Developing an Interface Between Network- and Project-Level Pavement Management Systems for Local Agencies

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A network-level pavement management system (PMS) has been used by cities and counties of the San Francisco Bay Area since 1984. Several agencies need to extend the analysis to the project level. Network-level PMS decision support systems use microcomputers to provide relatively simple support. However, project-level PMS elements currently require much more detailed analysis, which often requires the physical testing of materials. Much project-level analysis must take place outside the computerized decision support process. The Bay Area project-level PMS elements were developed to provide the needed support while maintaining an interface with appropriate analysis techniques used in the network-level decision support system. The project-level PMS programs use the existing data in the network-level PMS data base and allow the addition of information from analysis conducted outside the computer programs. A guide for conducting project-level evaluation to identify feasible alternatives and develop cost-effective treatments was prepared. The project-level programs allow the definition of contract and construction packages and manual intervention to adjust the date of construction when constraints not considered by the program are present. The calculation of the effects of maintenance and rehabilitation use the same general principles employed in the network-level analysis; however, the approach is modified to make use of the more-complete data collected.

A network-level pavement management system (PMS) has been used by cities and counties of the San Francisco Bay Area since 1984 (*1–3*). As the agencies used the network-level PMS elements, they found that they also needed assistance with the analysis at project level. Project-level PMS elements have been developed for the Bay Area PMS through the support of the Metropolitan Transportation Commission (MTC), Oakland, California (*4*). The project-level decision support system was developed to interface with the network-level elements to make it more adoptable and usable by Bay Area agencies.

BACKGROUND

The Bay Area network-level PMS elements were developed under the guidance of a group of Bay Area public works personnel employing the diffusion of innovation concepts to make the PMS easier for Bay Area public works agency personnel to use (*2*). To continue these concepts through developing the project-level PMS elements, a committee was formed of public works personnel who use the Bay Area PMS and were interested in the project-level system. This group reviewed the elements as they were developed and provided feedback to the developers. They are currently testing the procedures. Diffusion of innovation concepts was again employed to help make the system more adoptable and usable for public works agencies.

Pavement management is generally described and developed at two levels: network and project. The primary differences between network- and project-level decision support tools include the level for which the decisions are being made and the amount and type of data required (*5,6*).

The differences in decision level are normally found in the quantity of pavement being considered and in the purpose of the decision. In network-level analysis, agencies generally include all of the pavements under their jurisdiction; however, they may also break out subsets, such as primary arterials, that are managed separately from the remaining network. The quantity of pavement considered at the project level is normally a single management section, which also often corresponds to an original construction section, though sections may be combined or subdivided in analysis and design.

The purpose of the network-level system is usually related to the budget process of identifying funding needs for pavement maintenance and rehabilitation and determining the effects of various funding scenarios on the health of the pavement system and on the overall welfare of the community. The primary results of network-level analysis include fund needs, forecasted conditions for funding scenarios, and priority listings of pavement sections for programming maintenance and rehabilitation. At the project level, the purpose is to provide the best maintenance or rehabilitation strategy possible for the selected sections of pavement for the available funds. The primary results of the project-level PMS include an assessment of the cause of deterioration, identification of possible strategies, and selection of the "best" strategy, given the constraints.

Data collection is expensive and time-consuming. When engineering analysis and design are being conducted to determine the type of maintenance or rehabilitation to apply to a section of pavement, it is often difficult to determine exactly the type and amount of data required until some of the data have been collected. Excessive data collection is one of the problems causing PMSs to fail or be discontinued (*3*). To avoid excessive collection, the absolute minimum data nec-

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essary are normally collected at the network level. This allows the PMS to be implemented with less initial investment; however, the data collected for the network level are not adequate for making most project-level decisions. More-complete data must be collected on individual management sections of pavement identified as candidates for maintenance or rehabilitation when the project-level analysis is needed. If the project-level data are retained when collected, a more-complete data base can be developed without an excessive investment in data collection at any one time. The need to minimize initial data collection is a primary reason for developing separate network- and project-level PMS elements.

BAY AREA NETWORK-LEVEL PMS ELEMENTS

Network-level elements were developed first because they were the ones that the Bay Area public works personnel thought they needed most (*3*). Once the decisions with which the users needed assistance were identified, only the data needed to support those decisions were identified for collection. This approach produced a streamlined system requiring a minimum amount of data to manage the system at the network level.

The network-level system contains five general categories of components:

1. An inventory of the pavement network,
2. A method to determine the condition of the pavement segments,
3. A procedure to determine maintenance and rehabilitation fund needs,
4. A method to select candidate sections when funding is constrained, and
5. A method to show the impact of budget decisions on the health of the network, fund backlogs, and future fund needs.

The pavement network is divided into segments with relatively uniform characteristics. Each segment is expected to receive the same maintenance or rehabilitation treatment. These segments are used as both management and data collection sections.

The PAVER surface observable distress-based pavement condition index (PCI) was modified for use in the Bay Area. It is used as the network-level measure of condition (*7,8*). The number of distress types was reduced to seven, and the distress survey procedures were simplified. The PCI from the latest inspection, the PCIs from all prior inspections, and the distress type, severity, and quantity for each section from the last inspection are retained in the data base. The condition of each section, in terms of PCI, is projected over the analysis period using a family curve concept adjusted for the performance of individual management sections. The projected condition of each management section is then connected to a maintenance and rehabilitation cost at a designated period through a set of decision trees that assign a network-level funding category treatment to each management section identified as needing maintenance or rehabilitation. The development of treatments, costs, and decision trees is described elsewhere (*1,2,8*). The funds needed for each management unit are calculated and summed by treatment type for each year of the analysis period to determine network budget needs unconstrained by available funds.

When funds are limited, an analysis is used to designate those management units for funding that provide the best network value for the money. A cost-effectiveness analysis is used to rank pavement sections for fund allocation, which is similar to a benefit-cost analysis except that a surrogate effectiveness is used in place of a directly calculated benefit (*2*). The area under the PCI-versus-age curve for individual sections is defined as the effectiveness. The basic hypothesis is that user utility (noncosted benefit) is the mirror image of performance (*9*). The ratio of the expected effectiveness per year for the identified maintenance or rehabilitation treatment to equivalent uniform annual cost per square yard is calculated for each section of pavement. The ratio is then weighted for level of usage. The weighted cost-effectiveness ratio is used to rank the sections to determine which ones should be selected for funding.

To determine the area under the PCI-versus-age curve, the PCI is projected to a terminal condition. It is also adjusted to reflect the expected influence of the maintenance or rehabilitation treatment used to determine the cost and projected until it reaches the same terminal condition. The area between these two curves is calculated to determine the effectiveness of the treatment.

The pavement manager can allocate different percentages of the funding to preventive maintenance to help select the best division of funding between preventive maintenance and rehabilitation. Different total funding levels can also be analyzed in a series of funding scenarios. The network-level support elements provide information on the sections selected as candidates for maintenance and rehabilitation, condition of the network, deferred funds, and stopgap funds required. It is expected that the pavement manager will use a series of these analyses to compare funding scenarios in order to develop recommendations for required funding levels and select the best considering the funds allocated to pavement maintenance and rehabilitation. However, the treatments used in the network-level analysis were primarily developed to identify budget needs and fund-allocation effects; they were never intended to be applied to the pavements without a project-level analysis.

Engineering analysis and design are required to determine the specific treatment to be applied to any pavement management section identified for rehabilitation by the network-level analysis. In addition, whereas the equations and relations used in the network-level analysis to calculate the treatment's impact on the PCI are believed to be adequate for that decision level, the developers were concerned about their applicability to project-level decisions. The network-level methods for calculating effects of treatments on PCI are described in detail by Smith et al. (*10*).

PROJECT-LEVEL ELEMENTS

Although the Bay Area public works agencies have been responsible for maintenance and rehabilitation design for many years, the implementation of the network-level PMS introduced them to more treatments and more structured analysis concepts than previously used. They then requested that the Bay Area PMS be extended to provide assistance at the project level and offered to assist by guiding the development and trying the elements as they were developed. Although the project-level PMS elements constitute a new class of decision support for the public works personnel, the developers and the user committee were determined that it would not duplicate effort from the network-level system. The results of the network-level programs are used as the starting point for the project-level analysis.

The data used in the project-level analysis were selected to interface with the data collected at the network level. The future need for this interface was considered in the development of the network-level elements. This might not be a problem in most state PMS support systems, because many appear to have started at the project level and progressed to network-level elements. But in most local agencies, PMS started with network-level elements and progressed to project-level elements. A more-complete description of the data is provided later.

In early trials, the using agencies ran their network-level analysis and then put the resulting section information into the project-level analysis. If they didn't get similar results, they believed something was wrong with the project-level system. Once a user becomes comfortable with a network-level system, the project-level system should give similar results when the same data are used if the project-level system is to have any credibility. The same general analysis concepts used in the network-level decision support software were used in the project-level elements whenever appropriate.

The Bay Area network-level system uses a 5-year analysis period. In the project-level system the user can choose from 1 to 5 years for the analysis period. This allows the user to pick the years for which the more-detailed analysis will be completed. The project-level analysis begins with candidate sections identified by the network-level decision support system; however, other sections can be manually added to the analysis list, and those selected by the decision support system can be removed from further analysis.

Outside Constraints

Programmed and concurrent activities outside the pavement maintenance arena affect pavement maintenance and rehabilitation planning, especially at the project level. Programmed activities are constraints that affect the scheduling of the treatment, such as planned renovation of an underground utility. Concurrent activities are those that are traditionally completed, or required by policy to be completed, when pavement maintenance or rehabilitation is applied. Concurrent activities affect the cost associated with applying the treatment and include activities such as sidewalk repair, drainage repair, structure adjustments, and safety structure construction.

To address this, the Bay Area PMS data base was modified so that constraints could be entered. The pavement manager identifies whether the activity will constrain pavement maintenance and rehabilitation or whether the work will be performed concurrently. Dates for constraining activities are entered, if appropriate. For constraining activities, the project-level decision support program adjusts the affected management section treatment dates to no earlier than the constrained date. For instance, if a water line under the street is scheduled for replacement in 1993, the street work will not be scheduled before 1993.

The costs associated with constraints can be entered; however, if a cost is entered, the pavement manager must also identify whether the cost should be considered in the cost analysis. Costs associated with renovation of utilities are normally borne by the utility agency; these need not be entered because they are not associated with the pavement repair and would not affect the analysis. However, costs required to adjust the height of guard rails and utility structures (e.g., manholes and valve boxes) in the street for an overlay would be included and considered in the cost analysis, because they vary with alternatives. Costs to repair sidewalks may need to be tracked, because they are borne by the public works agency, but they should not be considered in the cost analysis to determine the best treatment, because they do not affect pavement performance nor are they associated with a specific treatment. Both types of cost are tracked by the program and reported in the final analysis.

Contract and Construction Package Development

Management sections that have uniform characteristics reflecting past construction and maintenance efforts in cities and counties often include relatively small pavement areas. Many times the network-level analysis will identify many sections for the same treatment spread over the network for each analysis year or several diverse treatments to small street sections with a small geographic area. To gain efficiencies of scale, most public works agencies prefer to apply the same treatment to several management sections within a geographic area at one time. This is often called a chip seal program or overlay program. Agencies seldom apply an overlay to two blocks, heater scarify and overlay one block, skip two blocks, apply a chip seal to one block, and skip two more blocks before reconstructing three blocks, all along a section of street; they generally try to find an appropriate treatment for all of the sections with minor changes in surface preparation, base modification, or overlay thickness. If two management sections need a treatment in 1 year and the management section connecting them is identified as needing a similar treatment soon, the agency often applies a treatment to all three sections in the same year. Thus, considerable modification in management section selection occurs in the development of final projects by grouping management sections into contract or construction packages based on geographic location, type of treatment, and date of treatment.

The Bay Area project-level programs allow the user to define these packages. The basic information is retained on individual management sections in the data base; however, the management sections are combined for final analysis and treatment development at the project-level. The programs allow the development of construction and contract packages during all phases of project-level evaluation. Once the package has been defined, the costs, PCI increase, and cost-effectiveness will still be calculated for each management section; however, the cost-effectiveness will be weighted on a square-yardage basis for the entire package and that value will be compared to the cost-effectiveness of other packages. Individual management sections not included in contract and construction packages are considered a single section package in the analysis.

Project-Level Evaluation

Currently, much of the project evaluation must be completed outside the actual computerized decision support programs. The program is set up to allow the engineer to begin analysis, reach some point at which information is not available to complete the next step, leave the program, return to the program later, and continue the analysis without losing any information or steps.

Pavement evaluation is a complex engineering problem that requires a systematic approach to quantify and analyze the many variables that influence identification and selection of appropriate maintenance and rehabilitation treatments. In new design, many design parameters are assumed or developed from laboratory tests. However, many of the materials to resist damage induced by traffic and the environment are in place when maintenance and rehabilitation are being planned, and the existing material properties can be determined along with the condition, traffic, and other constraints. Project-level analysis can be approached as a series of steps to determine the cause of deterioration and identify relevant constraints (*11*). The answers are then used to identify practicable treatments. However, it is essential that the process determine the cause and extent of deterioration to ensure that the solution addresses the cause of the problem rather than just a symptom.

The size of the project and importance of the street or road to the agency influence the amount of time and funds that will be expended in project-level evaluation. Pavements on high-volume major roads and streets should be subjected to more testing and evaluation than those on low-volume roads and streets. The concepts and evaluation procedure described are valid for a road or street with any volume of traffic; only the amount of testing and time spent in reaching the conclusions should vary.

A question-answer–oriented project-level evaluation should address the following questions (*11,12*):

1. Is the pavement structurally adequate for future traffic?
2. Is the pavement functionally adequate?
3. Is the rate of deterioration abnormal?
4. Are the pavement materials durable?
5. Is the drainage adequate?
6. Has previous maintenance been abnormal?
7. Does the condition vary substantially along the length of the project or between lanes?
8. Does the environment require special consideration?
9. What traffic control options are available?
10. What geometric factors will affect the design?
11. What is the condition of the shoulders?

Questions 1 through 6 address the cause of deterioration; Question 7 helps determine if there should be a change in the basic management section; and Questions 8 through 11 identify special constraints that must be considered. Detailed checklists have been presented by Smith and Darter (*11*) and AASHTO (*12*).

The Bay Area network-level PMS uses the distress-based PCI as the basic measure of condition, and it is a good tool for the network level. But at the project level, although PCI can be used to identify abnormal rates of deterioration and variances in the performance of subsections of a management section, it does not adequately define either the functional or structural condition. Information on the specific type, amount, and severity of the distresses is more important. Extrapolated distress data are stored for each management section of pavement in the network-level Bay Area PMS data base; however, it may be necessary to collect more-complete or more-recent distress data for project-level analysis, because the distress data are generally based on a sample of the section area in the network-level analysis and it may have been some time since the inspection was completed. The distress data often need to be supplemented with additional measures of condition to address the questions just described; however, sometimes the distress information alone is adequate.

To guide the Bay Area PMS user through this question-answer process, a manual was prepared that describes ways to ask the questions, data to be used to answer the questions, and alternatives to be considered. By adopting project-level PMS elements that complement the network-level system, the minimum required data can be collected during the network-level surveys and more-complete data can be developed and captured by the PMS over a long period through project-level elements when that data are necessary to support the decisions being made. The data used at project-level complement rather than duplicate the data collected at network level. Data collection is spread over a longer time, which makes the PMS more adoptable to an agency selecting a PMS to implement; unnecessary data, or data that become obsolete, are not retained to impede analysis or affect future decisions. This allows only the data to be collected only when they are needed and reduces implementation costs.

Decision trees were used to identify alternatives in the network-level analysis, so the same concept was applied to the project level. Decision tables were prepared for each of the seven individual distress types and the three severity levels for a reasonable range of densities. Practicable treatments were then identified for each category. In general, as density increases, the treatments change from localized repair to area coverage; as severity increases, the treatments change from light surface repairs to heavy rehabilitation. These decision trees generally provide more than one alternative; in some cases they provide several. They are meant to be advisory and used by the newer engineer to identify feasible treatments and strategies.

The distress-based decision trees were modified to show how the alternatives would be modified if the pavements also experienced structural and functional problems. Feasible maintenance and rehabilitation strategies are identified for a pavement section on the basis of the individual distress type, severity, density combination present when the section is structurally deficient, excessively rough, or has poor surface friction.

Structural adequacy indicates the ability of the pavement to withstand the expected traffic loadings. The presence of certain distress types—for example, alligator cracking and rutting—can be used to determine how the pavement has performed structurally to the present; however, it is difficult to use distress to predict structural performance, especially if traffic has changed recently or is expected to change significantly in the future. All rational overlay design procedures use some method to determine the additional thickness needed for future traffic loadings. To supplement the distress data available, the analyst is requested to conduct an overlay design for the existing pavement. It is assumed that the pavement is structurally adequate if an overlay is not required. No specific overlay design procedure is required by the program, but deflection testing or component analysis based on cores and borings is recommended in conjunction with traffic projections, at least for higher-traffic pavements. Most local agencies do not have deflection-testing equipment; however, several consulting firms provide deflection testing and overlay design services. The California Department of Transportation deflection-based overlay design procedure is generally recommended for the Bay Area agencies if other methods are not being used by the agency or consulting firm conducting the analysis. It is recommended that structural problems be considered first because if a structural overlay or other rehabilitation treatment is applied, it will generally correct roughness and surface-friction problems also.

Functional adequacy is normally used to describe how well the pavement meets its basic purpose of providing a smooth and safe riding surface. It is usually measured in terms of roughness and surface friction. The Bay Area network-level PMS does not address roughness or surface-friction problems directly. Some indications of such problems can be surmised from distress information, for example, that pavements with severe distortion problems are generally very rough and that pavements with severe rutting generally have surface-friction problems in wet weather. However, other measures may be advisable during project-level evaluation, but many agencies do not have the funds to quantify the measures mechanically. Particularly for lower-volume pavements, a quick ride over the section by the design engineer is normally used to determine if the pavement has roughness problems so severe that they be addressed specifically. However, more-quantifiable methods of measuring surface roughness are described in the manual for those agencies that have the resources and the need to measure roughness. While most agencies will not purchase roughness equipment, consulting firms can provide the measuring and analysis services. Roughness analysis should be completed before consideration of skid problems, because the feasible treatments for correcting roughness problems can also correct surface-friction problems.

Surface friction is not generally measured by cities and counties, but accident location maps—especially wet-weather–accident locations—can be used to find areas that have surface-friction problems. Methods to measure skid in localized areas are described for the agencies because several law enforcement agencies in the area use them in accident analysis. The agencies are encouraged to use these devices during project-level evaluation when they are available, especially on their high-volume roads and streets and at intersections at which skid-related accidents have been reported. Skid-measuring services are also available from a few consultants.

The rate of deterioration is often used to program the time at which maintenance or rehabilitation should be applied, as well as to assist in determining the cause of deterioration. Timing of the application is explicitly used in both the network and project-level programs of the Bay Area PMS through the projected PCI. High rates of deterioration are considered to be associated with structural deterioration of pavements, and environmentally caused deterioration is expected to have a slower rate. If the pavement life has exceeded the original design life and has recently reached a level at which rehabilitation is being considered, the pavement may be capable of being rehabilitated with a minimum-cost treatment if traffic is expected to be the same; this may be much less expensive than the network-level treatment identified by the PMS software. However, if the pavement requires rehabilitation in a period much shorter than its design life, or if the traffic is expected to increase dramatically, reconstruction or some other extensive rehabilitation technique might be necessary. Rate of pavement deterioration can be measured in terms of the PCI change per year or increase in the amount of a distress type. Past and projected rates of deterioration are available from the Bay Area PMS programs based on PCI.

The localized variation along a section or between lanes can be determined by plotting the PCI versus section length or across lanes; however, the network-level system stores only the average PCI for the management section, and that is normally based on a small sample of the section area. For at least the major arterial streets, a more-complete distress survey is recommended. The PCI calculation program provides the PCI values and distress information for the individual inspection units, which can then be used to determine if there is significant variance; if there is, the sections can be subdivided for further analysis.

Information on drainage and material durability is not available in the network-level data. The manual advises the engineer on how to consider drainage and material durability in developing alternatives to find those that will address the cause of deterioration; it also gives some guidance on how to identify problems associated with each. In general, the presence of either will reduce the alternatives. Special environmental constraints are often not considered important in city and county analysis; however, in the Bay Area, several agencies have pavements both near the bay and in the adjacent hills. The subgrade types and the natural drainage differences between these locations affect the performance and must be considered in the analysis, often leading to the selection of different alternatives. Finally, the other constraints such as geometric factors and traffic control options are used to develop a final set of alternatives.

The PMS decision support programs are then used to conduct a life-cycle cost and cost-effectiveness analysis to identify the treatment that provides the best return the least funds. The engineer can select one treatment for each package to be given priority or allow the program to select the one with the highest cost-effectiveness ratio. A number of iterations may be required for some sections to complete the process of identifying the best solution and developing construction and contract packages.

PRIORITY SETTING

The treatment costs and effectiveness values are entered into the project-level programs to adjust the network-level fund allocation. The same cost-effectiveness analysis used in network-level analysis is used to rank pavement sections identified for maintenance and rehabilitation from highest to lowest weighted effectiveness-cost ratio. In the network-level system, available funds were defined for each year of the analysis period. This same procedure is used in the first ranking by the project-level program. Sections are selected for funding from the ranked list. The following equation is used to calculate the weighted effectiveness ratio (*2*):

$$\text{WER} = \frac{(\text{AREA/YR})\ \text{WF}}{\text{EUAC/SY}} \tag{1}$$

where

WER = weighted effectiveness ratio,
AREA = area under PCI curve,
YR = years affected,
WF = weighting factor for usage,
EUAC = equivalent uniform annual cost, and
SY = square yards in management section.

Following this ranking process, the program user may again intervene manually and adjust the construction dates of selected construction and contract packages and require that they be completed in a designated year, regardless of the cost-effectiveness rating. This lets the PMS user intervene and move sections and packages within the ranking to account for conditions not fully accounted for in the ranking procedure. For instance, sections identified as being excessively rough or lacking adequate skid resistance may be designated for repairs in a given year, even if they are not selected by the ranking system. At this point, the sections and packages are reranked. A final listing will then be provided. If the required funding for mandatory sections exceeds the available funding, an error message is provided.

PROJECT-LEVEL CALCULATION OF EFFECTS OF MAINTENANCE AND REHABILITATION

The PCI-versus-age curve must reflect the influence of the maintenance and rehabilitation treatments being analyzed. All maintenance and rehabilitation treatments have two impacts on the PCI-versus-age curve: first, the PCI will be increased; second, the remaining life will increase. Those treatments that return the PCI to 100 are considered rehabilitation; those that improve the PCI to a value less than 100 are considered maintenance.

Currently for rehabilitation, only one curve is available for the Bay Area PMS for flexible overlays and one for reconstruction as asphalt concrete pavements for each surface type and functional classification grouping. Other curves will need to be developed for different thicknesses of overlays and possibly for overlays applied at different condition levels in the future when data are available. In the meantime, the project-level priority-ranking program uses the estimated life extension of the rehabilitation treatment defined by the engineer to account for the expected difference in overlay lives or other treatments.

The projection is adjusted to force it to go through a terminal PCI at the time of the treatment plus the life extension. This is the same concept used to adjust the projected PCI without maintenance or rehabilitation to reflect the difference between the predicted and observed PCI, as described elsewhere (*1,2,8,10*). If the life extension is 18 years, the PCI will be assumed to reach the terminal PCI value at 18 years after application of the overlay plus any remaining life of the existing pavement.

When a treatment is applied to an asphalt pavement that does not replace, rework, or completely cover the surface of the pavement (such as a seal coat, patching, or crack sealing), all distress is not necessarily repaired and the PCI is not increased to 100. Because the PCI is based on distress, the amount of increase in PCI depends on the distresses repaired. The amount that the PCI will increase can be calculated if the distress types being repaired and the effect of the repairs are known (*13*). Although only extrapolated distress is stored in the Bay Area PMS data base, that information can be used to reasonably estimate the PCI increase due to application of the maintenance for use with the analysis concepts, if an adequate percentage of the section area has been inspected.

Not all repair types completely eliminate a distress. For instance, crack sealing can change a medium-severity transverse crack into a low-severity crack, but it does not eliminate the crack. A patch is considered a distress, so patching changes the repaired distress into a low-severity patch. Some distress types cannot be repaired by certain treatments—for instance, a seal coat will not correct rutting. Some distresses can be eliminated by a treatment; low-severity weathering and raveling can be eliminated by a slurry seal. A default set of changes for different treatments is included, but the user has the option of modifying the expected consequence of maintenance treatments on specific distress types and severities.

As an example of how this process is applied, consider the distress information on the asphalt-surfaced pavement shown in Table 1. When the longitudinal and transverse cracking is sealed, full-depth patching is applied to the medium-severity alligator cracking, and a seal coat is applied, the PCI is changed, as shown in Table 2. This procedure is used at the project level to estimate the impact of the increase in PCI due to maintenance. The future PCI is then projected from the expected increased PCI using a curve-shifting procedure (*10*). This basically assumes that the pavement will deteriorate at the same rate that it did when the PCI of the original pavement condition was equal to the PCI after the maintenance. Thus, the pavement deterioration is expected to follow the original curve, but the deterioration begins at the improved condition level. The increase is applied to the curve adjusted for past performance, so the influence of that performance is reflected in the area under the PCI-versus-age curve. As more data on actual field-reported PCI changes become available, the projected deterioration rate will be verified and corrected.

FUTURE IMPROVEMENTS

Some improvements, primarily those that require more data to better define expected performance, where identified in the description of the program. Other improvements address the basic analysis concepts and supporting procedures.

The described procedure requires that the analyst select a treatment for each construction and contract package or allow the program to select one based on a ranking procedure.

TABLE 1 DISTRESS AND DEDUCT VALUES FOR SAMPLE PAVEMENT

ORIGINAL CONDITION			
DENSITY	DISTRESS	SEVERITY	DEDUCTS
2%	alligator cracking	low	16
5%	alligator cracking	medium	39
1%	longitudinal and transverse cracking	low	2
3%	longitudinal and transverse cracking	medium	17
100%	weathering and raveling	low	17
		total deducts	91
		corrected deducts	52
		PCI = 100 - 52 = 48	

TABLE 2 DISTRESS AND DEDUCT VALUES FOR SAMPLE PAVEMENT AFTER CRACKS ARE SEALED, MEDIUM-SEVERITY ALLIGATOR CRACKING IS PATCHED, AND SEAL COAT IS APPLIED

DENSITY	DISTRESS	SEVERITY	DEDUCTS
2%	alligator cracking	low	16
4%	longitudinal and transverse cracking	low	7
5%	patching	low	10
		total deducts	33
		corrected deducts	20
		PCI = 100 - 20 = 80	

The developers have investigated several decision support approaches and have selected an incremental cost-benefit analysis to use when the users become comfortable with the current process.

Most of the project-level evaluation must be conducted outside the program with the aid of decision tables. The use of expert system methodology to assist in this process is being considered for future implementation.

SUMMARY

The Bay Area network-level PMS system allows management sections to be defined and identified, several sorting keys to be established, and the condition to be defined using a distress-based PCI. The future condition can be predicted, network-level budget funding treatments can be assigned to pavement types and condition categories, the total funding needs for the network over a 5-year period can be identified, and different fund-allocation strategies can be tested.

Project-level PMS elements have been developed that complement the network-level system. The project-level programs use the data available in the network-level Bay Area PMS data base, enable the use of more-detailed project-level evaluation data, allow the addition of information from analysis conducted outside the computer programs, and consider non-pavement constraints such as expected utility work. Whereas the network-level analysis uses a 5-year analysis period, the project-level analysis allows maintenance and rehabilitation programs to be developed for periods of 1 to 5 years. Currently, some of the project-level analysis elements developed to assist in treatment selection must be conducted apart from the program software; a manual with decision tables was prepared to assist with these tasks. The project-level programs allow the user to establish contract and construction packages by combining several management sections to form a set that is considered as a unit for the rest of the analysis. The project-level priority-ranking program allows manual intervention to adjust the date of construction when there are constraints not covered in the program. The calculation of the effects of maintenance and rehabilitation uses the same general principles as the network-level analysis (*2*); however, the approach is modified to incorporate the more-complete data used in the development of cost-effective project-level treatments. Funding recommendations are based on a cost-effectiveness analysis that was also used in the network-level analysis.

The interface between network- and project-level PMS elements must be carefully established to avoid duplication of effort and to maintain credibility of both systems. The systems should complement each other and allow information from one system to support the other.

ACKNOWLEDGMENTS

The developments discussed in this paper were supported by MTC, Oakland, California. Several San Francisco Bay Area public works personnel and MTC staff members have provided invaluable guidance and assistance in the project.

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Publication of this paper sponsored by Committee on Pavement Management Systems.