Economic Analysis of Field Implementation of PAVER Pavement Management System

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The results of an economic analysis of the performance of the PAVER pavement management system at a military installation are presented. PAVER was developed by the U.S. Army Corps of Engineers over the past 10 years for use by military installations, cities, and counties. It provides the user with practical management tools, including data storage and retrieval, pavement network definition, pavement condition rating, project prioritization, inspection scheduling, determination of present and future network condition, determination of maintenance and repair needs, performance of economic analysis, and budget planning. The economic analysis was performed based on data collected during a prototype evaluation test (PET), which consisted of PAVER data gathering for the entire installation and monitoring of the use and cost of use of PAVER by the installation personnel. Although the PET took two years, the official cost-monitoring period was four months. The monitoring team consisted of 21 pavement engineers. Two economic analyses were performed: (a) the "PET data comparison", an analysis based strictly on the data collected during the four-month PET, and (b) the "estimated data comparison", an analysis based on estimated times and costs for expected annual use. The results of the PET data comparison showed that the annual cost of pavement management with PAVER is approximately half that with the current operating method. The results of the estimated data comparison showed that the annual cost of PAVER is approximately 30 percent that of the current method.

PAVER is an automated pavement management system that provides the user with practical management tools, including data storage and retrieval, pavement network definition, pavement condition rating, project prioritization, inspection scheduling, determination of present and future network condition, determination of maintenance and repair (M&R) needs, performance of economic analysis, and budget planning. PAVER uses the System 2000 (a trademark of Intel Corporation) as the data base manager. This system and other "interface" programs allow the user to generate preformatted reports of critical information. This information allows objective input to the decisionmaking process. A complete description of PAVER is provided in a paper by Shahin and Kohn in this Record and in another paper by the same authors (1).

This paper presents an economic analysis of PAVER based on a full-scale field prototype evaluation test (PET) at a U.S. military installation. The official PET monitoring was started on February 16, 1981, and ran through June 15, 1981. The pavements of the military installation under study are equivalent to 212 lane miles. The test was monitored by 21 pavement experts from Major Command Headquarters of the U.S. Army Corps of Engineers and several installations. Two analyses are presented, one based on the PET data only and the other based on the PET data and estimates.

DESCRIPTION OF PET

The PET was started by letting a lump sum contract in September 1979 to collect all the necessary information to create a full data base on the study pavements. This contract included the following items:

1. Divide the pavement network into branches and sections and provide maps documenting the division.
2. Perform a pavement condition survey on all paved areas: roadways, parking areas, motorpools, helipads, runways, taxiways, and aprons.
3. Collect pavement structure information from as-built drawings and core borings.
4. Collect all information regarding drainage, secondary structures, and shoulders.
5. Input data into data base and verify the input.

The total contract price of the data collection was \$91 437. Breakdowns of the amount of pavement surveyed and the contract cost are given in Table 1 and in the table below, respectively (1 lane mile = 7330 yd^2):

Item	Cost (\$)
Inspection	64 800
Coring	15 650
Keypunch	1 650
Data verification	9 000
Contract overhead	327
Total	91 427
Additional computer input	1 000
Total	92 427
Cost per lane mile	
Total	436
Inspection	306

Based on the data given in Table 1, the cost of inspection was calculated to be \$306/lane mile. This reflects the inspection cost for a sampling rate of 51 percent.

It was learned from the PET that the initial sampling rate need not be this high for the initial implementation to provide adequate information on pavement condition. It is anticipated that a sampling rate of approximately 15 percent would be sufficient. By using this reduced sampling rate, the estimated contract cost for full-scale implementation given below was derived:

Activity	Contract Cost (\$)
Inspection	19 100
Keypunch (or input)	500
Data verification	2 600
Computer time	1 000
Coring	15 650
Terminal equipment	500
Total	39 350

Table 1. Amount of pavement surveyed.

Branch Use	No. of Branches	No. of Sections	Equivalent Lane Miles	Total Section Area (yd^2)
Roadway	94	188	78	569 862
Parking	75	224	88	648 500
Motorpool	2	7	25	181 569
Runway	1	1	4	26 431
Taxiway	0	0	0	0
Apron	4	4	16	121 875
Helipad	1	1	1	7 147
Total	177	425	212	1 555 384

Note: A branch is an easily identifiable entity of the network, such as "Washington Boulevard"; a section is a portion of a branch that is uniform in construction history, structure composition, traffic, etc.; a sample unit is an inspection unit of approximately 2500 ft^2 for asphalt sections and 20 slabs for jointed concrete pavements. The total number of sample units was 5198, and the total number of samples inspected was 2637, for a sampling rate of 50.7 percent.

These values were obtained by linearly interpolating the contract prices for the 51 percent rate.

During the PET, the form shown in Figure 1 was used to record the computer time and person hours associated with using PAVER and to provide an estimate of the time involved in performing each task manually. A portion of the data from the returned forms is given in Table 2. The hours recorded for M&R project development given at the bottom of the table were estimated by the Engineering Planning Division at the installation. The 120 h shown were used with PAVER information in planning a total of 36 projects when end-of-year money was available. The figure of 480 h is an estimate of the time required to do the same work without the aid of the PAVER system. The installation personnel indicated that without the PAVER system several projects would have had to be eliminated due to lack of time. Thus, the installation would not have been able to obligate the full amount of money available.

A review of the data indicated that the principal time savings occurred in developing long-range plans, budget information reports, M&R cost estimating, and economic analysis. The savings come from the extra computing power offered by PAVER that is not available under the current operating method. By projecting the totals given in Table 2 over a one-year period, the following totals are estimated:

Category	Time
PAVER time	525 person-h/year
PAVER computer time	17 391 ccu's/year
Current method time	1748 person-h/year

The ccu's given above were incurred both interactively and through the PAVER "batch process" procedure. Interactive runs cost about $0.12/ccu; the ccu cost in the batch process can vary from $0.015 to $0.075/ccu, depending on the selected priority. To develop a weighted average cost for computer use,

Figure 1. Form used to record time and cost data during PET.

NAME: ____________

ACTIVITY DESCRIPTION: ____________

RESOURCES	PAVER	PREVIOUS METHODS	REMARKS
COMPUTER COST			
LABOR HOURS & RATE			

the costs and percentages of use given below were used:

Priority	ccu Cost ($)	Use (%)
P01	0.015	20
P02	0.025	
P04	0.05	
P06	0.06	30
P10	0.075	10
P15	0.12	40
Weighted avg	0.0765	

These percentages of use were verified with the chief of the Buildings and Grounds Division. The resulting average cost based on this table is $0.0765/ccu. The Buildings and Grounds Division chief indicated that, as the installation becomes more familiar with PAVER, it is likely to use more of the lower priority (i.e., P01) than the PET indicates. This will result in a reduced computer cost.

The data presented in this section are used in the economic analysis in the following sections.

ECONOMIC ANALYSIS

General

The economic analysis of the PAVER system and the current operating method is developed in the following two ways:

1. The alternatives (i.e., the PAVER system and the current method) are compared based on the PET data projected annually. An inherent assumption in this comparison is that the activities performed during the four months of the PET represent normal annual operations. This comparison is referred to from now on as the "PET data comparison".

2. The alternatives are compared based on estimated times and costs for expected annual use. The data used for this analysis are based on Table 2 and additional input from the chief of the Buildings and Grounds Division at the study installation. This comparison is referred to from now on as the "estimated data comparison".

The analysis method used was a present-worth analysis that used a life of eight years for the PAVER system.

Assumptions

The economic analysis presented here is based on the following assumptions:

Table 2. Summary of PAVER use and estimated current system time.

		PAVER		
Date	Activity	Time (h)	Computer Charge Units	Current Time (h)
6/3/81	Develop $200 000 bids	4	135.561	
6/8/81	List of work requirements	0.25	217.222	
			23.110	
6/13/81	Edit cost in work requirements	1.5	598.786	
	Generate work-requirements reports and add sections to work required	1	258.121	
6/20/81	Develop construction projects	0.25	187.407	
6/14/81	Develop BMAR plan			11
6/20/81	Generate work requirements	0.5	116.445	
6/20/81	Generate areas	0.5	29.177	
6/22/81	Inspection			2
6/24/81	Inspection			2
7/81	Phase I and II of M&R project development	120		480

Note: BMAR = backlog maintenance and repair.

1. The installation was selected as an average installation so that the cost of the PET should be representative of the costs of implementing the system at other installations of similar size. However, the selected installation has used a manual management system over the past years.

2. The data processing equipment necessary to operate the automated system (ASCII terminal and acoustical modem) is purchased by the installation. The terminal cost is distributed over the systems supported by the terminal.

3. The data base is maintained for all installations by a single organization. The costs of management are split between installations for unit cost purposes.

4. No additional employees are needed at the installation level to operate the system.

5. PAVER offers the user more information and procedures than are currently available. These items are here considered benefits.

Constraints

The following constraints on the analysis should be noted:

1. The use of PAVER during the four-month PET is not necessarily proportional to a full year's use because different types of activities are required at certain times of the year. Therefore, the two analyses are performed as indicated under the heading "General" above.

2. Time estimates of activities during the PET were made while the PAVER system was in use. Thus, a true dichotomy of tasks was not possible.

Current Operating Method

The current method of operation at the installation is a manual card-file procedure. This method has been developed by the installation personnel and has been in operation for several years. The procedure basically consists of a card catalogue of pavement sections in which information on pavement structure and past major maintenance is recorded.

PET Data Comparison

The costs based on PET data for the current method consisted of 582.5 person-h (Table 2). These hours were split among three engineers, which resulted in an average rate of approximately $15/h. If one uses the total hours given in Table 2, the current method cost is calculated to be $8737 for four months, or approximately $26 200/year.

Estimated Data Comparison

Activities performed during a normal year have been categorized into six groups. The time and costs for these categories are given in Table 3. The total estimated annual cost is $17 238/year. These costs are based on discussions with the Buildings and Grounds Division chief at the installation and the breakdown of the costs in Table 2.

Table 3. Estimated data comparison of annual activities and costs for current operating method.

Activity	No. of Hours	Avg Hourly Rate ($)	Cost ($)
Periodic pavement inspection	160	13.44	2 150
Determination of M&R requirements and setting of M&R priorities	240	15.74	3 778
Validation of M&R projects	80	15.00	1 200
Annual work plan	80	14.26	1 141
Long-range planning	160	15.74	2 518
M&R cost estimating	480	13.44	6 451
Total	1200		17 238

Benefits

There are no tangible benefits associated with the current method of operation. However, there are certain intangible benefits associated with its continuation: (a) The current method is a local method that is user acceptable, and (b) no sophisticated equipment is required. These benefits, however, are particular to the test installation studied, since most other installations have no manual system.

Risks

If the current operating method continues, the following risks should be considered:

1. The number of projects not funded will most likely continue to rise, and the total dollar requirement for pavement maintenance will increase.

2. No common ground of communication will be established between the installation engineers and Major Command engineers.

3. No objective procedure for pavement rating will be established, which will reduce the chances for division of maintenance money based on the condition of the pavements.

4. Continual backup of work and inconsistent evaluation procedures will decrease pavement life.

Automated PAVER System

The PAVER system was fully implemented at the installation (i.e., all paved areas were inspected). The initial inspection and data input were performed under a lump-sum contract. The actual cost of this initiation along with operation costs from the PET will be considered.

PET Data Comparison

The "operating" costs from the PET for PAVER, as given in Table 2, are 175 person-h and 5796 ccu's for computer use. The cost of a person hour is again the average of $15/h, which results in a four-month cost of $2628, or approximately $7886/year. The computer cost used was $0.0765/ccu, as computed earlier. This yields a computer cost of $443 for four months, or approximately $1330/year. This is the actual computer time cost; there are also support costs associated with computer use. These can be itemized as follows:

Item	Unit Cost
Connect time	$8.50/h
Tape storage	$0.25/day
Disc storage	$22/1000 sectors/ month
Communication line (telephone)	$29/month
Computer paper	$21/box
Equipment (terminal and modem)	$1500

The connect-time costs are based on Boeing Computer Service rates (the Corps of Engineers vendor at the time of the PET). The computer connect time for the PET was approximately 15 h. Based on the $8.50/h rate, the connect time is calculated to be $129 for four months, or $387/year.

Tape storage was not used during the PET, so no tape charges are included for the PET analysis. No tapes were used in the PET as a matter of conve-

Table 4. Summary of PAVER costs from PET data comparison.

Item	Person Hours[a]	Avg Hourly Rate ($)	Cost ($) Four Months	Annual	Initial
Labor	175.25	15.00	2629	7 886	
Computer ccu's[b]			443	1 330	
Computer connect	15.13	8.50	129	386	
Disc storage				1 848	
Communication line (telephone)				348	
Paper				21	
Terminal equipment					500
Initiation cost					92 437
Total				11 819	92 927

[a]Four months.
[b]At $0.0765/ccu.

Table 5. Estimated data comparison of annual activities and costs for PAVER system.

Activity	Time (h)	Avg Hourly Rate ($)	Cost ($)
Periodic pavement inspection	160	13.44	2 150
Determination of M&R requirements and setting of priorities	96	15.67	1 504
Validation of M&R projects	40	15.00	600
Annual work plan	40	14.26	570
Long-range planning	24	15.74	378
M&R cost estimating	120	13.44	1 613
One person year of FESA support, all bases			1 600[a]
Total			8 415
Computer support			2 948
Total	480		11 363

Note: FESA = Facilities Engineering Support Agency.
[a]Twenty five installations requiring one person year (GS-12) - $26 951 x 1.5 (overhead) = $40 000 per base = $40 000/25 base installations = $1600/installation.

nience. The current disc storage charge is $22/1000 sectors/month. The installation data base is approximately 700 sectors of disc space. This results in an annual charge of $1848.

Since the Autovon telephone lines of the study installation will not support teleprocessing equipment, a commercial telephone line was necessary. The monthly charge for the service was $29, or $349/year. No long-distance service was required since the computer vendor has an "800" telephone number.

The terminal equipment for the PET was a Teletype 43 terminal with a 30-character/s acoustical modem. This equipment can be purchased for $1500. Since the terminal supports three systems (two in addition to PAVER), only one-third of the cost was assigned to the PET as an initial cost ($500). Approximately one box of paper per year is needed to support the PAVER system, at a cost of $21. These costs are summarized in Table 4.

Estimated Data Comparison

In the case of the current operating method, the activities performed during a normal year have been categorized into six groups. The costs for these groups (see Table 5) were estimated through discussion with the Building and Grounds Division chief and the breakdown of costs and times given in Table 2. The annual cost has been divided into $8415 for labor and $2948 for computer costs. The computer support costs are calculated as follows:

Tape loading: (2 times/week) (52 weeks/year) ($6/mount) = $624.
Update tape: (2 tapes) (35 times/year) ($6/mount) = $420.
$624 + $420 = $1044.
Tape storage: (2 tapes) ($0.25/day) (365 days/year) = $183.
On-line storage (disc space): $22/1000 sectors/month. Average data base size is 8000 sectors. Assume tape loaded to disc 2 months/year. Annual cost = ($22) (8) (2) = $352.
$1044 + $183 + $352 = $1579.
Phone line cost = $348.
Paper cost = $21.
Computer time cost = $1000.
Total cost = $1579 + $348 + $21 + $1000 = $2948.

To reduce overall costs, a tape mount system was assumed to be used in normal annual operation of the PAVER system.

Estimated costs for PAVER implementation can thus be summarized as follows (the initial costs are based on the initial cost of the PET given earlier in this paper):

Category	Cost ($)
Initial cost	39 350
Annual labor cost	8 415
Annual computer support cost	2 948

Benefits

Tangible

Analysis of specific projects indicated that the use of PAVER could reduce the cost of maintenance and have an effect on long-term cost avoidance. One specific project was the Branch IWASN Section 04 (Washington Boulevard). As obtained from the installation Contracting Office, the bid price for reconstruction of this section was $50 417.25. This section was scheduled for an overlay; however, based on its rate of deterioration (from a second pavement-condition-index inspection), it was estimated that the overlay would last only 5 years. The reconstruction, on the other hand, was estimated to have a design life of 25 years. The overlay price would have been approximately $12 173 based on current competitive bid prices. Over the design life of the reconstruction, five overlays would have to have been placed, which would have resulted in a total cost of $60 865 without inflation. This represents a cost avoidance of $10 448. Other cost avoidances are likely to occur due to timely maintenance through the use of readily available information from PAVER. To quantify this cost avoidance, however, several years of data are needed. Therefore, a conservative cost avoidance of only $10 500 is estimated to occur on an annual basis.

Intangible

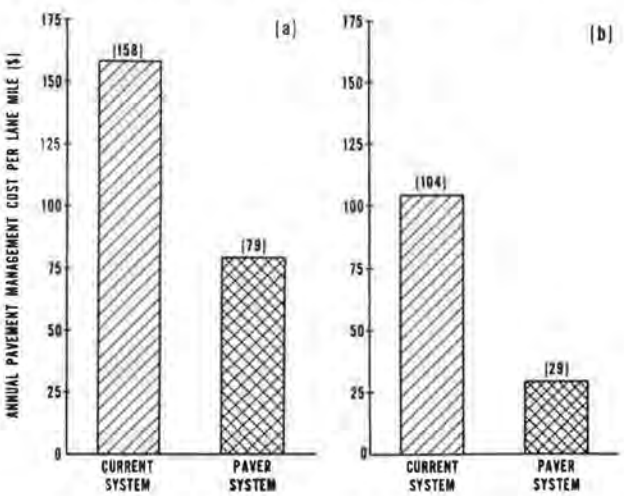
One of the major benefits of using the PAVER system

Table 6. Summary of economic analysis.

Method	Inflation Rate (%)	Present Value ($)	EUAC ($)	EUAC per Lane Mile ($)	Total Benefits ($)	Present Value - Total Benefits ($)	EUAC per Lane Mile Including Benefits ($)
Estimated Data Comparison							
Current	0	101 160	18 962	89	0		
	5	117 850	22 090	104	0		
	10	137 904	25 849	122	0		
	15	161 955	30 358	143	0		
PAVER	0	106 027	19 874	93	84 000	22 027	20
	5	117 027	21 936	115	84 000	33 027	29
	10	130 246	24 414	115	84 000	46 246	41
	15	146 099	27 385	129	84 000	62 099	55
PET Data Comparison							
Current	0	153 752	28 820	136	0		
	5	179 120	33 575	158	0		
	10	209 600	39 288	185	0		
	15	246 156	46 140	218	0		
PAVER	0	162 286	30 420	143	84 000	78 286	69
	5	173 729	32 565	154	84 000	89 729	79
	10	187 479	33 142	166	84 000	103 479	92
	15	203 969	38 233	180	84 000	119 969	106

Notes: EUAC = equivalent uniform annual cost.
Data based on interest rate of 10 percent and analysis period of eight years.

Figure 2. Comparison of annual pavement management cost per lane mile: (a) PET data comparison and (b) estimated data comparison.



is that the Major Commands have a uniform method of comparing the pavements at all installations. This will help determine the distribution of maintenance funds and help establish an overall level of service for the installation. This uniform rating will also increase the communication between the Major Commands and the installation engineers. In addition, the pavement user will experience greater safety, comfort, and reduced vehicle maintenance because of better overall pavement condition.

At the installation and Major Command level, the PAVER system also adds a great deal of analytic power through programs such as ECON and the M&R Guidelines (1). From the PET data, it appears that a time savings of about 2.5 h can be expected for an economic analysis calculation. This reduced computation time is a benefit to the user. Increased accuracy of the analysis is also expected.

Major benefits experienced at the installation during the PET were that the work-requirements and M&R guidelines reports were of great use in developing contract documents. These reports provided quantities and cost estimates of the maintenance activities, which could take a considerable amount of time to calculate by hand. The quantities were then used in the project preparation phase. The time savings are reflected in the last inputs in Table 2. It was felt that it would have been impossible to turn out the required number of year-end projects (36) without the PAVER system. Having the data stored saved a considerable amount of time in locating documents and reduced the time of field measurements, since only spot checking was necessary.

PAVER also offers the user access to factual data about the condition of the pavement system. Under the current system, these data are the subjective opinion of the pavement engineer. Provision of the objective data allows for more accurate calculations and sounder management decisions. The PAVER system will also provide a means for a new pavement engineer to become familiar with the overall network condition and inventory in a short time.

Results

The results of the economic analyses for the PET data comparison and the estimated data comparison are presented in Table 6. The present-worth analysis was performed for an eight-year analysis period, assuming a 10 percent interest rate. The analysis was repeated for inflation rates of 0, 5, 10, and 15 percent, respectively. The following is a brief definition of the terminology used in Table 6:

1. Initial cost--A one-time cost realized at the beginning of the analysis period,
2. Present value--The cost in today's dollars of the initial cost plus the discounted amount of future costs,
3. Equivalent uniform annual cost (EUAC)--The present value amortized over the analysis period (present value multiplied by capital recovery factor),
4. EUAC per lane mile--The EUAC divided by the total number of lane miles of pavement inventoried, and
5. Total benefits--The total amount of tangible benefits (in this case, cost avoidance) realized over the analysis period (the total benefits are not discounted).

SUMMARY AND CONCLUSIONS

This paper presents an economic analysis of the

PAVER prototype evaluation test at a military installation. Two analyses were performed: (a) an analysis based strictly on the data collected during the four-month PET (PET data comparison) and (b) an analysis based on average annual estimated data (estimated data comparison). The estimated data were based on the PET data and input from the Buildings and Grounds Division chief at the study installation.

The results of the economic analyses for the PET data comparison and the estimated data comparison are given in Table 6. Figure 2 graphically summarizes the results of the two methods of data comparison for an analysis period of eight years, an interest rate of 10 percent, and an inflation rate of 5 percent. The results of the PET data comparison clearly show that the annual cost of pavement management with PAVER is approximately 50 percent of the cost of the current system. The results of the estimated data comparison show that the annual cost of pavement management with PAVER is approximately 30 percent of the cost of the current system.

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The views expressed in this paper are ours and do not necessarily reflect the views of the U.S. Department of the Army or the U.S. Department of Defense.

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Development of a Statewide Pavement Maintenance Management System

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A framework for a statewide pavement maintenance management system (PMMS) is presented that describes the general system approach, criteria for monitoring pavement conditions, methods and types of data to be collected routinely to define pavement conditions, suggested computer data systems needed to support and implement the PMMS, and a system for establishing project priorities. The overall objective of such a system is to develop and implement maintenance management schemes for optimum selection of various repair strategies based on cost-effective analyses that consider repair needs and priorities. In this PMMS, criteria are applied to determine what portion of the total state network is likely to need maintenance and therefore should be monitored. Monitoring parameters in the form of maintenance needs indicators or "trigger values" are identified. These indicators—present serviceability index, skid number, age, and traffic—are also used to develop recommended sampling or monitoring frequency intervals. Procedures have been developed for nondestructive testing and analyses of structural remaining life for pavements that show structural distress of a certain extent and severity. These pavements are classified by using a visual pavement condition rating system, which provides a uniform method for assessing pavement conditions on a statewide basis. Finally, the PMMS includes a framework for establishing project priorities based on need and condition and presents guidelines to aid in formulation and evaluation of maintenance alternatives. The proposed system uses roughness, skid resistance, deflection, and traffic data currently maintained by most state transportation agencies. It is structured to facilitate implementation with minimal difficulty to a user agency and makes maximum use of the experience and judgment of agency engineers. Finally, it is modular, permitting easy future modifications and improvements to various aspects of the system as they become available.

Highway departments across the nation are experiencing serious monetary problems as aging highways and increasing rates of pavement deterioration are placing larger demands on pavement maintenance requirements. The nation's pavements are deteriorating faster than they are currently being rehabilitated, which results in increasing numbers of pavements needing repair. This situation is aggravated, to a large extent, by obsolete state funding structures that are unable to yield sufficient revenue in times of high inflation and reduced motor-fuel consumption as well as budgetary cutbacks at the national and state levels. As a result, many states have been forced to defer such repair, thus allowing many pavements to deteriorate to an even poorer condition that makes future rehabilitation more extensive and costly.

In light of such fiscal pressures, most state transportation agencies have recognized the need to establish a systematic, rational procedure for identifying pavement repair needs and priorities and selecting cost-effective design alternatives. The pavement maintenance management system (PMMS) framework appears to be providing a solution to highway agency problems, and many agencies have already developed and implemented such systems as a management tool to aid in prioritizing those projects that are in need of rehabilitation (1-4). A PMMS also provides a medium for feedback in which the consequences of past actions can be incorporated into the decision process; it facilitates consistency and uniformity in funding allocations to optimize and achieve the best values possible for public funds and provides improvements and cost savings by means of improved organization and coordination of activities.

Although the primary benefit of a PMMS is economic, in that improved maintenance management will provide greater values for dollars spent, the system also enhances the opportunities for optimal, correct decisions; this leads to improved technology and efficiency for various activities and provides capability to defend funding allocations. It is intended to provide a means for presenting information on in-service pavements that can be used to identify needs and program investments as well as design and construction requirements.

The essential requirements of a PMMS include the capacity for updating and modification as new data and better models become available, incorporation of alternative strategies, identification of optimum