Implementation of an Urban Pavement Management System

P.C. CURTAYNE AND T. SCULLION

The city of Johannesburg is nearing the end of the first stage in the implementation of a pavement management system. This work was centered on assisting the road authority in identifying roads that require resealing or overlays. It is based on a model that relates pavement condition to maintenance requirements and to the timing of future inspections. This system has already been used to good effect in preparing the maintenance program for 1981. This paper describes the nature and scope of the work in order to show what techniques have been found useful and what problems can be expected. An important feature of this system is its basic simplicity. It requires only the minimum amount of information, which is reasonably easy to collect. The favorable reaction by the staff to this innovation is discussed and special attention is focused on the threat that the introduction of more-mechanized methods of pavement assessment poses to the job satisfaction of road inspectors.

Over the past decade, considerable attention has been given to the development of pavement management systems. Yet the full-scale implementation of such systems is still in its infancy. In fact, in 1979 Finn (1) reported that no agency in the United States had yet implemented a pavement management system on a complete roadway network.

In South Africa, there is growing interest shown by both rural and urban authorities in developing a more formal approach to the management of their pavement networks. However, the Johannesburg City Engineer's Department is the only urban authority that has made significant progress in implementing a suitable system.

This paper describes the nature and scope of this work and emphasizes aspects that are thought to be unique to this system. Some of the problems encountered during implementation are highlighted, and an attempt has been made to assess the advantages of the system from the point of view of the maintenance engineer and to indicate what the future prospects are.

BACKGROUND AND OVERVIEW OF EARLIER WORK

The municipality of Johannesburg has an extensive pavement network made up of some 2700 km. These are divided into 4500 streets that total 22 000 city blocks. Currently, special maintenance treatments (i.e., overlays and surface treatments) are applied to approximately 2.0-2.5 million m^2 of pavement (about 9 percent of the total) each year.

The standard procedure for the selection and scheduling of these projects for special maintenance would take the following course:

1. An annual inspection of the pavements was made by the road inspector. Since it was impossible to inspect all the pavements in the network each year, a selection was made based on the road inspector's knowledge of probable problem areas and sometimes with the advice of or requisitions by colleagues such as the district engineers.
2. From the results of this inspection, a preliminary list of projects was prepared for the maintenance engineer.
3. The maintenance engineer then prepared the final program of work for the following year on the basis of this list, available resources (particularly the budget), and auxiliary discussions and inspections of doubtful cases.

Records were kept of special maintenance work carried out on the various streets by way of a card-index system.

The inadequacies of these procedures were well recognized during the 1970s. The card-index system was satisfactory for answering such queries as when South Street was last resurfaced but it was unable to cope with such queries as which streets had single seals older than six years. The procedure for identifying maintenance requirements had many drawbacks, which are discussed in detail by Gordon and Curtayne (2). In summary, they are the lack of consistency in the rating of pavements, the lack of control over the choice of roads to be inspected, and the lack of records of the results of past inspections.

The first innovation to be introduced was the establishment of a computerized street inventory (in association with other sections of the department that had similar problems) and the addition of the history of special maintenance from the manual card-index file.

The second development was the creation of a pavement management system that could operate in conjunction with this inventory. Initially, a model had to be established by which the maintenance requirements could be assigned from a description of the condition of the pavement. This model is to a large extent a formal expression of local experience and the policy of the department and takes the form of sets of rules similar to the decision trees described by Finn (1).

The method of establishing the model involved the assessment of the maintenance requirements of a set of pavements by a panel of raters (made up of experienced engineers and road inspectors) and the correlation of these assessments with quantitative descriptions of the pavement distress. [Full details of this procedure have been given by Gordon (3). Summarized versions have also been published in conference proceedings (2,4).]

The subjective manner in which this model was developed was necessary for the following reasons:

1. It was thought that the most meaningful information could be derived from local experience. There are few objectively determined relationships of this type given in the literature, especially ones that would be suited to local conditions.
2. To be accepted by the officials of the department, the model had as much as possible to be compatible with their current practices and policies.
3. The demands of the model (i.e., input and output and computer requirements) had to be compatible with the resources and organization of the department.

The model was completed and tested in 1978. The next step was to implement it in the working environment of the department. Because of staff changes that affected key personnel, this was only done toward the end of 1979. Full details of the implementation to date are given elsewhere (5) but are summarized in the next section.

Note that the implementation of this system was

Figure 1. Computer output of assessments.

RECOMMENDED MAINTENANCE REQUIREMENTS
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TOWNSHIP- TURFFONTEIN
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STREET	1	2	3	4	5	6	7	8	9	SQ M	RAND	TYPE	YEAR	
STREET- GARDEN STREET														
GERMAN ROA TO XAVIER ROA	SS									5200	6240	SS	1980	
XAVIER ROA TO CORONATION		SS								3200	3840	SS	1980	
CORONATION TO EASTWOLD W		SS								15700	18840	SS	1980	
EASTWOLD W TO SIDE ROAD	SS									3200	3840	SS	1980	
										-----	-----			
										27300	32760			
										-----	-----			
STREET- BELLAVISTA ROAD														
TENNYSON O TO SOUTH RAND			SL							4800	2400	SS	1980	***
SOUTH RAND TO VAN HULSTE			SL							10600	5300	SS	1980	***
										-----	----			
										15400	7700			
										-----	----			
STREET- DE VILLIERS STREET														
DONNELLY S TO LEONARD ST						VR				8000	17600	VR	1983	
LEONARD ST TO CORNWALL R								VR		14200	31240	VR	1983	
										-----	-----			
										22200	48840			
										-----	-----			
										-----	-----			
STREET- ALLIN STREET														
BELLAVISTA TO SIDE ROAD								SL		4800	2400	RI	1982	***
										----	----			
										4800	2400			
										----	----			

aimed at fulfilling the immediate needs of the department as soon as possible. Therefore the main requirement has been one of simplicity. Accordingly, no instruments are used in field rating and no mathematical techniques [such as those described by Karan and Haas (6)] are used in assessing priorities. However, the nature of the system is such that more-sophisticated techniques can be incorporated in the future.

IMPLEMENTATION

Output Specifications

Of the various goals associated with pavement management systems, it was decided that the most important for the first stage of implementation was to assist the road inspector in planning the inspection of the pavements and in selecting those to be recommended for special maintenance. Although the system was planned to incorporate further applications in the future (such as those discussed below), the emphasis was on introducing a useful application as soon as possible. In this regard, three computer output forms were designed.

Assessment of Maintenance Requirements

During inspection, the road inspector describes the condition of the pavement according to a set format (i.e., condition rating) and also adds his or her own assessment of the maintenance requirements. The model, by using this information together with data on the inventory (e.g., traffic and road widths), produces assessments of the maintenance requirements, which are displayed in the form of the output shown in Figure 1. For each township, the streets that have been rated are listed. These streets are broken down into lengths that have the same rating (demarcated by intersections with cross roads). The assessment is given in terms of the following:

1. Type of treatment (e.g., slurry, single seal, double seal, overlay), denoted by a symbol (e.g., SL, SS, DS, VR);
2. Urgency or priority of treatment (1, highest priority; 9, lowest; 10, pavement does not require maintenance in the following year but should be reinspected at a later date, which is stored in the inventory for future use);
3. Amount of work involved in terms of area and cost;
4. Opinion of the inspector, which gives the recommended type of treatment and year in which it should be done; and
5. Whether opinion of the inspector differs substantially from the result obtained from the model, in which case asterisks are printed in the last three columns. This acts as a warning that the input data, the model, or the inspector's assessment may be in error. On the other hand, the inspector may have taken factors into account that are outside the scope of the model. The inspector's opinion would therefore prevail. This is regarded as an important feature of the pavement management system and will be discussed again below.

The layout of this form provides a visually acceptable presentation. It is easy to see which streets have urgent maintenance requirements and how different lengths of pavement within one street differ with respect to these requirements.

Summary of Maintenance Requirements

The summary of maintenance requirements gives the total amounts for the various types of maintenance treatment for each priority level (Figure 2). Separate amounts are allocated for each maintenance type in the budget. This output can then be used to determine to which level of priority work can be undertaken for each type of treatment.

Recommended Inspection Schedule

As stated above, one of the main aims of the recom-

Figure 2. Summary output of maintenance requirements.

SUMMARY OF RECOMMENDED MAINTENANCE EXPENDITURE

* AREA * (RANDS) *

PRIORITY	SLURRY SEAL	SINGLE SEAL	DOUBLE SEAL	VENEER CARPET	SLURRY + S.S.	+ D.S.
1	26000 (13000)	60000 (66000)	25000 (37500)	12000 (24000)	500 (800)	2000 (3800)
2	16000 (8000)	30000 (33000)	20000 (30000)	48000 (96000)	000 (000)	000 (000)
3	10200 (5100)	2500 (2750)	14000 (21000)	5320 (10640)	1000 (1600)	4000 (7600)
4	20930 (10465)	36000 (39600)	8600 (12900)	2765 (5530)	1550 (2480)	10250 (13475)
5	14872 (7436)	9656 (10621)	2300 (3450)	7632 (15264)	180 (288)	600 (1140)
6	14276 (7138)	82597 (90965)	75489 (113233)	13120 (26240)	2530 (4048)	000 (000)
7	105326 (52663)	43290 (47619)	18290 (27435)	5392 (12784)	000 (000)	000 (000)
8	17932 (8966)	81070 (89177)	5489 (8233)	38790 (77580)	000 (000)	8290 (15751)
9	62970 (31485)	21000 (23100)	3600 (5400)	29576 (59152)	2590 (4144)	12056 (22906)
TOTALS AREA	288506	366213	172768	163595	8350	37196
RAND	144253	402834	259152	327190	13360	70672

Figure 3. Output of inspection schedule.

RECOMMENDED INSPECTION SCHEDULE

TOWNSHIP- ROBERTSHAM

	REASON
STREET- MOUNT IDA ROAD	
LANDSBOROU TO TOBY STREE	SLURRY =4YRS
JERMYN STR TO LANDSBOROU	SLURRY =4YRS
STREET- XAVIER STREET	
SIDE ROAD TO SWORDER ST	REINSPECTION
SWORDER ST TO BITCON ROA	REINSPECTION
STREET- COLLEGE ROAD	
FIRST AVEN TO SWIFT ROAD	VENEER >10YRS
SWALLOW RD TO FIRST AVEN	VENEER >10YRS
STREET- PAUL KRUGER STREET	
CHURCH STR TO SCHOEMAN S	VENEER =10YRS
SCHOEMAN S TO PRETORIUS	VENEER =10YRS
PRETORIUS TO BOOM STREE	VENEER =10YRS

mended inspection schedule is to control and assist the inspection of pavements. The output shown in Figure 3 lists streets that should be inspected during the following cycle, which is based on two criteria:

1. Age of the surfacing: Inspections are recommended for slurry seals older than three years, all seals older than six years, and overlays older than nine years.
2. Relation to previous inspections: A priority of 10 assigned by the model means that maintenance is not required and a date for the next inspection is recommended. This date overrides the age requirements; i.e., it further reduces the number of pavements to be inspected.

Also included in this output is the reason why the road is due for inspection. [Note that these output forms are in a state of adaptation. Several versions have been tried in order to find the format that best suits the conditions in practice.]

Implementation Activities

Apart from the preparation of these computer programs, there were various other activities that required special attention. Some aspects of these were the following:

1. Training of inspectors: Special training is required for the preparation of the input form and for the use of the output forms. The input form requires an accurate understanding of the terms used. Although most of these are standard (7), their special application for this work was set out in a guide (8) for ready use by field inspectors. The involvement of the road inspector in preparing both the input form and the guide was an important part of this phase of the work.
2. Checking and completing the inventory: When the inventory came to be used, it was discovered that it contained many omissions and errors. A laborious process of checking and correcting the inventory against a street map was necessary. The inventory was completed on a suburb-by-suburb basis. Initially a set of suburbs in a region was completed in order to evaluate the system, to train officers in its use, and to detect any problems in operation.

Current Status

At present about 90 percent of the inventory has been completed, half of which has been checked and corrected. This inventory has already been used to identify pavements with surfacings older than the prescribed limits. These were duly inspected and evaluated, both subjectively and by the model. The exercise produced sufficient information to make a substantial contribution to the maintenance program for 1981 (by identifying some 1.8 million m^2 of the 2.5 million m^2 of work to be done). It also provided an important opportunity to reevaluate the model. There were numerous discrepancies between the assessments by the model and the opinion of the inspector. These were found to have three sources:

1. Misunderstanding of the procedure for field rating, which was greatly improved by subsequent training by using the new guide (8);
2. Normal differences of opinion, which, as shown by Gordon (3), can be very wide, even among experienced engineers--one of the aims of the pavement management system is to deal with these differences; and
3. Inadequacies of the model, indicated by some of the errors.

The assessments supplemented next year include

1. Those identified when more pavements reach the age limits (since the inventory will then be complete, this will include all such pavements);
2. Those with reassessments based on the analysis of this year's assessments; and
3. Those with any additional assessments that can be accommodated by the inspector.

In this way a complete cover of at least one assessment should be achieved within a few years while use is still made of the system in the interim period. After this has been achieved, the system can be used to its best advantage, which will give a complete picture of the inspection and maintenance requirements.

Future Development

A full pavement management system would encompass many features such as accounting and design. However, two applications envisaged and pertinent to problems currently being experienced by the department are the following:

1. Planning of resources: Separate teams are responsible for the various maintenance activities, such as slurry sealing and overlaying. Such teams take time to assemble and disband. Advance planning is necessary to provide an even flow of work through the years and timely enlargement or reduction in the size of the team.
2. Provision of pavement statistics: An area in which such statistics may be needed is the motivation for new equipment. For example, if a planer is being considered, it is important to know the area of asphalt surfacing, particularly in the central business district.

Apart from the conventionally stated benefits of pavement management systems, the above-mentioned examples underline the value of formal procedures for storing and processing pavement data.

EVALUATION

General

Despite several problems, a satisfactory level of implementation was achieved fairly quickly. This success is attributed in part to the simplicity of the first phase. The inventory contains only the minimum amount of information, which was reasonably easy to collect. A second reason for the success is that the system could be used in the practical decision-making process of the department during the early stages of implementation, even though compromises had to be made. Of particular importance was the fact that this was apparent to all levels of management.

Implementation Problems

The problems encountered centered on the fact that innovative activities such as the introduction of a management system tend to be outside the traditional duties and organizational structure of road authorities. Specific problems were as follows:

1. Staff changes: A large part of implementation concerns the motivation and training of staff who will have to carry out the work in the department. These are required at all levels of management (i.e., senior, middle, and field management). A change of staff at any of the levels can result in a lapse of motivation from that quarter. This can impede the momentum of the work severely and jeopardize the project. In the implementation of this system, changes have occurred at all three levels. However, apart from temporary setbacks, continuity has been maintained.
2. Organization: An innovation such as this requires the participation of staff and communication between them outside the normal organization channels, which makes it difficult to control and coordinate the various aspects of the work. Although this caused problems from time to time, they were largely overcome by individual motivation (from a perception of the value of the work) and from encouragement by senior management.

In general it was found that although goal setting and organizational considerations are of significance, the reciprocal criteria of motivation and momentum are crucially important. Motivation was promoted by (a) education at all levels regarding the nature and purpose of the work, (b) participation at all levels in goal setting and formulating of future work, and (c) early results that were meaningful to those concerned. Sustained momentum generates motivation. If this momentum is sufficiently great, the difficulty of bridging problems such as staff changes or organization conflicts is much reduced.

Reaction of the Department

Members of the department feel that developments to date have already brought about a marked improvement in the previous situation, in which pavements were often selected for maintenance on an arbitrary basis. They also believe that once this phase is finalized, far better control will be possible and maintenance programs will be set up with increasing confidence; improved resource planning will also be possible.

Their chief reservation is that the task of the road inspector now becomes much more mechanical and tedious. Although the number of roads to rate each year will decrease, their assessment will take much longer. Also, the road inspector has, until now, been the main person to formulate the annual program and has therefore had a job of high responsibility and interest. It is feared that if this were taken away, the road inspector would lose much of his or her interest and the quality of the assessments would consequently suffer.

Future Role of Road Inspector

There are two main responses to fears that the job quality of the road inspector would suffer as the result of the improved pavement management system:

1. Because the assessments have been formalized to a much higher degree than before and because it will be known beforehand which roads need to be inspected, the task of inspection can be decentralized much more readily and can be shared by the four districts. If 25 percent of the network needs to be inspected annually, each district would be allocated about 150 km of road, which is not too onerous. The role of the road inspector would then be one of controlling the quality of work (probably by spot checks).
2. Within the new system, the road inspector is still the primary person responsible for the condition of the pavements in the network; it remains the inspector's responsibility to recommend the maintenance program each year. The outputs from the model are aimed to help in this task, but when differences occur between the model's output and the inspector's own assessment, the inspector has the opportunity to make the overriding decision. The advantage is that, because of the greater formalization, the inspector's work is much more easily supervised by the maintenance engineer. For example, the road inspector must be able to explain the decisions made.

Because of retirement, there has been a recent change of staff in the department, and a younger officer who has a less-thorough knowledge of the road network than his predecessor has been appointed the road inspector. This situation has been cited as one of the important reasons for needing a more formal pavement management system (2). Even at this stage of development, the system proved more effective in accommodating a change such as this.

CONCLUSIONS

Substantial progress has been made in the implementation of a pavement management system for the city of Johannesburg. This system has already been used to assist in preparing the program of special maintenance work for the following year. Much of this progress is attributed to the basic simplicity of the system and its early use within the department. Several problems were encountered but have to a large extent been resolved. However, they did emphasize the importance of (a) the initial use of simple applications that will have practical use early during development, (b) motivation of all levels of staff, and (c) sustained momentum of implementation.

The reaction by the department has been positive. The potential of even the first phase of development is seen as a great improvement on the somewhat arbitrary nature of previous methods.

Care should be taken to ensure that this system improves rather then detracts from the job value of the road inspector. This is achieved by ensuring that the previous responsibilities with the system are maintained, which will facilitate rather than dictate the inspector's decisions. This not only obviates negative consequences such as the deterioration of the quality of the field data but also has important positive effects, namely, that the experience and initiative of the officer can be fully exploited while he or she nevertheless is still under the explicit control of higher management.

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Pavement Performance Modeling for Pavement Management

R. DARYL PEDIGO, W. RONALD HUDSON, AND FREDDY L. ROBERTS

Systematic pavement management requires estimates or predictions of future pavement performance so that rational comparisons may be made among alternative courses of action. Performance models are required in two distinct contexts, depending on the pavement management level involved. At the project level, fairly detailed and specific models are required for predicting the performance expected for an individual pavement section. At the network level, general or average prediction models are required to provide estimates of the expected performance for a typical pavement or class of pavements. Accordingly, quite distinct modeling methods are indicated for these two different modeling needs. Performance-modeling requirements and data requirements for both network-level and project-level applications are discussed. An idealized experiment to collect data for performance modeling is presented. A specific performance prediction model based on stochastic concepts and treating pavement deterioration as a Markov process is presented as an example of the development of prediction models for network-level applications.

All highway agencies are faced with the problem of providing and maintaining a network of roadways to serve the public. This requires both a considerable capital investment and an adequate maintenance and rehabilitation program. During the past decade, various economic, social, and political factors have made it increasingly important that transportation agencies take every step to make the most beneficial use of their often-inadequate budgets. This has resulted in the rise of the pavement management system from a theoretical concept discussed by university professors to a practical reality under development and implementation throughout the nation.

As a result of this increasing emphasis, both the conceptual and the practical elements of systematic pavement management have been widely discussed (1-11). Great strides have been made, but significant problems have also been encountered. One such problem, which will be addressed in this paper, is the difficulty in predicting pavement performance.

Systematic pavement management is based on the idea that it is possible to determine, in a reasonably objective fashion, how best to use the public funds made available for providing pavements. Budgets are typically allocated on a one- or two-year cycle, and construction, maintenance, and rehabilitation activities are generally planned on an annual basis. Nevertheless, activities carried out (or postponed) now can have a significant impact on roadway conditions for several years or even decades. In order to make rational choices among alternative courses of action, it is therefore necessary to be able to predict or estimate the future performance of the roadway under each alternative action.

Pavement performance has in the past generally been defined as a summary or accumulation of pavement serviceability index based on objective measurements of roughness and/or pavement distress. This use of the word "performance" stems from the work of Carey and Irick (12), although their original definition left considerable room for greater generality. More specifically, performance has been equated with the area under the serviceability history curve or the shape of the serviceability curve. This is the concept of performance adopted in this paper. It should be mentioned, however, that there has been no universal agreement on the definition of pavement performance. For example, in the recent literature, pavement performance is defined variously as (a) the ability of a pavement to provide an acceptable level of serviceability with a specified degree of reliability at an assumed level of maintenance (13), (b) allowable repetitions of loading prior to the functional failure of the pavement (14), and (c) the probability that a critical life of the pavement will be achieved based on the onset of critical conditions (15).

Since serviceability is almost universally measured by using a serviceability index based on roughness or riding comfort, the generally accepted use makes pavement performance a function of pavement roughness. However, many other factors, such as skid resistance, structural adequacy, and cracking, may be important in determining the overall adequacy of a pavement. The word "performance" is a natural candidate to describe this overall adequacy, so it is somewhat unfortunate that it has been defined more narrowly as a function of roughness. We are hopeful that at some future time pavement specialists can agree to reserve the word "performance" to denote this overall adequacy.

PERFORMANCE-MODEL REQUIREMENTS FOR PAVEMENT MANAGEMENT

Performance models are used in two distinct contexts as a part of pavement management, depending on the pavement management level involved. At the project level, fairly detailed and specific models are required for predicting the performance expected for an individual pavement section. At the network level, general or average prediction models are required to provide estimates of the expected performance for a typical pavement or class of pavements. Accordingly, quite distinct modeling methods are indicated for these two different modeling needs.

Project-Level Models

At the project level, considerable information will be available regarding the pavement structure, the current and expected traffic, current and past dis-