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EVALUATION OF SELECTED PAVEMENT MANAGEMENT SYSTEMS FOR MICROCOMPUTERS

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

David Warner Jackson

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DEDICATIONS

This work is dedicated to three important people. My mother, Lucille Elizabeth Cross Jackson, who, rightfully, could not care less about the boring subject contained within but who I am sure is proud of it because it is the work of her son. She certainly is the finest mother anyone has ever had, and has provided unconditional support all of my life. My father, Warner Glen Jackson, Jr., is the best engineer I have ever seen, even though he did not have the luxury of attending formal engineering school. Most of what I know is what he has taught me. This work would never have been completed without the understanding and sacrifice of my wife, Kathie Lynn Garland Jackson, who allowed me to pursue my ambitions of education while she was alone.

ABSTRACT

Significant shortages in pavement maintenance funds compared to funds needed for proper highway maintenance have focused interest on pavement management systems as a tool for making cost efficient maintenance decisions. Lowered costs of microcomputers have increased the possibility of even smaller agencies being able to afford to implement and maintain a pavement management system (PMS).

Three public domain PMS software packages for microcomputers, the Caltrans/FHWA FPMS, the Tulare County, California PMS, and the San Francisco - Oakland Bay Area MTC PMS, were evaluated on the basis of total initial and annual cost, data collection requirements, available output, ease of use, and the validity of the methodology used by each system to develop a pavement condition rating. The evaluation consisted of applying each PMS to a sample street network in Knoxville, Tennessee, to determine the differences in condition rating, suggested repair strategy, prioritization, and estimated repair costs among the PMS on the same sample network. A detailed description of each PMS along with tabulated results of the sample network test is provided to assist potential users in selecting among the PMS discussed.

The Bay Area MTC PMS was determined to have more useful features, at roughly the same initial and annual costs than the other two PMS evaluated. The Bay Area MTC PMS is recommended as the system of choice for all sizes of agencies with pavement maintenance responsibility.

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CHAPTER I

INTRODUCTION TO PAVEMENT MANAGEMENT

INTRODUCTION

The subject of this study involves the meshing of two disciplines that have come into prominence in the last decade, namely microcomputers and management systems, and their combined application to pavement maintenance and rehabilitation. The result of this interface of disciplines is computer based pavement management systems (PMS). Pavement management systems are really not new in concept, having been in use in various forms for decades. But most have been either labor intensive manual systems or systems developed for use on expensive mainframe computers which severely limited the availability of the systems mainly to large public agencies -- in most cases state highway departments. The development of the personal computer in the late 1970's and early 1980's and the exponential growth of the microcomputer industry in the following years with the resultant drop in price has opened the possibility of a computer on every professional's desk in the very near future.

During the 1980's a combination of events led public works officials to seek more objective methods of

maintaining the street network. The interstate system and major arterials constructed during the early 1960's reached the end of their design lives. Development booms produced thousands of miles of new residential and industrial access roads often constructed with substandard designs and poor or no inspection. Traffic demand has increased and although passenger vehicle weights have generally decreased, trucks, which cause by far the most damage to the pavement structure, have increased in gross weight. Inflation rates eroded the buying power of public funds at the same time when controlled supplies of petroleum pushed liquid asphalt prices to all-time highs. Governments charged with providing safe highways have failed to provide for maintenance of probably the most expensive asset, in terms of replacement cost, that any municipality has -- the street network. Street maintenance and rehabilitation funding has traditionally been a small fraction of the amount necessary to check unnecessary deterioration for generally poor reasons. Government funding for street maintenance must first receive budget support from the elected government officials. Street maintenance is a dull topic, citizens seldom rally at City Hall demanding better streets, and while better roads is an oft-spoken campaign promise, the subject seldom becomes a hot election issue. Therefore elected officials whose first priority is usually being re-elected, find it easy to put off highway maintenance funds

until "next year." It should be noted that many governments have recently increased gasoline taxes and sold bonds for the purposes of rehabilitating the highway network. This trend is encouraging but it remains to be seen if the infrastructure has been neglected for too long.

Highway maintenance administrators are now faced with the problem of limited funds and many miles of streets needing maintenance or rehabilitation. Historically, subjective judgment has been the basis for selecting projects. The microcomputer offers a relatively inexpensive, powerful management tool with the capability to store and manipulate large volumes of data as would be required to characterize a pavement network. This paper is an attempt to determine if adequate software has yet been developed to allow the maintenance administrator to objectively allocate the limited funds in a cost efficient manner.

Specifically this study attempts to identify software packages that could be used by small to medium sized cities and counties with minimal modifications. As of this writing no generic pavement management system (PMS) is commercially available for microcomputers. A limited number of systems have been developed by government agencies for their own use either in-house or with the assistance of private consultants. These agencies generously make copies of their systems available to other jurisdictions at nominal costs.

Three of these systems, The Caltrans/FHWA FPMS, developed by the California Department of Transportation and FHWA, a version of the same system modified by the Tulare County, California, Public Works staff for their own use, and a system developed by a private consultant for the Metropolitan Transportation Commission of the San Francisco - Oakland Bay Area, are analyzed for possible use by jurisdictions in other areas. A fourth system developed by the Pennsylvania Department of Transportation was briefly studied and discarded as being too inflexible for use by other agencies.

A description of each system including data requirements and operational features will be presented. Each system was also applied to a sample network of streets in the Knoxville, Tennessee, area to compare and contrast the outputs of the systems over the same streets at the same time. The results of that test follows the system descriptions. Finally a conclusion as to the practicality and possible applications of each system is presented along with opinions on future research needed in the area of pavement management systems for microcomputers.

CONCEPTS OF PAVEMENT MANAGEMENT

Pavement management can be considered to encompass all of the processes associated with planning, design,

construction, maintenance, rehabilitation, reconstruction, and analysis of paved roadways. Certainly then decisions must be made as to the function the street is to serve, the traffic mix to be expected, materials available for construction and construction methods. Decisions on maintenance timing and techniques then become mandatory. Traditionally the planning and design components of pavement management have been in the domain of professionals. Origin - destination studies, long term growth and development forecasts and capacity analysis are among the tools used by transportation planners to determine when and where new highways are needed. Laboratory research on materials and large scale empirical studies on materials and construction methods such as the AASHO Road Test have provided objective assistance to professional engineers involved in highway design and construction. Significant effort and expense is directed to planning, design, and construction of multi-million dollar highways. But the responsibility for the maintenance of these valuable assets has often rested on poorly trained personnel with few organized tools for decision making. Complicating the matter is that while planners and designers normally have only a few alternatives to choose among, maintenance personnel not only have to select which maintenance or repair strategy is appropriate for each roadway, but also must decide which among literally hundreds of projects should receive attention.

Before proceeding further the differences between two distinctly different levels of pavement management, namely network level and project level should be clarified. Network level management consists mainly of planning and budgeting type analysis. Projections of funding levels required, benefit-cost analysis of alternative projects and tracking of systemwide pavement performance are examples of network level management. Project level management involves more technical and site-specific decisions. The selection of exact repair techniques to be performed on a particular section, grouping of projects for bidding, etc., are normally considered project level management activities.

THE SYSTEMS APPROACH

Engineers began to consider application of systems analysis methodology in organizing and analyzing information relevant to pavements through the mid to late 1960's (Ref 1). Figure 1.1 illustrates the broad elements or components generally included in a pavement management system.

Following the schema in Figure 1.1, planning and design activities normally should precede the development of a paved network. In actual practice, however, the maintenance manager of a street network may inherit many streets with no knowledge of the design of these pavements and no funds for for engineering testing to determine their structural

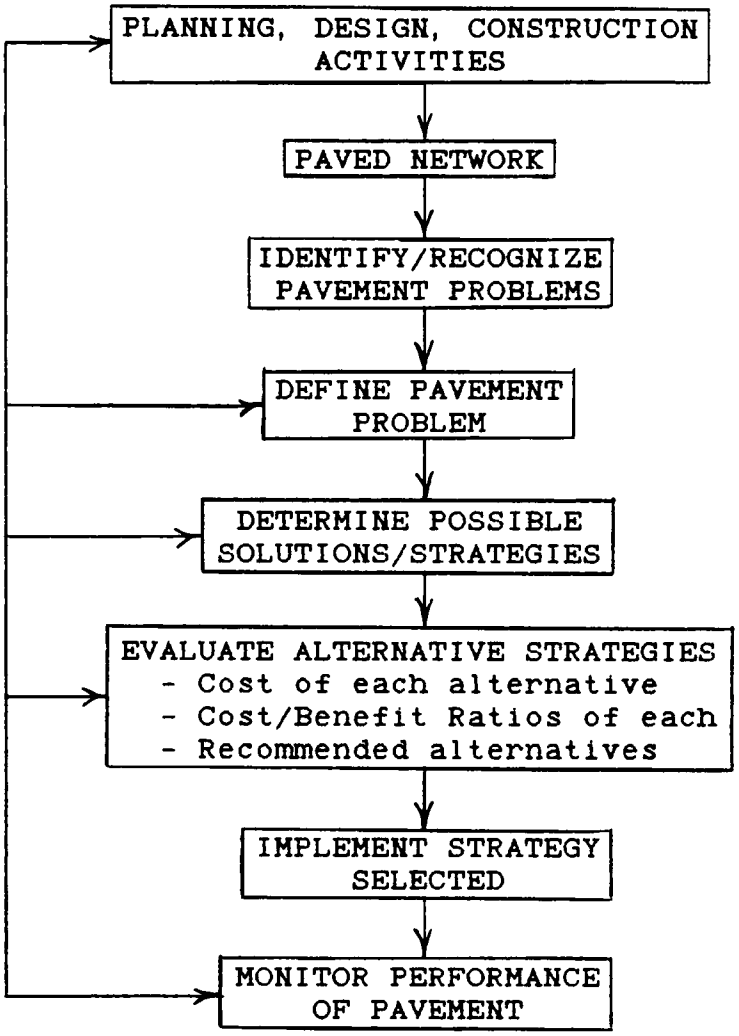


Figure 1.1 Possible components of a comprehensive maintenance oriented PMS

capacity. Indeed in rural areas many streets evolved over the years from dirt paths to gravel roads to some sort of paved street with no formal design. In an ideal situation, the design process of a street should specify the maintenance requirements at predetermined traffic or time intervals. Thus the majority of maintenance funds could be appropriated well in advance of need, emergency maintenance or repairs would only be performed as required. Needless to say, the process is seldom organized to allow a scenario such as described.

Upon completion of construction, the paved network will be in place. With the inacreasing age of a pavement it then becomes necessary to recognize problems that may occur to the pavements. This recognition or identification of problems can be accomplished by a visual pavement condition survey as part of a pavement management system, from traffic engineering studies of skid resistance after an unusual amount of wet weather accidents at a location, mechanical deflection testing for structural soundness, etc.

After the recognition of a problem or symptoms of a problem, it then becomes necessary to define the problem in narrow terms if possible, i.e., is the problem structural inadequacy or a local drainage problem? One then may develop several possible solutions to the problem. These may be a proven solution or an experimental technology depending upon future traffic load on the street segment.

If the PMS has the capability, all alternatives may be examined and an evaluation and quantification of the probable effects of each alternative could be performed. These alternatives may result in the extension of life of the pavement, improved skid resistance, better ride quality, etc. With the goal of providing safe, smooth pavements at reasonable costs, one should carefully evaluate the results of applying each alternative to the system. Total cost of each alternative, cost-benefit ratios (if benefits can be quantified), and other measurements of effectiveness could be calculated.

Some PMS are geared to select the "optimal" solution for the user and do not report the relative effectiveness of other possible solutions. For some applications this method may well be acceptable but within the pavement maintenance environment it may not be fiscally or politically feasible to implement the most cost effective solution. Therefore it becomes necessary for the user to be able to have adequate information on all possible alternatives to objectively select an acceptable solution.

One of the most important elements of a pavement management system is the monitoring of pavement performance, both prior to and after maintenance or rehabilitation. Whether objectively or subjectively, pavement monitoring is the only way to determine the effectiveness of various design and repair strategies on specific street segments.

The results of these monitoring efforts should be used to "fine tune" future design and maintenance efforts.

Any particular system may have all or only a few of the steps outlined. Computers may be used at various steps to inventory and organize large volumes of data and quickly explore multiple alternatives. In short, the system may be simple or complex, but the important point is to develop an organized, consistent method of analyzing the pavement condition.

The pavement management system described above is obviously oriented toward maintenance and rehabilitation, but the design component could also be expanded and benefit from being computerized. In fact, many maintenance oriented PMS are only beneficial at the network level but there are routines for detailed project level systems. While network level systems usually only differentiate between thin and thick asphalt overlays, it would be quite possible to include structural and detailed traffic data in the system and actually design an overlay for each section requiring such treatment. Pavement design procedures are in somewhat of a transition period as theoretical methods supplant empirical design methods. Part of the reason for the change is the evolution of the computer to allow high speed data processing. There is no reason why a more complete PMS including multi-layer elastic theory pavement design methods could not be developed for microcomputers today. It is

suspected that some states have this capability now with mainframe systems.

EVOLUTION OF PAVEMENT MANAGEMENT SYSTEMS

In reality, pavement management began with the planning of the first paved roads over 2000 years ago (Ref 1). At the time it is doubtful that anyone associated management with road building but decisions were being made and control was exercised over the construction efforts which would be consistent with accepted definitions of management. Pavements have significantly progressed from large hand placed stone that were used in road building in Roman times to the synthetic materials included in today's multi-layer pavements. Experimentation with pavements grew and reached a high level with the massive AASHO Road Test in Ottawa, Illinois in 1958. Interest generated by the AASHO test led groups of engineers in the U.S. and Canada (Ref 1,9) to attempt to expand the empirical results of the AASHO work into theoretical design methods through the use of systems analysis methodology. Working computerized PMS were completed as early as the late 1960's (Ref 4). These were massive systems prepared as demonstration projects and were capable of design, performance modeling, and economic analysis of design and rehab strategies. Interest in the subject and these early systems led several states to

develop their own PMS through the same time periods. Some states chose full blown systems capable of all facets of pavement management, others developed network level PMS to assist in budgeting, still others developed detailed project level systems to assist in maintenance efforts (Ref 4). These PMS were generally designed independently to meet the unique needs of each state, little effort was made to standardize any portion of the systems to allow cooperation across the country.

Through the mid- 1970's the U.S. Army Corps of Engineers developed a maintenance oriented PMS for use in analyzing flexible and rigid airfield pavements. The system was based on visual surface distress identification and provided an indication of the relative condition of each pavement by use of a Pavement Condition Index (PCI). The American Public Works Association (APWA) had an interest in developing a generic PMS for use by cities and counties so that standardized information could be generated and shared among its members. Through cooperation of the Army and APWA, the PAVER PMS was born. The system was based on the Army work with some modifications to allow easier use on streets. The system was massive and required the use of a mainframe computer. Recognizing that many of its members could not afford a computer of this magnitude, a timesharing approach was taken whereby the PAVER software was resident on a mainframe computer at Boeing Aerospace in Seattle,

Washington, and cities or counties could pay a nominal connection fee then access the system through a terminal over phone lines from their respective jurisdictions. Users would then enter or edit data or run analysis of their network and only pay for actual computer time. The PAVER project was first offered to APWA members in the early 1980's.

The PAVER system has not received the widespread use expected. Opponents cite the difficulties of large volume of data collection required, and the multitude of options available make the system awkward and complex to use. A few users accidentally or otherwise left open their lines of access to the mainframe computer in Seattle for long periods of time only to receive monthly computer use bills in the thousands of dollars. As of this writing a microcomputer version of PAVER is being prepared in response to some of these criticisms. Actually PAVER could be as simple or as complex as the user wishes. The ability to store a variety of data is provided, however the user may elect to start with minimal inventory data and expand as his needs change. This point was underemphasized by the APWA in its enthusiasm to draw attention to the comprehensive nature of their system.

ADDRESSING PRESENT NEEDS

As mentioned earlier the rapid emergence of powerful, low cost microcomputers simultaneously with shortages of pavement maintenance and rehabilitation funds has created a surge of interest in maintenance oriented pavement management systems as inventory and budgeting tools for local government agencies. State governments are likely to be using some form of their own PMS already and/or have too large a network to be used on present day microcomputers. The focus of this research will be on local government use. A few custom systems have been developed but with the exception of the micro version of PAVER, which may or may not now be available, no generalized PMS for microcomputers exists. Therefore this study attempts to analyze three custom designed microcomputer PMS to determine the features each system possesses, options not presently available, and potential applicability of the systems to other sites. The systems chosen for study are believed to be the most likely candidates available for general use.

CHAPTER II

CALTRANS/FHWA FPMS (Johnson City Version)

INTRODUCTION/OVERVIEW

The California Department of Transportation (Caltrans) developed a mainframe computer-based pavement management system (PMS) in the mid-1970's in an attempt to inventory the present condition of the state maintained flexible, rigid, and bridge approach pavements, study the deterioration trends of the various pavement designs in use, and objectively allocate maintenance and rehabilitation funds according to need and expected benefit (Ref 13). In 1983 the flexible pavement portion of the system (FPMS) was translated into BASIC programming language for use on microcomputers (Ref 11). The significantly lower capital cost and flexibility of microcomputers opened the door for more users to take advantage of this new version of the Caltrans/FHWA FPMS.

The Caltrans/FHWA FPMS itself is conceptually simple and straightforward. A pavement surface condition inventory is performed usually by technicians according to guidelines developed by Caltrans (Ref 12). The inventory identifies various types of pavement distresses and segregates these distresses according to severity and extent observed. This

inventory information for each road segment is used to enter a decision tree matrix which infers possible repair/maintenance strategies according to the combinations of distresses, severity, and extent noted. Subsequently the proposed repair strategy is combined along with ride quality ratings and traffic volumes to yield priority ratings which help identify roadway sections requiring the most attention according to the inventory data input. Approximate costs of performing the recommended repairs to each section can be obtained from the FPMS based on predetermined unit cost data. Although project level information can be derived from the Caltrans PMS, the system is intended to be more useful as an aid for network level decision-making.

The basic Caltrans/FHWA FPMS is directed toward rural roads and urban or rural expressways with shoulders and open channel drainage systems. This system was modified to allow use by the City of Johnson City, Tennessee as part of a demonstration project sponsored by the FHWA and administered by the University of California, Berkeley through the cooperation of the University of Tennessee, Knoxville. The modification chiefly involved a few additional condition information items concerning roadside and road surface, curb and gutter, shoulders, drainage ditches, shoving, rutting, and potholes. The additional data are not used within the decision tree structure and are for informational purposes only.

PAVEMENT CONDITION SURVEY

The lifeblood of the FPMS is the pavement condition survey data. This survey data is combined with limited traffic data and ride quality data (if available) to determine repair strategies and also to prioritize the projects within the system. The condition survey is in fact a visual inspection of the surface of the pavement only intended to identify the presence, severity, and extent of seven types of flexible pavement distresses (alligator cracking, block cracking, transverse cracking, longitudinal cracking, ravelling and weathering, rutting, and patching) plus general information on shoulders, curb and gutter, drainage ditches and potholes. There is no provision within the FPMS to incorporate structural evaluation data, i.e., the results of any mechanical or laboratory testing of pavements. Thus the pavement condition survey in many cases utilizes subjective ratings by field technicians. Caltrans has developed a set of rating instructions (Ref 12) intended to guide the field technicians in their ratings and reduce the subjectivity of the survey. It is highly recommended that the field technicians responsible for gathering the condition data receive training in identifying the respective distresses along with the evaluation of severity and extent values which can be somewhat difficult since the distresses often appear in combinations within the same

sample area. In the likely event that the condition survey will be performed by teams of individual raters, it is important to "calibrate" the raters over a control section so that the ratings will be reasonably consistent from individual to individual. For the FPMS to be useful on a network-wide and year-to-year basis, consistency among individual technicians is very important. The Caltrans FPMS requires a condition survey of all street sections within the management system boundary. Caltrans performed a study (Ref 13) as to the most practical survey interval for their purposes. The result was a recommendation to survey the entire network every two years, or to survey one-half of the network on an annual schedule.

DISTRESSES AND RATING

Because of the importance of the pavement condition survey, a more detailed description of the survey is in order. As mentioned earlier, the Caltrans FPMS is based on the identification of seven pavement distresses. The potentially most serious distress included in the survey is alligator cracking. Alligator cracking is load-related, that is the cracking is normally along the wheel paths and results from loading of the pavement in excess of its structural capabilities. The severity of alligator cracking is rated by subjectively indexing the field condition

observed into either Type A, B, or C cracking (Ref 3). Type A is the first stage of cracking with the appearance of mostly longitudinal, basically non-interconnected fatigue cracks in the wheel paths of the roadway , Type B alligator cracking is identified by interconnected cracks within the wheel paths which yield the characteristic "alligator skin" look to the cracked surface. Type C is intended to identify the most severe alligator cracking and load-related cracking outside the wheel paths.

The Caltrans FPMS takes the position that the width of the individual cracks are not of high importance compared to the presence of the fatigue cracks themselves, therefore no width of crack information is gathered. Successfully sealed cracks are considered equal to hairline width untreated cracks since the presence of the crack serves as the indication of an overstressed pavement section which may require attention.

The extent of all the types of alligator cracking is reported as the percent of wheel paths exhibiting this type of cracking. The presence of cracking in both wheel paths even without cracking between the wheel paths would constitute an extent of 100% cracking. The Type C cracking (outside of wheel paths) is rated for presence only with no extent classification reported.

Block cracking is the presence of sharply defined cracks in the shape of relatively large (up to about 5' by

5') polygons over a section of pavement not subject to wheel loadings (Ref 12). Severity of block cracking is not rated with the extent reported as the percentage of block cracking observed within a particular segment of roadway.

Transverse and longitudinal cracking are the other types of cracking included in the Caltrans FPMS survey. Transverse cracking is the presence of cracks roughly perpendicular to the travel lanes often caused by shrinkage of the pavement surface or reflection cracking perhaps associated with an asphalt overlay of jointed portland cement concrete pavement. Severity of transverse cracking is represented by the average width of crack observed within a pavement segment. Successfully sealed cracks of any width are rated as hairline (under 1/8" width) cracks, reopened sealed cracks are rated as to the width of reopening of the crack. Extent of transverse cracking is somewhat unusually reported as the number of transverse cracks per 100 ft. station, whether full lane width or partial width.

Longitudinal cracks are cracks running roughly parallel to the centerline of the roadway. Longitudinal cracking can be the symptom of poorly constructed asphalt joints, reflection cracking, or inadequate lateral support if present along the outside edge of the pavement. Severity of longitudinal cracking is rated according to the average width of crack, the same as with transverse cracking. Extent of longitudinal cracking is related to the total

length of cracks observed within a 100 ft. station. Sealed cracks are handled in the same manner as sealed transverse cracks.

Ravelling and weathering are other pavement distresses included in the pavement condition survey. Ravelling is defined in the Caltrans FPMS as disintegration of the pavement downward through the pavement section due to separation of the aggregate and the liquid asphalt binder (Ref 12). Weathering is defined as the loss of surface aggregate leaving a rough textured surface, possibly caused by oxidation and/or stripping of the aggregate from the liquid asphalt or insufficient liquid asphalt binder in the plant mix (Ref 12). Ravelling along the center of the travel lane caused by loss of petroleum products from the motor vehicles is separately reported as drip track ravel. Drip track ravel is reported only as to the number of locations where this problem occurs within the survey, no severity rating is included for this form of ravel.

Weathering and ravelling severity is classified according to the loss of fine or coarse aggregate. If these general categories do not adequately describe the distress, the inspectors are encouraged to elaborate on the condition within the remarks column of the rating form. Extent is recorded as to the percentage of the segment where ravelling or weathering is observed.

Rutting is localized consolidation and possibly lateral displacement of the pavement structure, usually along the wheel paths, caused by wheel loadings. The severity rating is related to the depth of the rutting. Rutting less than 3/4" in depth and in sections under 20 feet in length is not included in the survey. The extent of rutting is reported as the percentage of wheel paths within the section where rutting is observed.

Patches of all types and conditions are to be reported within the pavement condition survey. Because the surface has been penetrated, even superior constructed and performing patches are considered as a pavement distress. Severity of patching is subjectively rated as good, fair, or poor according to the observed condition of the patch and the effect on ride quality caused by the patching. The patches within the surveyed segment are rated according to the average severity rating of all patching found within the survey segment, rather than on an individual basis. Extent of the distress is recorded as the total percentage of the segment that has been patched, whether permanent or temporary.

Because of the wide variety of quality of patch found in field conditions, it is likely that the patches themselves will on occasion be found with combinations of the previously mentioned pavement distresses showing through

the patched areas. These other distresses are reported individually as if found in the undisturbed pavement surface.

RIDE SCORE

Because the Caltrans/FHWA FPMS was originally designed as a management tool for use with higher type state highways with relatively high speed traffic, the ride quality was considered of significance. Caltrans elected to use a PCA-type ride meter which records the cumulative vertical movement between the rear axle and body of a test vehicle.

The ride score is quantified by the following formula:

$$\text{RIDE SCORE} = \frac{\text{Summation of 1/8" vertical movements}}{\text{Length of segment (miles) X Constant}}$$

(Eq. 2.1 , from Ref. 11)

After collection of ride score data, Caltrans wished to identify an acceptable upper limit ride score for the highways within their jurisdiction. Teams composed of either all technically trained personnel or all non-technical volunteers subjectively rated pavement sections with various ride scores in an attempt to correlate the ride score results with what was considered "acceptable" ride quality (Ref 13). The study resulted in a ride score of 45 as being adopted as the acceptable upper limit for the highway network. A ride score of 45 is thought to be

roughly equivalent to a Present Serviceability Index (PSI) rating of 2.5 on the AASHTO rating scale of 0 to 5.

Because of the typically lower speeds found alone city streets, ride quality is not as important for lower classifications of streets. For this reason, the modifications of the Caltrans/FHWA FPMS for use by the small urbanized area of Johnson City, Tennessee included a reduction in significance of ride quality as to pavement performance, as will be explained later in this text.

MANPOWER/EQUIPMENT REQUIREMENTS FOR CONDITION SURVEY

As mentioned previously, the Caltrans FPMS provides only "snapshot" looks at the present pavement condition within the network, and no mechanism is provided to project future pavement condition. For this reason it is expected that the managed network will be surveyed once every two years in order to determine trends in the condition of various segments and monitor the effectiveness of maintenance or repair techniques applied to certain segments. The survey data must be gathered manually by field personnel who will need to walk over the network in order to observe the pavement surface in enough detail to accurately fill out the rating forms. Since with the exception of ride score (which is practically omitted from this version), no mechanical testing results are used as input to the system, the field

technicians will require only a few basic measuring tools to record the width/length of pavement, width/length of crack, area of distress, depth of rutting, etc.

It is suggested that the survey teams be composed of 2-person crews, which would have several advantages over using single person teams. The extra person would record and arrange data while the other person physically measures the distresses. It allows consultation among the two persons on questionable distresses and their severities and extents, and this would increase the consistency of survey results. The speed of data collection is dependent on the skills of the technicians, condition of the pavements surveyed, terrain and weather of the area, traffic volume encountered during rating, etc. The actual productivity of the crews may vary considerably, but for comparison purposes it should not be unreasonable to expect a 2-person crew to average 10 lane miles per day including lower classifications of streets.

ASSEMBLAGE OF THE COMPUTERIZED DATA BASE AND AVAILABLE OUTPUTS

The pavement condition survey by itself is of little use unless the data are arranged and analyzed in a systematic method. This is where the Caltrans/FHWA FPMS computer software package is required. The FPMS is a

database manger that allows the entering and editing of pavement condition data in a systematic manner. Then the condition data can be compared with preset distress intervals or "trigger values" and the software generates recommended repair strategies based on the severity and extent of distresses found.

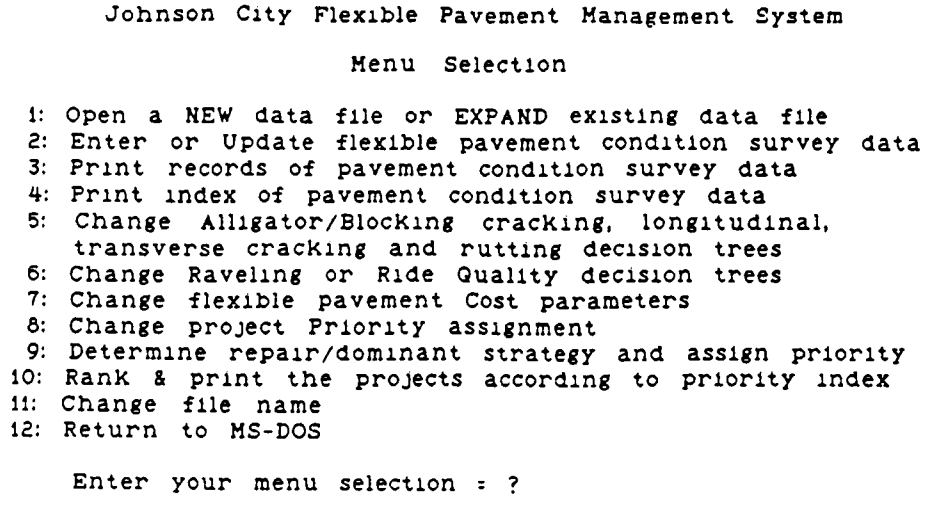
The FPMS is designed to operate in the IBM-PC/XT/AT microcomputer environment utilizing the advanced BASIC (BASICA) programming language. The software itself can be contained on one double-sided/double-density 5-1/2" floppy diskette. The data files may also be stored on floppy disks but efficiency of the system is enhanced, especially for larger networks, if hard disk storage is available. The FPMS was tested on IBM-compatible microcomputers which will run the software but also may require slight software or hardware modifications to fully utilize the FPMS. The requirement or degree of modification necessary will depend on the machine used.

For condition surveying and data entry purposes, the street network is broken into segments consisting of one lane of a particular street being recorded as an individual segment. Streets should be broken into segments with similar characteristics. Changes in paved width, pavement section, traffic volumes and/or mix, are among reasons to subdivide continuous streets into multiple segments. There are no limits on segment length, however one should keep the

segments short enough so that the same repair strategy may be used over the entire segment length, for network level analysis. Each segment (lane) then becomes an individual record when entered into the computer. The data is stored in a file/subsection/record hierarchy, that is the data is entered as individual records, linked together records form a subsection within the system and these subsections are grouped into files. The FPMS is presently capable of accommodating up to 9999 individual records, but the software users manual recommends grouping no more than 2000 records into any individual file.

The procedure for data entry is simple. The user activates the FPMS by loading and running the software through BASICA. The system is menu-driven, and the user is guided with prompts and instructions on the monitor. He simply selects his choice from the menu or fills in the various data fields as he wishes. Figure 2.1 illustrates the main menu. The main menu allows the user to choose to 'enter/edit' data, receive hard copies of data, receive output on suggested repair strategies, prioritize the subsections according to maintenance/repair suggested, or change any of the decision tree trigger values.

When beginning a FPMS, the user will first be required to spend a considerable amount of time entering pavement condition data. The user would choose selection number 'one' on the main menu illustrated in Figure 2.1 and open a

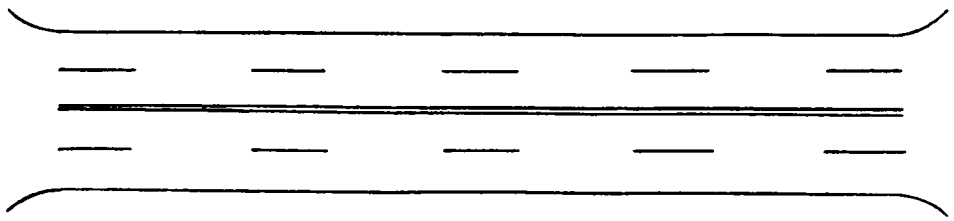


Source: Reference 11

Figure 2.1 Caltrans/FHWA FPMS main menu

new data file. At this point the user would be prompted to enter a data file name and select the number of records to be opened within that data file. Some thought should be placed into grouping of the data prior to entry as it may be helpful to group the records by location in the city or by class of street (arterial, collector, etc.) within a certain data file for the easy analysis and retrieval of data. At this point the user will need to estimate the number of records required for the storage of data within the file; this can be based on the number of segments on the field survey sheets gathered for the streets to be included in this particular file. The user can then return to the main menu and by selecting option 'two', begin to enter the pavement condition survey information into the computer.

For the Johnson City version of FPMS, the user is requested to enter two pages (screens) of data for each record (lane). The screen display gives the user title information including the file presently open, total number of records initialized within the file, and the particular record he is viewing. The records are grouped according to route and record number. As mentioned, each lane of a street segment is treated as an individual record. To form a complete street segment, the records are linked together as shown in Figure 2.2. Thus one may link together the four individual records representing each lane of a four-lane street into one segment which may may be analyzed as a unit.



A STREET SEGMENT IS SELECTED FOR INSPECTION FOR INCLUSION IN THE PAVEMENT MANAGEMENT SYSTEM

WESTBOUND 1	record #1
WESTBOUND 2	record #2
EASTBOUND 2	record #3
EASTBOUND 1	record #4

EACH LANE IS SURVEYED AND ENTERED INTO THE COMPUTER AS A SEPARATE RECORD

THE STREET SEGMENT IS "REASSEMBLED" IN THE DATA BASE BY DESIGNATING ONE RECORD (LANE) TO BE A "HEADER" RECORD AND ASSIGNING THE OTHER RECORDS (LANES) TO BE LINKED TO THIS HEADER RECORD. UP TO 10 RECORDS PER SEGMENT MAY BE LINKED.

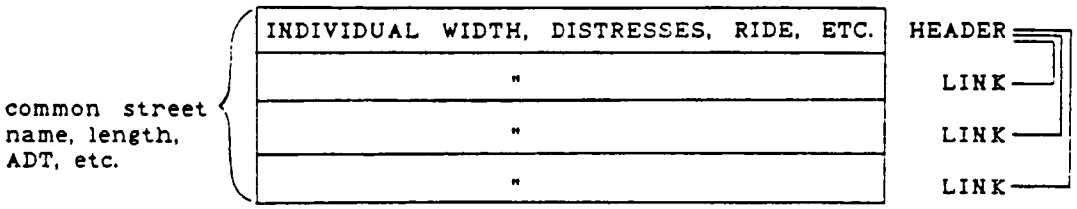


Figure 2.2 Structuring of records within the Caltrans/FHWA FPMS

This is accomplished by typing in the record number to be linked together on the entry screen. One of the records is required to be considered the "header" record (it does not matter which record) and the other records of the subsection are considered "links" to this header. Up to 10 records may be linked together, which is adequate for most situations. It may be mentioned at this point that very narrow streets can be considered to be one record even if they serve two-way traffic. This may be appropriate for very low volume streets where traffic generally travels in the center of the roadway unless passing another vehicle. For editing purposes the software gives the user the option to access the data base either by record number or route name. This can be beneficial since it would normally be much easier to simply enter the desired route/street name rather than trying to remember the appropriate record numbers associated with the individual routes or streets.

Each record contains two pages of information as illustrated in Figure 2.3. Title information is entered identifying the county, route, length, width, specific bounds (from-to), traffic data, and date of survey. This title information need be entered only on page one of each record and is automatically carried over to page two. All title information with the exception of travel direction, lane and ride score is also automatically carried over to the other linked records. However, it should be noted that

```
File name:DAVID     Total # of records initialized: 43     Record #: 43
          Johnson City Flexible Pavement Management System

        Next Link Record #:     : Header/Linked record (H/L): :
        County:             :   Route:              :
        Sgmt width:     :ft Total # of Lanes: :  Length:    :miles
        From:             :     To:               :
        Direction: :   Lane: :  Speed:  :mph   % of Truck:    :
        ADT:       :            Ride Score:  :

             Pavement Condition Survey Date:  :  :19  :
        Alligator Cracking  (% of Wheel Paths)   A:  :
        Alligator Cracking  (% of Wheel Paths)   B:  :   C:  :
        Block Cracking      (% of Length)        :  :
        Transverse Cracking   Width(inch):     :#/100ft Stn: :
        Longitudinal Cracking Width(inch):     :#/100ft Stn: :
        Drip Track Ravel                    # of Locations: :
        Ravel and Weathering        (F/C): :   Area (%)   :  :
        Rutting               Depth(inch):    :Length (%) :  :
        Patching                  (G/F/P): :   Area (%)   :  :
       ------------------------------------------------------
```

PAGE ONE

```
File name:DAVID     Total # of records initialized: 43     Record #: 43
          Johnson City Flexible Pavement Management System

        Next Link Record #:     : Header/Linked record (H/L): :
        County:             :   Route:              :
        Sgmt width:     :ft Total # of Lanes: :  Length:    :miles
        From:             :     To:               :
        Direction: :   Lane: :  Speed:  :mph   % of Truck:    :
        ADT:       :            Ride Score:  :

             Pavement Condition Survey Date:  :  :19  :
        Intersection        Shoving/Corrugation (1 to 3)  : :
                            Slippage Crack      (1 to 3)  : :
        Roadside Condition  Curb and Gutter (0 to 3)      : :
                            Shoulder        (0 to 3)      : :
                            Drainage Ditch  (0 to 3)      : :
        Potholes                                          : :
        Comments   :                                        :
                   :                                        :
                   :                                        :
       ------------------------------------------------------
```

PAGE TWO

Source: Reference 11

Figure 2.3 Caltrans/FHWA FPMS sample screen entry form

when editing records the program does not automatically update all linked records' title information when one record of a segment is edited. Only when the segments is first created is title information carried over to linked records.

'Page one' allows entry of severity and extent ratings of the seven categories of distresses considered by the FPMS. These data are utilized for entering decision trees and generating reports. 'Page two' stores data on intersection and roadside conditions, number of potholes within the records segment, and contains space for any remarks deemed appropriate. Data from this page is used for informational purposes only and is not correlated to the decision trees.

Data entry is a fairly slow process. The user must sort through the survey forms and fill in the data element fields on the screen. It seems to be a minor inconvenience that the program does not automatically go to page two of the record when page one is finished. After saving page one of a record, the program indicates the record is complete even though no information may have been entered or edited on page two. The user must also save the information on each page of each record before moving on to the next page or the data are lost.

After the database has been created the user has the options of indexing and listing the records or directing the data through the decision trees to receive repair strategy,

priority, and cost data. The indexing feature (menu choice 4) proves to be quite handy, especially for large data bases with many individual records and routes. The user may enter a route name and the FPMS will provide a printout, either hardcopy or to the monitor, of an index showing record number, route, and brief title information identifying the individual records. (See Figure 2.4) This can be quite useful for keeping track of the record numbers associated with individual routes and should prevent the user from having to keep written listings of record numbers. The data base index may also be generated by record number if the user wishes to see the routes associated with a particular set of record numbers.

A printout of the condition survey data for each record is available through menu choice 'three'. This option is accessible by record number only, making the above mentioned indexing feature useful in determining the desired record numbers. Output is in a form similar to the input format, with the information from pages one and two on the input screen combined onto one page for each record. This option could be useful for producing a hardcopy of the pavement condition survey that may be needed for some purpose, or if computer access time is limited. Otherwise the edit option would be more efficient for viewing the database on a record by record basis if only a few records need be viewed.

Johnson City Flexible Pavement Management System Filename : DAVID

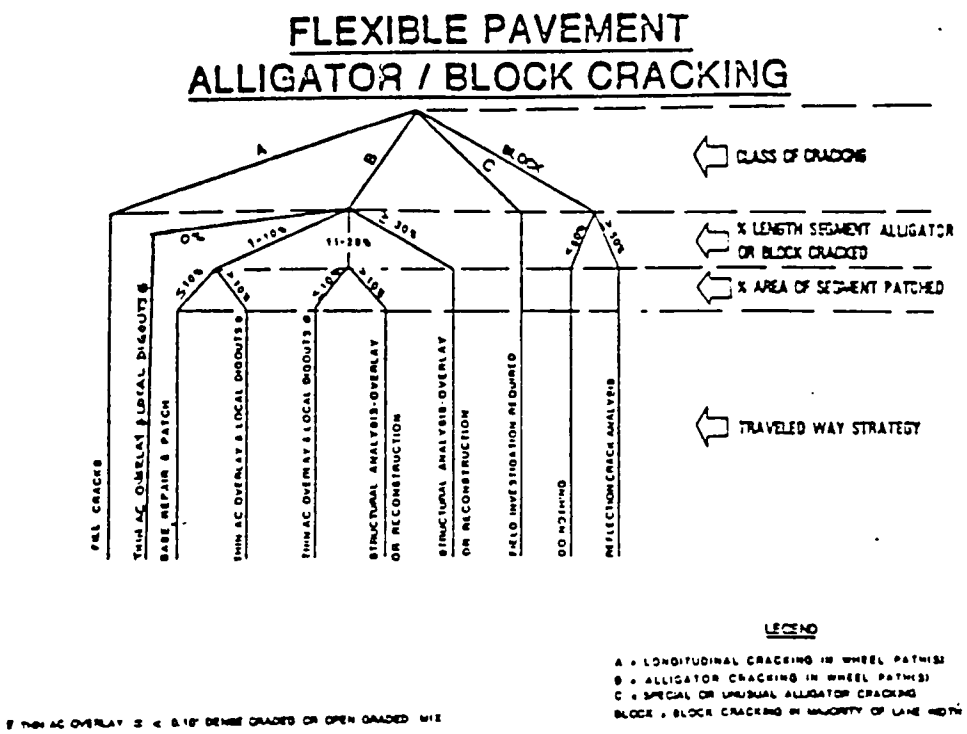
Record Number	Route	Direction Lane	From	To	Total Lanes /Length	H or L /Linkage
1	PEACHWOOD	S1	PLUMWOOD	HAZELWOOD	2/ .33	H/ 2
2	PEACHWOOD	N1	PLUMWOOD	HAZELWOOD	2/ .33	L/
3	HAZELWOOD	N1	PLUMWOOD	PEACHWOOD	2/ .20	H/ 4
4	HAZELWOOD	S1	PLUMWOOD	PEACHWOOD	2/ .20	L/
5	SPRUCEWOOD	S1	COTTONWOOD	PLEASANTWOOD	2/ .15	H/ 6
6	SPRUCEWOOD	N2	COTTONWOOD	PLEASANTWOOD	2/ .15	L/
7	PLEASANTWOOD	E1	HAZELWOOD	SPRUCEWOOD	2/ .20	H/ 8
8	PLEASANTWOOD	W1	HAZELWOOD	SPRUCEWOOD	2/ .20	L/
9	COTTONWOOD	W1	MYRTLEWOOD	MYRTLEWOOD	2/ .20	H/ 10
10	COTTONWOOD	E1	MYRTLEWOOD	MYRTLEWOOD	2/ .20	L/
11	IRONWOOD	N1	COTTONWOOD	PLEASANTWOOD	2/ .19	H/ 12
12	IRONWOOD	S1	COTTONWOOD	PLEASANTWOOD	2/ .19	L/
13	BURWOOD	S1	COTTONWOOD	PLEASANTWOOD	2/ .17	H/ 14
14	BURWOOD	N1	COTTONWOOD	PLEASANTWOOD	2/ .17	L/
15	SISK RD.	S1	PLEASANT RIDG	WESTGATE	2/ .28	H/ 16
16	SISK RD.	N1	PLEASANT RIDG	WESTGATE	2/ .28	L/
17	PLEASANT RDGE	E1	BRADSHAW RD.	SISK RD.	2/ .45	H/ 18
18	PLEASANT RDGE	W1	BRADSHAW RD.	SISK RD.	2/ .45	L/
19	PLEASANT RDGE	E1	DEER CREEK DR	BRADSHAW RD.	2/ .30	H/ 20
20	PLEASANT RDGE	W1	DEER CREEK DR	BRADSHAW RD.	2/ .30	L/
21	PLEASANT RDGE	E1	MERCHANTS RD.	DEER CREEK DR	4/ .25	H/ 22
22	PLEASANT RDGE	E2	MERCHANTS RD.	DEER CREEK DR	4/ .25	L/ 23
23	PLEASANT RDGE	W1	MERCHANTS RD.	DEER CREEK DR	4/ .25	L/ 24
24	PLEASANT RDGE	W2	MERCHANTS RD.	DEER CREEK DR	4/ .25	L/
25	JENSO	W1	RUTH	CLINTON HWY.	2/ .13	H/ 26
26	JENSO	E1	RUTH	CLINTON HWY.	2/ .13	L/
27	RUTH	S1	KENSI ST.	JENSO ST.	1/ .06	H/
28	BOUNDS	N1	TILLERY	KENSI	1/ .09	H/
29	KENSI	E1	BOUNDS	RUTH	2/ .06	H/ 30
30	KENSI	W1	BOUNDS	RUTH	2/ .06	L/
31	KENSI	E1	CLINTON HWY.	BOUNDS	2/ .13	H/ 32
32	KENSI	W1	CLINTON HWY.	BOUNDS	2/ .13	L/
33	PLEASANT RIDGN	1	WESTERN AVE	SYCAMORE	2/ .3	H/ 34
34	PLEASANT RIDGS	1	WESTERN AVE	SYCAMORE	2/ .3	L/
35	WESTERN AVE	W1	CLIFTON	PLEASANT RIDG	2/ .27	H/ 36
36	WESTERN AVE	E1	CLIFTON	PLEASANT RIDG	2/ .27	L/
37	UNIVERSITY AV	W1	SUTHERLAND	21ST	4/ .3	H/ 38
38	UNIVERSITY AV	W2	SUTHERLAND	21ST	4/ .3	L/ 39
39	UNIVERSITY AVE	1	SUTHERLAND	21ST	4/ .3	L/ 40
40	UNIVERSITY AVE	2	SUTHERLAND	21ST	4/ .3	L/
41	SUTHERLAND	W1	LIBERTY	WASHBURN	2/ .6	H/ 42
42	SUTHERLAND	E1	LIBERTY	WASHBURN	2/ .6	L/

Source: Reference 11

Figure 2.4 Sample Caltrans/FHWA FPMS index option output

DECISION TREES AND PRIORITIZATION

The features of FPMS discussed above have capabilities to those of an off-the-shelf database manager software package. However, the Caltrans/FHWA FPMS includes what could be categorized as a primitive "expert system" which can be used to suggest repair strategies based on the distresses found within the street segments. The "expert system" is in the form of a series of decision trees developed using the knowledge and experience of the engineers. A study was performed to determine the physical characteristics and average service life of various pavement repair strategies typically used in California to combat particular pavement distresses. It is not explicit whether this study was the basis of the decision trees, but the decision trees incorporated in the FPMS are consistent with the results of the study. A decision tree structure is utilized for each of the pavement distresses included in the condition survey. A sample decision tree is shown in Figure 2.5. The tree structure branches at preset breakpoints corresponding to severity and/or extent of distress observed. The end of each possible branch contains either a repair strategy intended to correct that particular distress or a suggestion to perform additional analysis of the problem. The basic idea is to suggest a repair or analysis for each particular distress observed within a segment of



Source: Reference 11

Figure 2.5 Caltrans/FHWA FPMS decision tree for alligator and block cracking

street, and then select from that group of strategies the most comprehensive and compatible repair strategy that theoretically would address all problems observed for that individual section. That compatible repair strategy is projected as the controlling strategy for that section. The results of this analysis may be reported to the user by choosing option nine on the main menu. The system will output a listing giving the problems found within the section, the severity and extent of each problem and the repair strategy for each problem along with the suggested controlling strategy. (See Figure 2.6) The FPMS has the built-in flexibility in that it allows the user to change the trigger values within the decision tree that determine which repair strategy will be suggested. However, there is no easy way to modify the possible repair strategies to fit within the normal maintenance or rehabilitation activities of the user.

This FPMS is truly intended for management assistance at the network level. Several of the branches within the decision trees suggest further analysis of the observed problem rather than give specific repair instructions. The user should recognize this and not attempt to blindly apply the repair strategies at the project level. After a particular pavement rehabilitation project is selected, it will be necessary for the engineer to take a closer look at

Johnson City Flexible Pavement Management System

County:KNOX Route:PEACHWOOD Total # of Lane:2 Length: .33miles
Segment width: 24 feet
From:PLUMWOOD To:HAZELWOOD ADT: Speed:30mph Ride Score: 1
Cost: 2707 Priority:16.0000 C.S.:Base repair and patch

Lane/Severity	Problem	Repair Strategy
S1/10%	Alligator A cracking	Fill cracks
5%	Alligator B cracking	Base repair and patch
.125",4 /100ft	Transverse cracking	Do nothing
.25",1 /100ft	Longitudinal cracking	Fill cracks
1", 5%	Rutting	Correct rutting
F 1%	Patching	Base repair and patch
N1/.125",1 /100ft	Transverse cracking	Do nothing
.25",1 /100ft	Longitudinal cracking	Fill cracks
1", 3%	Rutting	Correct rutting

Source: Reference 11

Figure 2.6 Caltrans/FHWA FPMS sample priority assignment and suggested repair strategy

the problems in the field before deciding upon the exact repairs to be made.

After flowing through the decision tree matrix, the FPMS also produces a priority rating of the segments which is intended to give an indication of the seriousness of the problems within a particular segment. The priority matrix, Figure 2.7, is designed to yield a unique numeric value for each possible combination of ride score, controlling repair strategy, and traffic volume range. Values range from 1 to 16 with 1 being the most severe (major structural problem AND bad ride AND ADT over 5000 vpd) and a priority of 16 indicating no distresses and a low ride score found within the segment. Limited changes to the priority matrix are possible. The program allows the user to change the ride score trigger value, the ADT range values, and the priority numbers may be changed. However the upper boundary value is fixed at 16 for a section with no distresses and a low ride score. No interactive user changes are possible to the use of major and minor structural problem and ride score as the matrix headings.

The developers of the Caltrans/FHWA FPMS did not wish to derive numeric rating values such as Pavement Condition Index (PCI), Present Serviceability Index (PSI), etc., on the grounds that such rating systems may end up with the same final value for different pavement problems. Their opinion is that it is better to devise a method whereby the

Flexible Pavement Management Sysytem Priority Assignment
The range of priority: 1 <= Priority <=16

Ride Score>=45	>5000	ADT Range >=1000 to =<5000	<1000
Major structure problem & bad ride: Structure analysis/Overlay & Reconstruction	01	02	11
Minor structure problem & bad ride: Thin AC overlay & local digouts	03	04	12
Bad ride only	05	06	15
Ride Score< 45			
Major structure problem only: Structure analysis/Overlay & Reconstruction	07	08	13
Minor struction problem only: Thin AC overlay & local digouts	09	10	14
No structure & ride problems	16	16	16

Source: Reference 11

Figure 2.7 Caltrans/FHWA FPMS priority index

priority number itself will infer the nature of the problems within a particular pavement segment. This line of reasoning led to the development of the priority matrix which, as stated earlier, provides a unique priority number for each possible combination of problems, volume, and ride score. The reasoning presented is that it is more appropriate to give an indication of the nature and magnitude of problems present than to assign a value intended to give some indication of the "serviceability" of the pavement.

Ride score and traffic volumes are extremely favored in selection of the priority value. Crossing over the ride score trigger value alone can result in changing the priority rating by 6 points and the combination of stepping up one level in volume range and crossing the ride score threshold can result in a change in priority rating of up to 11 points. These are rather dramatic changes when one remembers that the range of possible values is only from 1 to 16. Using the unchanged Caltrans/FHWA FPMS priority matrix, a multi-lane street carrying 40,000 vehicles per day with major structural problems but a ride score of 44 would receive a priority of 7; a two lane street carrying 5001 vehicles per day, with minor structural problems and a ride score of 46 would receive a priority rating of 3. First of all the decision trees include no hard and fast rule or complex calculation to differentiate between major and minor

structural problems, the breakpoints are somewhat arbitrary. Ride score, downplayed in this version, still plays a major role in the priority assignment even though the threshold value is not adjusted for varying traffic speeds and volumes. Certainly it is oversimplified to assume that one value can represent an acceptable ride quality over all speeds and for widely varying traffic volumes even when limited to state routes.

If needed for purposes of acquiring federal funding, Caltrans has developed a regression formula that correlates the observed distresses into an AASHTO PSI value. The formula is straightforward and discussion is not within the scope of this text.

PROJECT COST DATA

Menu selection nine performs a multitude of tasks on the database records selected. Not only are repair and analysis strategies suggested but a priority is assigned and an estimated cost to perform the suggested repairs is calculated and listed. This cost will be a total cost for the linked segment. Unit cost data are stored in the FPMS and accessible through main menu selection 'seven'. The unit cost data should be periodically reviewed for accuracy and updated if necessary. This section is reasonably

flexible with the major criticism being the inability to modify the repairs to fit local operations.

One may have noticed that the priority ratings are not reported in integers but in decimal numbers. The cost data is used in some manner to break ties among equal priority projects. The method is not explained anywhere within the system but appears to be inverse to the priority hierarchy. A priority of 4 is more serious than a priority of 5 but a priority of 4.2500 seems to infer higher repair cost than a priority of 4.0050.

OTHER OPTIONS

The remaining main menu choices, 11 and 12, allow the user to rename a file if desired and to exit the FPMS work session and return to the computer's disk operating system (DOS).

SUMMARY

Overall the microcomputer version of the Caltrans FPMS is a simple, easy to use package that can serve adequately as a pavement condition inventory system with limited ability to provide suggestions on maintenance and rehabilitation. It was intended to be oriented toward rehabilitation and reconstruction of the California state

highway network but appears more suited to what this author considers to be maintenance and rehabilitation type activities. The suggested repairs include crack sealing, patching and relatively thin overlays (maximum built in value is 2.4" thick) which are normally associated with normal pavement maintenance and rehab. The largest effort will be to collect and update the pavement condition survey information, which is suggested to be collected every two years. The data collected includes visual survey information only with the FPMS unable to process mechanical or laboratory testing results. The major cost will likely be the labor cost of the field personnel. The FPMS has no provisions to forecast future pavement conditions or predict the service life of repairs made to the network, therefore it would be necessary to maintain the FPMS for several years in order to notice any trends in overall network or individual section pavement condition. Even smaller cities will require a couple of man-months to collect the data. It may be practical to employ temporary help to collect the data if training on distress identification can be provided. If a municipality or other authority cannot make a commitment to provide the funds to collect survey information in the future, it is questionable to begin the system, since little meaning can be derived from one survey. Although even one survey may be beneficial in pointing out where problem areas are located. One of the major weaknesses

of the Caltrans/FHWA FPMS is that no maintenance history information can be stored within the system. Thus it would be necessary to maintain records outside the FPMS in order to analyze the effectiveness and service life of repairs made to the network which somewhat reduces the utility of the system. It may be possible to get around this problem by using an expanded comments section on the survey record screen to store the maintenance history.

Another drawback in transporting the program outside the California state highway system is that the repair strategies or suggestions for further analysis are fixed and could only be modified by changing the program itself. This is not surprising since the FPMS was written by Caltrans for its own use, but it would be beneficial for local users to be able to modify the repair strategies to fit their needs.

The cost estimate pricing information is changeable and should suit most needs. The program contains routines to print the record information should the user have need for hardcopies.

CHAPTER III

TULARE COUNTY (California) PMS

INTRODUCTION/OVERVIEW

Tulare county is located in south central California with an economy largely based on agricultural production. With approximately 3100 lane miles of roads falling under the maintenance authority of the Public Works office, keeping track of necessary repairs is no small task. The problem is compounded by the fact that several of the roads have not been paved with hot mix asphalt cement they have only received surface treatments, several roads are completely unpaved. The structurally weak roads and large percentage of truck traffic due to the agriculture production creates the need for frequent maintenance and made management of the paved network almost beyond manual means.

As mentioned earlier in the text, the flexible pavement portion of the Caltrans/FHWA FPMS (Ref 11) was adapted for use on microcomputers in the mid 1980's. The Tulare County Public Works office obtained a copy of the software for testing but was not completely satisfied with several of the concepts embodied in the system and the inflexibility of the

decision tree structure included in the Caltrans FPMS micro version. Specific objections were:

-The Caltrans FPMS places a premium on ride score in the assignment of priorities. This is understandable to a degree since the system was developed for state routes with higher speeds and a significant percentage of portland cement concrete streets. But with Tulare County being a rural county with mostly two lane lower speed roads, and asphalt surfaced streets, ride score is not as important.

-Tulare County wished to modify the repair strategies within the decision tree structures to incorporate local maintenance techniques. The system does not allow the user to modify this information therefore modification of the software source code would be necessary if inclusion of the local repair strategies was important.

-The Caltrans FPMS makes no provision to store maintenance history records within the system. Tulare County realized how important this data can be and did not wish to keep a separate file for maintenance records outside the PMS.

-The Caltrans FPMS has limited report generating capability. Because of the relatively large size of their pavement network, the Public Works staff wished to be able to sort and receive reports on specific sections of the system.

-The Public works staff wanted to include the Pavement Condition Index (PCI) concept within the PMS.

With the approval of Caltrans, two members of the Public Works department, Allen Wilson and Philip Slitor, obtained a copy of the source code for the micro-version Caltrans FPMS and successfully modified the software to suit their needs. The system could be considered a hybrid of the Caltrans FPMS and the U.S. Army Corps of Engineers - APWA PAVER PMS (Ref 15). As will be discussed, the PCI concept was borrowed from PAVER and added to the basic Caltrans system.

The Tulare County PMS contains routines for storing and editing of pavement condition information and maintenance history data. The system is capable of checking the pavement condition records and alerting the user to common errors or inconsistencies in the data. PCI of the street segments may be calculated, and repair priority, suggested repair strategy, and estimated cost may be received from the PMS. Results of the analysis or records may be indexed and reported in several forms convenient to the user.

The Tulare County PMS has been developed to meet the unique needs of Tulare County, therefore other jurisdictions may require modification of the system to meet their needs, but even in original form it is more advanced and provides more options than the Caltrans FPMS.

PAVEMENT CONDITION SURVEY

The most basic part of any pavement management system is the inventory of pavement condition. As with the other PMS discussed in this text, the Tulare County PMS depends upon a manual visual inspection of the pavement surface to provide information for analysis of the network. No provisions are made to incorporate mechanical or laboratory testing results as part of the survey information. The pavement condition survey method is not drastically modified from the Caltrans version, instead data elements of local interest are collected in addition to the basic Caltrans data. As will be seen, many of the additions are due to the variety of terrain and pavement types found in Tulare County.

The system requires the field surveyor to inspect for eight pavement distresses plus evaluate the quality of ride and gather other descriptive data. The distresses recognized are; Alligator cracking, transverse cracking, longitudinal cracking, block cracking, ravelling, bleeding, rutting, and patching. Many of the distresses are categorized exactly as the distresses included in the Caltrans FPMS and explained in detail in discussion of that system. Therefore this section will concentrate on distresses defined differently by Tulare County or not included in other systems.

Alligator cracking is divided into two categories, Type A and Type B, with the former being the hairline parallel cracking in the wheel paths that signifies the beginning of the problem. Type B is rated for severity and extent. (The Caltrans FPMS has no severity rating for the individual types, the types themselves are intended to serve as a severity indication.) Severity is determined by the width of the individual crack. Extent is defined as the percent of wheel paths exhibiting alligator cracking (Ref 10). The Caltrans Type C alligator cracking, outside of wheel paths, is not considered by Tulare County.

Ravelling, categorized as ravelling AND weathering by Caltrans, is broken into fine, medium, and course categories which seem to represent the surface texture of the road rather than loss of particular size of aggregate since the medium severity class includes loss of both fine and coarse aggregate but causes moderate deterioration in ride. Rutting is inspected for extent of this distress in the wheel path only, no depth of rut is considered.

Bleeding is a distress not included in either the Caltrans/FHWA FPMS or the Bay Area PMS. Bleeding is a condition where free asphalt cement is present on the pavement surface. Bleeding is caused by excess asphalt cement present in the pavement or poorly applied seal coats and can be compounded by high temperatures. No severity measurement is taken, extent is defined as the percent of

wheel paths where bleeding is observed. Philip Slitor of the Tulare County staff indicated that, "Ravelling and bleeding are the most common problems observed. Probably because of the consistent higher temperatures and low humidities." (Ref 16)

As mentioned in the introduction to this section, one of the objections Tulare County had to the Caltrans FPMS is the importance attached to ride score. Interestingly enough, although the method of determining ride score is significantly changed, the item still prominently figures in priority setting. Crossing over the threshold value can change the priority rating from 2 to 7 points on a priority scale of 1 to 18.

Ride score is subjectively rated on a scale of 10 to 90 in steps of 10 with the lower score representing a better ride quality (Ref 10). A ride score of 50 is defined to be the breakpoint between an acceptable and an unacceptable ride. The method used to determine ride quality is based on noise and vibration felt by the driver, also whether a need to reduce speed is sensed.

One can question the need for multiple steps in the scale when considering the subjectivity of the measurement and its use in the PMS. The Caltrans/FHWA ride score is a mechanical measurement with the equipment permanently mounted in a testing vehicle (Ref 13). This allows the instrument to be periodically calibrated over a test section

to produce consistent objective results. On the other hand the Tulare County method could involve several different inspectors in multiple vehicles with different riding characteristics. It is hard to imagine consistent ratings under these circumstances. This potential problem could be minimized by allowing the same inspector in the same vehicle to rate the ride score separately but this could require more than one inspection of the same location. The need for multiple steps is even less apparent considering the use of the measurement in the PMS. The ride score is a large factor in setting priority but in looking at the priority matrix, Figure 3.1, one can see that the system only checks to see if ride score is 50 or more. A simple good, fair, poor scale, or even just good - bad rating system would serve the same purpose.

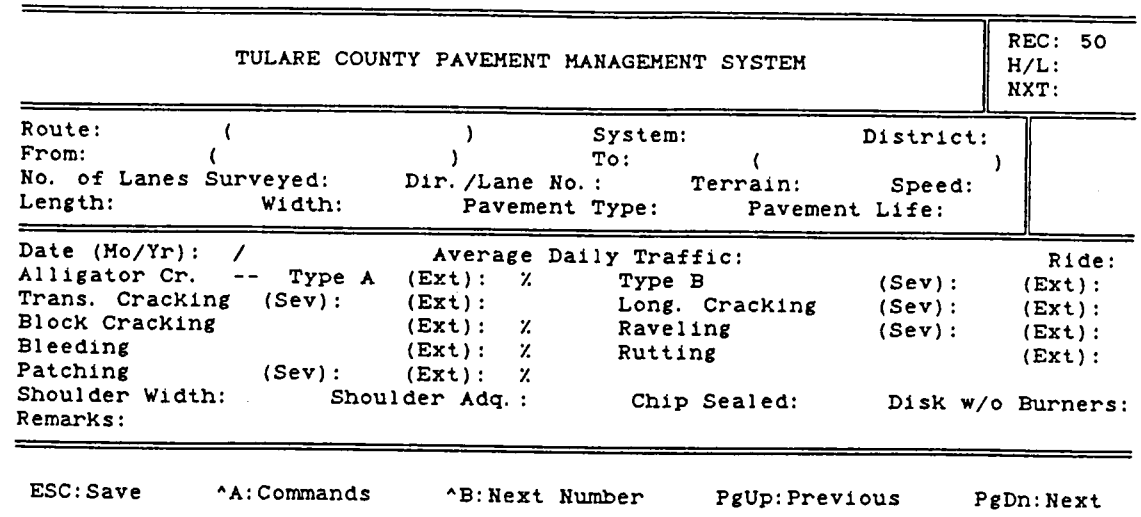
Other information gathered on the survey form, Figure 3.2, is routine section identifying data similar to the Caltrans/FHWA FPMS. Exceptions are terrain type because of the wide variety encountered, pavement type, where the rural nature of the county really shows, with the choices being asphalt cement, road mixed asphalt surface (RMAS), gravel, and dirt. An estimate of pavement life, really pavement age, is required for the PCI calculations. If the pavement has received a chip seal that is noted, also an opinion is given on whether a RMAS road could be disked and regraded without application of external heat. Certainly this would

TULARE COUNTY PRIORITY MATRIX

		PRIORITY CATEGORY		
	STRUCTURAL CONDITION	ADT>1200	400<=ADT<=1200	ADT<400
RIDE >=50	Severe structural problem. PCI<30	1	2	11
	Moderate structural problem. 30<PCI<70	3	4	12
	Minor or no structural problem. PCI>70	9	10	15
RIDE <50	Severe structural problem. PCI<30	5	6	13
	Moderate structural problem. 30<PCI<70	7	8	14
	Minor or no structural problem. PCI>70	16	17	18

Source: Reference 10

Figure 3.1 Tulare County priority matrix



Source: Reference 10

Figure 3.2 Tulare County PMS sample screen entry form

only be relevant in hot climates with a large number of surface treated roads. The shoulder data and road evaluation data is for informational purposes and not part of the PMS.

Unlike the Caltrans/FHWA FPMS which requires a complete inspection of the network, the Tulare County version uses a sample survey of the system. A one lane wide, 100 to 200 ft. long inspection unit per segment or per mile is an acceptable sample for each record. The reason for this relatively small sample is the large size of the road network, 3100 lane miles, would require an inordinate amount of time to sample. Even with the small sample size it was reported to take "about a year" to complete the pavement survey. The sample unit location in not marked or recorded as it is not considered important to the system to monitor the deterioration of any particular sample unit, instead a sample unit representative of the average condition of the segment is to be chosen during each survey. Recommended survey interval is two to three years.

Computer entry of the condition survey data is quite similar to the Caltrans/FHWA method. A menu of possible operations appears at the beginning of the system and the user need only type in the number associated with the desired option. An improvement in the system over the Caltrans/FHWA version is the listing of existing data files when trying to open or expand a data file. This prevents the user from having to maintain a separate listing of

files. Selection of option 3 on the main menu allows entry of condition survey results into a computerized data base.

The Tulare County version is based on the record system similar to Caltrans/FHWA, with each lane of each segment of roadway being a record. All information is on one page. Narrow streets may be considered as one lane streets even if two way traffic is permitted. The first record of a segment is considered the header record, other lanes of multi-lane streets may be linked together to form a full width segment of the same street. A facsimile of the pavement condition field survey form is produced on the screen. Data from the field survey is entered into the appropriate portion of the screen. Data from the field survey is entered into the appropriate position of the screen and saved into the data base. Editing is as simple as typing in the record number to be edited, entering the new data over the data to be replaced, and saving the screen. A disappointing omission in the Tulare County version is the ability to access the data base by route name instead of record number only. It is more convenient for the user to simply be able to enter the street name of interest than having to associate a record number with each street. The Caltrans/FHWA version allows access by route name, it is curious that this feature was taken out by the Tulare County staff.

An interesting option is the ability of the system to check entered survey data for common errors. Missing or out

of range data fields are brought to the attention of the user by display of error messages indicating possible problems.

PAVEMENT CONDITION INDEX

Tulare County wished to add the Pavement Condition Index (PCI) concept to the PMS in order to get a general idea of the overall state of repair of their street network. As with the Bay Area PMS, they took advantage of the previous work of the U.S. Army Corps of Engineers and American Public Works Association by adopting the method of calculating PCI used in the PAVER PMS. The same 0 to 100 scale and concept of deduct curves is adopted.

The Tulare County staff had access to the PAVER deduct curves and wished to find a mathematical expression to produce similarly shaped curves for the distresses included in the Tulare version. The staff adopted the idea that the pavement would deteriorate to the end of its design life at a PCI of 60. Rate of deterioration would increase between PCI values of 60 to 20. The pavement would be in such poor condition at a PCI of 20 that the time for further deterioration to a PCI of 0 would be fairly long.

The expression chosen for producing the deduct curve is as follows:

$$Deduct = A(X)^{(B+C(X))} \qquad \text{Eq. 3.1, From Ref 10}$$

where:

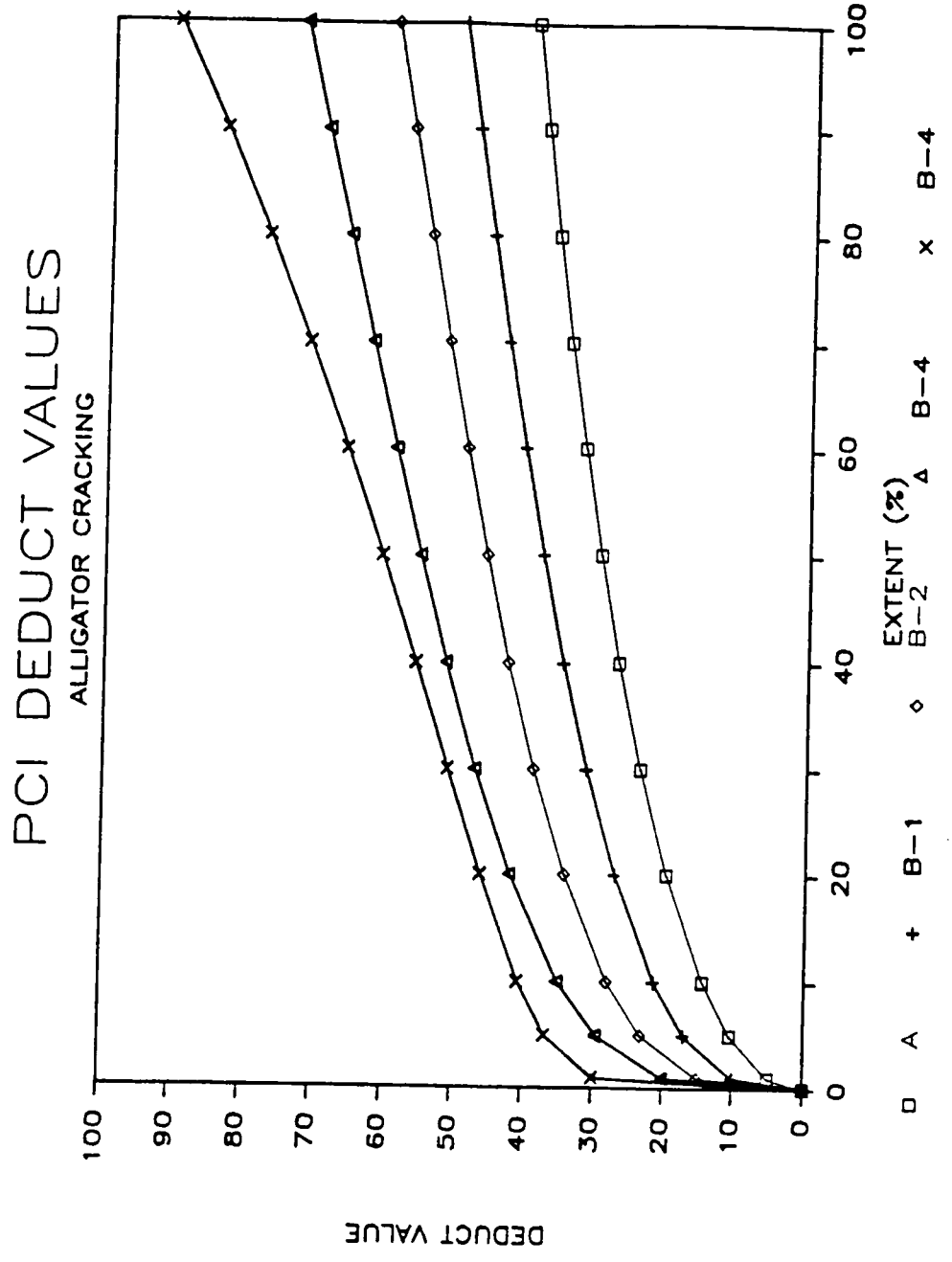
X = Extent rating for distress

A, B, C = Constants dependent upon type and severity of distress

Example deduct curves are shown in Figures 3.3 and 3.4.

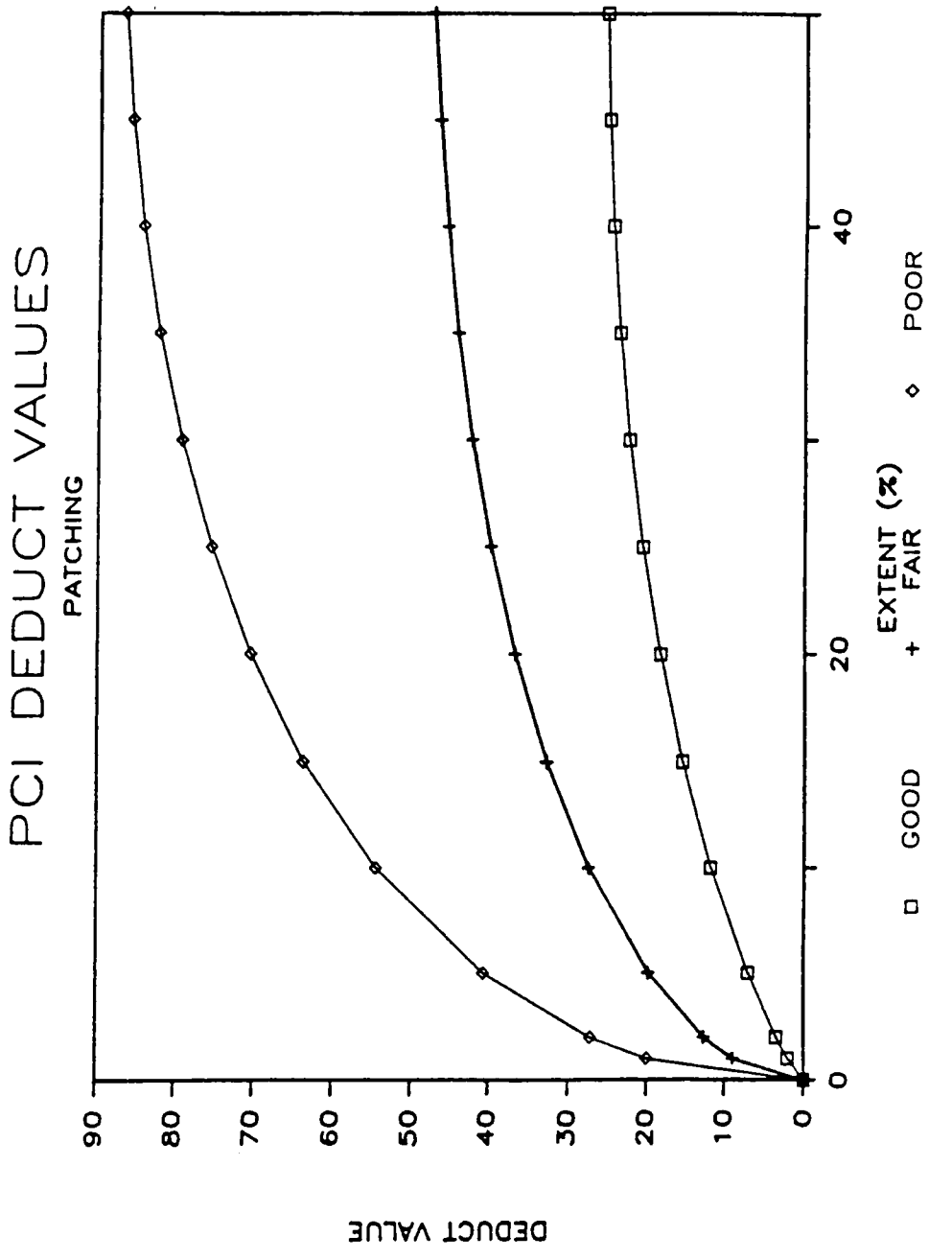
The deduct curves for this PMS are basically the result of subjective judgments by the Tulare County staff. Coefficients were chosen to give more weight to distresses and severities thought to be of more damaging nature, such as alligator cracking. The curves are not based upon any experimental testing by the Tulare County staff.

PCI is determined by entering each deduct curve according to extent of distress observed then intercepting the deduct value for each distress. The deduct values for all distresses are summed and subtracted from 100 to arrive at the PCI. This method does open the possibility of having the deduct value sum exceed 100 thus having a negative PCI. The Tulare County PMS follows the PAVER logic in realizing that, subjectively, the effect of having multiple distresses within a pavement section in less than the effect of each distress taken individually. In other words, a pavement engineer may subjectively rate a pavement with multiple distresses as poor but passable, PCI above 0, when the sum of individual deduct values may indicate the pavement to be



Source: Reference 10

Figure 3.3 Tulare County PMS PCI deduct curve for alligator cracking



Source: Reference 10

Figure 3.4 Tulare County PMS PCI deduct curve for patching

completely failed (PCI =0). A correction curve, Figure 3.5, is developed to address this problem and keep the PCI from dropping below 0.

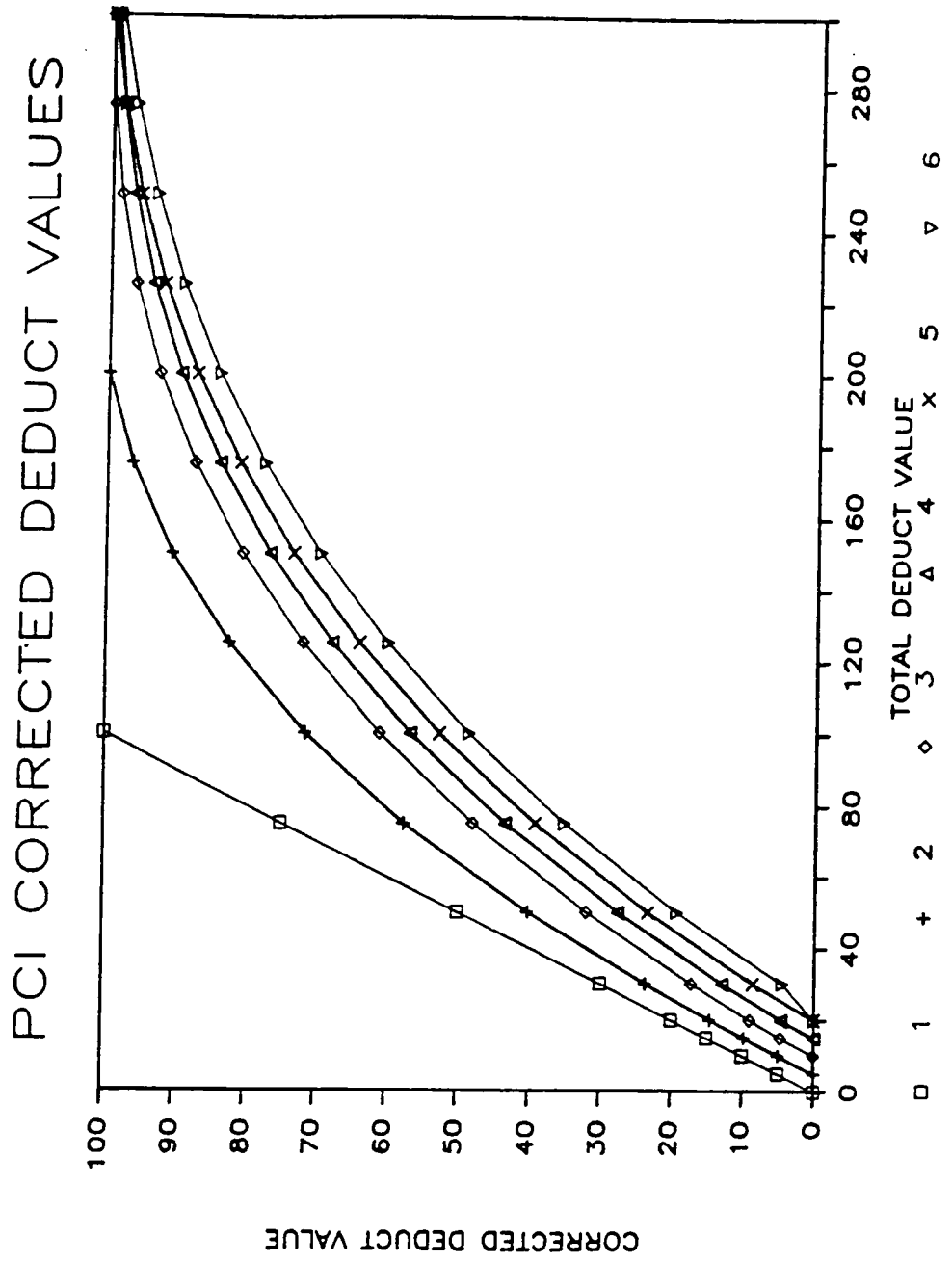
Average PCI for a route is calculated by simple ratios. The PCI for each section is multiplied by the length of the section, these values summed then divided by the total length of the route considered. Tulare County also chooses to weight the PCI according to traffic by including ADT in the formula below:

$$\text{PCI/user-mile} = \frac{\text{sum(PCI*Length*ADT)}}{\text{sum (Length*ADT)}} \qquad \text{Eq. 3.2}$$

From Ref. 10

The single PCI calculation is all that is provided by the PMS. No projections of future PCI or adjustment of PCI due to maintenance is possible with this system. However since it is possible to have multiple files, it is not known if the Caltrans limit of 9999 records is applicable to the Tulare County version, one could easily keep each inspection as a separate file and compare PCI over time or study the effectiveness of maintenance techniques.

This PMS differs from the Bay Area PMS (Ref 2), slightly in interpretation of PCI values. Tulare County considers 80 to be the breakpoint between good and fair pavement condition and does not model deterioration below PCI of 20. The Bay Area PMS uses PCI values of 70 and 25 for the same thresholds.



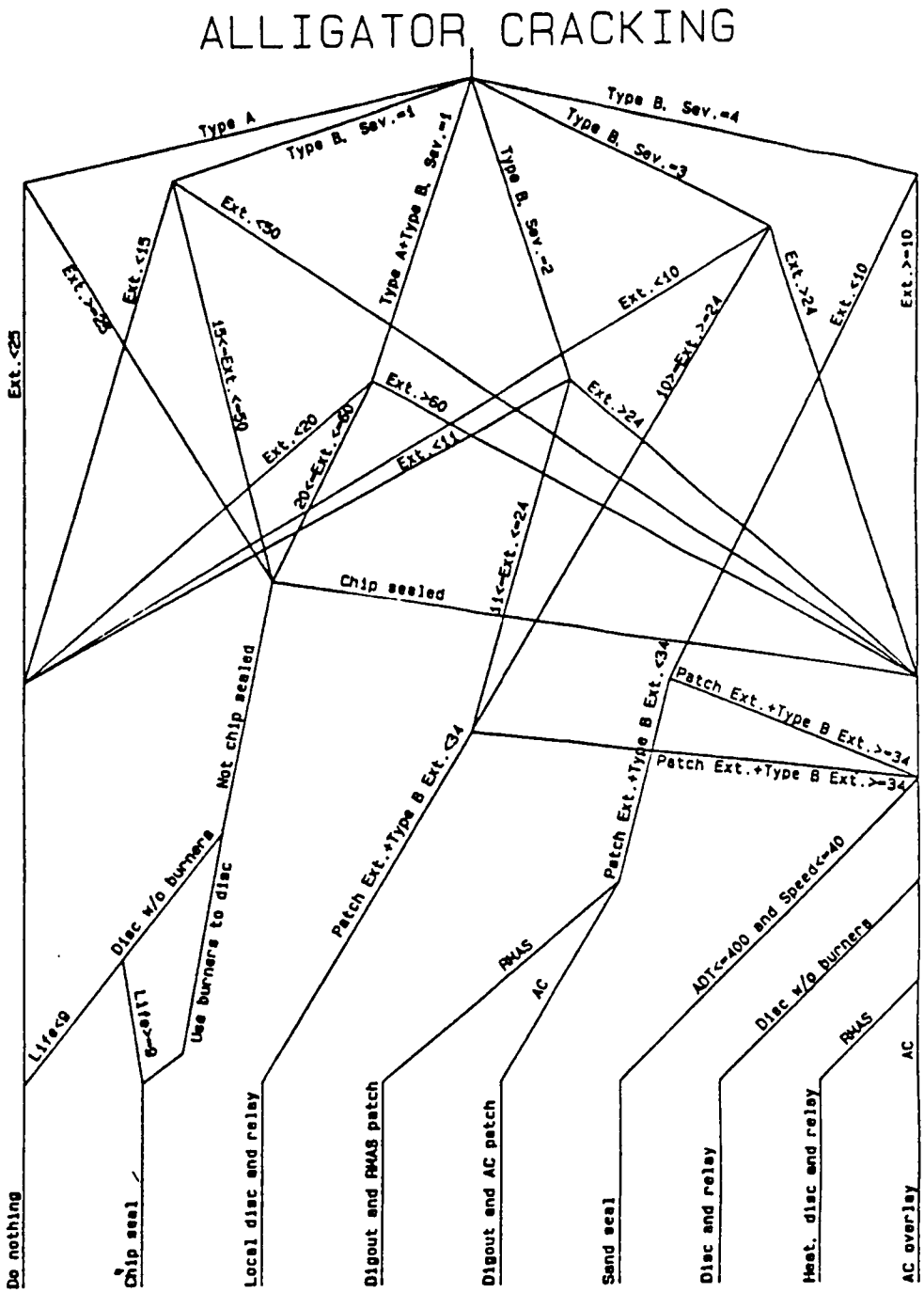
Source: Reference 10

Figure 3.5 Tulare County PMS PCI correction curve

SUGGESTED TREATMENTS/DECISION TREES

As with the Caltrans FPMS, the Tulare County version includes a primitive "expert system" in the form of decision trees. The purpose of the decision trees is to suggest a repair strategy for each segment and calculate estimated maintenance cost for that segment based upon unit cost data for each repair strategy. A separate decision tree is developed for each of the eight distresses recognized by the PMS. The procedure is identical to the Caltrans version in that type, severity, and extent threshold values are used in addition to presence of other distresses and traffic data in determining a suggested repair strategy to address each distress. It is quite possible that sections with multiple distresses will have more than one repair strategy after running through all applicable decision trees. The strategies are compared and the most comprehensive repair strategy becomes the controlling strategy for that section and is used for cost estimating. The decision trees are more complex and include more factors than the Caltrans trees; more repair strategies are also available. See Figure 3.6 for a sample decision tree.

The result of the decision trees should not be considered a substitute for engineering judgment. The decision trees do not include all potential problems of pavements, inspection of segments considered for repairs is



Source: Reference 10

Figure 3.6 Tulare County PMS decision tree for alligator cracking

a must to determine all repairs required for that particular segment prior to committing funds for projects.

Repair strategies and decision tree threshold values have been tailored for the special needs of Tulare County. Unfortunately changing any of the values is difficult for non-computer programmers. As reported earlier, the Caltrans FPMS had simpler decision trees with built in capability for the user to change threshold values but not the strategies. A quick aside is required at this point to look at software configuration in order to gain an idea of possible modifications. The Caltrans version is available to the user in executable form. In simple terms this means that the actual program code is not accessible to the user unless he is skilled at computer programming techniques and "tricks". This leaves the repair strategies pretty well fixed. The Tulare County version comes to the user as a actual source code. A user familiar with basic programming can access the proper lines of the program and modify the repair strategies and threshold values. With computer memory virtually no problem today, it is hard to understand the omission of a simple routine in both versions to allow customizing of maintenance techniques.

A similar problem exists in cost estimate calculation. The formulas and unit prices used in cost calculations are internal to the program. Again it is relatively easy to change the data statements within the program code as unit

costs fluctuate, but cost will not be static even for network level consideration, so why not include a method for the user to make routine updates?

Option 7 on the main menu, Figure 3.7 performs three functions, the aforementioned repair strategy and cost data and also will calculate a priority number for aid in selecting projects for repair. The priority number is a combination of the value from a priority matrix, Figure 3.1, page 54, and cost data. As seen in Figure 3.1, the priority matrix provides a unique integer for each possible combination of ride score, PCI, and ADT. Dirt and gravel roads are automatically assigned a priority of 99. As with the Caltrans version ride score and ADT heavily influence the priority integer. A decimal number to represent cost estimates of the project is added as a tie breaker among projects with similar integer values. The cost decimal is derived from:

$$\text{Cost Factor} = \frac{\text{Cost (\$1,000's)}}{\text{ADT} * \text{Length}} \qquad \text{Eq. 3.3, From Ref. 10}$$

Again, for whatever reason, the Tulare County version omits giving the user the option to directly modify the priority matrix without programming changes. The matrix itself (like the Caltrans version) appears to be too simplistic to be of muck value. Segments deteriorated to the point of needing reconstruction will receive the highest priority. Cost-

TULARE COUNTY PAVEMENT MANAGEMENT SYSTEM

MENU SELECTION

1. OPEN old data file.
2. CREATE a new data file or EXPAND existing one.
3. ENTER or edit pavement condition survey.
4. PRINT pavement condition survey records.
5. CHECK for errors in pavement condition survey.
6. Calculate PAVEMENT CONDITION INDEX (PCI).
7. RUN program for repair strategy, priority, and cost.
8. SORT records alphabetically and in order of priority.
9. Print INDEX of the segments sorted by location.
10. Print REPORTS of the sorted records.
11. Print summaries by PCI, ADT, surface type, width and terrain.
12. Enter or edit maintenance HISTORY data.
13. END this program.

Select a number:

Source: Reference 10

Figure 3.7 Tulare County PMS main menu

benefits of various levels of maintenance cannot be considered. PCI weighted by user mile data was seen to be calculated earlier but is not included in the PMS priority setting process. Actual project selection with limited funds should be based on more thorough field inspections.

MAINTENANCE HISTORY

A welcome addition to the Tulare County version PMS is the ability to store maintenance history data. The date performed and a code designating predetermined maintenance activities may be stored in the data base. This feature will allow the user to track the work applied to the same segments which along with PCI values may give an indication of effectiveness of maintenance. A complaint is that no space is available for entering actual maintenance cost information or more specific descriptions of the maintenance performed. Overlays come in several mixes and thicknesses, just to indicate an overlay has been applied is not descriptive enough.

REPORT GENERATION

The report generating features of the Tulare County PMS follow the same concepts as the Caltrans version with format modifications to suit Tulare County needs. Records may be

sorted by location, priority number, header record, or all of the previous. Option 8 on the main menu will perform the sorting as desired but other options must then be selected to receive hard copies of the sorted records. Option 9 will print an index of basically the record title information including PCI and traffic data but unfortunately ALL records within the file are printed. The Caltrans/FHWA version has the more practical option of allowing the user to print an index of records by route or range of record numbers.

Another report option, choice 10 on the main menu, will print a list of segments with information regarding major distress, controlling repair strategy, cost, and priority. The segments may be sorted by priority number, location, or record number and one has the option of listing all segments with all recommended repair strategies or, if interested, may list segments with the same recommended repair strategy. This could be particularly useful if trying to determine the amounts of various types of maintenance needed or if packaging projects for bid work.

A summary report listing total number of segments falling within certain ranges of network characteristics is available through option 11. The number of records falling within preset PCI, ADT, surface type, width, and terrain category is reported (Ref 10). A voluminous listing results because all records are used in this option and because intervals for the categories are very small. Also all

intervals are output even if no records fall within the interval. ADT intervals are 100 vehicles per day (with an upper limit of 10,000 vpd), width of street is reported in one foot intervals. It is hard to imagine the need for such detail for any reason. Smaller intervals for the PCI, ADT, and width would provide information just as useful much faster and eliminate pages of zeros as can easily happen with the present interval values. The summaries in their present form are likely to be printed only annually or at infrequent intervals.

The reports are tailored to Tulare County's specific needs. Summaries are provided for each of five districts in the county and according to their functional classifications. Many localities will not need the surface type or terrain categories since asphalt cement streets and similar terrain is prevalent in many jurisdictions. It is disappointing that the ability to select reports by route name or number has been eliminated. The PMS is much simpler for infrequent users or non-technical people to understand if common street names or route numbers are used.

The PMS would be more portable to other jurisdictions if records and results could be indexed according to any of the data elements the user desired. Significant software modifications would be required for the system to produce reports meeting different localities needs.

COMPUTER REQUIREMENTS

The Tulare County PMS may be used on an IBM-PC/XT/AT model microcomputer or an IBM-compatible machine, with a minimum of 256 kilobytes of RAM and one floppy disk drive. The program is written in BASICA programming language, a BASIC interpreter is required for use. The system was tested on an IBM-AT with IBM-BASIC and a Zenith Z-100 PC with GW-BASIC. The system ran smoothly on both machines with no apparent problems. Separate data disks can be used to store multiple files if another disk drive is available.

MANPOWER/EQUIPMENT REQUIREMENTS

No mechanical testing results are accepted by the Tulare County PMS therefore only simple measuring tools are required to complete the pavement condition survey. Man power requirements are difficult to estimate since they could vary widely according to length of segment and condition of the inspection unit. Based on sample field surveys, one could use 15 to 20 minutes per sample unit as an estimate. The survey requirements are very close to the Caltrans/FHWA FPMS requirements but because only a small portion of the network is inspected, survey time should be dramatically shortened. Even with the sampling technique it

is recommended that two person survey teams be used to speed the process and encourage consistency among surveyors.

SUMMARY

From testing of both the Caltrans/FHWA FPMS and the Tulare County version, it is obvious a great deal of work has gone into development of the latter version. Colorful screens with easy to read data fields and some user friendly prompts give the system a professional look. The system is straightforward to use and smoothly moves from option to option with no problems. Looking at analysis and output capabilities, the most significant changes are the addition of the PCI calculation and maintenance history storage capabilities. Both additions should aid the user in tracking pavement performance. While validity of the PCI is arguable, further discussion will be presented in the overall conclusion, monitoring the PCI over time by keeping each inspection as a separate record will at least give a general idea of changing conditions of the pavement. Since all pavements will require maintenance at some point unless allowed to deteriorate to failure, the ability to keep maintenance records is quite beneficial, although as noted earlier more detailed info would be better. The combination of maintenance history data and PCI should allow the user to

study the effectiveness and useful life of various maintenance and rehabilitation techniques.

The error checking routine appears to be beneficial, especially where data entry may be by clerical personnel unfamiliar with pavement management. It should be noted that this does not relieve the engineer from the responsibility of spot checking the survey data even to the point of visually checking a few segments for accuracy.

Considerable work has also gone into modifying the decision trees in the Tulare County version. The possible repair strategies have almost doubled from the Caltrans version and more factors are included in the tree structure. The Tulare County user's manual (Ref 10) does emphasize the fact that the repair strategies are for network level decisions only and should not be considered the best action to take without field investigation. Hopefully users will heed this advice and not blindly accept the recommendations of the system.

The reporting formats have been customized for the needs of Tulare County which limits their usefulness to other jurisdictions. Modifications would certainly be in order unless an area chose to use the same categories and classifications as Tulare County. The method required for modifying the PMS is one point of criticism. To be fair, a user with moderate BASIC programming skills could modify the software in a reasonable amount of time to include formats,

maintenance and repair techniques normal to their locality. The source code is well documented to allow easy location of data elements, algorithms, and headings in case modifications are desired. But it would be simple to include routines in the system to allow the user to modify items likely to need updating such as unit costs, repair and maintenance techniques, etc. It is recognized that this system was not modified for general distribution although it is public domain software and available at nominal cost to anyone, therefore the criticism should be taken in that light. This author believes it is too dangerous for possible novice users to modify the software itself when easier methods could be provided.

Overall the Tulare County PMS is seen to be an improvement over the Caltrans FPMS. Its condition inventory, PCI calculation, and maintenance history capabilities would appeal to most potential users and the system is simple enough to be a starting point for areas considering a PMS. Areas which could be improved are the inclusion of budget type cost data which could be manipulated and sorted as necessary by the user and expansion of the reports available. Certainly the option to sort based on more data elements and receive output more route or area specific would be welcome. Knowledgeable users can overcome some of the limitations by careful file structuring.

CHAPTER IV

BAY AREA METROPOLITAN TRANSPORTATION COMMISSION PMS

INTRODUCTION/OVERVIEW

The Metropolitan Transportation Commission (MTC) of the San Francisco Bay Area completed a study in 1982 of the road and street maintenance needs verses funding levels for jurisdiction within the Bay Area. The study revealed, what most studies of this nature would reveal, that inadequate funding for street maintenance and rehabilitation are being provided and that most jurisdictions have no organized method for allocating funds for street repairs within their boundaries. The results of this study prompted the MTC to recommend that guidelines be developed to help the cities and counties within its jurisdiction improve their maintenance and rehabilitation techniques and to develop a standardized PMS that could be utilized by all these local agencies in the Bay Area.

In that year ERES Consultants, Inc. was hired to perform a study of the street maintenance problems and develop a prototype PMS. Based on interviews and surveys of the jurisdictions involved, it was decided to develop a relatively simple PMS that could utilize a microcomputer for data storage and manipulation. A microcomputer was preferred

because of its lower capital cost compared to a mainframe. The PMS that resulted is a powerful, flexible management tool that should prove useful for network level decision making.

The PMS requires a sample pavement condition survey which involves a manual visual inspection of the network included in the management system. This pavement condition survey information becomes the data base for analysis and report generation by the PMS software. The Bay Area PMS utilizes a commercially available data base manager to manipulate the data base files, and interprets the results with the custom written PMS software to produce the desired outputs. This PMS chooses to assign a Pavement Condition Index (PCI) value to the individual roadway segments, which is intended to serve as an indication of the relative state of repair of the street segment. The PCI scale ranges from 0 to 100 with 100 representing a new pavement section and 0 indicating complete failure of the pavement. The PCI is calculated by deducting points from 100 depending on the number, severity, and quantity of distresses observed within the sample units.

Calculation of PCI values is actually a small part of the capabilities of the MTC PMS. Other features include the ability to project PCI values for a five year analysis period, with the options of either using predetermined repair strategies or with no maintenance over the analysis

period. Cost estimates to perform the recommended maintenance strategies are available using changeable unit cost data, and the system is flexible enough to allow the user to create several unique budget scenarios using different levels of maintenance for street segments of interest. The system will index and report the raw data items or calculated values according to criteria selected by the user.

NETWORK INVENTORY AND PAVEMENT CONDITION SURVEY

As with any practical PMS, the MTC PMS requires an inventory and pavement condition survey to take place prior to analysis or recommended maintenance. The MTC PMS addresses the managed street network as a combination of individual management units. Each management unit should be a portion of the network that the user would expect to apply the same maintenance or rehabilitation technique to. Thus a management unit may be as small as one segment of an individual street or as large as an entire subdivision or neighborhood where all the streets were constructed at roughly the same time using the same structural design. The system allows the user to assign unique street identification numbers and section ID numbers in order to group street sections if desired, and also to segregate the data if needed for later project level analysis. The

development of the street and section ID data base should take place prior to the pavement condition survey because of the sampling technique to be used which will be explained later. A sample of the initial pavement section inventory data required can be seen in Figure 4.1 which shows a typical office form. Most of this initial ID information may be obtained from maps and supplemented by brief field measurements where necessary.

The Bay Area PMS does not include provisions for use of mechanical or laboratory testing, all analyses are based on a manual visual inspection of the pavement surface only. For this reason the data item of "Date Present Surface Constructed (yr)" is included. If a street has not been overlaid, then the original construction date or best estimate thereof, is used. If the pavement has been resurfaced, then the date of application of the latest overlay is used.

When the preliminary studies prior to development of the PMS were performed, it was noted that over 95 percent of the Bay Area pavements had a bituminous surface; therefore, the decision was made to exclude portland cement concrete (PCC) pavements from the PMS. The pavement section inventory form will allow the user to include PCC pavements but the PMS will not perform any analysis of these sections.

BAY AREA SECTION ID ENTRY FORM

*STREET ID: _____ (A) *SECTION ID: _____ (A)

*STREET NAME: _____ (A)

*LOCATION BEGINS: _____ (A)

*LOCATION ENDS: _____ (A)

*NUMBER OF TRAFFIC LANES: _ (N) *FUNCTIONAL CLASSIFICATION: _ (A)

**LENGTH(ft): _____ (N) **WIDTH(ft): ____ (N) **AREA(SQ FT): _____ (N)

*SURFACE TYPE: _ (A) *DATE PRESENT SURFACE CONSTRUCTED(YR): __ (N)

GENERAL CODE: __ (A) TRAFFIC INDEX: __ (N) ADT: _____ (N) AREA ID: _ (A)

WIDTH OF PARKING/SHOULDER AREA(ft): ___ (N) FUNDING SOURCE: _ (A)

COMMENTS:

FUNCTIONAL CLASS:
- A-ARTERIAL
- C-COLLECTOR
- R-RESIDENTIAL/LOCAL

AREA IDENTIFIER:
- A THRU Z

SURFACE TYPE:
- A-AC
- C-AC/PCC
- S-Surface Treatment
- O-Overlay AC/AC
- P-PCC

GENERAL CODE:
- DRAINAGE/CROWN/ETC.

FUNDING SOURCE:
- A THRU Z

*MANDATORY **MANDATORY LENGTH AND WIDTH OR AREA IN SQUARE FEET

(A)=LETTERS AND NUMBERS (N)=NUMBERS ONLY

SKETCH:

Source: Reference 2

Figure 4.1 Bay Area PMS sample section ID form

Because the PMS was intended mainly for network level decision making, the consultant decided it was unnecessary to survey the entire street network. Rather, each management unit would be further subdivided into inspection units of 1000 to 4000 square feet in area. Then approximately 10 percent of the inspection units are surveyed for pavement distresses present. The inspection units may be located or identified in any manner convenient to the user; however, the developers of the system suggest the use of a standard length of 100 feet and full width of the pavement for each unit. For multi-lane streets where full width inspection units may exceed 4000 s.f., it is recommended to survey each direction of travel as a separate inspection unit. The inspection units may be permanently marked or the field inspector may randomly choose 100 ft. segments along the street to cover approximately 10 percent of a management unit. If within small management units only one or two inspection units are required for sampling, the surveyor should subjectively select a 100 ft. section that best represents the average condition of the pavement, not the best or worst sections.

The individual pavement inspection units are carefully inspected for evidence of surface distress with each distress ranked according to its severity and quantity observed. The Bay Area PMS was developed with the idea of being as simple as possible while retaining enough

capability to produce meaningful and useful results. The system draws concepts from the mainframe computer-oriented PAVER PMS developed by the U. S. Army Corps of Engineers and the American Public Works Association (Ref 15). PAVER includes 19 separate pavement distress types with different severity and extent classes. The Bay Area consultants felt that to include so many distress types would be counter productive for a network level tool as wanted by their clients. Therefore, a study was performed to determine the most prevalent flexible pavement distresses in the Bay Area and include only those in the PMS. The result was to include seven categories of distress: Alligator cracking (including potholes in this group), block cracking, distortions, longitudinal and transverse cracking, patching (including utility cuts), rutting, weathering and ravelling. Each category of distress is further categorized as low, medium, or high severity. A training manual for field personnel (Ref 3) was prepared with photographs illustrating examples of each distress and its different levels of severity. After the training and calibration of field technicians who will actually perform the surveys, data collection may begin.

The survey of the inspection units is a simple concept, but it can occasionally become tedious in the field and lead to inaccuracy. Thus the possibility of boredom experienced by field technicians may be of concern considering that the

pavement condition survey is fundamental for the entire PMS and must be as precise as possible. The field inspectors are given forms similar to those illustrated in Figure 4.2 which offer space for identifying information and the distresses found along with severity and quantity of each. A difficulty occurs when, as it frequently happens, distresses are found in combinations and intermingled within the same location. The inspector should make every effort to identify each unique distress and its severity and quantity, but if unable to reach a conclusion, he may report only the most severe distress observed. It should be noted that unlike some other PMS, particularly the Caltrans, distresses observed within a patched area are not listed separately; rather any distresses within the patches are used to determine the severity level of the patch.

DATA ENTRY

After several sections have been surveyed the user may begin to assemble the computerized data base. The system is menu driven, a sample of the main menu is shown in Figure 4.3. By selecting main menu choice 1, 'enter data', a submenu will be displayed which offers the options to enter either section description information, pavement condition survey data, or maintenance history data. The section description option produces a screen replica of the Bay Area

DATE (MO/YR) __ / __ STREET ID: _____ SECTION ID: _____

INSPECTION UNIT NO: __ SPECIAL: _ (Y OR BLANK) AREA(SQ FT): _____

SURVEYED BY_____

DISTRESS TYPES & CODES

1. ALLIGATOR CRACKING
2. BLOCK CRACKING
3. DISTORTIONS
4. LONG. & TRANS. CRACKING
5. PATCH & UTIL CUT PATCH
6. RUTTING/DEPRESSION
7. WEATHERING & RAVELING

SKETCH:

FIELD RECORDING FORM FOR EXISTING DISTRESS TYPES

DISTRESS CODES						
QUANTITIES (AREA OR FOOTAGE)						
SEVERTIES (L,M OR H))						

SUMMARIZED TOTALS FOR PCI CALCULATION OR COMPUTER ENTRY

Source: Reference 2

Figure 4.2 Bay Area PMS sample field survey form

****

PMS SYSTEM MAIN MENU

****

1. Enter Data
2. Edit Data
3. PCI Calculation
4. Select Report
5. Budget Needs
6. Budget Scenarios
7. Modify Treatment Criteria/Cost
8. Utilities
9. Exit to RBASE
10. Exit to Operating System

****

Type your selection or [ENTER] for Main Menu _

Source: Reference 2

Figure 4.3 Bay Area PMS main menu

section ID form which can be filled out to produce a computerized record of the section and street ID information. The network should be segregated into street segments and grouped into geographic sections on a base map prior to entering this data for the sections to be meaningful and useful. Actually all of the data included on this form could be prepared and entered prior to field surveys with only minor modifications likely to be needed after the survey.

The inspection unit option on the submenu creates a simple replica of the field survey form. This method should reduce errors in transferring the data from field forms to the computer since the formats match and no interpretation is required. Because of the simple format, data entry is relatively quick (compared to similar systems). Upon completion of each form the user may add the data to the data base and receive another blank form on the screen for entering new data, or place the data just entered on the screen for correction of mistakes prior to entry to the data base. Other possible actions include exiting the PMS, or the useful option of adding the data just entered to the data base and displaying the same info on the screen. This option seems unusual but it actually speeds entry of data since it is likely there will be more than one inspection unit survey form per street and perhaps multiple streets

within a segment. This option will fill in much of the redundant title information thus saving time.

The ability to store maintenance history data over a long term, option 3 on this submenu, may prove to be one of the more valuable options within the PMS. A simple form is created on the screen which allows the user to enter street and section ID plus date of maintenance, type of maintenance by code number, and cost of the repairs. This can allow the user to track the performance of his own methods of maintenance and keep an account of expenditures on each street section.

Main menu choice 2 allows the user to access specific portions of the data base for viewing or editing. The section ID forms, inspection unit forms, or maintenance history forms may be accessed by street ID, section ID, or if desired all records may be sequentially displayed. After accessing the records the user can choose to edit, delete, skip through to view the records. The user may select from three somewhat unique options which either CHANGE the record, actually just saves the edited version, RESETS the record, which basically abandons the edited version of the record and keeps the old data. or ADD a record while keeping the old record.

Entering and editing the original data and subsequent large blocks of data would be a suitable task for a keypunch operator instead of the PMS administrative user. After

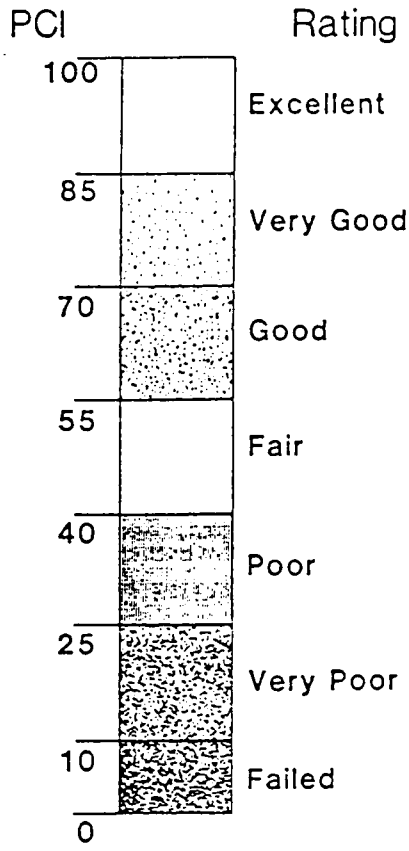
initial training to give the operator clues on spotting suspicious data values, there is no real reason for the engineering or administrative personnel to spend time on the system, other than spot checking progress, until at least a partial data base is assembled. The engineer may wish to periodically review the field survey forms and also visit a few inspection units to compare the survey forms with actual field conditions. As noted earlier, the distress severity classes are set up as either low, medium, or high. The inspectors are trained to use the medium severity class as a default value, that is the inspector should try to decide if the distress fits either the description of low or high severity and if not then it should be rated as medium. This method makes the surveyors' job easier but if the surveyors are not conscientious they can easily fall into the trap of rating too many distresses as having medium severity. The engineer or project manager must constantly be cognizant of this potential problem and encourage his inspectors to be as careful and precise as possible. This PMS is intended mainly for network level use with limited project level application which is why only a sample of the network is inspected in moderate detail. But the data that is collected is utilized for a myriad of computations intended to portray the condition of the paved network. An inaccurate data base would render the results meaningless and waste significant amounts of time and money.

PAVEMENT CONDITION INDEX

CONCEPT AND USE

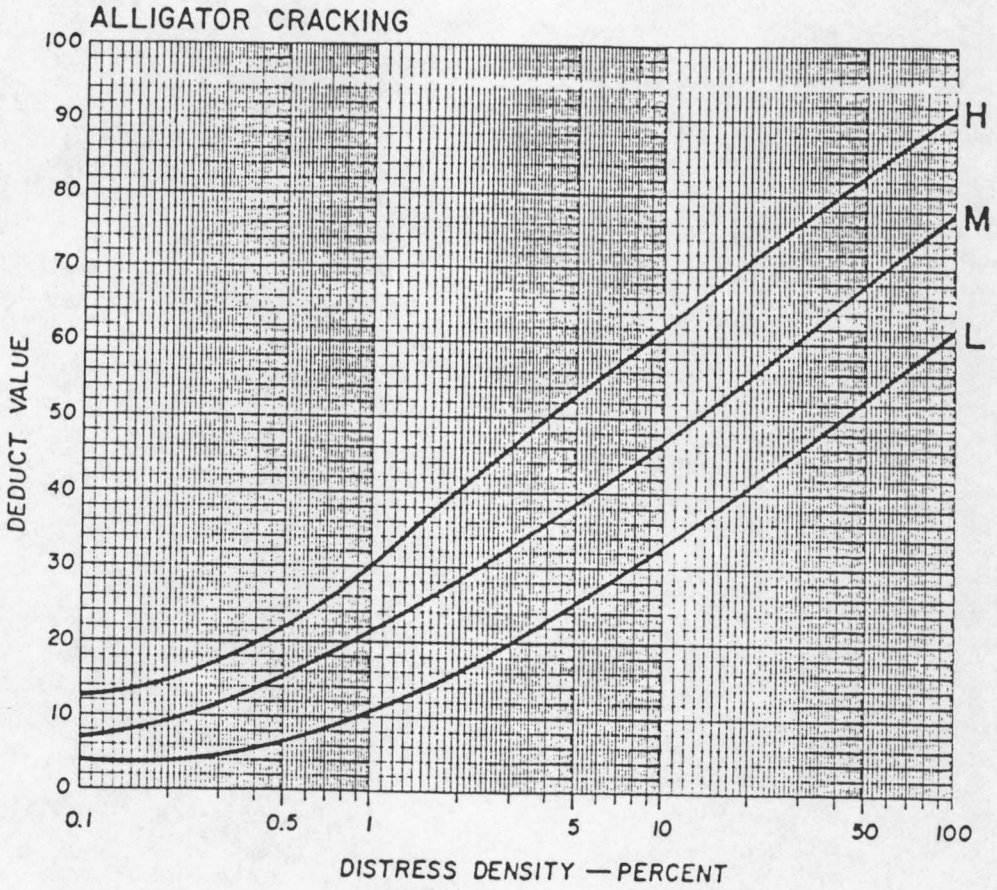
The Bay Area PMS makes use of a pavement condition index (PCI) to represent the relative state of repair or condition of the pavement. The PCI concept is to have a system which would allow technicians with limited training to subjectively rate a pavement surface and obtain a rating similar to that of an experienced pavement engineer. The Bay Area PMS incorporates a PCI methodology which is basically a simplified version of the one used in the PAVER PMS (Ref 15). A scale of 0 to 100 is used with 100 representing a new pavement, or new pavement surface, and 0 a completely failed pavement. Figure 4.4 indicates the subjective rating roughly associated with the numeric PCI values.

An inspection unit's PCI is developed by starting with a value of 100 (new pavement surface) and deducting points for each distress observed depending upon its severity and quantity observed. Deduct curves, samples of which are shown by Figures 4.5, 4.6, and 4.7, were developed for each type of distress which then are used to determine the individual deduct values. The exact method used to develop the deduct curves is not exactly clear. Apparently the engineers who developed the distress identification manual



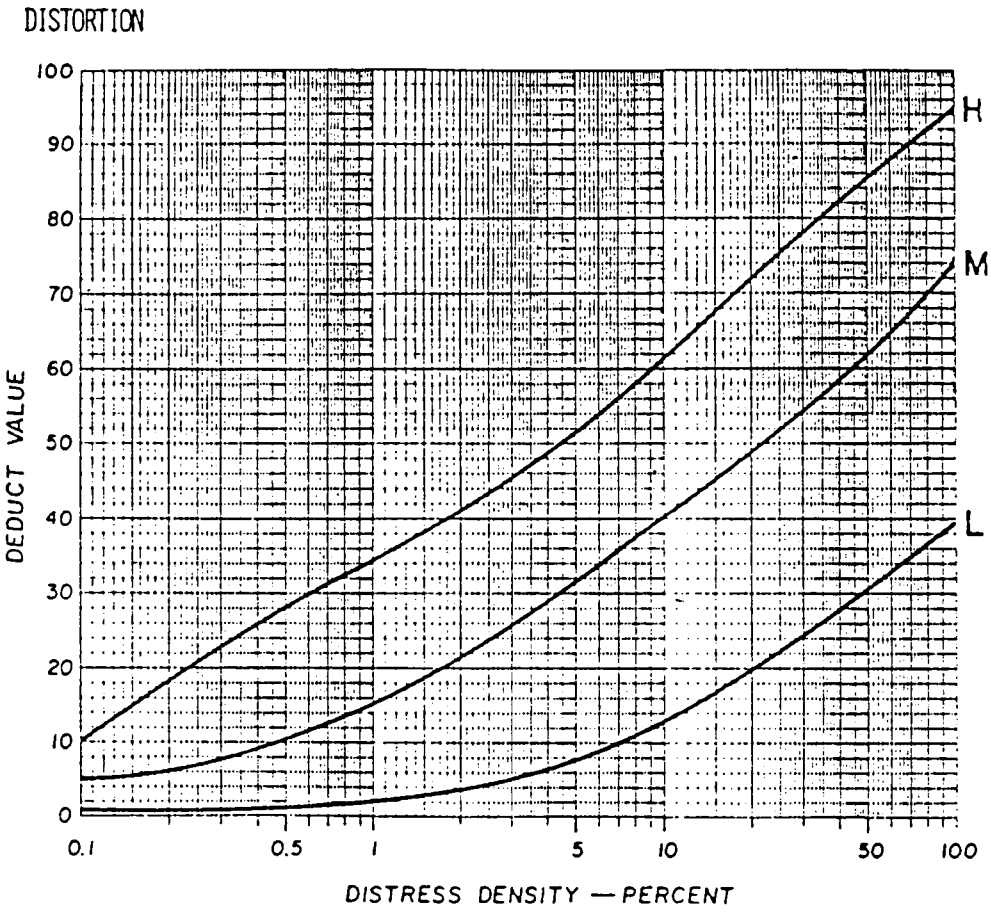
Source: Reference 2

Figure 4.4 Bay Area PMS PCI scale



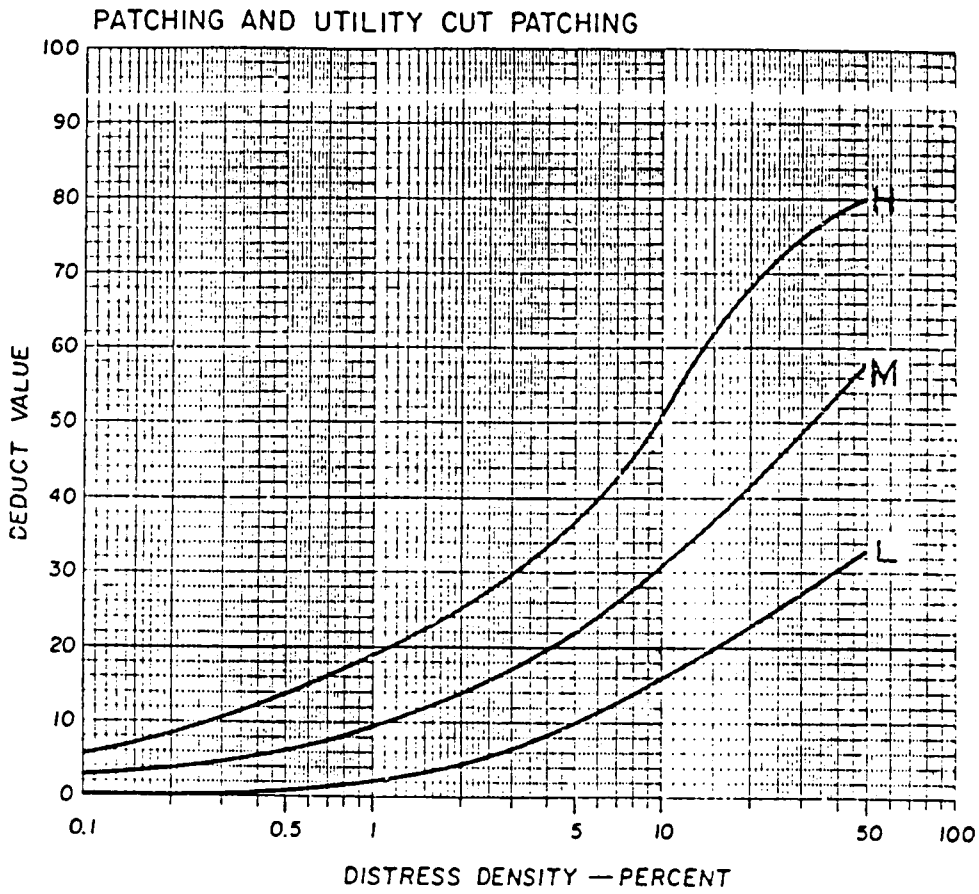
Source: Reference 2

Figure 4.5 Bay Area PMS PCI deduct curve for alligator cracking



Source: Reference 2

Figure 4.6 Bay Area PMS PCI deduct curve for distortions

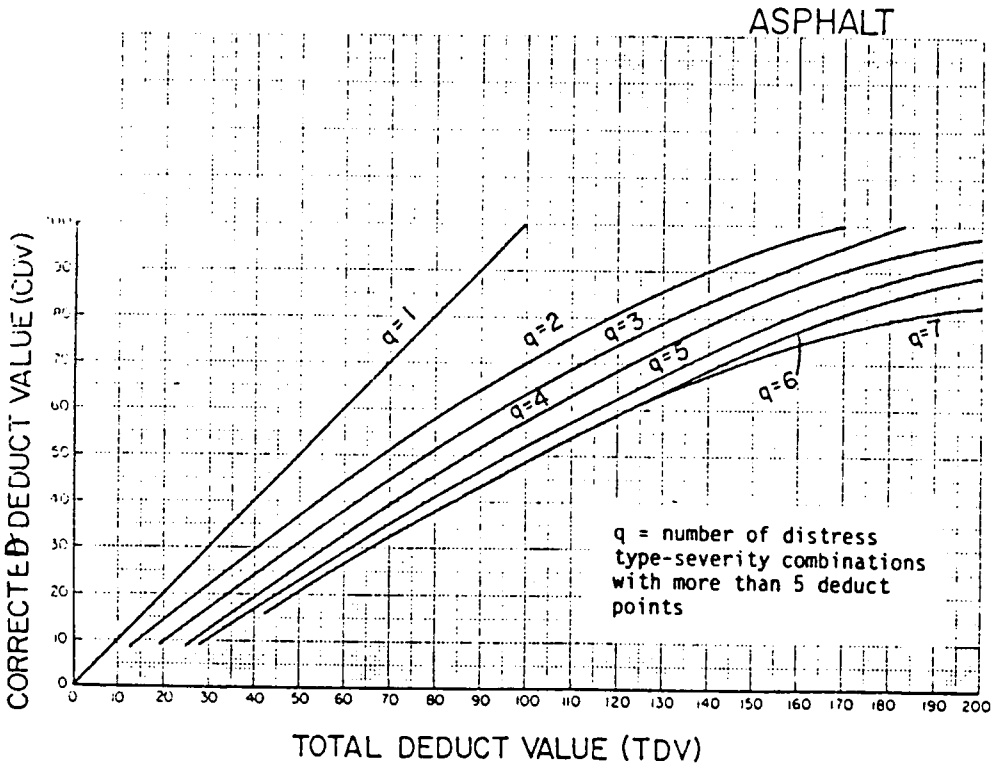


Source: Reference 2

Figure 4.7 Bay Area PMS PCI deduct curve for patching

(Ref 3) subjectively decided upon the relative condition of a pavement which exhibited the quantity and severity of each distress listed in the manual. The curves were prepared with the assumption that only one distress is found within each inspection unit. If multiple distresses are present, it is not impossible to end up with a total deduct value in excess of 100 which then yields a meaningless negative PCI value. Studies of the PCI values assigned to pavement sections with multiple distresses by a group of pavement engineers indicated that their simultaneous overall evaluation of the effect of multiple distresses was less severe than the sum of the ratings of the same distresses performed individually. To get around this problem a correction curve was developed (Figure 4.8), which is used to lessen the impact of multiple distresses within the same inspection unit.

The first step is to determine the individual deduct values for each observed distress and sum these to obtain a total deduct value for each inspection unit. One then enters the correction curve for multiple distresses using the total deduct value and the number of distresses with individual deduct values exceeding 5. This yields an adjusted deduct value which is subtracted from 100, thus producing a PCI value for the inspection unit. All PCI values with common section ID are averaged to produce the section PCI. Occasionally an inspector may observe a



Source: Reference 2

Figure 4.8 Bay Area PMS PCI correction curve

location along the street that is in significantly different condition than the rest of the street. If the inspector or project manager feels this location warrants attention, then a special inspection unit may be created to include a sample of the unusual pavement condition. Calculation of the section PCI including special inspection units differs slightly from the simple averaging method mentioned earlier.

The formula is:

$$\text{Section PCI} = \frac{(T - S)PCIn + (S)PCIs}{T} \qquad \text{Eq. 4.1}$$

From Ref. 2

with T = No. of normal inspection units in section
S = No of special inspection units in section
PCIn = Average PCI for normal inspection units
PCIs = Average PCI for special inspection units

This method actually attaches slightly more importance to the special inspection units than the simple average method. One should be fairly certain that the special inspection unit is significant and should be identified since the PCI will be biased by its inclusion. It is quite possible to survey the street network and manually calculate the PCI for each street and/or segment using the method presented by this PMS since the process is simple and requires no complex calculations. However the topic of interest is the microcomputer based PMS; therefore, the possibility of a manual system will not be expanded upon.

It should be noted that as maintenance is performed on the network the PCI is adjusted upward to reflect the effects of the maintenance. The old PCI from inspection unit data is discarded and the new PCI is used from that point for projections as described below and for any other calculations. It is not explicit how the system decides on the amount of adjustment for each maintenance technique, but it is likely that the deduct values are modified by adjusting the severities of distresses previously observed and recalculating the PCI. This conjecture is based on the procedure used for projecting PCI (Ref 2) and described below.

PROJECTION OF FUTURE CONDITION

Any PMS that can produce some form of PCI for the streets within the managed area is useful to an extent. One can derive an idea of the relative condition of the network and the data may be indexed in various ways to determine the relative condition of streets in particular locations, various classifications of streets, etc. But the Bay Area PMS also has the capability to produce a simplified forecast of the future PCI to open the possibility of multi-year budget planning, more efficient maintenance scheduling, etc.

Truly projecting pavement performance would be a complex task indeed. Structural information, traffic characteristics, weather effects and many other variables would have to be modeled to produce an accurate prediction for detailed project level use. The Bay Area PMS makes no attempt to develop a theoretically based pavement condition projection, instead individual management units are assumed to follow the performance of pavements of similar structure.

A series of "family curves" were developed for each combination of functional classification of roadway and pavement type. As of this text only nine curves are known to exist with the possible combinations of residential, collector, and arterial functional classifications and AC, AC/AC, and ST pavement structures. Because of the limited number of AC/PCC pavements found in the Bay Area, insufficient data has been collected to produce the family curve associated with this pavement structure. The curves are based on empirical findings.

Performance data in the form of PCI vs. time were taken from studies in four Bay Area counties (Ref 2). No individual pavement was monitored over time to determine its performance, instead several samples of pavements with different PCI and age values within each group were selected. As data becomes available on performance of pavements over time through use of this PMS, the consultant

indicated that the family curves may be revised to reflect the results of actual field performance (Ref 2).

Past studies (Ref 2) had indicated that mathematical equations which produced W-shaped and reverse S-shaped curves could be used to approximate the deterioration in pavement condition over time. The MTC consultant tried both equations on the sample data and found the reverse S-shaped curve to more closely approximate observed pavement deterioration down to the point where PCI is about 25 (Ref 2). Because at a PCI value of 25 the pavement is not far from failure, the performance below that level was not deemed of importance wherefore the reverse S-shaped curve was accepted as the representative shape of the deterioration curve. The equation itself is:

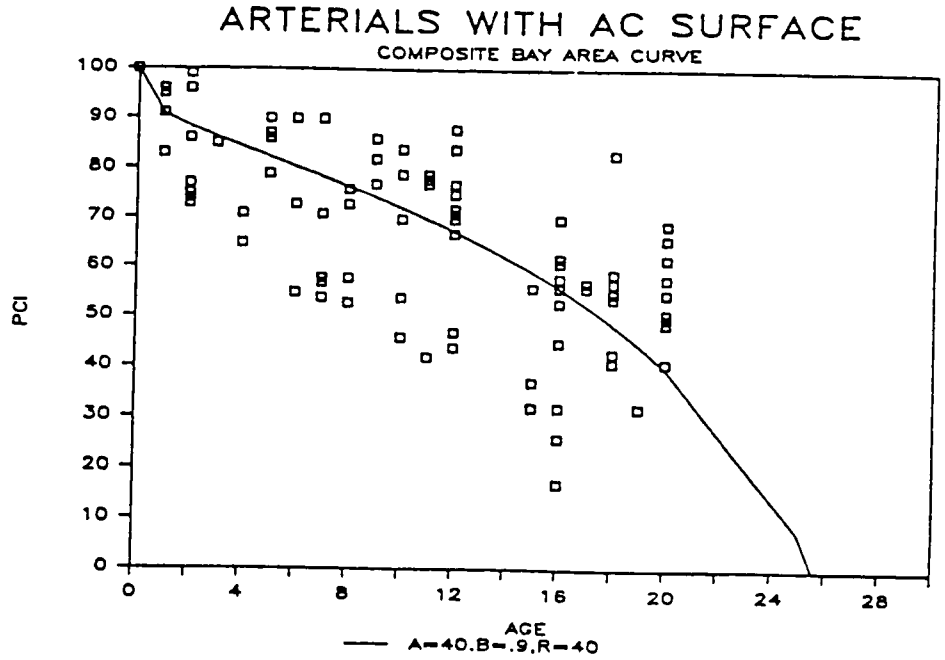
$$PCI = 100 - \frac{R}{(\ln A - \ln AGE)^{1/B}} \qquad \text{Eq. 4.2}$$

From Ref. 2

where:

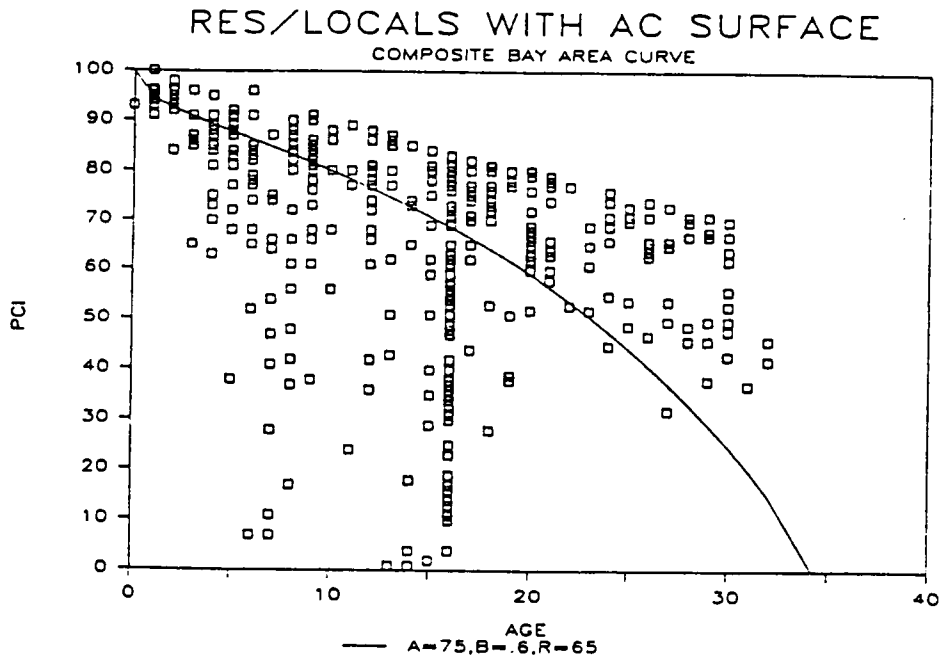
A = Constant which controls the X-intercept (age axis)
B = Constant which controls the sharpness of the curve in the upper PCI regions
R = Constant which controls the inflection point of the curve
AGE = Time since construction of the pavement surface

As indicated by the sample set of family curves for the Bay Area PMS, Figures 4.9 and 4.10, there was a wide scatter of data from the test results. A nonlinear regression technique was used to find the best fit for the reverse S-



Source: Reference 2

Figure 4.9 Bay Area PMS sample family curve for arterial streets with AC surface



Source: Reference 2

Figure 4.10 Bay Area PMS sample family curve for residential/local streets with AC surface

shaped curve through the data points. Reference 2 mentions that a series of computer programs developed at Texas A&M University and Cornell University were integrated to fit the logarithemic equation (Eq. 4.2) to the data through a series of iterations. The same program is expected to be utilized by MTC personnel as modifications to the family curves become necessary.

As indicated by the wide scatter of data points shown in the sample family curves, Figures 4.9 and 4.10, no individual pavement can be expected to exactly follow the representative curve. Rather the PCI projection is based on one observation, the latest if more than one is available, of PCI and forcing the appropriate family curve through this single data point. The methodology as used by the Bay Area PMS is a simple ratio curve shift, using the following formula:

$$A.F. = \frac{(100 - PCIa)}{(100 - PCIf)} \qquad \text{Eq. 4.3, From Ref 2.}$$

where:

A.F. = Family curve adjustment factor
PCIa = Section calculated PCI *
PCIf = PCI from family curve *

* at same pavement age

Given the above adjustment factor the PCI at any age for a given pavement is predicted from:

$$PCIpx = 100 - A.F.(100 - PCIf)$$

Eq. 4.4, From Ref. 2

where:

PCIpx = Predicted PCI at pavement surface age X

Thus if one particular pavement's PCI is calculated to be 75 and the family curve indicates the value would be 70 if the deterioration exactly matched the curve then the adjustment factor for this one section would be:

$$A.F. = \frac{100 - 75}{100 - 70} = \frac{25}{30} = 0.83$$

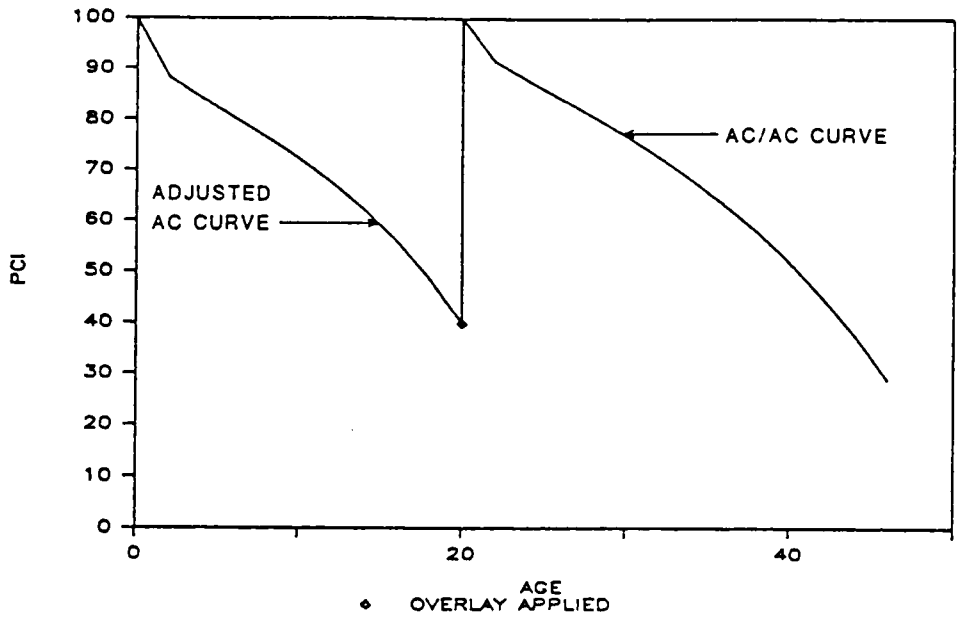
Predicting the future PCI for this pavement would then be simply a matter of multiplying the value taken from the family curve at the desired age by 0.83.

The Bay Area PMS probably lies within the upper range of the state-of-the-art of microcomputer based pavement management systems but the reader should notice the great simplification required to keep the system down to a usable size and keep the data base down to a size acceptable for present microcomputers. For this reason the numbers themselves produced are not as significant as the relative relation of the values to each other. Thus significant differences in actual future PCI vs. predicted PCI for any individual pavement may be observed but on a network wide level the average PCI for groups of management units is

probably within acceptable tolerances for multi-year budgeting, etc.

The PCI projections discussed above assume that no maintenance or rehabilitation will be performed on the pavement prior to failure. In reality most pavements receive some maintenance, whether proper or improper, before being allowed to become impassable. The Bay Area PMS recognizes this and allows consideration of the effects maintenance may have on the PCI value.

The most extreme case would be total reconstruction of the pavement section in question. After reconstruction the PCI would automatically be raised to 100 and future deterioration would be simulated using the family curve for AC pavement for the appropriate functional classification. Since the PCI is based on only visual inspection of the surface, a resurfacing project would also raise the PCI to 100 but in this case the future deterioration would be modeled by the appropriate family for an overlaid pavement, either AC/AC or AC/PCC. Figure 4.11 illustrates the PCI adjustment for an asphalt cement pavement overlaid with asphalt cement. This author, as stated earlier, understands the need for simplification within the PMS software but feels it necessary to point out some questions about the validity of generalized curves for overlaid pavement. No apparent adjustments are made for variables such as the condition of the pavement prior to overlay, preparation of



Source: Reference 2

Figure 4.11 Bay Area PMS PCI adjustment curve for AC/AC pavement

the pavement (crack sealing, patching, etc.) prior to overlay, drainage problems in the area, etc. Some consideration is taken of these factors in the life cycle cost analysis discussed later. It is recognized that this PMS is intended for network level use only and some errors may cancel out for large network analysis.

But municipalities often do not wish to commit the resources necessary to reconstruct or resurface all streets which need that level of treatment. Often temporary or limited maintenance such as crack sealing or patching is all that is done to the streets. It can be generally agreed that the resulting PCI would not be 100 since surface distresses will still be observed, but what should the PCI be? Certainly, the maintenance should improve the condition somewhat but exactly how much and then what should the deterioration curve look like? These are complex questions not easily answered and would be difficult enough to analyze for one pavement section much less an entire network. The Bay Area PMS attempts to generalize the behavior of pavements after maintenance in what this author believes to be one of the more questionable aspects of the program.

The method begins with reasonable concepts. Treatment of cracking or patching in not assumed to eliminate the distress but serves to lower the severity of the distress, and that a proper seal coat effectively cures weathering and raveling problems (Ref 2). In an attempt to quantify the PCI

improvement for each treatment, studies were performed where a pavement was rated before and after application of a treatment or combination of treatments. The results were graphed and multiple regression techniques were used to attempt to find some reasonable equation for the expected PCI increase due to a particular combination of maintenance treatments. One of the equations that resulted and is used in the system is:

For crack sealing only: (from Ref. 2)

$$PCIi = 0.43 + 0.00556(PCI) + 0.00323(PCI)^2 - 0.0000431(PCI)^3 - 0.000000105(PCI)^4 + 0.00000000201(PCI)^5$$

where:

PCIi = Expected increase in PCI
PCI = PCI prior to maintenance

The R^2 statistic for this equation is noted to be 0.08 (Ref 2). The R^2 statistic is sometimes referred to as the coefficient of determination and in general is used as a measure of the closeness of fit of a regression line to a set of data points (Ref 7). An R^2 value of 1.00 or 100 percent would indicate exact fit of the regression line to the data points. As one can see an R^2 value of 0.08 indicates a wide scatter of data around the regression line. To be fair it should be mentioned that the R^2 value 0.08 for crack sealing only was the poorest fit of the three equations developed. The R^2 statistic for the equation representing PCI increase due to crack sealing and surface

sealing was reported to be 0.09 and the R^2 value for the PCI increase due to crack sealing, surface sealing, and patching was 0.52 (Ref 2). The drastic improvement in the regression equations ability to predict the PCI increase when patching is included is not surprising when one considers the effect the PMS assumes patching to have on the system. As alluded to earlier the assumption is made that patching lowers the severity of alligator cracking, distortions, and poor patching to the lowest severity class (Ref 2). Review of the deduct curves for alligator cracking, distortions and patching, Figures 4.5, 4.6, and 4.7, pages 91 to 93, reveals relatively high deduct values for high severity distresses of all three types. Therefore patching should significantly improve the PCI, especially when the original PCI is very low. But the two lower correlations are so poor as to almost be meaningless. Perhaps the developers of the system should have discarded an attempt to project this increase or continued to look for better methods before including this module in the software. The developers do mention that the results of the regression techniques were not outstanding (Ref 2) and that research of actual performance data for various maintenance strategies would be desirable as data becomes available.

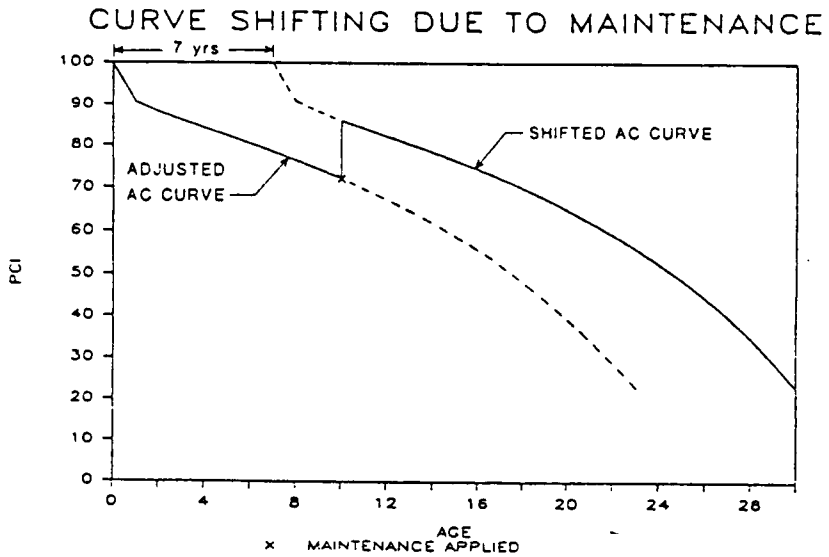
After the PMS increase is determined it becomes necessary to use some method to predict the rate of

deterioration of the pavement after application of maintenance which fails to raise the PCI to 100. The method adopted is a simple curve shift as indicated by Figure 4.12. The PCI for the street or section is raised to the revised value and the original family curve is used from that point on. The accuracy of this method cannot be estimated until actual performance data over time becomes available.

BUDGET AIDS

One of the more difficult tasks of the administrative person responsible for maintaining the streets within a jurisdiction is budget preparation and allocation. Thus one of the areas where a PMS can be of considerable aid is in trying to determine the most cost effective way to use the normally limited pavement maintenance funds. But prior to budgeting it is advisable to have an idea of the anticipated costs of maintenance or rehabilitation of the network.

The Bay Area PMS was designed primarily as a network level inventory, condition assessment, and budgeting tool. The approach taken is to identify those street sections in need of attention by checking the PCI, then selecting a recommended treatment from the combination of PCI, distress, and generalized cause of distress associated with the street. Unit costs of each treatment is stored in the data base which is used to estimate the repair cost of each



Source: Reference 2

Figure 4.12 Bay Area PMS PCI curve shift due to maintenance

section. A prioritization routine is then entered to rank the streets according to recommended order of repair.

One of the criticisms against use of a PCI is that the PCI in itself provides no indication as to the distresses prevalent within a pavement section or to the possible causes of those distresses. This PMS somewhat acknowledges this criticism by choosing to include distress an causation information in repair strategy determination. Pavements with relatively high PCI normally would receive only preventive maintenance, pavements with very low PCI would be expected to require major rehabilitation. But the difficult decision is selecting the repair strategy for those pavements falling into the fair to good category. The Bay Area PMS bases the repair strategy for those middle ground pavements on whether or not the observed distresses are caused by loading. The distresses considered to be load-related are presented below:

Distress	Severity	Primary Cause
Alligator Cracking	L, M, H	Load
Block Cracking	H	Load
Longitudinal Cracking	H	Load
Patching	L, M, H	1/2 load, 1/2 other
Rutting	L, M, H	Load

(From Ref 2)

The pavement conditions are then broken into five categories for analysis (Ref 2), with Type I representing the higher PCI rated pavements down to Type V basically representing

failed pavements. The only real acknowledgment of the causation of distress is in the differentiation between Type II and Type III pavements with the lower class having equal PCI (50 - 70) but different cause of distress.

The purpose of categorizing the pavements is for use within a decision tree structure which suggests recommended repair strategies. The decision tree is broken in separate limbs for each of the three functional classifications, each functional classification is then subdivided according to the four possible surface types and each surface type has a different suggested repair treatment for the five categories of pavement condition. Thus the decision tree ultimately branches out to 60 possible treatments although several treatments are used for more than one limb. The determination of these treatments is for purposes of obtaining network level cost estimates, they are not reported to the user as comprehensive solutions to pavement problems. the developers of the Bay Area PMS strongly suggest against use of the system for project level decisions, field investigation is encouraged.

The treatments themselves were selected using the advice and experience of local Bay Area Public Works engineers. Because of the wide variation of useful service lives of the treatments, i.e., surface seals may last only 1 - 3 years where thick overlays may be useful after 20 years, the system uses the equivalent uniform annual cost (EUAC)

for each alternative treatment to select the most cost effective solution. A separate program not part of the PMS (Ref 2) allows the user to develop the EUAC of alternatives based on interest rates and inflation factors of his own choosing. The user does have the option of modifying the treatments and cost data used by the PMS. Option 7 on the main menu allows the user to access the default treatment data and review the present treatments and costs. The treatment list included with the system is quite extensive but the user may wish to add local repairs frequently used if not covered. The cost data should be spot checked for accuracy and revised as often as required.

The Bay Area PMS is set up to project budget needs for a 5 year analysis period. The system takes the PCI from field reports then uses the PCI projection method based on family curves as described earlier to predict the PCI for each year of the analysis period. Each section is routed through the decision tree structure for every year of analysis and selected for either preventive maintenance or rehabilitation based on beginning and projected PCI values. The system has built in PCI thresholds for determining when and what level of maintenance to schedule. These built in threshold values are not changeable by the user but that should not cause much of a problem in transporting the system from one locality to another. the program is not intended to make judgments at project level detail therefore

for network wide budgeting there should be no reason to worry about fine tuning this portion of the system. In reality it would require a sophisticated user to have ability and data to justify modifying these budgeting thresholds.

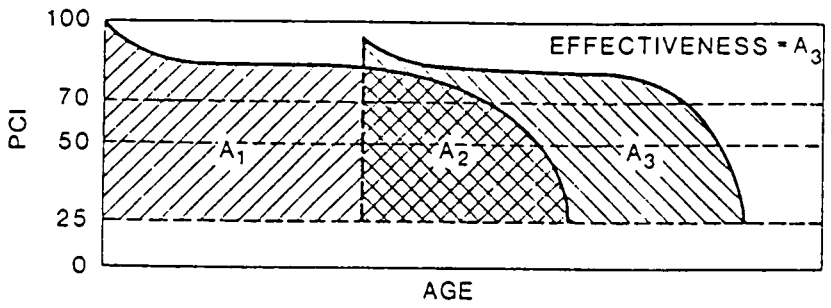
With the idea that it is generally overall more cost efficient to attempt to keep the street network in a good state of repair, the PMS tries to improve all street sections to a PCI of 70 or more as quickly as possible. This will tend to shove most of the capital intensive projects to the early portion of the analysis period. Practically it will be necessary to use a portion of available funds for preventive maintenance and emergency repairs. But the value of this module of the PMS is in the estimation of total funds required for pavement maintenance and rehabilitation over the 5 year period.

When the smoke clears from the politics involved in budget allocation it is unlikely that sufficient funds will have been earmarked for street maintenance. This presents the administrator in charge of street maintenance with two important decisions to make; first, which street segments should be receive attention and second, what level of repairs should be given to the segments selected. The second decision should be made only after field reviews by the engineer. But prioritization of the potential projects and rough approximations of the projects that can be

addressed with available funds is possible with the Bay Area PMS. The Budget Scenario option, number 6 on the main menu, includes a method of prioritizing projects and allows the administrator to explore different alternatives with available funds.

The prioritization is accomplished with a rather complex weighted effectiveness ratio (Ref 2). The effectiveness alone is chosen to be the area under the pavement performance curve, above PCI value 25, the Bay Area does not analyze pavement conditions below PCI values of 25, attributed ONLY to the repair strategy selected. Of course if the pavement is allowed to deteriorate to or below a PCI of 25 before rehabilitation then the effectiveness will simply be the area under the performance curve developed for that particular repair strategy. If repairs are effected prior to the end of the useful life of the pavement, PCI above 25, then the unused area under the original surface performance curve is subtracted from the area under the rehabilitation curve as shown in Figure 4.13. The effectiveness is defined (Ref 2) as the remaining area.

Since the real idea is to provide the most benefit for the least dollars then factors representing cost and traffic were considered important to include. The costs up to this point have been in the form of EUAC so in the interest of consistency this is retained. Actually section area is considered so the cost is converted to EUAC/s.y. To try to



Source: Reference 2

Figure 4.13 Bay Area PMS sample effectiveness ratio curve

include the volume of users in the equation and overcome favoring mostly local streets which normally have a lower repair cost per s.y., a traffic factor is included.

Evidently Bay Area jurisdiction do not routinely keep traffic volumes for many of their streets therefore a general factor for functional classification is used. A weighting of 1.00 for arterials, 0.75 for collectors, and 0.60 for local streets accounts for traffic. The bottom line of all this, the weighted effectiveness ratio, is calculated for use in priority setting. The units would seemingly be PCI-yr/EUAC/s.y. with the higher the number the more benefit derived. The pavement sections are actually segregated according to suggested level of repairs, rehabilitation or preventive maintenance.

The user may then enter the total funds available, the inflation rate expected during budget cycle and the percentage of funds allocated to rehabilitation. The PMS recognizes that streets with lower PCI not selected for maintenance or rehabilitation may still require emergency maintenance during any one budget year. Streets identified as needing rehabilitation but not falling within the priority list in any one year are assigned one time "stop-gap" maintenance funds based on PCI and functional classification.

The system takes the total budget figure, subtracts the desired rehabilitation percentage, then assigns the stop-gap

maintenance money with the remainder used for preventive maintenance.

COMPUTER REQUIREMENTS

The Bay Area PMS was designed to be used on IBM or IBM-compatible microcomputers. The system requires the commercially available RBase data base manager (from MICRONIM) software package to manipulate the pavement condition data and interface with various modules of the PMS. The system will operate with RBase 4000 but was tested with the later version RBase 5000 software with no apparent problems. Minimum hardware requirements are an IBM-XT with 384 KB of random access memory, one 10 MB hard disk, and one floppy disk drive. A printer will be required to receive hard copies of the analysis.

An IBM-AT model computer will drastically improve the speed of operation of the system and is recommended if funds are available. Also because of the large size of the PMS and RBase software (over 2 megabytes total) a 20 MB hard disk would allow the computer extra room to be used for other projects at little additional cost.

MANPOWER/FIELD EQUIPMENT REQUIRED

The inspection units are designed to allow one person to collect the required data in 15 to 30 minutes per inspection unit. Most residential streets and other streets with few defects would fall along the low end of that range. Multi-lane streets or streets with high levels of distress may take up to 30 minutes per unit to inspect. Realizing that roughly 5 inspection units are required for every mile of street, an estimate of man hours required to survey the network can be established. Two person teams of raters would likely be faster and provide more consistent results than single person inspection methods. The system accepts no mechanical or laboratory test results therefore only simple measuring tools need be issued to the field inspection teams.

The Bay Area PMS recommends variable condition survey intervals depending on class of street, PCI, etc. Practically, reinspecting the network on a 2 to 3 year interval is sufficient. Anything shorter could be questioned on a cost-benefit basis and longer intervals would not provide a clear picture of pavement performance.

SUMMARY

The Bay Area PMS is a comprehensive, well structured system that should serve well as a network inventory and budgeting tool. The system is very similar to the PAVER PMS developed for mainframes (Ref 15) with condensed pavement condition survey requirements in response to a common criticism that the PAVER PMS was too complex. The similarities are not surprising since Roger Smith, who developed this system, has been involved in the PAVER project. As with any system, forethought and preliminary planning is required to decide upon groupings of streets, where to divide streets into sections, etc. But after the office planning is complete, the field data collection should go relatively quickly. The system requires a sample of only approximately 10 percent of the system to be surveyed as opposed to some systems which require full inspection of the network, namely the Caltrans PMS, yet the information collected for the Bay Area PMS is no more detailed than the Caltrans system. The Bay Area PMS makes no pretensions at being applicable for project level analysis, repair strategies are only used internal to the system for developing cost estimates for budget purposes. The system will allow the user to utilize local repair strategies within the PMS and experiment by using the stand

alone ECON program to develop and analyze the costs of new combinations of repairs.

The basis for most of the system is calculation of a PCI value for each section. The PCI in and of itself only gives an idea of the relative general condition of the pavement at the time of inspection but the PCI projection ability will allow the user to estimate the rate of future deterioration based on just one inspection. Herein is where the bulk of the criticism of the system is directed.

The complaint is not really against the family curve method for the first projection. It is understood that simplifications must be made in most analysis of complex situations and for network level analysis the family curves are reasonable. But for a system as large as the Bay Area PMS, and it is large for most microcomputers, it seems logical to include the ability to use two or more points along the pavement performance curve to predict future deterioration. The system does allow the inventory of maintenance history info which will let the user note the magnitude of costs and perhaps spot trends in problems with particular sections. However the system discards old PCI values upon reinspection or maintenance (although they can be dumped to a separate disk file) when it seems more reasonable to keep all the values and use the multiple PCI's for developing individual performance curves for the sections. This could become very valuable as the data base

is built up over the years and provide insight to the actual effectiveness of various maintenance techniques. This possibility may have been explored and discarded as too complex by the system developers. The user can get around this problem of keeping track of PCI over time by keeping the old inspection info in the data base even though it will not be used for calculations and analyzing the data himself to compare to the performance curves included in the PMS.

A multitude of reports may be generated by the system which can give the user hard copies of information on anything from the inspection unit data for each section, to PCI values both presently and projected to a replacement cost of the entire network, which surely will surprise most people at the magnitude of the cost. These reports may be sorted by almost any parameter included in the PMS which certainly is attractive.

The budget needs option which provides an estimate of maintenance funds for each of 5 years is a useful option, especially for larger jurisdictions. The individual year totals are not practical because the PMS attempts to upgrade the system as soon as possible thereby heavily front loading the budget needs list. 80 to 90 percent of the 5 year funds will be recommended to be spent in the first two years. The 5 year total budget figure should be more useful in projecting approximate funding over the period which could proportioned as desired. It must be mentioned that these

numbers are estimates only. One should be very cautious in blindly accepting this or any other output of the system in the first few years of operation until calibration of the PMS is attained.

The budget scenarios module does provide a ranking of potential projects according to effectiveness ratio which would be of use when filling out the rehabilitation projects for each year. Certain projects with relatively low efficiency ratios will receive funding because of location, development in the area, political or other reasons. The ranked list of projects will be beneficial in selecting non-political projects. The portion of the program which selects projects for consideration according to the split of funds allowed for preventive maintenance, rehabilitation, and stop-gap maintenance seems superfluous for a couple of reasons. The system uses simple percentages to divide the funds and simply goes down the list of projects until the allocated funds are exhausted and prints the results. Practically, at this point, the projects should be selected according to investigations from engineering staff and not from generalized information.

The system is flexible in terms of allowing the user to include his own unit cost data and traditional local repair strategies. The user should be able to fine tune the system to produce reasonable cost estimates.

Overall the Bay Area PMS is a powerful, flexible decision aid that medium to large size jurisdictions should find helpful. Smaller areas may not truly benefit from all of the options but the condition inventory and maintenance history features should be beneficial.

CHAPTER V

SAMPLE NETWORK TESTING RESULTS

For a comparison of the three pavement management systems, a sample network consisting of approximately 10 lane miles of different functional classifications of streets in the Knoxville area was selected. For the purpose of this research it was felt appropriate to choose street segments with obvious surface defects that would trigger responses from the PMS so one could observe any differences in condition ratings, suggested repairs, priority ratings, and repair cost estimates, that each PMS would assign to the same street segments. For this reason, only relatively short street segments with obvious distresses were included in the sample network. One exception to this approach was one recently overlaid segment of Sutherland Avenue, which was included to observe the output each PMS produced for a street in relatively good condition. The street segments were selected totally at random and are not intended to represent the typical condition of Knoxville's streets.

The majority of the segments selected (65%) are local streets. It is likely that local streets would compose the majority of lane miles within most cities though carrying a minority of traffic. Also, inspecting local streets was somewhat easier for the one-person survey crew (the author).

The streets were surveyed according to the method recommended for each PMS. For the Caltrans/FHWA FPMS the entire network was surveyed; for the Bay Area PMS approximately 10% of the network was surveyed; and for the Tulare County PMS one sample unit within each segment was surveyed.

No modifications were made to any PMS for this comparison. All the systems may be modified by the user to some extent and it may have been possible to adjust the systems to yield fairly uniform results from PMS to PMS. But one of the objectives of this study is to compare the "off the shelf" versions of the systems since many potential users are likely to start using the systems with no or few modifications. All types of outputs were generated for each street segment by each PMS; however, because of the differences in the available options of the three systems, only their common outputs are compared for this evaluation. For example, the Bay Area and Tulare County systems generate a Pavement Condition Index value for each segment while the Caltrans/FHWA FPMS does not. Therefore the PCI comparison could be performed for the first two systems only. All of the three PMS assign a form of priority rating and suggest repair strategies for each segment, and thus these items could be compared for all the systems. Also, since each PMS will produce repair cost estimates for each street segment in the network, cost estimates for the sample network are presented for comparison.

Figure 5.1 is a comparison of PCI values generated by the Bay Area PMS and the Tulare County PMS. It must be remembered that each segment was surveyed for each system on the same day, therefore it should be in the same relative condition. However as the table illustrates, the PCI values vary widely. PCI differences as high as 22 were found with PCI percent differences as high as 34.4 percent (both for Ironwood St.). In fact, there was more than 10 percent difference in PCI value between the two PMS for 75 percent of the segments surveyed. The average difference in PCI values for the sample network was 8.95. In general the Bay Area PMS produced higher PCI values than the Tulare County version as can be seen by the network average PCI of 59.4 vs. 56.3.

PCI is a subjective rating, and, therefore, some difference is not surprising; but the magnitude of difference was unexpected. Also, while the Tulare County PMS PCI's were generally lower, on 3 occasions the PCI assigned by it was 10 or more points higher than those by the Bay Area PMS. This eliminated the possibility of a simple conversion formula between the two systems. While exact reasons for the differences are hard to pinpoint, one possible reason is the way the deduct curves for the various distresses were created. Both systems borrow the PCI methodology from the PAVER PMS. The PAVER deduct curves were developed through empirical and subjective tests by the U.S. Army Corps of

SEGMENT	FROM	TO	FUNC. CLASS [a]	PCI BAY AREA	PCI TULARE CO. [b]	ALGEBRAIC DIFF. [c]	PERCENT DIFF. [d]
Peachwood	Plumwood	Hazelwood	L	73	65	8	11.0
Hazelwood	Plumwood	Peachwood	L	55	41	14	25.5
Sprucewood	Cottonwood	Pleasantwood	L	83	75	8	9.6
Pleasantwood	Hazelwood	Sprucewood	L	83	81	2	2.4
Cottonwood	Myrtlewood	Myrtlewood	L	67	60	7	10.4
Ironwood	Cottonwood	Pleasantwood	L	64	42	22	34.4
Burwood	Cottonwood	Pleasantwood	L	71	62	9	12.7
Sisk Rd.	Pleasant Ridge	Westgate	L	61	46	15	24.6
Pleasant Ridge	Bradshaw	Sisk	C	51	61	10	16.4
"	Deer Creek	Bradshaw	C	45	45	0	0.0
"	Merchants Rd.	Deer Creek	C	46	44	2	4.3
"	Western Ave.	Sycamore	C	40	53	13	24.5
Jenso	Ruth	Clinton Hwy.	L	59	52	7	11.9
Ruth	Kensi	Jenso	L	58	63	5	7.9
Bounds	Tillery	Kensi	L	57	66	9	13.6
Kensi	Bounds	Ruth	L	44	50	6	12.0
"	Clinton Hwy.	Bounds	L	50	41	9	18.0
Western Ave.	Clifton	Pleasant Ridge	A	46	52	6	11.5
University Ave.	Sutherland	21st	A	49	32	17	28.6
Sutherland Ave.	Liberty	Washburn	C	85	95	10	10.5
			Network Average:	59.4	56.3	8.95	14.5

a - L = local; C = collector; A = arterial

b - Rounded to nearest integer since Bay Area PMS values are reported as integers.

c - Absolute value

d - Percent difference was taken to be : $\frac{\text{HIGH PCI - LOW PCI}}{\text{HIGH PCI}}$

Figure 5.1 Comparison of PCI values for the Bay Area PMS and Tulare County PMS generated for the sample network

Engineers and modified for municipal use by the APWA. Roger Smith, who developed the Bay Area PMS, was involved in the PAVER project for APWA and relied heavily on that work as the basis for the Bay Area PMS deduct curves. The Tulare County staff had been exposed to the PAVER PMS and elected to incorporate the PCI concept as part of their modification of the Caltrans/FHWA FPMS. Philip Slitor of Tulare County stated, "We wanted to have deduct curves similar to those found in PAVER for the distresses included in our system. We only tried to find mathematical expressions that would yield roughly the same shape as the PAVER curves."(Ref 16) Since PCI is based on subjective data, consistency rather than accuracy is important, but at least in this investigation the PCI methodology included in the Bay Area PMS would appear to be based on more accepted rationale than the Tulare County PMS.

It is interesting to note that 55 percent of the streets included in the sample network would be considered by definition of the Tulare County PMS to be beyond their design life. Tulare County has defined a street to have reached its design life when PCI falls to or below 60. None of the streets would be considered by the Bay Area PMS to be in poor condition, since the Bay Area definition of a poor street is, PCI < 40. The streets were selected because of the presence of surface distresses, but in the opinion of this author most of the streets would be in fair to good

condition which would be consistent with the Bay Area PMS's evaluation. It may be interesting to report that, in this author's opinion, the Western Avenue segment surveyed was in the worst condition of all the segments in the sample network. In fact the City of Knoxville has cold planed a portion of Western Avenue adjacent to the segment surveyed in preparation for resurfacing. But the Tulare County PMS assigned lower PCI values to 7 other segments that appeared to be in better condition.

Figure 5.2 is a comparison of the priority assigned to each segment by each PMS. The Caltrans/FHWA and Tulare County PMS's use the priority matrix method for ranking projects. This approach resulted in the most seriously deteriorated segments receiving the highest ranking. Since this portion of the Tulare County PMS is almost identical to the Caltrans/FHWA FPMS, no significant differences in their rankings are observed.

The Bay Area PMS effectiveness ratio ranks projects in a totally different manner. Basically projects are ranked according to a formula that accounts for extended life of the pavement due to maintenance, functional classification, cost, and size of the project. Recalling that effectiveness is defined as the additional area under the PCI vs. time curve due to maintenance activities (Ref 2), the effectiveness ratio (E.R) is:

SEGMENT	FROM	TO	PRIORITY RANKING CALTRANS [a,b]	TULARE CO. [a,b]	BAY AREA [a,c]
Peachwood	Plumwood	Hazelwood	16(14)	14(12)	10243 (6)
Hazelwood	Plumwood	Peachwood	14(12)	14(12)	6815(13)
Sprucewood	Cottonwood	Pleasantwood	16(14)	18(18)	32695 (2)
Pleasantwood	Hazelwood	Sprucewood	16(14)	18(18)	33302 (1)
Cottonwood	Myrtlewood	Myrtlewood	16(14)	14(12)	4537(20)
Ironwood	Cottonwood	Pleasantwood	16(14)	14(12)	4670(19)
Burwood	Cottonwood	Pleasantwood	16(14)	14(12)	10191 (7)
Sisk Rd.	Pleasant Ridge	Westgate	14(12)	14(12)	9647 (8)
Pleasant Ridge	Bradshaw	Sisk	9 (3)	7 (3)	7155(12)
"	Deer Creek	Bradshaw	9 (3)	7 (3)	7299(11)
"	Merchants Rd.	Deer Creek	9 (3)	7 (3)	7561 (9)
"	Western Ave.	Sycamore	1 (1)	3 (1)	7336(10)
Jenso	Ruth	Clinton Hwy.	12 (7)	12 (7)	6532(15)
Ruth	Kensi	Jenso	12 (7)	12 (7)	6379(16)
Bounds	Tillery	Kensi	12 (7)	12 (7)	6566(14)
Kensi	Bounds	Ruth	12 (7)	12 (7)	6014(18)
"	Clinton Hwy.	Bounds	12 (7)	12 (7)	6130(17)
Western Ave.	Clifton	Pleasant Ridge	3 (2)	3 (1)	12058 (4)
University Ave.	Sutherland	21st	9 (3)	7 (3)	11396 (5)
Sutherland Ave.	Liberty	Washburn	16(14)	16(12)	26418 (3)

a - Numbers in parenthesis are priorities within sample network
b - Priority matrix values
c - Efficiency ratio

Figure 5.2 Comparison of priority assignment

E.R. = (Functional class. factor) * Effectiveness/EUAC/s.y.

where:

Functional classification factor = 1.00 - arterials
0.75 - collectors
0.60 - locals

Eq. 5.1, from Ref. 2

This approach tends to favor pavements in relatively good condition that can have their life extended by a reasonable amount by low cost surface treatments. To appreciate the differences in the ranking methods one may look at Figure 5.3 which compares suggested repair strategies from each PMS. Observing both Figures 5.2 and 5.3 one can see that the segment receiving the highest efficiency ratio, Pleasantwood, received a 'Do Nothing' repair strategy by both the Caltrans/FHWA and Tulare County PMS. In fact the highest three efficiency ratios were assigned to segments in relatively good condition.

Because the repair strategies are localized treatments one should not look so much at differences in exact repair strategy suggested as at differences in magnitude among treatments for the same segment. As illustrated by Figure 5.3, the same segment may be recommended for overlay by one PMS and for crack sealing or no maintenance by another PMS. The results shown in Figure 5.3 should discourage users from trying to use these PMS for project level decisions. This is not to say that the systems cannot be calibrated to a

			SUGGESTED REPAIR STRATEGY		
SEGMENT	FROM	TO	CALTRANS	TULARE CO.	BAY AREA
Peachwood	Plumwood	Hazelwood	Base repair & patch	Seal Cracks	Double chip seal
Hazelwood	Plumwood	Peachwood	Thin OL & digouts	Do nothing	Heater scarify & OL
Sprucewood	Cottonwood	Pleasantwood	Fill Cracks	Seal Cracks	Single chip seal
Pleasantwood	Hazelwood	Sprucewood	Do nothing	Do nothing	Single chip seal
Cottonwood	Myrtlewood	Myrtlewood	Correct rutting	Digout & patch	Heater scarify & OL
Ironwood	Cottonwood	Pleasantwood	Correct rutting	Digout & patch	Heater scarify & OL
Burwood	Cottonwood	Pleasantwood	Correct rutting	Digout & patch	Heater scarify & OL
Sisk Rd.	Pleasant Ridge	Westgate	Thin OL & digouts	Do nothing	Double chip seal
Pleasant Ridge	Bradshaw	Sisk	Fill cracks	Chip seal	Heater scarify & OL
"	Deer Creek	Bradshaw	Thin OL & digouts	AC overlay	Heater scarify & OL
"	Merchants Rd.	Deer Creek	Base repair & patch	Seal cracks & chip seal	Heater scarify & OL
"	Western Ave.	Sycamore	Structural Analysis	AC overlay	Heater scarify & OL
Jenso	Ruth	Clinton Hwy.	Thin OL & digouts	Apply binder modifier	Heater scarify & OL
Ruth	Kensi	Jenso	Thin OL & digouts	Seal cracks & binder modifier	Heater scarify & OL
Bounds	Tillery	Kensi	Thin OL & digouts	Seal cracks & binder modifier	Heater scarify & OL
Kensi	Bounds	Ruth	Thin OL & digouts	Apply binder modifier	Heater scarify & OL
"	Clinton Hwy.	Bounds	Thin OL & digouts	Seal cracks & binder modifier	Heater scarify & OL
Western Ave.	Clifton	Pleasant Ridge	Structural analysis	AC overlay	Heater scarify & OL
University Ave.	Sutherland	21st	Reflection analysis	AC overlay	Thick AC overlay
Sutherland Ave.	Liberty	Washburn	Do nothing	Do nothing	Single chip seal

OL = overlay ; AC = asphalt cement

Figure 5.3 Comparison of suggested repair strategies

specific locality and provide reasonable results. The point is that the systems are intended for budget preparation and planning purposes, and the repair strategies are probably accurate enough for these networkwide cost estimates.

Estimated repair costs for each street segment in the sample network are presented in Figure 5.4. As indicated in Figure 5.4, estimated segment repair costs varied widely from PMS to PMS. Unit costs for similar treatments among the three PMS's were adjusted to allow reasonable comparison. The Caltrans/FHWA FPMS produced the lowest total cost estimate at $133,249. The Tulare County PMS was next lowest at $163,638, 23 percent higher than the Caltrans/FHWA FPMS, with the Bay Area PMS total estimate highest at $274,613, 106 percent more than the Caltrans/FHWA estimate.

The difference in cost can be traced to the differences in suggested repair strategies among the three PMS. The Bay Area PMS recommended an overlay; for many of the street segments, while the other two PMS tended to suggest less costly treatments. A major portion of the difference in costs between the Caltrans/FHWA FPMS and the other two PMS was on the cost estimate for one street segment, University Avenue. The surveyed segment of University Avenue exhibited a high percentage of surface cracking. This triggered a reflection analysis repair strategy from the Caltrans/FHWA FPMS, while the Tulare County and Bay Area PMS each

			ESTIMATED SEGMENT REPAIR COST		
SEGMENT	FROM	TO	CALTRANS	TULARE CO.	BAY AREA
Peachwood	Plumwood	Hazelwood	$ 2,707	$ 572	$ 3,694
Hazelwood	Plumwood	Peachwood	15,000	0	19,339
Sprucewood	Cottonwood	Pleasantwood	1,367	265	3,860
Pleasantwood	Hazelwood	Sprucewood	0	0	4,017
Cottonwood	Myrtlewood	Myrtlewood	0	859	3,523
Ironwood	Cottonwood	Pleasantwood	0	2,449	3,755
Burwood	Cottonwood	Pleasantwood	479	552	3,946
Sisk Rd.	Pleasant Ridge	Westgate	21,000	0	6,323
Pleasant Ridge	Bradshaw	Sisk	11,177	2,577	23,461
.	Deer Creek	Bradshaw	22,500	21,479	27,241
.	Merchants Rd.	Deer Creek	377	4,411	22,132
.	Western Ave.	Sycamore	23,400	21,594	24,265
Jenso	Ruth	Clinton Hwy.	8,734	181	4,369
Ruth	Kensi	Jenso	2,286	218	3,735
Bounds	Tillery	Kensi	3,536	174	6,378
Kensi	Bounds	Ruth	4,031	84	2,911
.	Clinton Hwy.	Bounds	8,734	506	4,482
Western Ave.	Clifton	Pleasant Ridge	21,060	19,331	24,265
University Ave.	Sutherland	21st	17,250	58,172	71,766
Sutherland Ave.	Liberty	Washburn	0	0	11,097
		Sample Network Total:	$133,249	$163,638	$274,613

Figure 5.4 Sample network estimated street segment repair costs

suggested an asphalt overlay for the segment at 3 to 4 times the cost estimated by the Caltrans/FHWA FPMS.

SUMMARY OF FINDINGS

The purpose of applying each PMS to the sample network was not to determine which PMS yields "right" or "wrong" answers to pavement problems. Rather the purpose was to illustrate differences among the systems when presented with identical pavement problems. As shown by the previous tables in this chapter, the Bay Area PMS tended to rate the street segments as being in better condition than the other PMS. However, the Bay Area PMS also tended to suggest more costly repair strategies to each segment, which resulted in a significantly higher repair cost estimate for the sample network. In actual use the PMS should be modified to include repair strategies typically used by the local agency. The PMS should be calibrated over the years to produce cost estimates in general agreement with actual repair costs. Accuracy of cost estimates for each segment is not as important as the accuracy of the networkwide estimate. Repair strategies may be user modified in either the Tulare County or Bay Area PMS, while the Caltrans/FHWA FPMS repair strategies are fixed. All systems allow user modifications of unit cost data.

The Bay Area PMS assigned a higher priority to segments in relatively good condition where the suggested repair strategy would be crack sealing or a surface treatment, rather than a more serious repair such as an asphalt overlay. The Caltrans/FHWA FPMS and Tulare County PMS both assigned higher priorities to segments in poor condition in need of major structural repair.

The results of the sample network testing illustrated significant differences among the three PMS in condition rating, priority assignment, suggested repair strategy, and repair cost estimates. Potential PMS users should recognize the limitations and the specific approach taken by each PMS before selecting a PMS in order to avoid being disappointed by the results.

CHAPTER VI

SUMMARY COMMENTS ON PMS SOFTWARE STUDIED

BAY AREA MTC PMS

The Bay Area MTC PMS is the most impressive of the PMS tested and for good reason. No development cost data was obtained but one would speculate that many thousands of dollars were paid to the consultant for this custom designed system. The complete package of software and related manuals may be purchased directly from the MTC for under $150.00. However the system requires the RBase data base manager to operate, thus adding around $400.00 to the overall system cost, not including hardware. Although the system will operate on an IBM-XT or equivalent computer, the system will be noticeably sluggish on anything less powerful than an IBM-AT level of machine.

Those who can afford it will receive a useful tool for planning and budgeting pavement maintenance. The pavement condition survey methodology is simple and would be easy for the survey personnel to learn to perform quickly and accurately. Traffic volume data are not always available for all streets included in the managed network, especially for local streets. Recognizing this, the system uses functional classification for analysis purposes if ADT is not

available. After data collection, entry and editing of the data base is simple and should pose no problem. Unlike the other PMS studied, the Bay Area PMS does not utilize separate data files. All records are stored as one entity and may be accessed by street or section ID if desired.

PCI is not automatically calculated. The user must manually prompt the system to calculate the PCI. As future survey data is entered into the system one may recalculate only the latest data to save time. This brings up several criticisms of the system. First, unless the user sends the output of PCI calculation to a separate disk file, old data is overwritten and lost. This data could be valuable for reference purposes and, in the author's opinion, the system should use multiple PCI-time data for future PCI projections. Even though the system is already large by microcomputer standards, for some reason the developers chose not to include this concept. A source of irritation is the unsettling RBase error messages and file transfer information flashed on the screen during the PCI calculation operation. The user is never sure if the system is operating properly or not. Such write lines are common during program development to help the programmer know when file operations occur in case the program does not work. But the final product should not present such potentially confusing information to the user. Also, and this is serious if a serious problem does occur during operation, the system

simply crashes with perhaps a file error message. The user must either try to find the source of the problem and reboot the system or call for assistance from a more knowledgeable source. A professionally written program should NEVER crash and leave the user in the dark, except in case of hardware failure. An error message of some sort should be given and the user returned to a menu somewhere in the program. One feature that should appeal to all users is the generous report generating ability. Reports on any input or calculated data may be produced and sorted up to a dozen ways if the user desires. Neither of the other systems compares to the Bay Area PMS with regard to report capability. The only negative comment is that it is difficult, if not impossible, to generate short, concise reports for limited sections for budget analysis. For example, if one wishes to view the recommended expenditures for a particular street or segment for year 2 of the 5 year budget cycle, he must generate the entire five year report just to receive data for the desired year. The reports are comprehensive and evidently intended to be printed infrequently.

Administrative staff will like the budget scenarios that can be explored through the Bay Area system. With cost efficiency as the goal, the combination of efficiency rating, with more sophisticated traffic and economic analysis data than the Caltrans/FHWA-based systems, and the

ability to examine several project and funding combination, the Bay Area PMS simply outperforms the other two systems. The PCI concept, although open to question, is included and can provide a relative indication of trends in network pavement condition. The PCI projection feature is questionable and may be grossly in error for any individual segment but on a network-wide basis could be helpful in estimating the general increase/decrease in pavement condition for different funding levels. Suggested repair strategies are downplayed by this PMS, being used only for cost estimation purposes as further indication of the network level planning orientation of this system.

Persons unfamiliar with computers and pavement management concepts may well find the Bay Area PMS too complex to consider for their first system. Likewise small jurisdictions with few paved roads may not need all the features offered and be just as well off with one of the other systems. The system seems powerful enough to allow use on a regional basis as was intended. Private consultants could also implement and maintain the system for smaller agencies who do not wish to tie up their own personnel for such activities. But for knowledgeable users the Bay Area PMS should serve as a useful decision making tool and be strongly considered for application. As mentioned earlier, the system does have weaknesses, and there are areas for improvement but as a total package it is more powerful than

the other two systems and the best choice for cost efficient management assistance.

TULARE COUNTY VERSION OF CALTRANS/FHWA FPMS

The Tulare County FPMS is a simple, easy to use PMS with enough features to be practical for areas with limited technical expertise or areas just getting started in pavement management. The system is contained on a single floppy disk and may be used effectively on the lower cost IBM-PC without hard disk storage. Additional floppy data disks may be used as needed to create a low cost data base.

The PMS functions well for inventory of pavement condition data and maintenance history data. The latter being a feature not available in the original Caltrans/FHWA FPMS. Over a period of years the PMS can assemble a data base that, while not as fancy as the Bay Area PMS, should prove useful to most agencies. The Tulare County PMS does not have the PCI projection function nor the budget analysis features of the Bay Area PMS, but the user can offset these weaknesses by careful file structuring to allow comparison of pavement condition over time. Budget analysis must be by manual or other programs but that portion of the Bay Area PMS is not a necessity, just convenient to have as part of the total package.

A major disadvantage of the Tulare County PMS is that the degree to which the system has been customized for the county's own use may conflict with established formats of other agencies. The reports generated are comprehensive, unfortunately they tend to be like the Bay Area PMS reports in that the entire multi-page report must be printed each time instead of having the option of partial reporting. But the report structure is formatted for the unique district and street classifications used by Tulare County. If another user wishes to live within that format he should have no problems, however it is hard to speculate the time and difficulty involved in rewriting the software to tailor available reports to each users need. Interested parties could contact the Public Works staff with specific questions. Small but irritating items include the way the PMS forces the user to use a six digit route code instead of the actual street name for indexing and reporting purposes. The code may be comprised of alphanumeric entries but only in a format similar to Tulare County route codes. Why the system does not simply use the common street name is puzzling. The Caltrans/FHWA FPMS has the ability to access the condition survey data by route name or record number. For some reason the Tulare version will only access the information by record number, which forces the user to memorize record numbers or keep a cross reference handy.

The Tulare County PMS will store maintenance history records which are valuable and not included in the Caltrans/FHWA version. The PMS also includes PCI generating ability, again an addition from the Caltrans/FHWA version. No projection or adjustment of PCI due to maintenance is possible but by storing PCI records in separate files for each year, general changes in the network condition can be monitored as well as pavement condition response to specific maintenance strategies. Priority matrix concepts, decision tree structures, and cost estimating procedures are quite similar to the Caltrans/FHWA PMS with the decision trees being somewhat more complicated by allowing more factors to be considered within several of the trees. Unlike the Caltrans/FHWA PMS, this PMS does not allow the user to interactively modify trigger values either within the priority matrix or decision trees, nor interactively update unit cost data. Instead the user must modify data statements within the software source code. Admittedly the code is written in a fashion which makes modifying the source code fairly easy, but it would have been simple to allow interactive modifications and computer novices may shy away from the PMS rather than modify the PMS in this manner.

Overall the Tulare County PMS is attractive with its colored screens and operates quickly and smoothly. It offers several features not found in the Caltrans/FHWA FPMS while retaining the simplicity of that PMS. It would be a

reasonable choice for beginning users or even medium sized cities without staff time to devote to a more complex PMS such as the Bay Area PMS. The Tulare County staff has done a commendable job in enhancing the PMS.

CALTRANS/FHWA FPMS

The Caltrans/FHWA FPMS suffers from being among the earlier developed microcomputer PMS. Persons like Philip Slitor and Allen Wilson at Tulare County, California have had time to use the PMS and make improvements where felt necessary. As a result of the Tulare County PMS, one can find few reasons to consider use of the original Caltrans/FHWA FPMS. It lacks the capability to inventory maintenance history, does not produce useful reports, has no network wide condition information like the PCI, and since both are basically free and will run on the same hardware, offers no cost advantage over the Tulare County version. The only positive feature is the ability to interactively modify trigger values within the decision trees and priority matrix, although the user cannot modify the repair strategies themselves.

Anyone considering the Caltrans/FHWA FPMS should obtain a copy of the Tulare County PMS for comparison. The improvements should be obvious.

CONCLUSIONS AND RECOMMENDATIONS

Comprehensive pavement management systems may include all facets of providing paved roads from planning to design, construction, maintenance and reconstruction. Large design-oriented programs requiring the use of a mainframe computer have been developed (Ref 1) that could be used for project level assistance, but these systems have not received general use at local levels. The PAVER PMS (Ref 15) was promoted by the APWA as a detailed maintenance/rehabilitation oriented system that would be simple enough for small rural areas to use yet containing the capacity to store and analyze pavement condition data at a detail level an engineering staff at a large city would find satisfactory. The PAVER PMS met with limited success, somewhat because it was perceived by smaller jurisdictions with limited technical staffs as being too complex. Also because the massive software required the use of a mainframe computer and could only be accessed through timesharing over phone lines to Seattle, Washington where the software resided.

Perceived interest for a simpler, lower cost PMS that would have a better chance for acceptance by small to medium sized cities led to this research. The three PMS presently thought to have a high potential for general use, the Caltrans/FHWA FPMS, Tulare County PMS, and the Bay Area MTC

PMS, were evaluated and the results of this evaluation are presented in Figures 7.1a, 7.1b, and 7.1c.

These figures illustrate the different features available with each PMS. All three PMS evaluated in this research are applicable for maintenance or rehabilitation assistance only. All are dependent on subjective pavement surface inspections by technicians with limited training. The only sure way to determine the cause of problems within a pavement, or assess the remaining structural capacity of the pavement is through deflection testing or core sampling and laboratory analysis of the pavement materials. The only provision for acceptance of mechanical or laboratory testing results is the ride score value for the Caltrans/FHWA FPMS. Fortunately, for flexible pavements it is possible to infer quite a bit about possible problems within the pavement structure by observing surface distresses. This is the premise used by the PMS studied to assist the user in network level decision making. The subjective nature and limited scope of input data accepted by each PMS renders the systems unsuitable for project level analysis decisions. All systems warn the user against direct use of the outputs for project level work.

Of particular interest to any agency will be the initial and annual cost of pavement management. A city with 1000 lane miles of paved streets could implement the Caltrans/FHWA FPMS for about $15,000; $1,000 for hardware,

CRITERIA	PAVEMENT MANAGEMENT SYSTEM Caltrans/FHWA	Tulare County	Bay Area MTC
COST			
Software	Public domain ($20 copying fee)	Public domain ($10 copying fee)	PMS only - $150 Rbase 5000 - $400
Hardware (minimum required)	$1,000.00 (IBM-PC)	$1,000.00 (IBM-PC)	$2,000.00 (IBM-PC/XT)
Estimated Man-Hrs to survey:		a	b
200 lane miles	200	50	125
500 lane miles	500	125	300
1000 lane miles	1000	250	625
2500 lane miles	2500	625	1550
Estimated Man-Hrs to input data:			
200 lane miles	40	40	40
500 lane miles	100	100	100
1000 lane miles	200	200	200
2500 lane miles	500	500	500

a - Man hours listed are for surveying a 4-10 percent sample of the street network as recommended by the PMS user's manual.

b - Man hours listed are for surveying a 10 percent sample of the street network as recommended by the PMS user's manual.

Figure 7.1a Cost comparison of Caltrans/FHWA FPMS, Tulare County PMS, and Bay Area PMS.

CRITERIA	PAVEMENT MANAGEMENT SYSTEM		
	Caltrans/FHWA	Tulare County	Bay Area MTC
INPUT			
Maximum number of street segments that may be included in PMS	9,999	9,999	Limited to computer storage capabilities
Traffic data	ADT, traffic mix, speed	ADT, functional class., speed	ADT, functional class., traffic mix
Form of input	Manual visual pavement surface inspection and mechanical ride score or subjective ride score	Manual visual pavement surface inspection and subjective ride score	Manual visual pavement surface inspection
Recommended portion of network to be surveyed	100%	4 - 10%	10%
Mechanical/laboratory testing results accepted	Ride score only	No	No
Maintenance history storage	No	Yes	Yes
Input error checking	No	Yes	No

Figure 7.1b Comparison of input requirements of the Caltrans/FHWA FPMS, Tulare County PMS, and Bay Area PMS.

CRITERIA	PAVEMENT MANAGEMENT SYSTEM		
	Caltrans/FHWA	Tulare County	Bay Area MTC
OUTPUT			
Reports of pavement condition survey	Yes	Yes	Yes
Maintenance history	No	Yes	Yes
Prioritization of segments	Yes, by priority number	Yes, by priority number and PCI	Yes, by priority number and PCI
Grouping of segments into projects	No	No	Will group by section ID
Future pavement condition projection	No	No	Yes
Pavement design capabilities	No	No	No
Summary condition reports [a]	Yes, index listing of segments by route or record number.	Yes, by PCI, ADT, width, surface type and terrain, but the entire network is used. Cannot receive reports on subareas.	Yes, by most data fields, and may be broken into subareas by section ID.
Estimated segment repair costs	Yes	Yes	Yes
Projected budget needs	No	No	Yes
UTILITY			
Sorting capabilities	Will index by route or record number	Sort alphabetically or by priority number	Multiple, can sort on 12 to 18 data fields depending on report desired.
Ease of modification to suit local needs	User can interactively modify certain threshold and unit cost values; easy to understand.	User must modify source code, but system is designed for easy access to source.	User may interactively modify unit cost data and repair strategies; moderate difficulty.

a - Reports listing pavement distresses found and/or average condition rating assigned to the segment, subarea (geographically grouped segments), or entire network as specified by the user, if system will allow.

Figure 7.1c Comparison of output and utility of the Caltrans/FHWA FPMS, Tulare County PMS, and Bay Area PMS.

$10,000 for the pavement condition survey, $2,000 for data entry, and approximately $2,000 in administrative time. Assuming a two year survey interval, this system could be maintained for an approximate annual cost of $7,000. The Tulare County PMS would cost somewhat less to implement and maintain due to the use of a sample pavement condition survey rather than a complete inspection as recommended by Caltrans/FHWA. Initial cost for the Tulare County PMS would be expected to be about $7,500 for a city with 1000 lane miles of paved streets. Annual costs thereafter should be in the range of $3,500. The Bay Area PMS software is the most expensive with a total cost of $550, including $400 for the Rbase data base manager, but as indicated by Figure 7.1a, condition survey and data entry costs are comparable to the other systems. Implementation costs for the Bay Area PMS would be approximately $13,000 for a 1000 lane mile network with annual maintenance costs of $5,500.

Major differences in the systems as indicated in Figures 7.1a, 7.1b, and 7.1c, are in storage of maintenance history data, sorting and reporting options available, the Pavement Condition Index concept, and projection of future pavement condition. The Caltrans/FHWA FPMS contains none of the above features. The Tulare County PMS will inventory maintenance history data, will sort alphabetically or by priority number, and will produce summary reports. The PCI

concept is included in the Tulare County PMS, but as discussed in Chapter III, the methodology used for PCI value generation is questionable.

The Bay Area MTC PMS is significantly more complex than either of the two other PMS evaluated. In addition to the features found in the other PMS, the Bay Area PMS contains routines to project future pavement condition and suggest pavement maintenance budgets over a 5-year budget cycle. The user can receive reports on pavement condition sorted by up to 18 separate criteria selected by the user. The increase in available output is produced without increased user input as compared to the other PMS.

In conclusion, recognizing the importance and usefulness of pavement management systems it is surprising that not all jurisdictions have some form of a PMS. Even smaller cities may have street networks with replacement values in the hundreds of millions of dollars, while larger cities have street systems worth billions of dollars. Yet decisions on maintenance of these networks are often made in a disorganized fashion with little idea of whether the funds are being spent in an efficient manner. All jurisdictions should have some form of PMS even if it is just a street map with notes on when and what type of maintenance was performed on each street segment.

The important point is not how sophisticated a PMS an agency user, but how useful the PMS is and how helpful it is

for decisions on pavement repairs. A very simplistic system that is utilized and results in cost efficient pavement maintenance is preferable to a complex, expensive PMS that no one understands or uses.

RECOMMENDATIONS

Given the relative closeness in costs of implementing and maintaining each PMS evaluated, the Bay Area PMS is recommended as the best overall PMS studied and would be suitable for use by all sizes of cities or agencies. The Bay Area PMS will provide more management assistance at roughly the same cost and with the same volume and detail level of input as the Caltrans/FHWA FPMS and the Tulare County PMS. Administrators with pavement maintenance budget responsibility will benefit from the Bay Area PMS's "Budget Needs" and "Budget Scenarios" options.

For agencies interested only in the inventory of pavement condition and maintenance history information, the Tulare County PMS would meet those needs and provide a simpler format to the user than the Bay Area PMS. However, the Bay Area PMS could initially be used only for data inventory and expanded as the agencies' needs increased.

RECOMMENDED CONDITION SURVEY SAMPLE SIZE

Each PMS studied had a different recommendation for percentage of the network to be surveyed. Caltrans/FHWA recommends the inspection of 100 percent of the managed network; Bay Area recommends a sample size of 10 percent of the inspection units within each management unit; and the Tulare County version recommends only one 100 to 200 foot long, one lane wide, inspection unit per segment (or per mile of road for segments over a mile in length). Depending upon average segment length, the Tulare County procedure will result in a sample size of 4 to 10 percent. After this research it is the opinion of the author that no more than 10 percent of the paved network need be surveyed for network level analysis. The surveys are only visual, somewhat subjective inspections of the pavement surface intended to give a general idea of problems with the pavement. Despite its 100 percent sampling scheme, the Caltrans/FHWA survey method produces an average distress rating. Only one average frequency of cracking and crack width is reported for each segment even though several different crack widths or extents of distress may actually be present in the pavement. In performing the survey for this project, very little difference in condition within an individual segment was noticed. Localized failures caused by drainage problems, utility problems, etc., will be observed but these should be

addressed on a project level or emergency treatment basis and are not included in any PMS studied. Significant changes in condition of a street should be cause to subdivide the street into smaller segments of like condition. It should be noted that all street segments within the managed network are included in the sample. However, the sampling scheme suggests that the condition rating for each segment be based on the inspection of only a small portion of each segment. Close inspection of roughly 10 percent of the network should be adequate for budgeting and planning purposes. Tulare County chose a smaller sample size, one inspection unit per segment for segments up to one mile in length, because the magnitude of the street network in their jurisdiction prohibited their staff from performing a more detailed survey in a reasonable length of time.

RECOMMENDED TYPE AND FREQUENCY OF DATA COLLECTION

A survey frequency of two years should be adequate. Pavements deteriorate quicker when in poor condition, when water can enter the base and subbase courses and cause damage. These segments would be identified for rehabilitation in the first year budget. Pavements in good condition are not likely to significantly deteriorate within a two year period unless damaged by weather or changes in traffic loadings. One must keep in mind that the purpose of using

the types of PMS studied for this research is not to keep an up-to-the minute condition listing of the pavements; it is for network level decision making assistance. An engineer should further inspect each segment that is a candidate for receiving repair funds.

Another tendency is to have the survey crews collect all kinds of data that would be "nice to have." Unless a specific need for the data exists or unless it is used directly by the PMS software, it is not advisable to spend the time to collect the information. Long survey time and mounds of unused data tend to cause frustration and loss of confidence in the system which may ultimately lead to elimination of the funding for PMS activities. If additional information is needed it should be stored within the computerized data base. The surveyor should be able to collect all needed data on one form and the data entry person should be able to simply enter the data into the computer. One suggestion for speeding up data entry and reducing errors is to use a facsimile of the screen form for field inspections. All one has to do for this purpose is make a "screen print" of a blank form displayed on the monitor and then make copies as needed. For the Caltrans/ FHWA FPMS a copy of the one page output form could be made rather than the two page input form. Even with the small sample network one has to be very careful when transferring

the condition survey data from the field forms to the screen forms because they are different.

PAVEMENT CONDITION INDEX CONCEPT

Part of this research was to study the Pavement Condition Index (PCI) concept and determine if the concept was beneficial and should be a part of a PMS. Supporters of the Pavement Condition Index concept are adamant about its importance to a PMS, while opponents of the concept are just as sternly against its inclusion in a system. Certainly the PCI is not an exact representation of all the problems that may occur within a pavement since only a limited number of distresses are used in generating PCI values. The PCI concept also seems inherently inaccurate considering that an overlaid pavement is rated by this approach as being equal to a new pavement structure (both rated 100). No correction is made for previous problems of the pavement or for any preparation of the surface prior to resurfacing. The Bay Area PMS does recognize that deterioration of the overlaid section may likely occur quicker than a new pavement section and adjusts for this. But the newly overlaid section still is assigned a PCI of 100. Another criticism of the PCI is that the number gives no indication of the exact problems present in any given pavement. Several combinations of distresses may yield the same PCI value. This argument was

the basis for the creation of the priority matrix used in the Caltrans/FHWA and Tulare County PMS where a unique priority number is assigned for each of several combinations of distresses present, traffic data, and ride score. The Bay Area system answers this criticism somewhat by providing information on the percentage of deduct values that were load related, non-load related, or other.

Calculation of the present PCI is not theoretically based. As explained within the description of the system, the deduct curves for the Bay Area PMS were subjectively developed based on the opinions of experienced pavement engineers on the effect of individual distresses on the rating of a particular pavement. As an example a pavement section exhibiting 10% light severity alligator cracking as its only distress would receive a PCI rating of 67 based on the deduct curves provided with the Bay Area PMS (Ref 2). According to the PCI concept this is the same relative rating an experienced pavement engineer would assign to the pavement. In effect the idea is to capture the knowledge of the engineer in the PMS so that inexperienced technicians may produce ratings similar to the engineer's without the expense of hiring the engineer to inspect the pavement.

The PCI projection curves used in the Bay Area PMS are based on use of a mathematical equation (Ref 2) to produce a reverse S-shaped curve which was found to best represent the shape of pavement deterioration vs. time.

This curve is then fitted to a sample set of pavement performance data collected from observation in the San Francisco - Oakland Bay Area through use of regression analysis techniques. For any individual segment, this generic curve is forced through the single PCI value for a given time and future PCI estimates may be read from the curve. Obviously this is just a guess at future condition and for any given segment the estimate may be significantly in error.

Tulare County chose to use a mathematical expression that would approximate the shape of the PAVER curves. An exponential expression (Ref 10) was selected and the constant and exponent were modified according to type and severity level of distress observed. No attempt was made to project future pavement condition.

All of the above information indicates that the PCI is certainly not based on any exact science. Nevertheless the PCI can be useful for some purposes. It is useful to have some means to quantify the overall condition of the paved network so one may track to see if particular maintenance techniques are effective and if the network condition is generally improving or deteriorating. Also from a practical standpoint, a street maintenance supervisor must ultimately justify his funding requests to non-technical administrators who may not understand or care about pavement distresses. Simple numeric ratings like the PCI can be used for such

budgeting purposes or other occasions when a general condition rating will suffice. The user must realize the limitations of the PCI and be careful to avoid letting misleading PCI values cause undeserving projects to receive funding. The Caltrans/FHWA priority number or Bay Area PMS effectiveness ratio may also be used for the same budgeting purposes with the effectiveness ratio considering more factors and probably more meaningful. The negative side of these other ratings is that no network wide condition level trends can be inferred.

Based on the results of this research, it is the opinion of this author that, for network level decision making assistance, and long term planning, the PCI has its place and is worth including in a PMS. It may be part of the process to prepare a preliminary list of candidates for maintenance but the inherent compromises in its derivation should be kept in mind.

FUTURE RESEARCH NEEDED

Just as pavement design procedures are in a stage of transition and relying more on theory based methods, so should pavement management systems. This transition will likely be slow due to the wide variety and poor quality control of pavements already in place. Development of lower cost mechanical testing equipment would certainly enhance

theory based pavement management systems. Continued advances in speed and data storage capabilities of microcomputers should allow development of PMS with more project level aid such as design modules for overlay design and more accurate prediction of remaining pavement life until structural failure.

Much of the nation's highway network is overdue for maintenance. With maintenance funding levels continuing to lag below minimum levels necessary to sustain the highway system, pavement management is a concept that should become common among all levels of government in the very near future.

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