Integrating Maintenance Management and Pavement Management Systems

Gordon A. Sparks, *University of Saskatchewan*
Ray Gerke, *VEMAX Management, Inc.*
Doug Kaweski, *VEMAX Management, Inc.*

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

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

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

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

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

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

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

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

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

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

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

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

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

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

EXAMPLE

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

TABLE 1 Initial Network Condition

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

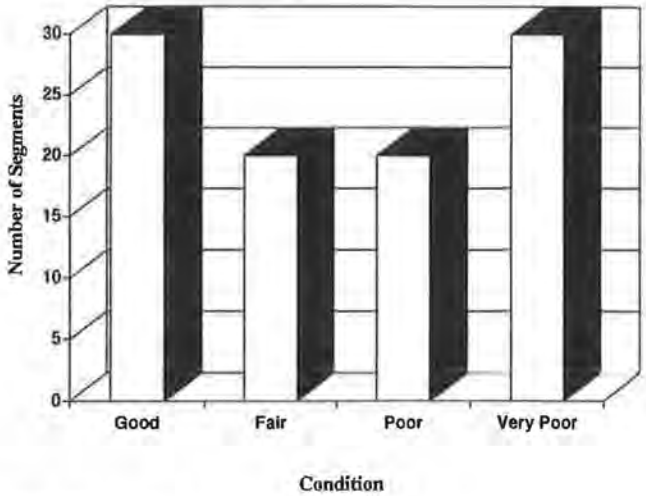

FIGURE 1 Initial network condition.

TABLE 2 Available Treatments

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

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

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

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

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

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

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

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

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

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

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

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

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

TABLE 3 Probabilities for "Do Nothing" Option

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

TABLE 4 Probabilities for Routine Maintenance Option

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

TABLE 5 Probabilities for Seal Maintenance Option

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

TABLE 6 Condition States

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

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

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

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

TABLE 7 Probabilities for "Do Nothing" Option—Reevaluation

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

TABLE 8 Probabilities for Routine Maintenance Option—Reevaluation

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

TABLE 9 Probabilities for Seal Maintenance Option—Reevaluation

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

TABLE 10 Probabilities for Overlay Option—Reevaluation

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

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

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

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

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

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

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

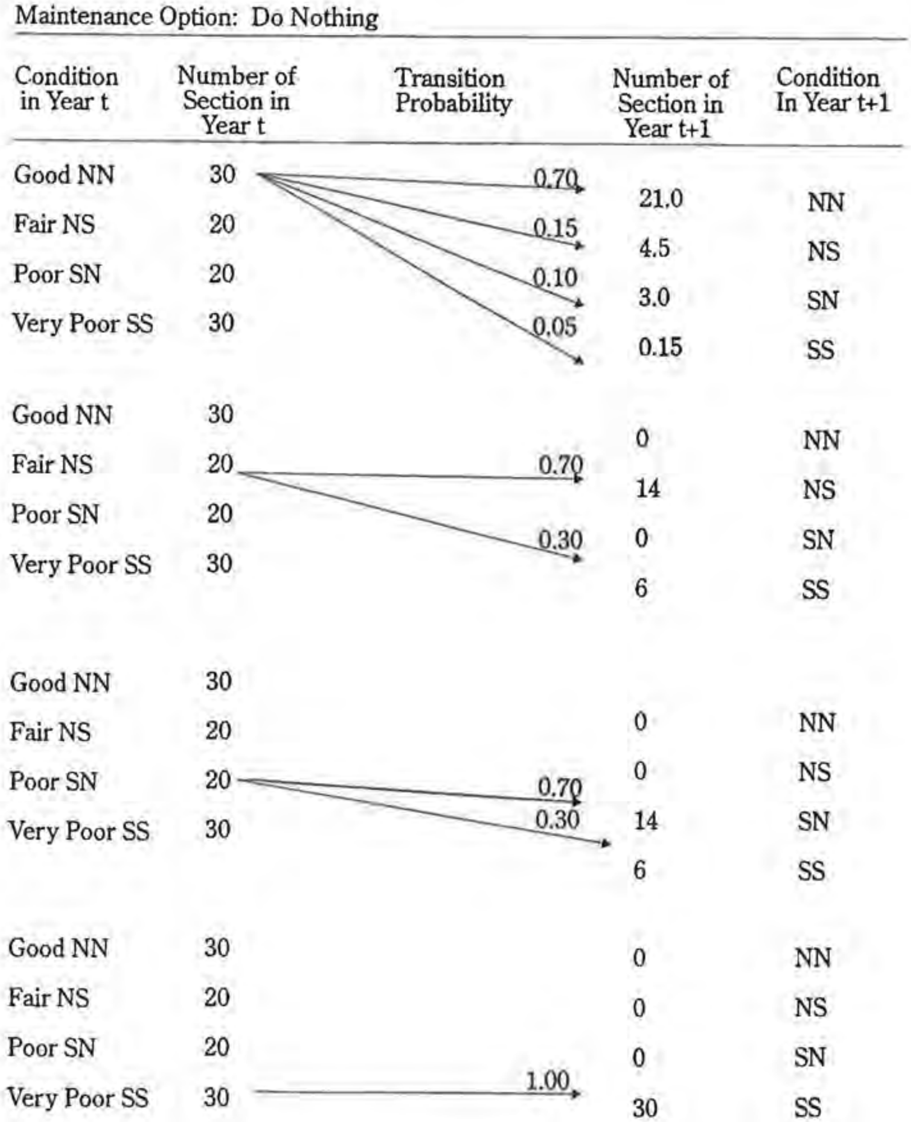

FIGURE 2 Condition transitions from Year t to $t + 1$.

TABLE 11 Transition of Roads in Good (NN) Condition

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

TABLE 12 Combination Strategy

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

TABLE 13 Network Condition Treating Worst First (Bottom Up)

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

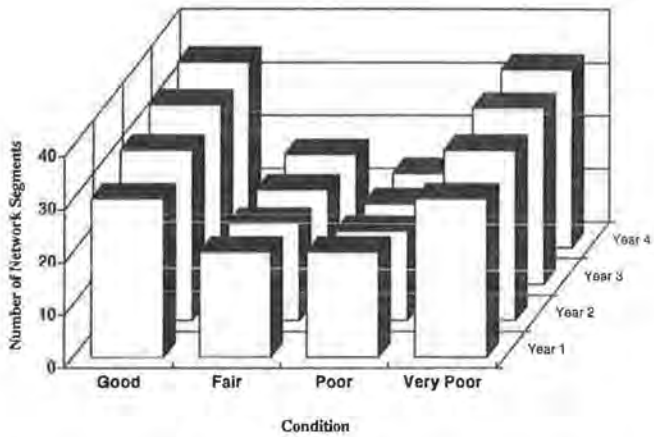

FIGURE 3 Distribution of network condition (treating worst first).

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

Discussion of Issues

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

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

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

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

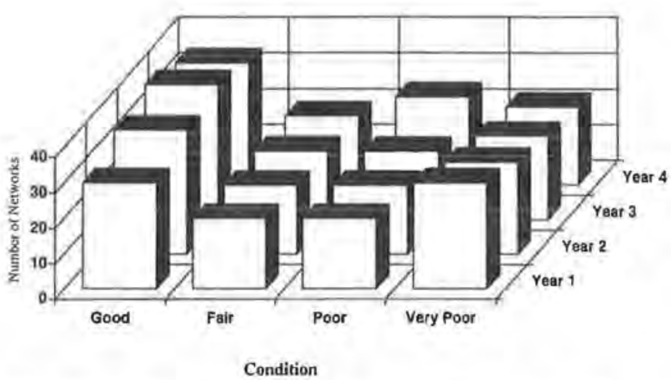

FIGURE 4 Network condition routine maintenance first (top down).

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

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

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

CONCLUSIONS

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

REFERENCES

1. *Pavement Management Systems.* Organization for Economic Cooperation and Development, 1987.
2. *Accounting and Reporting for Physical Assets By Governments.* Canadian Institute of Chartered Accountants, 1987.
3. Byrne, R. Asset Management and New Accounting Standards for Local Governments. *Municipal Engineering in Australia,* Dec. 1991.
4. Flynn, L. New Act Mandates New Management Systems. *Roads and Bridges,* Vol. 30, No. 3, March 1992.
5. McGoldrich, B. Cutting the Fat. *Infrastructure Finance,* Spring 1993.
6. Williams, R. *Total Asset Management Familiarization Program—Accrual Accounting for Total Asset Management.* New South Wales Treasury, Australia, March 1993.
7. *Financial Reporting by Local Governments.* Australian Accounting Standard AAS27 (7/91). Public Sector Accounting Standards Board of the Australian Accounting Research Foundation, 1991.