

# Long-Term Cost-Benefit Analysis of Pavement Management System Implementation

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Many agencies in the United States, Canada, and other countries have implemented pavement management systems (PMSs) over the past two decades. Although the technology and implementation have developed rapidly, the costs and benefits of pavement management have generally been assessed only on a qualitative basis. A major reason for this is the difficulty of quantifying benefits to both authorities and users. The qualitative costs and benefits of developing and implementing a PMS, including those of a general and specific nature, are defined and classified. General benefits include better chances of making correct decisions, improved intraagency coordination, and better use of technology; specific benefits, such as justification of programs, would accrue primarily to elected representatives and senior management. It is suggested that the true, quantitatively based indicators of PMS cost-effectiveness involve the ultimate savings in real highway expenditures plus user cost savings. If these "secondary benefits" of user cost savings can be quantified and if they indicate a substantial degree of PMS cost-effectiveness by themselves, then the basis exists for quantitative justification of the PMS. On the basis of data from pavement management implementation in the province of Alberta, it is demonstrated how user cost savings can be calculated for an increase that actually occurred in average network serviceability, even though the budget remained constant. (In real terms it decreased. Consequently, the analysis was conservative.) The ratio of these user cost savings to PMS costs [i.e., cost-benefit (C/B) ratio] ranged up to about 100:1 or more for a variety of scenarios and assumptions. Although it does not

represent an exhaustive economic analysis, the case application illustrates that it is a quite sound way in which to look at the value of a PMS. Moreover, it has been found to be a very effective tool for senior administrators with which to justify implementation of a PMS. A second state-level evaluation was carried out on the Arizona PMS on the basis of available data. It was intended for comparison and for verification of the approach used. The C/B ratios are not as high as those for Alberta (partly because of differences in the data and because of the assumptions that had to be used), but they are still substantial and support the general principle of the analysis techniques used.

**I**n light of tougher current economic realities, public administrators faced with the need to implement a pavement management system (PMS) must first prepare the business case or financial justification. Senior administrators and elected officials have become aware of the need for cost-recoverable programs that can return to the public real dollar savings. These savings are in terms of better use of funds and rates of return on the initial investment that result in the program's paying for itself within short periods. In some agencies, however, the initial PMS implementation costs can take a large portion of 1 year's annual rehabilitation budget. Consequently, a frequently asked question is "Why should we spend that much of this year's budget when we could use it to pave many miles of road?"

The implementation costs for a PMS can be estimated on the basis of the industry standards for data collection, software acquisition, consultant services, and in-house staff time required to monitor the project. It is more difficult to determine the benefits (short, medium, and long term) that will accrue to the agency. The initial costs can seem frighteningly high by comparison.

This paper presents an analysis framework for public administrators to follow when preparing the business case study for justification of pavement management implementation. It is based primarily on the analysis of an existing pavement management system in the province of Alberta, Canada. Also, an analysis of the PMS in Arizona is carried out for the sake of comparison.

### COST-BENEFIT ANALYSIS OF PMS

Many agencies in Canada and the United States have established formal PMSs to assist their staffs in maximizing the investment in roadway facilities. As of January 1993, every state in the United States must have a PMS in place if the state is to continue to qualify for full FHWA funding allocations. This alone has hastened the development of PMS technology.

The technology of pavement management systems has developed rapidly over the past two decades, but the quantification of costs and benefits has lagged.

Currently under way in the United States is an FHWA project to collect data and case studies with the objective of quantifying the actual benefits realized through pavement management implementation. One of the first products arising from this project was a report by Hudson (1), who identified two primary areas of costs associated with pavement management. They are as follows:

1. The cost of developing a PMS, including the cost of obtaining the necessary and appropriate data for using the PMS and keeping them current, and
2. The true costs of the highway pavements.

The ultimate savings in real highway expenditures are the true indicators of the cost-effectiveness of a PMS. Actual pavement investment and related costs must be considered along with savings and benefits that can be realized from effective PMS implementation. Many problems exist in documenting the true costs associated with the highway investment because accounting procedures (such as the inclusion or exclusion of overhead or indirect costs in unit costs) vary from agency to agency. Obtaining cost information may also be impeded because few if any agencies have fully implemented a PMS over a long term. Also, actual highway investment may be difficult to assess if construction costs occurred over a long time span without a common basis for comparison. Similarly, it is diffi-

cult to obtain accurate maintenance cost information particularly tied to pavement location.

An NCHRP Synthesis (2) summarized the findings of a questionnaire on pavement management practices sent to all state and provincial highway departments. Respondents were asked to identify benefits received by their agencies through PMS implementation. Fifty-three descriptive benefits were identified by respondents under the headings of budget funding requests, legislature, prioritization, improved project selection, rehabilitation strategies, data collection and pavement condition data, understanding of the value of the highway system, data storage and analysis, uniformity of approach, communications, and dollar savings. Regarding the dollar savings, only potential savings were discussed, because sufficient long-term data were not yet available. A common thread throughout the list was that of a "better understanding or perception of the highway cost-benefit relationship."

A review of the list of benefits to be realized, as summarized by Hudson (1) and essentially reiterated in the NCHRP Synthesis (2), suggests that the quantification of benefits will be difficult. Of the 13 benefits listed, only the savings in user costs can be calculated with some confidence, based on the results of the Brazil United Nations Development Programme (UNDP) study; those results were updated for U.S. conditions in a study for FHWA by Zaniewski et al. (3).

The Brazil UNDP cost study, undertaken by TRDF under the auspices of the World Bank between 1975 and 1981, endeavored to develop vehicle operating cost (VOC) and pavement deterioration models for the economic evaluation of alternative highway investments. This work and the FHWA study previously noted have made it possible to quantify user cost savings as a result of rehabilitation (4,5).

If sufficient historical data are available, there can be some measure made of the effectiveness of dollars spent on the system, as well as an assessment of the improved serviceability level of the network.

Another benefit may be quantified as the savings attained through PMS implementation within a fixed rehabilitation budget. These agency savings reflect the improvement in the strategic selection and timing of projects that deliver "a bigger bang for the buck" to the agency.

### CASE STUDIES

The Ministry of Transportation and Highways of British Columbia requested that a cost-benefit analysis be performed to assist the ministry in its decision to proceed with pavement management. As discussed in the previous section, the quantification of costs and benefits is difficult, and so, to assist in this quest for evaluation of potential

PMS expenditure, case study data were sought. The province of Alberta was extremely helpful in this search. It is the implementation of Pavement Information and Needs System (PINS) and Rehabilitation Improvement and Priority Programming System (RIPPS) in Alberta between 1986 and 1990 that forms the basis of this cost-benefit study. A secondary discussion of the state of Arizona's PMS cost savings is also presented to support the basic study.

## ALBERTA PINS/RIPPS

In 1980 the Alberta Transportation and Utilities Department began a three-phase project to develop and implement a provincial pavement management system. Two phases of the system were completed and implemented by 1985. Those were PINS and RIPPS. The third phase, which includes project-level analysis and life-cycle costing, is at the preliminary design stage as of 1993.

Alberta was chosen as a case study for two reasons. First and most important, the Alberta system has been in operation for 5 Fiscal Years, and accurate data are available on its beginning condition and costs. Second, although partial data are available on systems implementation in Idaho, Minnesota, and Arizona, it was felt that a sister province and next-door neighbor to British Columbia would be more pertinent to the analysis.

Summary data on the primary highway network are presented in Table 1. Between 1986 and 1990 the paved network length increased 7.2 percent, from 11 909 to 12 767 km of two-lane-equivalent highway. This was largely due to a provincial program to upgrade the primary highway network using a combination of capital and rehabilitation funds. The increased length reflects the addition of asphalt concrete surface to existing asphalt concrete base pavements as part of a stage paving and construction program.

The condition of the primary network expressed using the composite performance measure of pavement quality index (PQI) in 1986 was 6.3 on a scale of 0 to 10, in

which 10 is perfect. PQI is a combined function of the strength [structural adequacy index (SAI)], roughness [riding comfort index (RCI)], and surface distress [visual condition index (VCI)]. By 1990, the average primary network PQI had risen to 6.8. What is remarkable about this increase in performance is that through two 5-year periods during which the funds available for rehabilitation were fixed at \$40 million/year (with no adjustment for inflation), and in spite of a larger, aging network, a 7.9 percent improvement in overall network condition occurred during the second 5-year period. The only difference in the two periods is the use of PINS/RIPPS and the addition of 11 000 km of new pavement.

Using this information, a cost-benefit case is made, as presented in Table 2. Several assumptions made in preparing the evaluation are as follows:

1. The 1986 PQI is a reflection of the prior expenditure of \$40 million/year [Canadian (Cdn)] for the previous 5 years, and the 1990 PQI is the result of the expenditure of \$40 million/year (Cdn) for the 1986-1990 period.

2. Although maintenance costs are part of an overall pavement management system, no value is assigned to them because of the following considerations:

- Accurate data on pavement-related maintenance costs are difficult to obtain;
- PINS/RIPPS address rehabilitation needs only; and
- Maintenance costs are relatively small in relation to rehabilitation costs, so they can reasonably be assumed to have stayed constant.

TABLE 2 Summary of Cost-Benefit Case Study, Province of Alberta (Canadian dollars)

Description	Road Needs 1981 - 1986	PINS/RIPPS 1986 - 1990
Rehabilitation Funds	\$200 million	\$200 million
PQI	6.3 (1986)	6.8 (1990)
Length	11,909 km	12,767 km
Savings on Vehicle Operating Costs		\$492 million
Replacement Value - adjusted for PQI	\$5.38 billion 3.39 billion	\$5.80 billion 3.94 billion
Increase in Value (Agency Savings)		\$550 million
Total Savings		\$1.042 billion
<b>Costs</b>		
PMS Development		\$650,000 (1)
Operating Costs (5 years)		
a) \$42/km (including road bans/strength)	\$5,000,000	(2)
b) \$25/km (excluding road bans/strength)	\$2,900,000	(3)
Equipment costs @ \$60,000 p.a.	\$300,000	(4)
Total Costs		
a) 1 + 2 + 4	\$5,950,000	
b) 1 + 3 + 4	\$3,850,000	

TABLE 1 Summary Data on Primary Highway Network, Province of Alberta

Period	PQI Primary	Length Primary
1982	-	-
1986	6.3	11909
1987	6.3	12226
1988	6.6	12519
1989	6.8	12693
1990	6.8	12767

3. No value is assigned to salvage although it could be as high as 20 percent of original materials, because the percentage of the network requiring full reconstruction is not known.

4. The number of registered vehicles in Alberta is estimated at 1.8 million vehicles that travel an average of 20 000 km/year. The actual number of vehicle-km traveled is calculated from Statistics Canada data on fuel consumption; however, the translation of this number into vehicle-km traveled is difficult because of (a) change in the average fuel consumption of vehicles and (b) the fleet mix in the province. Data were obtained from the Canadian Automobile Association (CAA) and from the Provincial Division of Motor Vehicles.

5. Pavement data acquisition equipment purchases are included in the calculation as one-tenth of the original purchase price plus a debt value. This is because the equipment will be used over a 10- to 15-year period, and the costs should be shared equally over the period.

### User Cost Savings

The VOCs were calculated on the basis of an adaptation of the Brazil UNDP study to Canadian conditions, as follows (6):

$$\text{VOC}_j = (a + b \text{PQI}_j) \times (\text{VMT}) \times \text{IF}_j \times \text{DF}_j$$

where

- $\text{VOC}_j$  = VOC for year  $j$ ,
- $\text{PQI}_j$  = PQI for year  $j$ ,
- VMT = vehicle miles traveled,
- IF<sub>*j*</sub> = inflation factor,
- DF<sub>*j*</sub> = discount factor,
- $a = 0.31182$  (assuming 1986 is base year) and
- $b = -0.02735$  (assuming 1986 is base year).

The VOC savings is the difference between 1.8 million vehicles traveling on a network with a PQI of 6.3 and the same number of vehicles traveling on a network with a PQI of 6.8. The VOC savings or user savings are estimated at \$492 million (Cdn) as a result of the improved network condition.

The Brazilian UNDP user cost model is very complex and takes into account the following variables: vehicle speed (constrained by vertical gradient, engine power, braking capacity, horizontal curvature, road roughness), fuel/lubricant consumption, tire costs, vehicle maintenance costs, depreciation and interest, occupancy and cargo delay, and administrative overhead.

### Agency Savings

To determine the agency savings, a calculation was made to find the protected value of the network expressed as

savings in value. The network value is estimated by Alberta Transportation in 1990 dollars to be \$5.8 billion (Cdn). Discounting the value for the 1986 length results in a 1986 value of \$Cdn 5.38 billion. An attempt was made to adjust this "replacement" value for network condition using the following logic. If replacement value equals a PQI of 10 (i.e., all roads in the network are new), then a PQI of 6.8 represents an adjusted system value of \$3.94 billion (Cdn), and a PQI of 6.3 represents an adjusted system value of \$3.39 billion (Cdn). The difference between these two values is the savings in value. It is equal to \$550 million (Cdn). This increase in value was achieved by the expenditure of \$200 million (Cdn) in rehabilitation, \$35 million (Cdn) in new construction, and \$5.95 million (Cdn) for the PINS/RIPP system. The return on investment is, therefore, \$310 million (Cdn).

### System Costs

With respect to cost, the PMS development cost in 1980 is calculated at \$495,000 (Cdn) using the following figures:

	<i>Cost (\$Cdn)</i>
Consultant cost	450,000
In-house engineering	45,000
Total	<u>495,000</u>

This was adjusted to 1986 dollars, for an adjusted total cost of \$650,000 (Cdn).

Annual operating costs for the system in 1989 were \$980,000 (Cdn), which includes all staff and equipment time (including outside contractors) and equipment operating costs for field and office data collection and entry. These costs equal \$42/km. The entire primary network is tested on a 2-year rotation for surface distress and roughness, and on a 2-year rotation for strength. The field data collection costs also include skid resistance, frost probes, and spring load ban monitoring. Using a unit cost of \$42/km (Cdn) for all costs, the 5-year operating cost of PINS/RIPPS is \$5 million (Cdn). If the road ban program, skid monitoring, and strength programs were deducted, the unit cost would be reduced to approximately \$25/km (Cdn), or a 5-year cost of \$2.9 million (Cdn).

The implementation costs for the pavement management system can also be compared to the total value of the road network or to the total rehabilitation investment or to both over the development period. In Alberta the PMS development and operating cost over 5 years equated to 2.5 percent of the rehabilitation budget [\$5 million (Cdn)/\$200 million (Cdn)] and 0.08 percent of total value of the road network [\$5 million (Cdn)/\$5.8 billion (Cdn)]. By comparison, the annual rehabilitation budget equates to only 0.69 percent of the total value of the road network [\$40 million (Cdn)/\$5.8 billion (Cdn)].

## Cost-Benefit Ratios

The cost-benefit ratios for the Alberta case can be calculated using the user cost savings, the agency savings in values, or both, as summarized in Table 3.

It should be stated that not all of the cost savings (user or agency) are solely the result of the PMS implementation and that some savings would have occurred as a result of the expenditure of \$235 million (Cdn) in rehabilitation and new construction. The exact percentage of the savings directly attributable to the PMS is impossible to calculate.

However, to reiterate an earlier point, it can be said that in the 1981–1985 period the province spent \$40 million/year (Cdn) on rehabilitation and ended up with PQI of 6.3. As a result of a change in the way in which rehabilitation decisions were made with the introduction of PMS, the expenditure of \$40 million/year (Cdn) over the next 5 years resulted in an increase to 6.8. This increase occurred in spite of an aging network and decreasing value of the dollar.

## ARIZONA CASE STUDY

The state of Arizona case study is included to illustrate the potential savings that may be generated within the rehabilitation budget as a result of a PMS. These savings are real dollar savings achieved through selection of less costly rehabilitation strategies before a road becomes irreparable.

The state of Arizona implemented a pavement management system in 1980–1981 on its 7,400-mi (11 840-km) network of highways. The system replacement value is estimated at \$6 billion, which is similar to that of Alberta, and the state rehabilitation budget of \$52 million (Cdn) had doubled since 1975 as a result of the increased needs produced by a reduction in pavement condition. The PMS was developed in conjunction with a consultant to address the rehabilitation budget (or preservation budget, to use Arizona terms) specifically (2).

The main objective of the system was to develop a decision-making tool to maintain the network in its "most desirable condition within the available budget." A secondary objective was to provide statewide consistency in policy and level of service and to protect the state's road investment. The actual cost savings as a result of PMS im-

plementation are given in Table 4. In 1980–1981 the state highway budget was set at \$46 million (Cdn) on the basis of the previous 5 years' pavement data and in an attempt to maintain the 1975 condition. Using the PMS to generate the entire rehabilitation program and following through on its generated recommendations, the same level of service was reached with only \$32 million (Cdn). This was a real dollar savings of \$14 million (Cdn).

Two reasons were cited for the cost savings:

1. The PMS selected rehabilitation strategies that were preventive rather than corrective, and it selected roads for rehabilitation before they became irreparable.

2. The strategies selected were less conservative (and therefore less costly) than the pre-PMS strategies because of the refinement of the performance prediction models that occurred during system development. The state was fortunate to own a good data base on which the models could be developed. For instance, where 5 in. of asphalt overlay would have been used previously, 3 in. was selected with the PMS. The models indicated that for Arizona conditions, there was no difference in the rate of deterioration between 5 and 3 in. Hence, the latter was selected, at considerable saving. Not all of the technical decisions reflected this large a saving, but the overall savings added up.

Using the PMS to select the rehabilitation program for the 1982–1987 period and maintaining the same standard resulted in a potential saving of \$101.3 million (Cdn). Cost data on the system development and operation are not available in the literature (2). However, given that the Arizona highway system is approximately the same size as that in Alberta, similar costs are assumed for this comparison. The cost-benefit ratios would be as shown in Table 5.

TABLE 4 Cost Savings: The Arizona Case Study (millions of dollars) (2)

Interstate	Funds Needed *		Funds Available **	
	Interstate	Non-Interstate	Interstate	Non-Interstate
1980 - 81	\$32		\$46	
1982 - 83	13.2	23.1	17.0	23.1
1983 - 84	18.5	30.3	28.3	36.7
1984 - 85	19.0	36.6	37.1	43.0
1985 - 86	20.0	38.3	37.1	44.7
1986 - 87	21.0	40.9	48.0	47.3
Sub-Total	91.7 <sup>a</sup>	169.2 <sup>b</sup>	167.5 <sup>c</sup>	194.8 <sup>d</sup>
Surplus (c-a) Interstate	75.8			
Non-Interstate (d-b)	25.6			
Total Savings	\$101.3			

\* Funds needed as a result of the rehabilitation analysis

\*\* Funds available through FHWA formula

TABLE 3 Cost-Benefit Ratios for the Alberta Case: 1986–1990 (Canadian dollars)

Cost	User Cost Savings \$492 million	Agency Savings in Value \$550 million	Total \$1.04 billion
1. Including Road Bans Monitoring \$5.95 million	1:82	1:92	1:175
2. Excluding Road Bans Monitoring \$3.85 million	1:132	1:142	1:271

**TABLE 5 Projected Cost-Benefit Ratios: Arizona Case Study (Canadian dollars)**

	1980 Savings \$14 million 1 year	1982 - 87 Savings \$101.3 million 5 year
Cost including Road Bans \$5.95 million	1:14	1:17
Cost excluding Road Bans \$3.85 million	1:18	1:26

Note: Road ban monitoring involves weekly deflection at control sites throughout the province to determine load restrictions during spring thaw.

Although it is not as high as the Alberta ratios, it should be noted that the 1980 ratio resulted in a 1:14 benefit in the first year; it should also be noted that no accounting is made for user costs or savings in value that would increase the total benefits.

## SUMMARY

The costs of pavement management implementation can be expressed as a percentage of the total value of the road network or the total rehabilitation budget or both. The actual implementation costs can be readily estimated from industry standards for data collection, software, consultant fees, and in-house staff time. However, the monetary benefits directly attributable to the implementation of a PMS are difficult to estimate. A portion of the savings in both user cost and increased network asset value can be attributed to the rehabilitation expenditure regardless of

the system used to program the improvement. However, based on some reasonable and conservative assumptions, for the Alberta and Arizona PMSs, cost-benefit ratios demonstrate that even if a small percentage of the savings is attributable to a formal PMS, the benefits far outweigh the cost.

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