of the final areas of growth in response to predicted shortages. Job rotation is primarily used to familiarize personnel with mainline organizational functions and activities. The experience will help the employees make informed long-term career plans.

Cross training is used to provide the agency with technical personnel who can work in a variety of activities. It improves the agency's ability to shift its task and goal structures without disruptive turnover or performance "lags" while the agency restaffs to handle new challenges. The adjunct instructor program in Texas mentioned earlier is one example of effective cross training.

Effective training, innovative recruiting, forecasting and planning, and management development strategies—these are the areas covered in the study and this overview. They are more than buzzwords; they are the law if state departments of transportation are to meet the challenges of the coming years. The challenges come not only from the government or the people; they come from within. Work forces must be upgraded and human resources developed, because they are not only the future, they are the present as well.

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