Framework for Municipal Maintenance Management Systems

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Since the 1960s pavement engineers have been working on developing pavement management systems (PMSs). Any PMS includes several major activities such as planning, budgeting, construction, maintenance, and rehabilitation. To date experience has indicated that the system could be successful from a technical standpoint even if it is unsuccessful in the implementation process. Numerous techniques have been proposed and evaluated, but none has proved to be very effective. Agencies vary in their usage of maintenance management systems (MMSs), from not adopting a program to employing sophisticated techniques. The focus is on MMSs for cities. There is a significant difference between urban and rural highway networks. In cities several groups share the streets and the roads. Moreover the provision of an effective communication and coordination system among related groups has a great influence on the success of the MMS. The authorities that should be considered in the MMS include gas, water, telephone, electricity, sewer, and storm authorities as well as traffic departments. A framework for municipal MMSs was developed, with an emphasis on two points: (a) integration of a city's MMS with other related authorities provides better implementation, and (b) communication among related groups has a significant role in the success of any MMS. The conclusion reflects the importance of the communication channels to MMSs and the reliability of using the subsystems technique in integrating the municipality's MMS with other related authorities.

At present there is no universally acceptable definition of a maintenance management system (MMS). However the MMS can be viewed as the technique of optimizing the available resources to accomplish a predetermined minimum level of service by coordinating and controlling applications of planning, budgeting, scheduling, and evaluation. The MMS in broad terms is part of a pavement management system (PMS) that includes the following five major activities: planning, design, construction, maintenance, and pavement rehabilitation. City pavements require maintenance because of the impact from traffic, cuts in the roadway by utilities (utility cuts), and climatic conditions. Well-planned maintenance and rehabilitation slow the rate at which a pavement deteriorates. PMSs have not received the same desired research as the design and construction of new pavements. During the last several decades the focus of pavement engineers has changed from new construction aspects to pavement management development. This shift has occurred because pavements constructed before 1970 are approaching the end of their design lives (*1*). Therefore the use of maintenance and rehabilitation systems has increased significantly among road agencies.

With time maintenance issues have become top priorities in most countries because of the natural process of deterioration of national road networks. Many of these major pavement networks are approaching the end of their design lives, and the budgets for these networks are less than what they were in the past. Moreover continuous construction of many new roads and highways increases the need for MMSs. In many cases road maintenance is so inadequate that even newly constructed roads are deteriorating faster than normally expected (*1*).

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City road networks have a greater need for MMSs than rural road networks because city roads are exposed to more deterioration factors. Cities have experienced greater increases in the volume of utility cuts that cause noticeable deterioration to existing asphalt pavements. Because of utility network expansion and the need to maintain existing lines, utility cuts occur even on newly constructed pavements. Patching these trenches has resulted in a noticeable decline in both riding quality and the structural integrity of these pavements. Utility cuts in cities include those for electricity, water, storm, sewage, gas, and telephone systems. Trench depths and widths vary within each utility type as well as among the various utility types (*2*).

STUDY SCOPE AND OBJECTIVES

The MMS provides reliable information that agencies can use to develop a budget and to produce maintenance and rehabilitation schedules. When the MMS is absent the budget and activity schedules are based on on-site inspections. This approach results in subjective decisions that are generally influenced by the previous year's experience.

NCHRP Synthesis of Highway Practice 110 (*3*) has shown that the MMS has been used for pavements for approximately 40 years in the United States and has often been considered a good technique for optimizing resources and planning schedules. The most common problem associated with MMSs is that the MMS experience has indicated that the system can be successful from a technical standpoint but perhaps unsuccessful in terms of implementation. Numerous techniques have been proposed and evaluated, but none has proved to be very effective. Agencies vary in their usage of MMSs, from not adopting a program to employing sophisticated techniques. Between these two extremes some agencies are in the process of developing an MMS. Pavement evaluation is generally determined by some rating procedures, which consider surface distress, roughness, skid resistance, and structural capacity. The purpose of this paper is to develop a framework for a municipal MMS. The following points are suggested to be part of the development of an MMS:

1. Integration of a municipal MMS with other related authorities as subsystems would provide a means for the better implementation of an MMS. The subsystems include traffic departments as well as water, power, gas, and telephone authorities. Utility cuts in pavements account for the greatest amount of pavement distress

in most cities. The PMS is managed by pavement engineers, traffic systems are controlled by traffic engineers, and the MMS is controlled by maintenance engineers. Utility systems are handled by the utilities' technicians and engineers. The integration of these groups as subsystems within the MMS is an essential factor for a successful municipal MMS.

2. The implementation of an effective PMS within any agency requires effective internal communication and cooperation. Communication among related groups has a significant role in the success of any MMS.

GAPS IN CURRENT KNOWLEDGE

The optimization concept of most MMSs needs to be integrated with utility works and management systems that include water, gas, electricity, sewage, storm, and telephone systems. These systems usually include some sort of maintenance management or data base system that can be linked to the master data base of the MMS.

At the network level an optimization methodology needs to be developed by comparing repair alternatives for each project with other project alternatives. This methodology should consider the effects of alternatives on a project and the impacts of possible alternatives on the network.

Sampling systems for pavement evaluation vary in the number of samples per unit length. This technique is effective for rural highways where there are no utility cuts and the serviceability and structural deterioration are distributed uniformly along the pavement. However city or urban roads are exposed to utility cuts that create significant condition variations within the same road. This situation requires a new sampling technique to give a representative road evaluation. The technique considers the deterioration caused by utility cuts and reports related utility information that could help to justify and simplify coordination with utility authorities.

Although most of the MMSs have been developed adequately in terms of technical aspects, there are several problems associated with implementation phases that need to be characterized and resolved to improve the efficiency and effectiveness of the MMSs. Pavement engineers should differentiate between a municipal MMS and a rural MMS by considering the administrative problems. These problems involve the fact that several groups share road works and that there are technical problems associated with utility cuts. Generally the effects of utility cuts on pavement life and pavement restoration standards should be incorporated into the MMS evaluation and prediction models.

In examining the pavement cost impact of utility cut restorations, Emery and Johnston (*4*) found that there were many investigations that indicated the negative impacts of utility cuts. All of the studies in this area indicated that the impact of utility cuts significantly reduces the functional life of the pavement. Anani and Al-Swailmi (*2*) found that there is a significant difference between the deflection readings obtained with a falling weight deflectometer (FWD) meter for patched and unpatched pavements (i.e., 80 and 40 for patched and unpatched pavements, respectively). Figure 1 illustrates the deflection profiles obtained from one street tested in that study. The tests were performed with a constant loading of 4000 kg (9,000 lbf). One profile represents the FWD readings from inside the utility-patched trench, and the other profile represents the unpaved part of the pavement 1 m (3 ft) from the trench edge. The significant increase in deflection readings for the utility-patched pavement verifies that the patched section is significantly weaker than the unpatched part of the pavement. Some other studies have claimed that the utility impact accounts for up to two-thirds of the service life (*4*). Shahine and Crovetti (*5*) have shown that patching of utility cuts has a significant effect on both pavement performance and load-carrying capacity. They have shown that the effect is more severe for pavements that are patched while they are in good to excellent overall condition. Heavy traffic accelerates the deterioration process because of weakened support around the patched section and the pavement edges. Figure 2 (*6*) shows the general deterioration trends of pavements as a result of the impact of traffic, time, and other factors such as utility cuts. Any delay in timely and proper maintenance results in greater costs. Those costs include the repair cost and added user operating costs from low serviceability and interest rates on money.

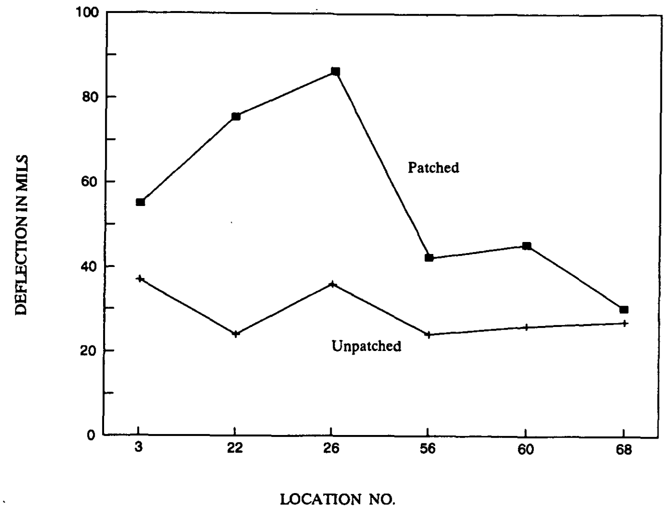

FIGURE 1 Maximum deflection comparison between patched and unpatched pavements (1 mil = 0.001 in.) (*2*).

COMPARISON BETWEEN MUNICIPAL AND RURAL MMSs

There are significant differences between urban and rural roads. Beneath city roads a tremendous number of utility lines run parallel to and cross the roads. The only means of access to construct and maintain these utility lines is to dig up the road pavement. Among the problems associated with utility repairs are the achievement of an adequate backfill compaction and the provision of a smooth finished surface on the asphalt patch. As a result of this situation urban roads experience a significant deterioration rate. Therefore the development of an MMS for urban roads is more complicated than the development of one for rural roads. To develop an effective MMS for a city, all related technical, political, and administrative factors must be considered. Considerations should include the utilities embedded in the pavement layers such as sanitary manholes, inspection chambers, drainage catch basins, and all of the utility lines beneath the pavement layer such as water and storm, telephone, electric power, and gas lines. Figure

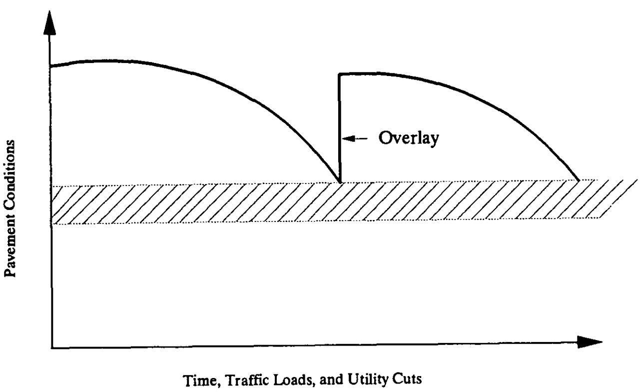

FIGURE 2 Effect of maintenance on pavement performance (*6*).

3 compares typical rural road and municipal road cross sections with utility lines. Each utility line is associated with a unique method of construction in terms of backfill, utility protection, space from adjacent utilities, and depth from the pavement surface. For example a telephone cable should not be closer than a certain distance from a high-voltage electric power cable. Main sewer and storm lines could be as deep as 9 m (30 ft), depending on the topography of the city, because flow is by gravity. Therefore a minimum slope should be maintained to provide an appropriate flow. These differences between urban and rural roads indicate the importance of developing an MMS to meet urban road requirements.

A patch is considered a defect regardless of its performance. A patched area or the area adjacent to the patch usually does not perform as well as the original pavement section. Most utility contractors are specialized in particular utility work but have limited experience in road construction. This results in pavement patches with poor structural and serviceability conditions. Since utility cuts are increasing because of rising utility maintenance, it is necessary to develop a performance impact methodology within the MMS for municipal roads and streets. The effect of asphalt patching on the quality of highways is recognized by the AASHTO *Maintenance Manual* (*7*).

DEVELOPING A NEW SYSTEM

Because of the possible interactions in an urban MMS, it is necessary to develop an MMS with appropriate mechanisms for handling utility maintenance activities. The objective of this technique is to link utility subsystems with the MMS to make an effective MMS by eliminating conflicts associated with utility activities. Therefore the development of an MMS for municipal roads and streets is associated with special conditions that result from the interactions of utility activities. The system should include the

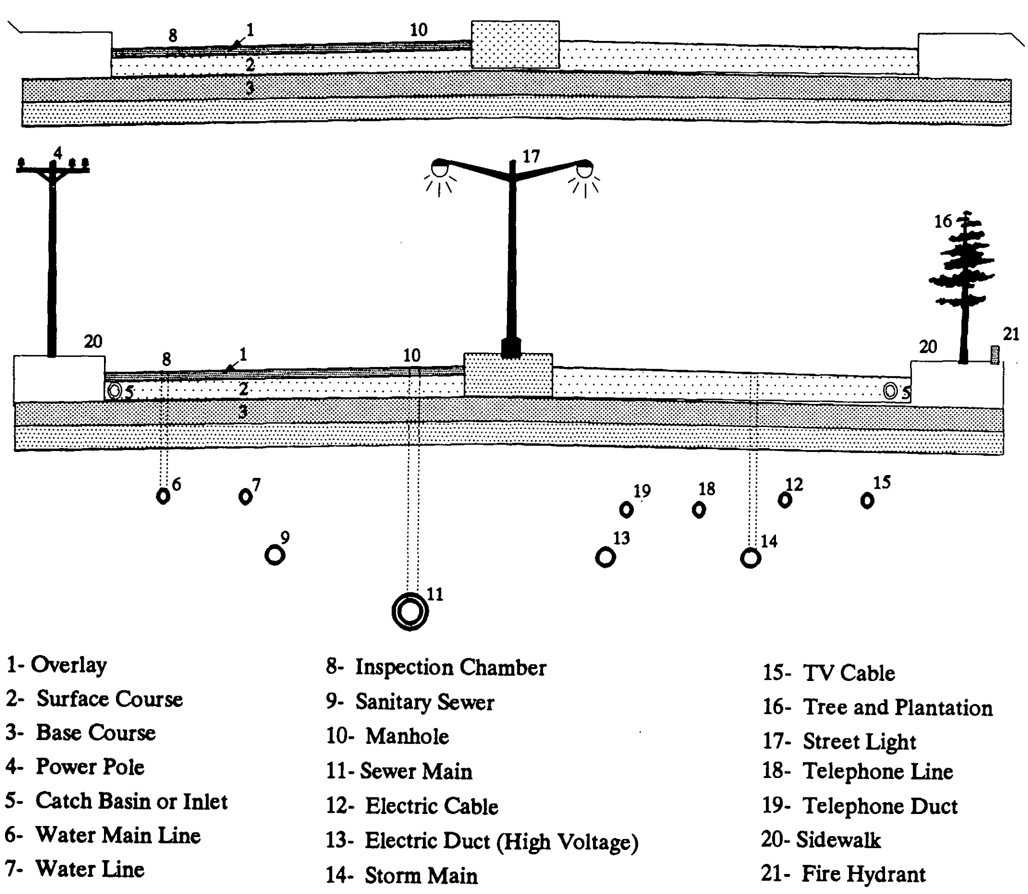

FIGURE 3 Comparison between rural (*top*) and urban (*bottom*) road cross sections.

proper information management system. The data should be sorted according to several categories (i.e., utility type, stress type, severity level, etc.). Occasionally the required data have been gathered and stored previously, but the main problem remains: where and in what format will it be used?

The *NCHRP Synthesis of Highway Practice 135* (*8*) discussed the development and implementation of a PMS. Before an MMS is developed, four preliminary tasks must be accomplished. Figure 4 shows a recommended sequence for those tasks.

INTEGRATING THE CITY'S SUBSYSTEM WITH AN MMS

This section gives a general overview of each external agency, known as a subsystem, that has some activity on the roads and streets of a city. This overview will help to emphasize the role of each subsystem in the MMS. It is always a difficult task to coordinate pavement maintenance activities with utility maintenance activities. Moreover there are coordination problems among the utility agencies as well. Although coordination with these utility agencies is often a very complicated procedure, it is an essential part of maintenance management activities. Therefore if maintenance work is to be accomplished efficiently the coordination problems associated with the external agencies must be overcome. Agencies may organize multiagency committees to provide better coordination for city maintenance activities (*9*). Every city has the major utilities that play a role in the study as subsystems within the city's system. These subsystems include water and storm, telephone, electric power, and gas networks as well as the traffic department. On the basis of city's size, cities vary in how many subsystems are included in the development of an MMS. These subsystems vary in their political organizations. Some of them are departments within the organization of the city, such as water and storm departments. Some of them are public agencies but not within the city organization, such as the department of transportation (DOT). The third type consists of private companies that are regulated by either the city or the state, such as electric power and telephone companies. Figure 5 shows a typical organizational structure for the subsystems. The variations among these agencies in terms of political aspects and technical interests make conflicts very likely. A brief description of each subsystem is discussed in the following sections.

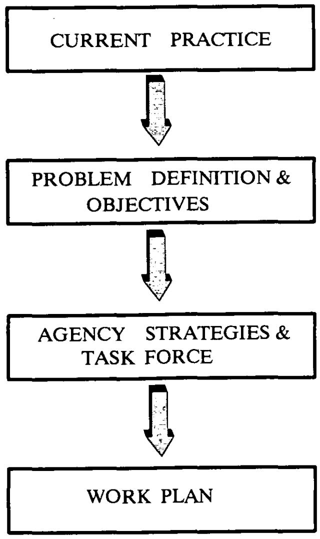

FIGURE 4 Basic tasks toward developing an MMS.

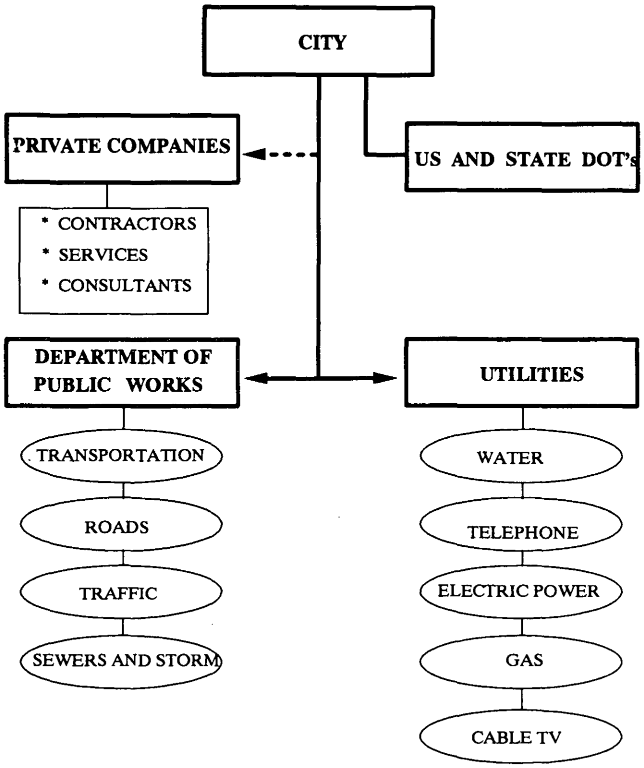

FIGURE 5 Typical organizational relationship for a city's subsystems.

Water Network Subsystem

Each street or road contains at least one if not two main and lateral water lines. By looking at the sizes of these water networks and the associated daily activities, one can realize the magnitude of the interaction with road maintenance and rehabilitation activities. Tremendous conflicts can result if this interaction is done with a lack of coordination.

Telephone Network Subsystem

The telephone network covers all streets and roads of the city. In some cities telephone contractors do all the work, including trench backfilling and asphalt patching. In such situations backfilling and asphalt patching are of the lowest quality because of the lack of experience and interest. This results in poor riding quality and continuous failures and settlements. Telephone cable work requires special techniques in terms of cable protection, cable joints, and other technical aspects. Therefore the construction crew is focusing primarily on their technical work with the telephone cable. Instead of hiring a pavement subcontractor for road works, utility contractors prefer to contract out the complete project because this saves them coordination time and markup differences. As a result some telephone contractors are licensed to do road construction in addition to their telephone work. Other telephone contractors have sister companies that are licensed to do road work. To overcome this problem the city should regulate the pavement-related activities done by companies that do telephone construction or maintenance work by requiring preapproval of pavement contractors on the basis of their license and experience. Alternatively the city can bid out road construction and telephone work as two projects, with each bid having its own requirements on the basis of the nature of the work.

Electric Power Network Subsystem

The electric power network is very similar to the telephone network in terms of its complexity. The electric power networks like telephone networks require contracting and construction supervision revisions. This is accomplished by modifying the contracting system and linking electrical construction and maintenance activities with the city's MMS.

Gas Network Subsystem

Although the gas network is not very extensive, it involves continuous activities because of new gas line construction and maintenance of the existing network. To achieve effective coordination and minimize conflicts, these activities must be linked with the city's MMS.

Cable Television Lines

The network of cable television lines contributes the least to conflicts because cable television lines make up the smallest network in the streets. This results in less maintenance activity. Cable television construction and maintenance activities, however, must also be incorporated into the MMS.

Traffic Control Subsystem

Traffic police departments play an important role in municipal MMSs. A number of states have issued written policies and procedures on lane closure and full road closure requirements (*9*). These policies are used to protect against conflicts between the routing of road traffic and maintenance activities. The use of lane closure requests is very effective in providing an organized procedure for pavement and utility companies to accomplish their planned and scheduled activities effectively. The lane closure request form should include information about the date and time of the closure, the name of the street, the duration and type of maintenance activity, and any other necessary information such as the name of the contractor or site engineer. Accident prevention and safety programs for maintenance activities should be considered a part of the lane closure request. The AASHTO *Maintenance Manual* (*7*) provides detailed information about the safety requirements that should be followed during maintenance work.

Sewer and Storm Catch Networks

Sewer and storm catch networks differ from other networks because of their large main lines. Any major maintenance activity with these main lines, such as relocation, replacement, or major repair, requires full closure of the road. In addition one of the major problems associated with sewer and storm catch networks is the difficulty of adjusting pavement service with sewer manholes and storm catch basins. Although these networks are not as big as telephone or water networks, they cover most of a city's road network.

FRAMEWORK FOR NEW MUNICIPAL MMS

As discussed earlier municipal road maintenance activities are combined with several coordination, administrative, and technical problems. These problems have been considered in developing a framework for a municipal MMS. Figure 6 shows the components of the recommended framework for a municipal MMS for urban roads and streets. These components are discussed in the following sections.

Inventory and Pavement Evaluation

An inventory of the roads and their structures should be established. The inventory should include all necessary data related to construction, materials, traffic, structural and serviceability con-

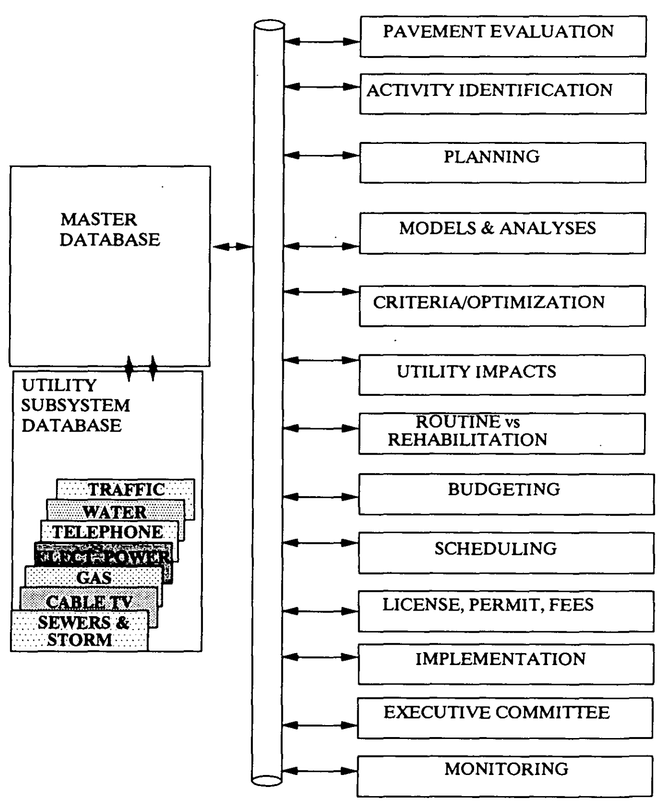

FIGURE 6 Framework for a municipal MMS.

ditions, and utility cuts. For accurate pavement evaluation periodic measurements and site tests of the structural and serviceability conditions of the pavement should be performed at certain distances. Utility cut information should be included in the inventory along with identification of the utility that made the cut.

Identification System (Coding System)

To make data manageable and accessible an identification system should be developed for the pavement evaluation, data collection, analysis, and reporting process. Since the main frame of the system is integrated with each utility agency (as shown in Figure 6) by the subsystem technique, a means of identifying each road distress is required. The identification system should indicate the location, distress severity, serviceability, and cause of the distress (utility cut or environment and traffic). The beginning and end of the section should be clearly defined. Therefore the network should be divided into blocks that are small enough so that they can be used to identify most of the utility repairs by location. At the same time to make data inventorying and information processing activities manageable, the block should not be too small. Figure 7 shows a recommended identification system. The original direction is from south to north and from east to west. Each street is divided longitudinally into stations, with a 15-m (50-ft) station length. Each street is divided into lanes, and each lane is divided into two halves, with right and left sides. This technique divides the paved area into rectangular units of 15 m (50 ft) in length by 1.2 m (4 ft) in width, which is half of the lane width. Parking and emergency lanes, sidewalks, and medians are identified by numbers, and their full widths are used. For each distress resulting from a utility repair the identification should include the utility type and contractor name, as shown in Figure 7. Although this identification technique seems complex, it will provide maintenance engineers with technical justifications for utility repairs and other information necessary for effective coordination. As a result the city will avoid paying for utility repairs that should be conducted by the utility agencies. At the same time the utility contractors will be more concerned about the quality of repaving the utility trenches, because they realize that they will be forced to redo their repairs if the quality of the patched area does not meet the minimum standard specifications. On the other hand different information is not always needed for each block on all roads. This means that the actual number of blocks in the network for which data entry is required is much less than the calculated number obtained by dividing a network area by the standard block area of 19 m^2 (200 ft^2). In other words for roads with similar conditions the computer program would have the capability (as a default setting) to enter their combined evaluations at once. This would be accomplished by entering the start and the end stations of a particular road instead of entering the stations block by block.

Planning

Planning involves an assessment of road performance on a networkwide basis. Generally the level of concern about the network exceeds the level of concern about individual projects. Planning involves the assessment of deficiencies in the network, the ranking of priorities, and the development of a schedule according to

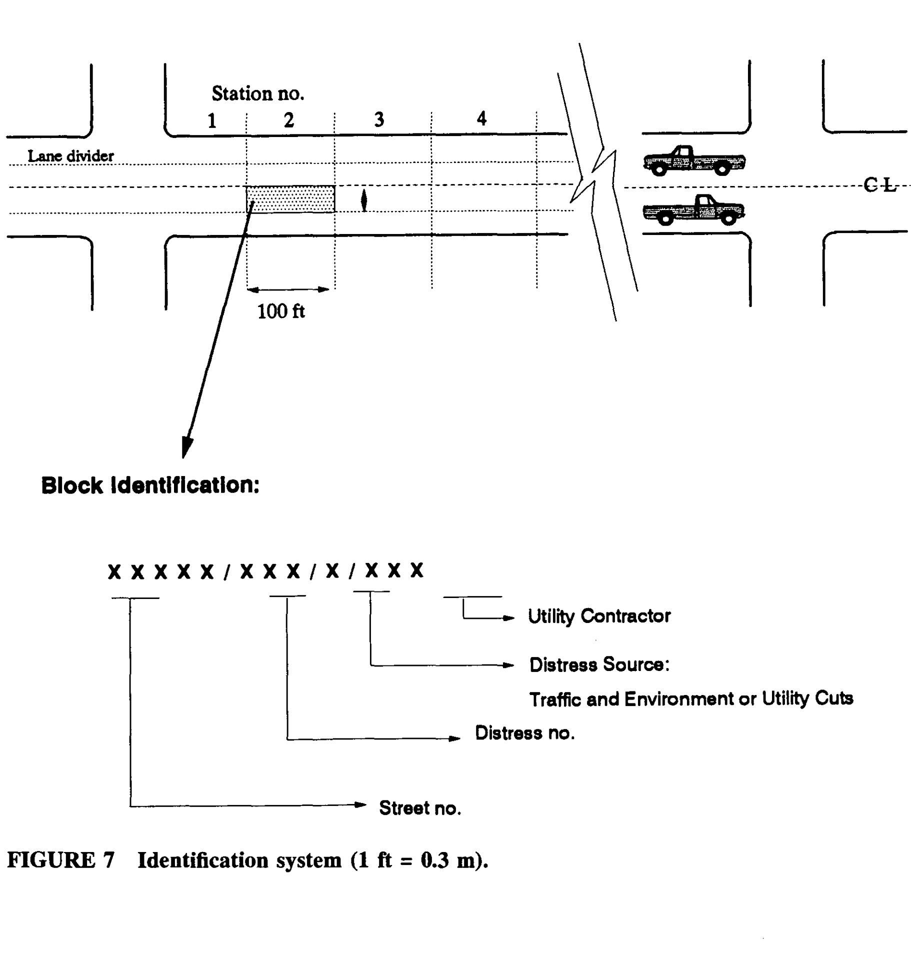

FIGURE 7 Identification system (1 ft = 0.3 m).

available budgets. If utility cuts or traffic loads increase or environmental conditions are extreme, the need for repairs occurs sooner than predicted. This indicates the importance of inspection frequency and interpretation by maintenance engineers.

Models and Analysis

Analyses should include a procedure for analyzing data over time to predict performance. The procedure should include a regression analysis to process repair alternatives and strategies in a format that addresses cost-effectiveness and prioritization in consideration of resource constraints.

Criteria and Optimization

The program establishes preventive maintenance and rehabilitation criteria. Criteria are based on structural and serviceability conditions. The pavement condition index (PCI) is recommended as an evaluation technique. PCI has been selected over other techniques because of its capability of balancing pavement evaluation between pavement serviceability and structural conditions. Criteria for rehabilitation is usually a PCI of between 55 and 70, and preventive maintenance takes place for pavements with PCIs of more than 60. The optimization procedure is based on the most cost-effective alternative.

Since the objective of this paper is to develop a mechanism to link utility agencies with the MMS, criteria and optimization are not discussed.

Impacts of Utilities

Various management systems that have the common objective of identifying the most cost-effective decision are used by utility agencies. Since the agencies share urban roads with municipalities, it is necessary to recognize the contributions (either positive or negative) of those agencies and integrate them into the MMS analysis process. The lack of recognition of the roles of utilities results in costly maintenance activities, plan conflicts, and controversial relationships among the involved agencies. In the absence of an MMS it is common for a utility company to dig a trench in a newly overlaid road because neither the utility nor the road agencies were aware of the others' schedules. The linking of utility agencies as subsystems in the MMS would result in a continuous interchange of information. Such awareness about utility schedules could generate rescheduling of rehabilitation activities to permit utility contractors to finish their repairs. Lack of an MMS results in confusion, contradiction, and poor construction quality.

Maintenance and Rehabilitation Alternatives

The MMS organizes road repairs on the basis of distress type and severity into either routine or rehabilitation repairs. The optimization procedure could change the types of repairs that are made. Because of funding constraints the road agency may be forced to substitute rehabilitation repairs, such as an overlay, by routine maintenance. The impacts of utilities on the MMS could lead to a delay in overlay activities because scheduled utility cuts must be done.

Budgeting

The development of maintenance budgets for a network should be based on the actual needs predicted from the MMS and previous experience. The budgeting process allows agencies to forecast major maintenance and rehabilitation requirements to maintain a particular condition level. The forecasting accuracy is highly dependent on the accuracy of the inputs. The inputs include pavement condition criteria, repair costs, and the expected present worth, which in turn depends on the inflation rate during the analysis period. By changing the rehabilitation criteria the budget forecast changes. Since the budget can be forecast for long-range rehabilitation it can also be estimated for current year maintenance as well.

Scheduling

Scheduling develops actual programs (schedules) for the maintenance and rehabilitation activities. Schedules are developed on the basis of budget constraints and the pavement evaluation process. Data processing models should be capable of predicting when a highway will require maintenance or rehabilitation. A certain level of variation between the actual and the predicted needs should generally be anticipated and adjusted. Maintenance engineers should reduce the effects of those variables that significantly influence long-term planning.

License and Fees

Because several parties are involved in municipal MMSs a license should be issued for each maintenance or rehabilitation activity. The license or permit will centralize the pavement repair process for either utilities or road agencies. At the same time the fees, if any, will be collected through the licensing process.

Implementation

Once the system has been developed to the level that it can be demonstrated, it is necessary to apply it to a pilot network. Such a demonstration project is important for refining the system and exposing any issues that have been overlooked. Through such a demonstration project the development engineers will be able to recognize areas where debugging is necessary or focus on areas for potential improvement. The task force will be more knowledgeable about the practicality of the system and will be receptive to the new format. The main objective of preliminary implementation is to investigate the adaptability of the new system to an actual layout.

At the completion of the trial application and after the final revision the system should be ready for full-scale implementation. The efforts of the technical and administrative teams should be organized to achieve a successful implementation. The implementation phase should be considered a training process for all personnel involved in the system.

Executive Committee

The support of top management is an essential factor for the MMS to remain effective. To maintain that support an executive committee representing all involved agencies should be established. After completing development of the system the task force members could become members of the executive committee. Such a committee would have a low-profile link to the system. The role of this committee is to maintain the communication channels that were established during the development process. This committee will resolve any conflicts between project groups. The committee should receive periodic reports about the activities of the previous period and the plans for the next period. These reports should include the problems associated with the previous period and the technical team's recommended solutions. The frequency of executive committee meetings depends on the size of the city and the necessity of their involvement in resolving conflicts.

Monitoring

Although monitoring is an easy task it is usually overlooked by most road agencies. The MMS is an ongoing development and updating process in terms of data and technology. The MMS team should monitor the efficiency of utilizing the system as it was planned. The monitoring of pavement performance should be a continuous process. This periodic monitoring includes determination of pavement characteristics such as structural capacity and serviceability conditions. Pavements on roads with normal conditions are commonly evaluated every 1 or 2 years. If a road is exposed to major utility cuts an updated evaluation is necessary regardless of the time since the last evaluation. The monitoring process should include an assessment of the reliability of the MMS and an evaluation of any deficiency associated with the system.

Master Data Base

The new MMS recommended here is associated with an increase in data sources because of the inclusion of utility agencies as subsystems within the master data base. With the increasing power of modern computers this will not be a computer processing problem as it was in past years. The cost of computers is rapidly declining. The equivalent hardware capabilities that cost $100 in 1960 would cost $10.74 in 1970 and $0.12 in 1990. At the same time software capabilities have been improved by about 60 percent (*10*). The difficult aspect is how to identify the data and analyze them while retaining the full identification code for each output report. The master data base includes the data along with a coding system that gives the system the ability to view reports for all of the involved agencies and groups. In addition to the typical analysis process the system can identify the responsibility of each utility agency and contractor in the maintenance and rehabilitation budgets. The subsystem technique links the inputs and outputs to the coding system, which results in a data base for each utility.

CONCLUSIONS

1. The development of related methodologic and analytical aspects has received most of the pavement engineers' attention, whereas system implementation requires more research and development.
2. Maintenance work activities on urban roads cause major traffic congestion and rerouting schedules. The nature of maintenance conditions therefore requires extensive planning and scheduling with the other groups that share the roads.
3. Conflicts between road and utility construction and maintenance activities result in a substantial dilution of resources and the diversion of capital from what should be the goal of the MMS. Municipal MMSs recognize the organizational and political problems associated with urban networks. The municipal MMS is a promising technique for protecting urban roads and provides reliable information and justification to show each group its rights and liabilities.
4. A municipal MMS will provide effective and efficient coordination, communication, and working environments instead of the fragmented situation that results when groups work independently.
5. A municipal MMS will provide a general concept of managing maintenance activities with a rational cost-effective approach. Because the groups that share urban roads are greater in number than the groups that share rural roads, this kind of technique has more operational potential for urban roads. This technique will assist all of the groups that share the road network in achieving their goals in a systematic manner.
6. Because of the urban environment, municipal MMSs require greater efforts and a larger budget than MMSs for rural roads.

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