Pavement Management at the Local Government Level

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Described in this paper are the results of a study of pavement management practices used by 13 local government agencies in the United States and Canada. Included is a discussion of factors to be considered in planning and developing a pavement management system based on the experiences of these organizations. In the planning phase consideration is given to resource requirements (personnel, equipment, and funds) and to information requirements (primarily the type of data to be collected). Specific considerations associated with actual development include: *(a)* section identification, *(b)* condition surveys, *(c)* maintenance and rehabilitation alternatives, *(d)* data utilization, and *(e)* report preparation. Practices of the 13 agencies relative to these considerations are summarized in a series of tables for ready reference. Development and annual costs as well as personnel requirements of the 13 systems are summarized. Development costs of the order of $100 to $300/mi appear to represent a reasonable range that might be anticipated. Annual costs to operate the system of about $100/mi are considered average. While personnel requirements will vary depending on the size of the system, it is important to recognize that one engineer within the organization should be responsible for and fully knowledgeable of the system.

At every level of government, insufficient funds are available to maintain our street and highway systems at current levels of serviceability *(1)*. Accordingly, public funds that have been earmarked for pavements must be used as effectively as possible. A proven way to mitigate the effects of these funding problems is through the use of pavement management considerations *(2, 3)*.

Considerable effort is now under way at the state level to implement working pavement management systems, and a number of states are already effectively using pavement management techniques for maintenance and rehabilitation activities, e.g., the states of Arizona *(4)*, California *(5)*, and Washington *(6)*.

At the local government level efforts are also under way to implement pavement management systems. Described by Monismith et al. *(7)* are a survey and evaluation of a number of these agencies that have already initiated such activities. [An overall indication of the state of pavement management activities as of 1985 is provided in the *Proceedings of the North American Pavement Management Conference (8)*.]

There are, however, many agencies at the local government level with a diverse range of street and highway systems and with a multiplicity of requirements for effective use of the systems. The purpose of this paper is to briefly describe the results of the study reported by Monismith et al. *(7)*. This study is sponsored by the State of California Department of Transportation and the Federal Highway Administration (FHWA) to enhance the development of pavement management activities at the local government level. It is considered worthwhile to present the results of the study obtained so far; essentially it consists of a summary of what 13 local government agencies, identified generally in Table 1, are doing to implement pavement management activities in their organizations. It is hoped that this summary will prove of assistance to local government organizations who may wish to undertake pavement management activities.

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TABLE 1 ORGANIZATIONS PARTICIPATING IN STUDY

Local Government Organization	General Location
City A	Western United States
City B	Central West Coast, U.S.
County A	Southwestern United States
City C	Central West Coast, U.S.
City D	Northern West Coast, U.S.
City E	Central East Coast, U.S.
City F	Central West Coast, U.S.
City/County A	Central West Coast, U.S.
City G	Western United States
County B	Northern West Coast, U.S.
County C	Western United States
City H	Southern West Coast, U.S.
Regional Municipality A	Eastern Canada

Summarized in Table 2 is general information about the organizations whose systems were evaluated. It is included to provide a perspective on all of the information presented.

The results will be discussed within a general framework for pavement management, illustrated in Figure 1.

PAVEMENT MANAGEMENT SYSTEMS FOR CITIES AND COUNTIES

The degree of completeness of a pavement management system (PMS) can range from a simple data base to a system that includes the feature of optimization. Between these two levels there is a range in possible systems. The level required will, to a large extent, be influenced by the objectives set for the system.

Based on discussions with personnel in local government agencies visited in conjunction with this project, there appears to be a primary requirement for a PMS at the city-county level:

TABLE 2 GENERAL INFORMATION

AGENCY	POPULATION	STREET/ROAD MILEAGE Miles	BUDGET, Dollars, × 10^3			DEVELOPMENT OF SYSTEM
			Rehabilitation	Maintenance	Rehabilitation and Maintenance	
City A	90,900	286 Centerline	1,500	288	1,788	Consultant
City B	100,000	550 Centerline	500		500	APWA - PAVER System
County A	1,600,000	3,700 Centerline (1,300 Paved Centerline)				County Staff (in-house)
City C	50,000	220 Centerline	500			Consultant and City Staff
City D	500,000					Consultant and City Staff
City E	219,000	1,736 Lane	600			Consultant and City Staff
City F	85,000	200 Centerline			1,400	City Staff FHWA - CALTRANS System
City/County A	700,000	850	6,000	3,000	9,000 (1985-86)	Consultant and City Staff
City G	46,000	360 Lane				APWA - PAVER System
County B	139,000	860	1,687	678	2,365	Consultant with State and County Staff
County C	125,000	3,150 Centerline	500	5,000	5,500	County Staff FHWA-CALTRANS System
City H	80,000	260	800	75	875	City Staff
Regional, Municipality A	225,000	500 Centerline			12,000 Can.	Consultant with Municipality Staff

the system should be simple to maintain and operate. It should be noted, however, that the definition of what is simple will vary from agency to agency, depending on its size and the resources available to support a PMS. It was also indicated that user-friendly, menu-driven software is a desirable attribute of a PMS. Such a system provides interactive use for data entry, editing, and retrieval of information rapidly and easily and at remote terminals by users at various levels of management. After the requirement for simplicity, agency priorities vary somewhat. Wells, et al. *(9)*, as the result of a development program in the PMS area by the Metropolitan Transportation Commission (encompassing the nine-county area surrounding the San Francisco Bay), have listed three features as being of primary importance in a PMS for local governments, as follows:

1. A procedure to objectively quantify pavement condition,
2. A listing of the most cost-effective maintenance treatments, and
3. A means of matching treatments to problems.

General Approach

The framework of Figure 1 provides the general format for pavement management activities. The data bank is the heart of the system. Exactly what is included in the data bank will depend on the system requirements. As a minimum, information concerning the condition of pavements in the network must be obtained. Based on pavement condition, it will be necessary to establish a set of actions considered appropriate for each condition state; i.e., single or multiple variable indices.

The best treatment from the feasible set must be determined. The treatment may be obtained from a consensus of knowledgeable people, usually within the agency personnel. This "best" action can also be determined by use of prediction models and optimization procedures.

Priorities can be developed based on ranking procedures; benefit-cost ratios; maximizing performance or condition of network; minimizing cost; or other methods may be developed using performance, benefits, and cost as primary considerations. In most cases, the needs will exceed the funds available. Priorities can be used to select sections for corrective action. It should be noted, however, that corrective measures for some sections may have to be deferred to a future year.

A careful evaluation of each section will be essential to ensure that the information in the network data base is correct and that there are no site-specific conditions that would alter the plan developed for the network branch of the system.

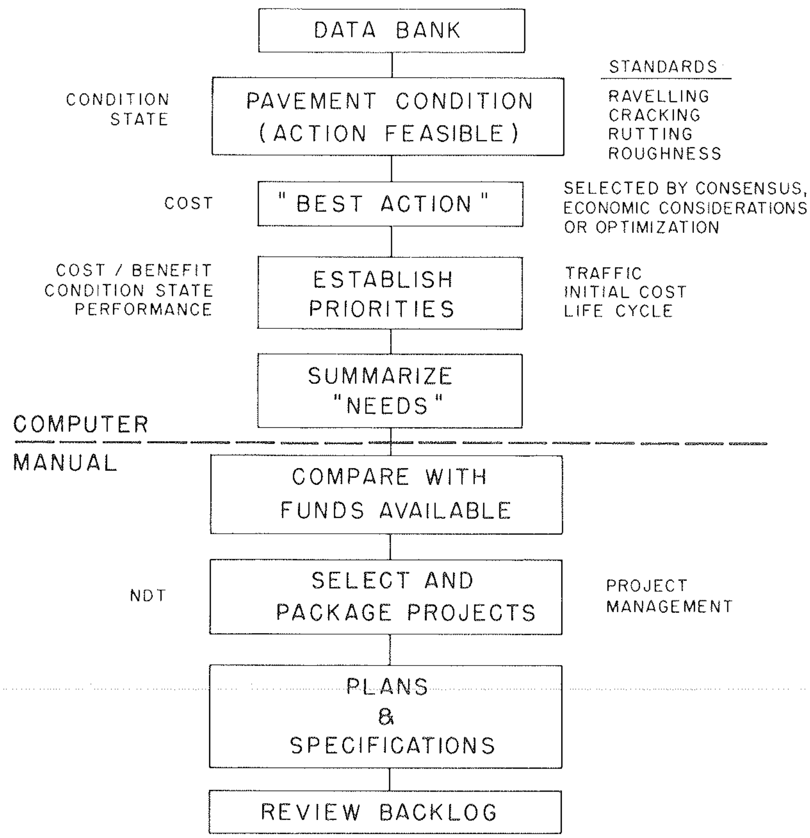

FIGURE 1 Framework for pavement management system: city and county level.

Finally, plans and specifications are prepared for implementation of the program.

Feedback is an important part of the PMS. That is, what is happening to the overall condition of the pavement network? Is it improving, deteriorating, or remaining the same? This review of the backlog of needs will be useful in requesting funds to maintain the pavement network at a desired level.

Planning a PMS

There are a number of factors to be considered in planning the development of a PMS. Some of the more important ones discussed with the agency personnel include

1. Availability of resources,
2. Information requirements,
3. Level of sophistication (completeness),
4. Data management,
5. Reporting, and
6. Administration.

Resource Requirements

Resources can be divided into three categories: *(a)* personnel, *(b)* equipment, and *(c)* funds. The resource requirements can be divided into two levels, i.e., those needed for development and those required for operation of the system.

Because of a shortage of personnel with training or background in development of PMS, most agencies have called on consultants to assist in the development process. There are exceptions, e.g., personnel in Cities *F* and *H* and County *C* have developed or adapted systems for their respective agencies. When consultants are retained, it is usually a joint effort, with the agency providing the kind of assistance for which it can be most helpful.

Cities and counties, for the most part, have not acquired equipment to be used in the field, i.e., car ride meters, deflection testers, skid testers, road loggers, and so on. Again, there are some exceptions in the case of deflection testing equipment; however, the majority of agencies rely on commercial companies to provide this type of equipment.

Computer equipment is available and is being used by all the agencies contacted. Some cities and counties have access to mainframe computers in house; some have microcomputers assigned within the department that will maintain the PMS.

Most of the agencies contacted would prefer to have their own computer, usually a microcomputer, assigned to the responsible department. In this way, the department can maintain direct control of the system, update it in a timely manner, produce reports when and of the type necessary, and interact with the data base for editing and retrieval. Generally, the system users want a user-friendly (interactive) capability and menu-driven program.

Funding is always a problem for cities and counties, both for development and operation of the PMS. As will be seen subsequently, the cost of developing a PMS can range from as little as $10,000 to as much as $500,000 or more (not counting data acquisition), depending on the level of sophistication required.

TABLE 3 STREET/ROAD IDENTIFICATION

AGENCY	CODE	ROUTE IDENTIFICATION	LIMITS: BLOCK-BY-BLOCK	LIMITS: MILE POST	LIMITS: OTHER	CLASSIFICATION: NUMBER	CLASSIFICATION	SPECIAL CONSIDERATIONS: LANE IDENTIFICATION	SPECIAL CONSIDERATIONS: INTERSECTIONS	SPECIAL CONSIDERATIONS: BUS LANES	SPECIAL CONSIDERATIONS: PARKING AREAS	SPECIAL CONSIDERATIONS: BICYCLE LANES				SPECIAL CONSIDERATIONS: OTHER	COMMENTS
City A	X	X	X			5	a) Principal Arterial; b) Minor Arterial; c) Principal Collector; d) Minor Collector; e) Local										
City B	X				X												
County A	X	X		X		2	a) Paved; b) Unpaved										
City C	X	X	X			6	a) Collector; b) Arterial; c) Local Residential; d) Local Business District; e) Local Industrial; f) Through Truck or Bus Route									X	Traffic index (State of California) associated with each classification.
City D	X	X	X			4	a) Arterials - nonFAU; b) Arterials - FAU; c) Collectors; d) Locals; NOTE: Further subdivisions used: 1) Core Area Street 2) Transit Mall Street 3) Transit (Tri-Met) Street 4) Light Rail Street 5) Light Rail/Transit Street 6) Industrial Area Street	X		X						X	
City E	X	X	X		X	8	a) Major Arterial; b) Arterial; c) Collector; d) Heavy Industrial; e) Light Industrial; f) Local; g) Residential; h) Cul-de-sac		X		X						

TABLE 3 *continued*

AGENCY	CODE	ROUTE IDENTIFICATION	LIMITS: BLOCK-BY-BLOCK	LIMITS: MILE POST	LIMITS: OTHER	CLASSIFICATION: NUMBER	CLASSIFICATION	SPECIAL CONSIDERATIONS: LANE IDENTIFICATION	SPECIAL CONSIDERATIONS: INTERSECTIONS	SPECIAL CONSIDERATIONS: BUS LANES	SPECIAL CONSIDERATIONS: PARKING AREAS	SPECIAL CONSIDERATIONS: BICYCLE LANES				SPECIAL CONSIDERATIONS: OTHER	COMMENTS
City F	X	X(1)	X		X	X	a) Arterial b) FAU Route c) Bus Route d) Collectors e) Residential	X	X			X					Sections identified by node numbers. (1) for FAU routes.
City/County A	X	X	X			4	a) Arterial - with buses b) Arterial - without buses c) Local - with buses d) Local - without buses		X	X						X	Consideration of tracks
City G	X				X	3	a) Commercial b) Primary c) Residential										Sections and 2500 $ft.^2$ sample units
County B		X		X		5	a) Principal Arterial b) Minor Arterial c) Major Collector d) Minor Collector e) Local Access	X									Segments less than or equal to 0.5 mi.
County C	X	X		X	X	3	a) Major - FAS/FAU b) Select c) Minor	X	X							X	Lengths between intersections (usually 1 mile maximum length). Roads classed as diskable.
City H		X	X			4	a) Arterial b) Industrial c) Industrial d) Residential			X						X	Design traffic level associated with each classification.
Regional, Municipality A	X	X			X		None										

In planning the PMS, a realistic estimate of the amount of funds available is very important.

Information Requirements

The three main types of data files considered by the agencies include *(a)* design and construction, *(b)* maintenance history, and *(c)* pavement condition.

The design and construction file can include information relative to parameters related to construction or reconstruction; for example, dates, traffic, soil support, materials, and layer thicknesses. More or less information can be included as desired.

The maintenance history file can include information relative to what was done to maintain a segment as well as its timing. Overlays, surface treatments, base repairs, and crack sealing are specific examples of maintenance activities. Historical information of this kind is useful to the engineer when packaging projects.

Information to be included in the pavement condition file will vary depending on local experience. Typical kinds of information for flexible pavements include surface type; transverse cracking; fatigue (alligator cracking); deformation (ruts and corrugations); edge deterioration (cracking, shoulder drop off); block cracking; patching; utility cuts; ride; and raveling.

In most cases agencies agree that they started by trying to collect more information than was necessary. This slows down the condition survey, reduces reliability of information, requires increased computer storage and programming and, in general, is nonproductive. The rule should be: Collect only what is necessary.

PAVEMENT MANAGEMENT SYSTEMS: SPECIFIC CONSIDERATIONS

When developing a PMS a number of items must be considered. These include

Section identification,
Pavement condition surveys,
Other files,
Maintenance and rehabilitation alternatives,
Performance prediction,
Network programming,
Optimization,
Data management, and
Reports.

Some of these items will be discussed in this section; they are based on results of the survey and are summarized in Tables 3 to 8.

Section Identification

Street or roadway identification is required for data collection, analysis, and reporting purposes. Codes or street names, or both, have been used for section identification. Alphanumeric codes can be used to describe street classification (arterial, collector, and so on); general location in city; maintenance responsibility; and number of issues. The codes are tied to specific street sections with defined limits. A street or road section should be a consistent pavement type [portland cement concrete (PCC), asphalt concrete (AC), and so on]; pavement structural section; and traffic volume. The beginning and ending of the sections or section limits should be clearly identifiable in the field. Table 3 provides a summary of the procedures used by the organizations interviewed.

Section Length

Some cities have elected to designate sections on a block-by-block basis. Other organizations have sections that are several miles in length. Selection of section length should give consideration to the following:

1. Uniformity of the section:

   Pavement type,
   Pavement structural section,
   Traffic volume,
   Age of pavement,
   Rehabilitation history, and
   Maintenance history.

2. Classification

   Functional (arterial, collector, residential); and
   Funding (federal, state, county, and city special funding categories).

3. Scheduling rehabilitation and maintenance activities.

As a general guide, section limits should be selected on the basis of uniformity, with consideration given to classification and scheduling. If this approach is followed, section length will not be a constant.

Classification

Most cities use a functional classification for their streets. Requirements for typical structural sections, geometrics, drainage, and so on, will be associated with the classifications used. These classifications may also be associated with funding categories. For example, major arterials may be eligible for federal funding, whereas rehabilitation of residential streets must be paid for by adjacent property owners. These considerations are important when scheduling rehabilitation and maintenance activities.

Other Considerations

The preparation of budgets requires an estimate of the area of pavement to be rehabilitated or maintained. Thus, the street or lane width, number of lanes, parking areas, and so on, in addition to section length, become important. It may or may not be necessary to measure street width. For example, if section limits are based in part on street classification and if geometrics are based on street classification, network budget preparation will not require street width to be measured as part of the inventory.

Intersections have special pavement and drainage problems that require separate considerations. These special problems can be handled by notes attached to street evaluation forms or by separate special forms. If special forms are used for intersections, the limits of the intersection need to be defined.

Considerable time and expense is often required to establish street section limits. As indicated above, construction, rehabilitation and maintenance history files, as well as traffic files, should be consulted before establishing limits. Unfortunately, many cities and counties have poor records that cannot be readily used.

Pavement Condition Surveys

Pavement smoothness (ride quality) and safety (skid resistance) are important functional considerations. Pavement distress, while important from a functional standpoint, is extremely important as an indication of structural condition.

Ride quality is usually evaluated during pavement distress condition surveys; e.g., by use of a car ride meter. Safety is often evaluated by measuring a pavement friction number or by accident frequency information, or both. These objective measuring techniques are not widely used by cities and counties at the present time. Subjective measurements of safety are sometimes made by recording the presence of flushing or bleeding.

Pavement smoothness and coefficient of friction are dependent on speed. The slower speeds of city traffic decrease the relative importance of these functional performance items compared with those of rural county or state roadway networks.

Types of Distress

Pavement structural condition surveys are performed to identify the type, extent, and severity of several distress types. Indications of permanent deformation (rutting, shoving, corrugations), surface distress (flushing, raveling, surface wear, fuel damage), cracking (alligator, longitudinal, transverse) and maintenance (patching) are usually included in these surveys (see Table 4). As seen in this table, the number of distress types and the detail to which the extent and severity of each distress type is recorded are highly variable among existing city and county pavement management systems. The detail required should be dictated by the end use of data. If selection of rehabilitation and maintenance alternatives is desired from recorded distress information, the distress condition survey forms should be developed to include the required detail. Experience suggests that the amount of detail required is usually much less than was originally envisioned.

Method of Data Collection

Condition survey information can be collected electromeechanically or by visual surveys. Visual surveys are usually performed by a single individual or a two-person team. Survey techniques require driving the street sections at a slow speed or walking along all or portions of the street section. Windshield or driving surveys may involve stopping of the vehicle for short periods of time. Walking surveys range from walking the entire length of the section to walking three to five randomly selected portions of a pavement section. Walking surveys provide more accurate data than riding surveys, but costs are higher. The degree of accuracy required of the data should be considered when selecting the data-collection methodology.

A variety of electromechanical devices are available to record pavement distress. These devices range from units with electronic input for recording data as they would appear on a manual input form to the use of enhanced video images to record the type, degree, and extent of selected types of pavement distress. None of the existing PMS reviewed for this study presently uses electromechanical devices.

Frequency of Surveys

Condition surveys should be performed at sufficient intervals to monitor pavement condition changes that will affect selection of rehabilitation or maintenance alternatives. Roadways in relatively poor condition may need to be surveyed annually, whereas new sections with relatively good performance can be evaluated every 2 to 3 years. Usually $1/3$ to $1/2$ of all pavement sections are evaluated annually. Thus, a 2- to 3-yr cycle is considered adequate by many organizations.

Condition surveys are most often performed in the spring. Current condition information is then available to assist in scheduling summer rehabilitation and maintenance activities. In addition, roadways are usually in their worst condition during the spring. However, some cities will perform condition surveys in the winter and summer.

Condition Survey Index

Condition survey information can be used together with an appropriate scoring system to develop a condition index. Most systems assign deduct points to specific types, degrees, and extents of distress. These deduct points are summed and subtracted from 100. This process results in a single value index to describe condition index.

Several systems used this pavement distress in combination with other numeric scores, such as roughness, drainage, and so on, to calculate a combined score, which is used to describe the roadway or street condition.

Supporting Information

In addition to the data and information associated with pavement condition, most pavement management systems provide for supporting data to be used for such things as priority scores, engineering analysis, and cost data. Table 5 provides a summary of the other general types of data collected.

Files for the supporting data are often referred to as *(a)* design and construction, *(b)* maintenance history, *(c)* rehabilitation and maintenance, *(d)* drainage, and *(e)* geometrics. There may be others; the above are mentioned as illustrations.

To illustrate further, the design and construction file would contain information to relate design to life-cycle performance; maintenance history would provide information on the sequence of actions (treatments) subsequent to construction and life-cycle evaluation. These supporting files could also provide

TABLE 4 CONDITION SURVEYS

AGENCY	PHYSICAL DISTRESS																												COND. INDEX		ROUGH-NESS		Deflection	SAFETY			COMMENTS
	TYPE																						METHOD OF DATA COLLECTION				FRE-QUEN-CY										
	RUTTING	SHOVING	CORRUGATION	FLUSHING	RAVELING	SURFACE WEAR	FUEL/DRIPPING DAMAGE	ALLIGATOR CRACKING	LONGITUDINAL CRACKING	EDGE CRACKING	TRANVERSE CRACKING	BLOCK CRACKING	SLIPPAGE	POTHOLES	PATCHING - THIN	PATCHING - THICK	UTILITY TRENCH	POLISHED AGGREGATES	REFLECTED CRACKING	SEALS	SPALLING	SLAB BREAKUP	FAULTING	VISUAL - WALKING	VISUAL - WINDSHIELD	ELECTRONIC	MECHANICAL	PERCENT SECTIONS PER YR.	TIME OF YEAR**	SINGLE VALUE	COMBINED VALUE	SUBJECTIVE	OBJECTIVE	OBJECTIVE	SUBJECTIVE	OBJECTIVE - FRICTION NO.	OBJEC. - ACCIDENT FREQ.	* - See final page ** of table.
City A	X	X				X		X	X		X			X		X	X								X			50	W Sp			X						
City B	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X					X				10			X	X			X			
County A	X	X	X	X	X	X		X	X		X			X				X						X				50			X	X			X		X	
City C	X		X		X			X				X		X**											X			50 50	M A O N	X								** - Special Report
City D	X				X			X	X		X		X												X			*	Jan Jul		X	X		**				* - 50% Arterials 30% Locals ** - Dynaflect Deflections
City E			X	X																					X			33	W Sp	X		X			X			Relative performance age evaluated.
City F	X				X	X	X	X	X		X	X		X	X	X	X			X				X	X			*		X		X		**			X	* - Sections not receiving Maint./Rehab. surveyed yearly. ** - Deflections meas. with Dynaflect on entire system
City/County A					X			X	X		X	X													X			50	Sp	X	X	X*		**				* - Contribution to ride qual. made by RR tracks is assessed. ** - Only when structural evaluation required.

TABLE 4 *continued*

AGENCY	PHYSICAL DISTRESS: TYPE																							METHOD OF DATA COLLECTION				FRE-QUEN-CY		COND. INEX		ROUGH-NESS		Deflection	SAFETY			COMMENTS
	RUTTING	SHOVING	CORRUGATION	FLUSHING	RAVELING	SURFACE WEAR	FUEL/DRIPPING DAMAGE	ALLIGATOR CRACKING	LONGITUDINAL CRACKING	EDGE CRACKING	TRANSVERSE CRACKING	BLOCK CRACKING	SLIPPAGE	POTHOLES	PATCHING - THIN	PATCHING - THICK	UTILITY TRENCH	POLISHED AGGREGATES	REFLECTED CRACKING	SEALS	SPALLING	SLAB BREAKUP	FAULTING	VISUAL - WALKING	VISUAL - WINDSHIELD	ELECTRONIC	MECHANICAL	PERCENT SECTIONS PER YR.	TIME OF YEAR**	SINGLE VALUE	COMBINED VALUE	SUBJECTIVE	OBJECTIVE	OBJECTIVE	SUBJECTIVE	OBJECTIVE - FRICTION NO.	OBJECTIVE - ACCIDENT FREQ	
City G	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X						X				10		X		X			X			
County B			X	X	X			X	X	X	X				X	X					X	X	X	X				50			X	X						
County C	X			X	X			X	X		X	X		X	X	X	X			X				X				33	Jan Jul	X	X	X		*				* - AC overlays assigned based on deflection data.
City H					X			X	X			X			X	X	X		X	X	X	X		X	X			*			X	X		**				* - Worst 1/3 of system 1st year; 4 yr. sequence then followed ** - Deflections meas. on cand. proj. using FWD
Regional, Municipality A	X	X	X	X	X	X		X	X	X	X		X											X				50	Sp Su	X	X		X					

*** - Key: W = winter, Sp = spring, Su = summer, F = fall; M = March, A = April, Jan = January, and Jul = July.

TABLE 5 OTHER DATA

AGENCY	HISTORIC					DRAINAGE				TRAFFIC				GEOMETRICS						OTHER				
	INITIAL DESIGN	SURFACE TYPE	CONSTRUCTION	REHABILITATION	MAINTENANCE	OVERALL	CURB AND GUTTER	SIDE DITCHES	VALLEY CUTTER	ADT	PERCENT OF TRUCKS	EAL/TRAFFIC INDEX	PEAK HR. TRFC. EST.	CROSS SLOPE	LONGITUDINAL SLOPE	NUMBER OF LANES	SEGMENT LENGTH	WIDTH	AREA	SIDEWALKS	UTILITIES	SPEED LIMIT	DIRECTION	LAND USE
City A	X		X	X	X		X		X	X								X	X	X	X			
City B																		X	X					
County A		X		X		X				X						X	X	X	X			X	X	
City C	X	X	X	X	X		X			X		X				X	X	X	X					X
City D		X	X	X	X	X	X			X	X					X	X	X					X	
City E						X										X		X	X					
City F										X	X					X	X	X	X			X	X	
City/County A	X	X	X	X	X		X			X		X			X	X	X	X	X					
City G		X	X		X		X					X				X	X	X	X					
County B	X	X	X	X	X					X	X		X			X	X	X	X					
County C		X	X	X	X	X				X						X	X	X				X	X	
City H		X	X*	X*	X*					X	*	X				X	X						X	X**
Regional, Municipality A	X				X					X		X				X		X	X					

* - Data gathered for segments during project design, not for entire network as yet.

** - Basis for classification of non-arterial or non-collector streets.

information required to calculate benefit-cost ratios based on such considerations as number of users, e.g., average daily traffic (ADT), type of users (equivalent axle loads), and the maintenance-plus-rehabilitation costs.

Drainage information, which could influence performance, may be included as a special file or in the design and construction file. Geometrics, signs, legends, and so on, could be added, provided some benefit or use could be identified.

One of the major problems in developing a PMS is the tendency to collect more information than is necessary or useful for the system. Experience indicates that care should be taken not to collect more information than is necessary to support the system. Thus, in developing a PMS, every bit of information to be collected should pass the following test as a minimum:

1. The data will be used to identify sections with poor performance,
2. The data will be used to establish priorities,
3. The data will be used to select maintenance or rehabilitation actions,
4. The information will be used to calculate the cost of maintenance and rehabilitation actions,
5. The information can be used to estimate life-cycle costs of each maintenance and rehabilitation action, and
6. The information can be used to estimate the life-cycle costs of newly constructed pavements.

Additional information can be selected; however, the criteria for selection should include how the information is to be used in the PMS or some other system useful to the agency. Avoid collecting information that would be "nice to have."

Maintenance and Rehabilitation Alternatives

Table 6 shows the types of rehabilitation and maintenance alternatives used by agencies surveyed in this study. From 3 to 16 alternatives are used in the various systems.

Performance Prediction or Network Programming (Data Utilization)

Figure 2 provides an illustration of the various levels of a PMS that can be produced, starting with a data base of information

TABLE 6 REHABILITATION AND MAINTENANCE ALTERNATIVES

AGENCY	THICK OVERLAY	INTERMEDIATE OVERLAY	THIN OVERLAY	THICK OVERLAY & INTERLAYER	INTERMEDIATE OVERLAY & INTERLAYER	THIN OVERLAY & INTERLAYER	MILL & FILL	MILL, FILL & OVERLAY	HEATER-SCARIFICATION & OVERLAY	IN-PLACE RECYCLING	CHIP SEAL	SLURRY SEAL	CAPE SEAL	SPECIAL BINDER SEAL	FOG SEAL	REJUVENATOR SEAL	RECONSTRUCTION	THIN OVERLAY & LOCAL DIGOUTS	THIN OVERLAY & LEVELING	INTERMEDIATE OVERLAY & LOCAL DIGOUTS		CRACK SEALING	SURFACE PATCHING	REMOVE & REPLACE PATCHING		DISK AND RELAY	HEAT, DISK, AND RELAY	COMMENTS
City A		X				X	X		X		X						X						X	X				
City B																												
County A	X	X	X						X	X	X	X			X	X	X					X	X	X				NO presently considered in system
City C						1-1/2" X	X					X	X				X						X	X				
City D			X								X	X					X					X		X				
City E	X	X	X						X		X	X	X		X							X	X	X				
City F		X	X			X	X			X	X	X	X		X		X	X	X			X	X	X				
City/County A		X			(1)		X	X				X					(1)	(1)	(1)									(1) Alternatives considered by design engineer.
City G	X							X	X	X	X				X							X		X				Other alternatives considered by PAVER
County B	X		X								X	X																Alternate rehab strategies may be considered.
County C	X	X									X					X						X	X	X		X	X	Also uses sand seal
City H	X	X	X	X	X	X			X	X		X			X	X	X			X		X	X	X				
Regional, Municipality A		X	X														X											

TABLE 7 DATA UTILIZATION

AGENCY	Basis for Prediction Models					Network Programming						Network Optimization Objective Function		Data Management Hardware				COMMENTS
	EXPERIENCE DATA	HISTORIC DATA - REGRESSION	HIST. DATA - TRANSITION MATRIX	SUPPLIED BY SYSTEM	MECHANISTIC	RANKING BY SCORES	PRIORITIES	AGENCY	CONSULTANT	AVAIL. TO OTHER USERS	PROGRAM DEVELOPED BY	MINIMIZE COSTS	MAXIMIZE BENEFITS	CARD	PERSONAL COMPUTER	MAINFRAME	PACKAGING CAPABILITY	
City A						X	X			X	Consultant	X				X		No prediction models
City B		X		X		X			X		APWA-COE					X		Prediction models not used
County A		X									In-house				X			Changed from mainframe to PC/AT in 1985
City C	X						X		X	X	Consultant				X	X		Initially on mainframe (1979) Changing to PC (1985)
City D	X					X			X		Consultant					X	X	
City E				X			X		X		Consultant					X		Priorities based on type of treatment - heavy overlays first
City F							X			X	CALTRANS-FHWA					X		Prior. based on cost effec. treat. Pvmts with high deflect. get first priority.
City/County A	X						X				Consultant				X	X		Changing to PC during second year
City G				X		X			X		APWA-COE					X		
County B		X				X		X		X	Washington DOT Consultant	X			X	X		Input and output optional on PC - manipulation and data storage on mainframe
County C	X					X	X			X	CALTRANS FHWA				X			
City H						X	X			X	In-house					X		
Regional, Municipality A			X			X	X		X		Consultant	X				X		

TABLE 8 REPORTS

AGENCY	STREET/ROAD LISTING	RANKING: CONDITION SCORE	RANKING: PRIORITY SCORE	RANKING: DISTRESS TYPE	RANKING: REHAB/MAIN ALTERNATIVES	RANKING: MAINT. AREA/DISTRICT	RANKING: RIDE QUALITY	RANKING: ROAD/STREET CLASSIF.	BUDGET: BY YEAR	BUDGET: BY REHAB/MAINT. ALTERN.	BUDGET: 3 - 5 YEARS	OTHER REPORTS: CURB & GUTTER CONDITION	OTHER REPORTS: SLIDE DUTCH CONDITION	OTHER REPORTS: VALLEY GUTTER CONDITION	OTHER REPORTS: SIDEWALK CONDITION	OTHER REPORTS: SAFETY	OTHER REPORTS: DESIGN & CONSTRUCTION	OTHER REPORTS: MAINTENANCE HISTORY	OTHER REPORTS: COST ANALYSIS
City A	X	X		X	X	X	X		X			X		X	X				
City B	X	X			X				X		X								
County A	X	X			X	X	X	X										X	
City C	X																	X	
City D	X	X						X	X										
City E	X	X			X				X	X	X								
City F	X	X(1)	X	X	X			X	X										X
City/County A	X	X	X	X					X	X							X	X	
City G	X	X			X				X		X								
County B	X	X	X	X	X	X		X	X	X	X							X	
County C	X		X		X				X								X	X	
City H	X	X	X	X					X										
Regional, Municipality A	X	X	X						X		X								

(1) By Dynaflect analysis, rater score.

(6). The five components of the data base are construction history, inventory, traffic, surface friction, and pavement condition.

It is not necessary to include all of the files indicated above; however, some agencies may want to add additional files for maintenance history, signing, drainage, shoulders, and so on.

The key information for most city and county systems will be contained in the traffic, construction history, and condition-rating files. Depending on what information is contained in the construction history file, a record of maintenance may be useful and may be incorporated in a separate file. With these data, various methods of use are available. These are summarized in Table 7 for the organizations involved.

The condition file can be used to evaluate the overall health of the pavement network by a simple tabulation of condition, as illustrated in Figure 3, taken from reports prepared for the city of Vacaville, California (not included in this study). In this report, each street segment has been ranked according to the severity and extent of fatigue (alligator) cracking. Severity ranges from 1 to 3 (with 3 being the most severe) and extent ranges from 1 to 4, according to the percent of the length affected (4 being the greatest extent). Thus, if fatigue cracking is considered to be the most critical condition rated, the first nine sections listed would be given first consideration for corrective action. Other statistical information could easily be produced from this type of information. For example, what percentage of the segments in the network have fatigue cracks in severity level 3 and extent 4?

The interpreting program referred to in Figure 2 translates (interprets) the information into a combined rating for each section using condition data in the data base. This is accomplished by applying weighting values to the extent and severity of each distress category.

The combined index can be used in a number of ways:

1. To establish priorities;
2. To summarize overall condition of pavements in the network, i.e., health of system;
3. To develop performance curves (predictions) over time; and
4. To provide performance trends based on budget level.

Priorities are necessary to determine which projects to rehabilitate when there are funding constraints. However, before priorities can be established it is necessary to identify which segments need rehabilitation or maintenance.

Figure 4 illustrates a technique for establishing threshold values for maintenance or rehabilitation. Using this method,

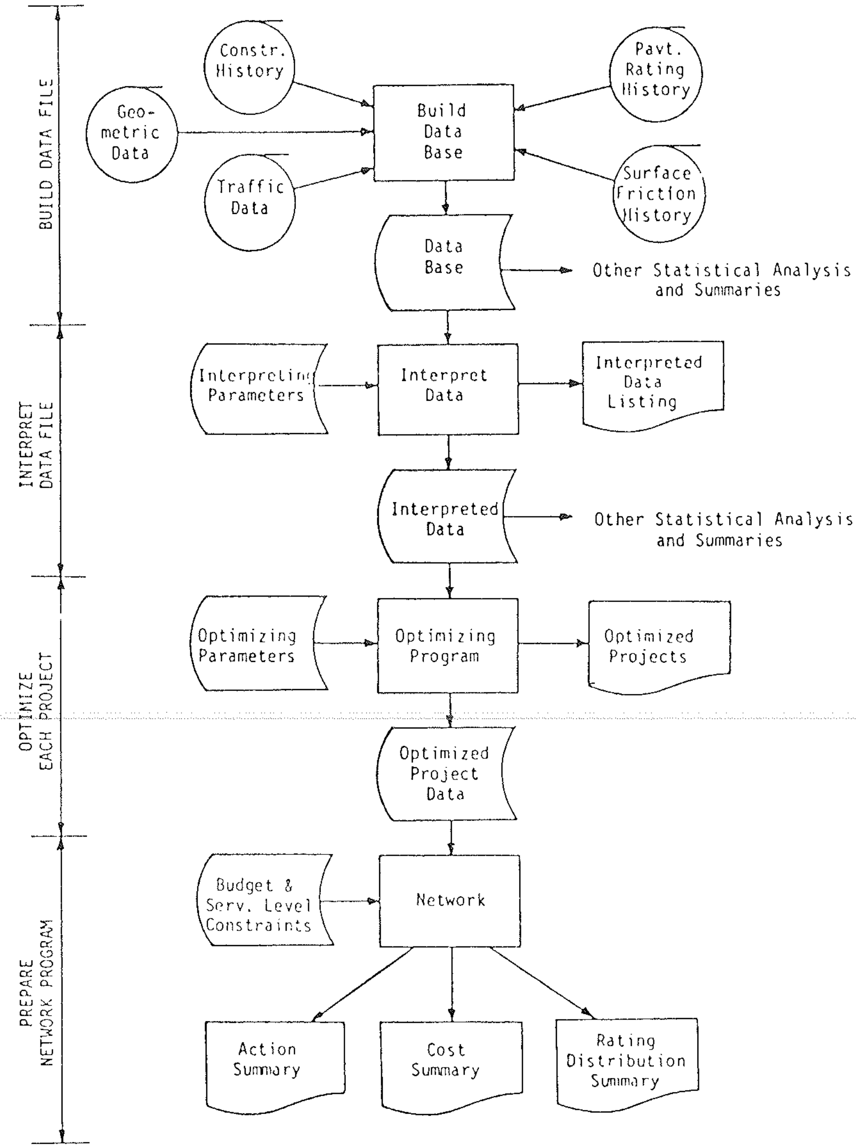

FIGURE 2 Conceptual flow chart of Washington State operations *(6)*.

deduct values are assigned to each type of distress to be remedied by treatment. Depending on the condition and traffic (as measured by the Traffic Index, TI), an action is recommended. If more than one deficiency is noted, a selection logic is used to define the action that will correct all recorded deficiencies below the threshold value, as shown in Figure 5. This latter technique is similar to procedures used by cities and counties that use the California Department of Transportation PMS *(6)*.

Thus, priorities can be established without prediction models or optimization. A procedure of this type is relatively simple; however, it relies almost entirely on engineering judgment and experience to identify threshold values and the best action or treatment. In many cases, this is all that is needed. If prediction models are available, it is possible to develop an optimization procedure. Only a limited number of systems for cities and counties incorporate such procedures. The general approach is to develop some objective function that is to be minimized or maximized; for example, costs can be minimized, or the ratio of benefits to costs can be maximized. Virtually all of the techniques used depend on some measure of performance and cost.

The benefits of optimization are considerable, providing the resources can be made available to develop and maintain such a system. Optimization will compare a large number of alternative treatments for a pavement section in such a way as to recommend the best action and the best time to initiate a treatment, depending on prevailing conditions.

Regardless of the level of sophistication incorporated into the system, the final step is to package the projects into a program for development of a set of plans and specifications, and eventually an action plan.

Reports

Existing data-management programs provide an opportunity for the user to sort and provide data in numerous report formats. Street listings, rankings, and budget information are examples of the reports provided by all surveyed PMS. Table 8 contains a summary of the various kinds of reports generated.

SECT	STREET	FROM	TO	DATE OF SURVEY	LNGTH	WIDTH	LNS	ALGT CRCK SEV	ALGT CRCK EXT	EDGE CRCK SEV	EDGE CRCK EXT	RAVL SURF SEV	RAVL SURF EXT	PAVM DIST SEV	PAVM DIST EXT	POTH
130	ALAMO DRIVE	VANDEN ROAD	LEISURE TOWN ROAD	05/28/85	0.65	25	2	3	4	3	2	2	1	1	2	1
420	ELMIRA ROAD	NUT TREE ROAD	CHRISTINE DRIVE	05/01/85	0.25	24	2	3	4	3	4	1	1	1	1	0
430	ELMIRA ROAD	CHRISTINE DRIVE	EDWIN DRIVE (WEST)	05/01/85	0.20	45	2	3	4	2	4	0	0	0	0	0
440	ELMIRA ROAD	EDWIN DRIVE (WEST)	LEISURE TOWN ROAD	05/01/85	0.45	60	2	3	4	0	0	0	0	0	0	0
470	LEISURE TOWN ROAD	CITY LIMIT	INTERSTATE 80	05/29/85	0.40	25	2	3	4	2	2	2	1	1	2	1
480	LEISURE TOWN ROAD	INTERSTATE 80	ULATIS CREEK	05/29/85	1.25	25	2	3	4	3	2	3	1	1	2	1
500	LEISURE TOWN ROAD	KINGSWOOD AVENUE	ALAMO DRIVE	05/29/85	0.70	25	2	3	4	3	3	2	1	1	2	1
650	MERCHANT STREET	ELM STREET	ALAMO DRIVE	05/01/85	0.30	45	2	3	4	0	0	1	1	1	1	0
950	SEQUOIA	LEISURE TOWN ROAD	YELLOWSTONE DRIVE	05/29/85	0.10	50	2	3	4	3	2	3	1	0	0	1
70	ALAMO DRIVE	CRYSTAL LANE	ALDERWOOD WAY	05/28/85	0.30	30	2	3	3	0	0	0	0	1	1	0
670	MERCHANT STREET EB	STEVENSON STREET	MAIN STREET	05/01/85	0.30	25	4	3	3	0	0	1	2	0	0	0
675	MERCHANT STREET WB	MAIN STREET	STEVENSON STREET	05/01/85	0.30	25	4	3	3	0	0	1	2	0	0	0
750	MONTE VISTA AVENUE	JUST WEST OF INTERSTATE 505	ROAD CLOSED	05/30/85	0.60	30	2	3	3	0	0	3	2	1	2	1
1020	YELLOWSTONE DRIVE	SEQUOIA DRIVE	NUT TREE ROAD	05/01/85	1.00	40	2	3	3	9	2	0	0	0	0	0

FIGURE 3 Listing of streets by severity and extent of alligator cracking, Vacaville, California *(7)*.

RIDE QUALITY

RATING	Deduct Values	TREATMENT TI 5	6	7	8
Acceptable	0	DN	DN	DN	DN
Tolerable	25	DN	DN	DN	OL
Unacceptable	60	OL	OL	OL	OL

AREAL CRACKING

SEVERITY	Deduct Values Extent (% of Area) N/O	1-25	26-50	>50	Deduct Values	TREATMENT TI 5	6	7	8
Acceptable	0	5	10	15	<19	DN	DN	DN	DN
Tolerable	0	13	19	26	19--23	DN	P	P	M&F
Unacceptable	0	23	30	40	26--30	OL	M&F	M&F	MF&O
					40	M&F	M&F	MF&O	RES

RAVELING

SEVERITY	Deduct Values EXTENT (% of Area) N/O	1-25	26-50	>50	Deduct Value	TREATMENT TI 5	6	7	8
Acceptable	0	4	8	12	<16	DN	DN	DN	DN
Tolerable	0	11	16	21	16--18	DN	SS	SS	OL
Unacceptable	0	18	24	31	21--31	SS	SS	OL	OL

ABBREVIATIONS

The following abbreviations are used to describe the severity and extent of the several distresses, and the recommended treatment.

CpS - Cape Seal
DN - Do Nothing
M&F - Mill & Fill*
N/O - Not Observed
P - Patch
SS - Slurry Seal
* - Includes recycled materials

CS - Crack Sealing
FS - Fog Seal
MF&O - Mill, Fill* & Overlay
OL - Overlay
RES - Restore or Reconstruct
TI - Traffic Index

FIGURE 4 Deduct values for pavement distress and recommended treatments *(7)*.

Street Listing

Street listings can be presented by sections for the entire street or for an area or district of the city by functional classification. These listings are useful as ready reference for present pavement condition and for location of sections for the annual pavement distress surveys.

Ranking

Ranking reports can be prepared based on a pavement distress condition score and from priority scores that may combine distress condition score, traffic, drainage, and so on, into a single numeric value. Reports that list roadway segments by distress type, ride quality, and rehabilitation or maintenance alternatives provide an opportunity for ranking actions. For example, all roadways with severe alligator cracking may be the highest priority for rehabilitation. Rankings can be provided within maintenance area or district or within functional classifications.

Budget

Reports describing yearly budget requirements are provided by all surveyed PMS. A few systems forecast budget requirements over a 3- to 5-yr period. Budget requirements by rehabilitation and maintenance alternative are provided by some systems on a routine basis.

COST AND PERSONNEL CONSIDERATIONS

Development and annual costs of the 13 systems, together with their personnel and equipment requirements, are summarized in Table 9. Costs to develop ranged from less than $50/mi to more than $400/mi. Values on the order of $100 to $300 appear to represent a reasonable range that might be anticipated by an organization. Generally, if little historical data are available, the costs will be on the higher side, e.g., City *D*.

Annual costs of about $100/mi to operate the system are considered to be average (see Table 9). This amount should provide a reasonable guide for budget-estimating purposes.

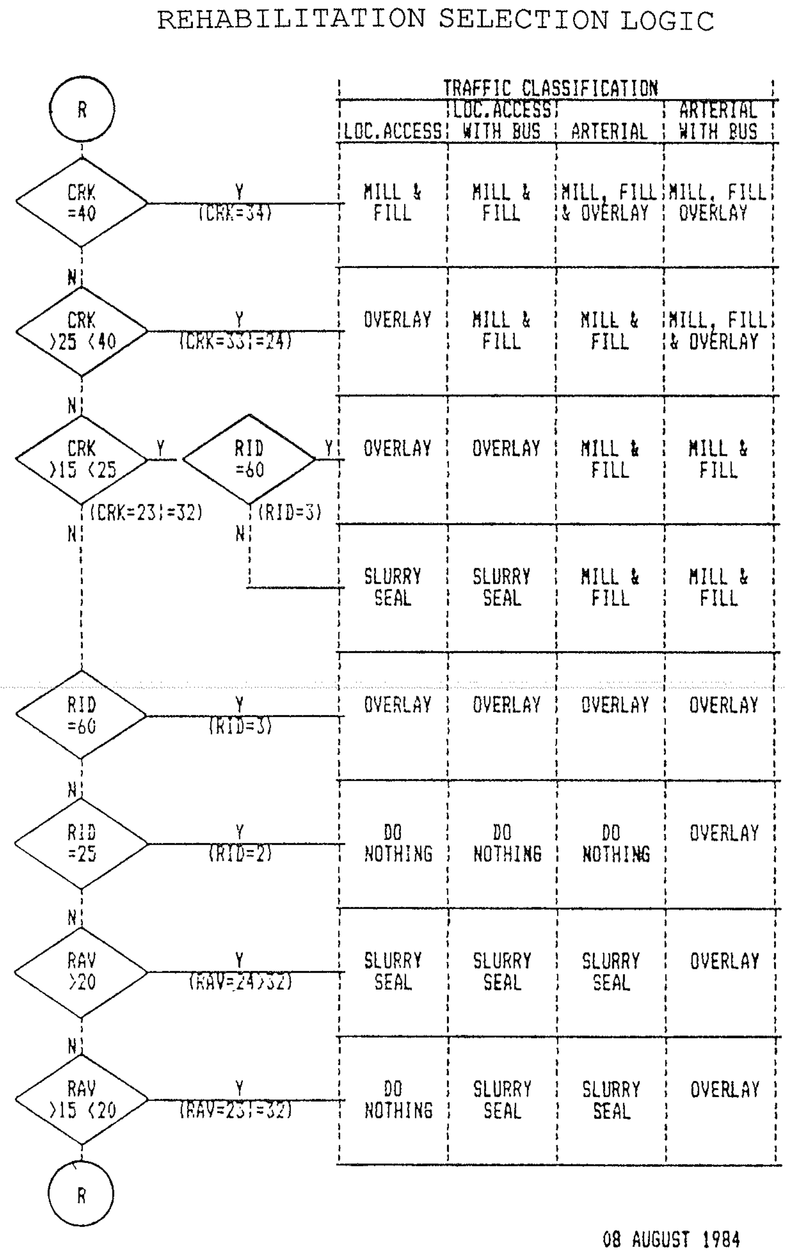

FIGURE 5 Rehabilitation logic *(7)*.

Personnel requirements will vary depending on the size of the system and whether the system is developed in house or by consultants. For smaller cities it would appear that a minimum of 2–3 person months are required to conduct the necessary activities associated with the system once it is operational. This requirement will increase as the size of the system increases, see Table 9. Regardless of the size of the system, however, one engineer within the organization should be responsible for and fully knowledgeable about the system.

As previously noted, and seen in Table 9, other than computer hardware, little additional equipment is required by the majority of the agencies surveyed. For decisions at the project level, after projects have been packaged (Figure 1) and before final designs are set, a number of organizations use the services of other organizations (e.g., consultants) to conduct structural evaluations to ensure that the treatments selected are correct.

CONCLUDING REMARKS

As funding becomes increasingly constrained, systematic procedures to assist in the decision process for fund allocation for pavement maintenance and rehabilitation activities assume greater significance. Pavement management systems, if properly formulated, can be of immeasurable assistance in this decision process to engineers responsible for road and street networks. To be effective, however, a commitment must be made to maintain and update the system and to follow the strategies proposed.

In the organizations surveyed in this investigation, the representatives stated that their systems were most helpful to them in making maintenance and rehabilitation decisions and that they planned continued use of the systems.

TABLE 9 COST AND EQUIPMENT REQUIREMENTS

AGENCY	DEVELOPMENT: COST, $ × 10^3: TOTAL	DEVELOPMENT: COST, $ × 10^3: MANPOWER	DEVELOPMENT: COST, $ × 10^3: EQUIPMENT	DEVELOPMENT: MAN-MONTHS: SURVEY DATA	DEVELOPMENT: MAN-MONTHS: DATA MANAGEMENT	DEVELOPMENT: MAN-MONTHS: SUPERVISION	DEVELOPMENT: MAN-MONTHS: TOTAL	DEVELOPMENT: EQUIP. REQUIREMENTS: VISUAL CONDITION	DEVELOPMENT: EQUIP. REQUIREMENTS: ROUGHNESS	DEVELOPMENT: EQUIP. REQUIREMENTS: DEFLECTION	DEVELOPMENT: EQUIP. REQUIREMENTS: FRICTION	DEVELOPMENT: EQUIP. REQUIREMENTS: CURING/BORING	DEVELOPMENT: EQUIP. REQUIREMENTS: COMP. HARDWARE	DEVELOPMENT: SOFTWARE	ANNUAL: % EVAL. ANNUALLY	ANNUAL: COST. $ × 10^3: TOTAL	ANNUAL: COST. $ × 10^3: MANPOWER	ANNUAL: COST. $ × 10^3: EQUIPMENT	ANNUAL: MAN-MONTHS: SURVEY DATA	ANNUAL: MAN-MONTHS: DATA MANAGEMENT	ANNUAL: MAN-MONTHS: SUPERVISION	ANNUAL: MAN-MONTHS: TOTAL	COST PER MILE: DEVELOPMENT	COST PER MILE: ANNUAL	COST PER MILE: DEVELOPMENT	COST PER MILE: ANNUAL	COMMENTS
City A	$ 30 CONS							X							50	$ 18	18		4	1	1	6	115	60			
City B	167 CONS							X							10	20 CS											Software costs approx. $5,000 per year.
County A	50-60							X							50	40-50			9	3	1	13	45	25			Future annual costs expected to be about $30,000 - $35,000 for 1,300 centerline miles of roads
City C	50	$48	$ 2	2	4	1	7	X					X	X	100	18	$10-CS 2-DE, 6-Supervision		1.5	1	2	4.5	227	90	1.00	.40	
City D	300*		46					X		X		X			See Tbl 4	***	**		18			****					*Development costs: $ 98,000 Consultants; 200,000 In-house **Data entry and data processing costs: $12,000 - $17,000 ***Personnel costs are approx. 80 percent of total ****2 engineers and 1 technician devote part-time to system
City E	39 CONS							X				X			33	30			12	3	3	18	35*	35			*Consultant's charges

TABLE 9 *continued*

AGENCY	DEVELOPMENT: COST, $ × 10^3: TOTAL	MANPOWER	EQUIPMENT	DEVELOPMENT: MAN-MONTHS: SURVEY DATA	DATA MANAGEMENT	SUPERVISION	TOTAL	DEVELOPMENT: EQUIP. REQUIREMENTS: VISUAL CONDITION	ROUGHNESS	DEFLECTION	FRICTION	CURING/BORING	COMP. HARDWARE	SOFTWARE	% EVAL. ANNUALLY	ANNUAL: COST, $ × 10^3: TOTAL	MANPOWER	EQUIPMENT	ANNUAL: MAN-MONTHS: SURVEY DATA	DATA MANAGEMENT	SUPERVISION	TOTAL	COST PER MILE: DEVELOPMENT	ANNUAL	COST PER MILE: DEVELOPMENT	ANNUAL	COMMENTS
City F	$ 11	6	5	3	6	6	15	X	N/A	(1)	N/A	(1)	X	X	See Tbl 4	$ 7	4	3	1	1	1	3	50	35	100	78	(1) By consultant
City/County A	400*		#30**	6	3	9	18	X					X	X	50	150	$60-CS 20-DE 30-DP						470	176	.57	.21	*Development Costs: $ 56,000 Consultants 300,000 In-house **Duplicate computer hardware in maintenance and engineering sections.
City G	15-20							X							10	30-35						12	100	200			One full-time employee performs all functions
County B	5	5			1.5	1	2.5	X					X	X	50	20	15	5	2	2	1	5	6	22	.03	.15	See (a) below
County C	40	30	10	2	8	2	12	X					X		*	16	15	1	4	1	1	6	13	5	.32	.13	*Once every 3 years.
City H	12.5							X							See Tbl 4		2.6 per 1000 segments		0.6	0.6							
Regional, Municipality A	250 CONS*							X	X			X			50								530 345	30 **			*Development cost for city: $95,000 **Consultant performs update every 3 years

(a) Low development cost due to availability of a compatible road log data test.

Finally, it must be noted that the user of the PMS should remember that the system cannot make decisions, only the responsible authority can do that. Thus, professionals will always be required to properly formulate and effectively use a pavement management system.

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