# A Comprehensive Ranking System for Local Agency Pavement Management

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**Pavement management systems for local agencies (cities and counties) require a method to determine how to allocate funds for maintenance and rehabilitation of pavements. This should provide a reasonable analysis of the impact of budget decisions on the pavement network condition and future budget needs. However, most local agencies have limited funds to collect data concerning their pavements as well as maintain them. An approach has been developed that uses a minimum of information to make reasonable budget analysis concerning maintenance and rehabilitation needs with unconstrained funding. Described in this paper is the way in which funding needs are then allocated when funding is less than needs. It includes consideration of the condition of the pavement, change of condition over time, cost of the maintenance or rehabilitation over time, and stopgap maintenance generated by deferring maintenance. This was accomplished by making it simple for the public works personnel to visualize and use. It is part of a network-level microcomputer-based pavement management system developed for San Francisco Bay Area agencies.**

Much has been published recently describing how cities and counties responsible for maintaining local roads and streets *(1–3)* have far more pavement funding needs than they can meet. There are 3.9 million miles of roads and streets in the United States. Local government agencies have jurisdiction over 2.8 million miles *(4)*. Many of these pavements are nearing the end of their design life at the same time that the agencies are receiving less real financial support than in previous years.

To achieve this miracle, pavement management systems are presented as providing assistance for pavements. In general, the effort is directed at better identifying the needs, examining alternatives, and allocating available funds to provide the taxpayer with the best pavements for the funds invested. The greatest need in local agencies is for assistance in planning and programming maintenance and rehabilitation.

The basic elements of a pavement management system (PMS) directed at maintenance and rehabilitation of pavements include *(5)*:

1. A network inventory,
2. A data base,
3. Analysis procedures for network-level management, and
4. Analysis procedures for project-level management.

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The network-level management procedures are directed at planning and programming. The basic goals are to determine how much funding is needed for a given analysis period, which sections of the pavement network need maintenance or rehabilitation, and the impact on pavement condition of different funding levels. A procedure can also be provided to identify which sections need reinspection in each year of the analysis period.

The project-level procedures include the detailed engineering analysis to determine the best maintenance or rehabilitation treatment to be applied to a specific section of pavement identified as needing maintenance or rehabilitation in the network-level analysis. It is the engineering required before the development of plans and specifications, including identification of feasible alternatives and selection of the most desirable maintenance or rehabilitation alternative given present constraints.

## BACKGROUND

This study was sponsored by the Metropolitan Transportation Commission (MTC), Oakland, California, and conducted through a contract with ERES Consultants, Inc., of Champaign, Illinois. MTC is the transportation planning agency for the 103 cities and counties in the San Francisco Bay Area. The origins of the PMS efforts by MTC are found in a 1982 MTC study to develop support for an increase in gasoline tax to fund local improvements for pavements *(1)*. They completed a study of local road and street maintenance needs and revenue shortfalls in the San Francisco Bay Area that indicated that local jurisdictions in the Bay Area were spending only 60 percent of funds in 1982 required to maintain roads in a condition considered adequate.

The results of this study prompted several Bay Area public works directors to ask MTC to assist them with an analysis of how Bay Area agencies could improve pavement maintenance and rehabilitation techniques and practices. This group strongly emphasized that simplicity was the most important characteristic to be included in a PMS if it were to be adopted and used by Bay Area cities and counties. They further recommended incorporation of only tried and proven techniques and practices that their staff personnel could understand and use. Finally, they indicated that the system must match the needs and resource capabilities of the jurisdictions.

In 1983, ERES Consultants, Inc., was retained to assist MTC in determining Bay Area PMS needs, PMS resources, and problems. In addition, they were to develop three basic elements of a standardized prototype PMS: a pavement condition index (PCI), effective maintenance treatments for the Bay Area, and a network-level assignment procedure. An extensive survey was completed to determine the status of PMS implementation as well as maintenance and rehabilitation needs in San Francisco Bay Area cities and counties. Most agencies perceived a need for better management support tools; however, most of these agencies generally believed that available systems were either too complex or did not provide adequate assistance. The data currently available to the cities and counties are very limited and it is believed that they cannot afford to collect such additional data. The results of these efforts are documented in a three-volume report available from MTC *(6)*.

On the advice of the participating agencies, MTC then decided to support the development of a PMS to meet the needs of these agencies. The committee suggested that the developed system use components from existing systems as much as possible while customizing the system to specific needs. They considered the resources available for developing and implementing pavement management systems by Bay Area cities and counties along with the commitment required by the available pavement management systems. The following objectives were set:

1. Network-level capabilities for scheduling maintenance and estimating budget needs,
2. Network-level prioritization for scheduling cost-effective maintenance and rehabilitation,
3. Network-level budget estimates for alternative performance levels, and
4. Capability to be expanded to meet project-level management requirements at a later time.

A unique three-way partnership was formed to develop the pilot PMS. ERES Consultants, Inc., was retained to provide continued technical assistance for the project, with R. E. Smith as the principal investigator on the project. MTC provided most of the funding, programming expertise, and staff time to assist the participating agencies. Six Bay Area agencies, including three counties and three cities, participated in the pilot program. They provided key experienced personnel for user guidance in the development of each pavement management module and tested each as it was developed. This provided continual feedback to the developers and programmers of the system.

## Determination of Budget Needs and Identification of Sections Needing Maintenance and Rehabilitation

One of the primary purposes of a pavement management system is to identify budget needs for current and future years to maintain the pavement network in an acceptable condition. In the Bay Area PMS, the analysis period was selected to be 5 years based on the normal budget procedures used by the pilot agencies. The pavement network is divided into relatively uniform segments that are expected to be given the same maintenance or rehabilitation treatment. These are then used as the basic management units in the analysis.

A modified form of the PAVER surface observable distress-based pavement condition index (PCI) was selected as the measure condition of the pavement management units and network *(5, 7)*. The distress types used to determine the PCI were reduced to the seven that were most prevalent as well as used in decision making by the Bay Area public works personnel. The distress collection was simplified by decreasing the detail required during collection. The condition in terms of PCI is projected into the future using a family curve concept adjusted for the performance of individual management units *(6)*. The condition of management units must then be connected to a maintenance and rehabilitation cost at a designated period. The funds needed for each management unit are calculated and summed for each year of the analysis period to determine network budget needs for each year.

Several approaches were considered for developing budget needs. A two-step approach was adopted. First, the most cost-effective level at which to maintain the pavements is determined in terms of cost/year of acceptable pavement life. Then the most cost-effective maintenance and rehabilitation strategies are determined to apply to the pavements at designated lower pavement condition levels. The general goal of this approach is to apply maintenance and rehabilitation at the most cost-effective condition level and return all pavements in conditions worse than this to the appropriate level based on unconstrained funding. Then, when funds are limited, an analysis is employed to select those that will be funded to provide the best network condition.

This approach required

1. Identification of maintenance and rehabilitation treatments that the Bay Area public works personnel would consider applying to their pavements;
2. Condition levels at which they would apply different treatments;
3. Treatment information including application cost, surface preparation cost, and life extension provided by the treatments; and
4. An analysis to determine the most cost-effective treatment for each pavement type and condition level.

Once these were determined, a set of decision trees was established for assigning the network-level planning treatments to each management unit needing maintenance or rehabilitation. The actual development of treatments, costs, and decision trees is described by Smith *(6)* and Darter et al. *(8)*. Once the budget needs are determined without considering funding constraints, they are compared with available funds and management units are selected for funding that provide the best return for the money expended. This paper is primarily intended to describe the ranking procedure and analysis used in this selection.

## Budget Analysis Concepts

The participating pilot agency public works personnel defined several budget analysis goals they wanted in a PMS. These included

1. The desire to provide the best return for the funds expended,
2. The need to identify funds for capital improvement expenditures separate from maintenance funds,

3. The desire to allocate funds to preventive maintenance as well as rehabilitation,
4. The need to identify deferred maintenance and rehabilitation funds, and
5. The need to consider stopgap or emergency maintenance and requirements.

These requirements were carefully considered in the light of other constraints, especially the need to keep the concepts as simple as possible and minimize the data that must be collected to complete the analysis.

When limited funds must be allocated among a number of different projects, some method of identifying the projects that are considered the most important must be developed. A simple ranking procedure could be used; however, that type of procedure is limited in the number of factors that can be considered. It also generally ranks those in the worst condition as the highest priority without regard to the return on the funds expended. As shown in the economic analysis described by Darter et al. *(8)*, the cost-effectiveness of maintenance and rehabilitation treatments changes with PCI, pavement type, traffic level, and so on. The pilot agencies requested a technique that would consider this but not require complex concepts nor be difficult to understand and use.

Cost-benefit analyses have been adopted as a decision support tool in the transportation field by some agencies *(9, 10)*. Many of the public works supervisors and personnel are professional engineers who are familiar with the concepts included in engineering economics needed for this approach. With all the costs and benefits known, they can be compared directly. Those projects that provide the greatest benefit for the funds expended are then selected *(10, 11)*. However, the benefit in analysis of public financed projects is not simple to define or calculate and if done improperly can be misleading *(12)*.

The initial direct costs to the public agency for pavement maintenance and rehabilitation can be relatively accurately determined; although future maintenance and rehabilitation costs are less well defined, they still can be reasonably estimated. The benefits of pavement improvements are normally based on the concept of reduction in time costs, vehicle operating costs, and accident costs *(10)*. When the facility is improved by decreasing these costs, the resulting savings are defined as user benefits *(13)*.

Considerable effort has been made in the last several years to determine the user benefits associated with travel time and operating costs *(9, 13–17)*; however, they are not always directly applicable to local agency situations and most of the indirect benefits have yet to be determined. To include user benefits in analysis of city and county pavement maintenance and rehabilitation improvements, three components are required:

1. A reasonable set of models that can be used to determine the change in vehicle operating costs due to the maintenance and rehabilitation applied to city and county roads and streets for vehicles traveling at city speeds,
2. A good set of traffic data for use in these models (current models require types and weights of vehicles), and
3. A reasonable method to measure the impact of maintenance and rehabilitation on city streets and county roads that can be related to user benefits (current models require roughness).

The user cost models currently available are based on traffic operating on pavements with 50 to 60 mph speed limits *(16)*, and they appear to be more reliable for determining user benefits related to geometric and capacity improvements than to pavement maintenance and rehabilitation. Fewer than half of the Bay Area cities and counties even have average daily traffic data on most of their streets, let alone traffic data by vehicle class or weight *(5)*. At present, accurate roughness measurements on city streets are expensive to collect, and most Bay Area agencies do not routinely collect the data nor do they have the funds to spend on the measurements.

In general, it is known that as traffic congestion increases and the pavement surface deteriorates, the travel time, vehicle operating costs, and accident costs increase. When maintenance and rehabilitation are applied, there is a period of increased travel time and increased accident occurrence resulting in decreased user benefits or increased user costs. When the improvement is completed, the travel time, vehicle operating costs, and accident rates generally decrease, resulting in increased user benefits *(10)*. Improvements may also allow an increase in traffic, which can affect the price of goods, employment opportunities, property values, and aesthetics. The environment may be adversely affected by construction and the additional traffic that would increase user costs. However, this has not been well quantified for city and country road and street conditions.

Early work on vehicle operation costs are found in works by Sawhill *(14)* and Winfrey *(9)*, and the AASHO Red Book *(15)*. McFarland *(13)* was the first to approximately quantify the effects of the pavement surface in terms of serviceability or roughness on user costs, including vehicle speed, user delays, operating costs, and accident costs. More recent work has been completed by the Federal Highway Administration *(16)* and the World Bank *(17)*, in which costs and benefits were developed as functions of pavement surface condition, highway geometry, and vehicle characteristics.

Of these, only the pavement surface condition, which is primarily measured by roughness in these models, would be affected by the maintenance and rehabilitation managed in the pavement management system of interest. Even then, it would only be the roughness of the pavement surface. In cities and counties, roughness is often caused by drainage structures such as valley gutters, inlets, and other structures that would not be corrected by most road and street maintenance and rehabilitation projects.

The difficulties encountered in determining user benefits have caused many agencies to ignore the user benefits in their analysis *(10)*. Others have used some value that is more easily determined as a surrogate for the user benefits in a cost-effectiveness analysis. The basic concepts of cost-effectiveness are similar to benefit-cost analysis *(12)*.

There are a series of steps required for cost-effectiveness analysis *(12)*. In the first step the goal of the system must be defined. In pavement maintenance and rehabilitation, that goal is to provide the best overall pavement condition for the funds expended. The second step includes the development of alternatives. When selecting pavement management units for funding, a number of different alternative strategies and fundable management units are available. The evaluation criteria must be selected in the third step, which must provide some measure of the effectiveness of the alternatives. In pavement maintenance and rehabilitation, this can include a measure of the pavement condition and how that condition varies over time, which should be considered over the same time period as the subject improvement. The cost must be calculated in the fourth step, and is usually formulated in terms of life-cycle costs, which consider all costs associated with the system over the life cycle of the alternative. They can be expressed as present worth or they can be annualized. In pavements, they are often divided by some area (lane-mile, square yard, and so on) to normalize for the varying sizes of the pavement management units being considered. The fifth step includes the selection of the fixed cost or fixed effectiveness approach. When multiple alternatives are considered using a ratio of effectiveness to cost, the fixed-cost approach is being used. In the sixth step, the candidate alternatives are ranked in order of their ability to satisfy the selection criteria. This type of procedure can be used to select an alternative for a single project or to select a set of projects to be funded from a group of candidate projects *(11, 18)*.

Pavement alternatives with the same condition but with different levels of traffic do not provide the same benefit. The benefits of the pavement used by the higher-trafficked pavement are greater than those of the lower-trafficked pavement. Weighting can be used to make the effectiveness a function of traffic use as well as condition.

### Cost-Effectiveness Analysis Used

Others have used the concept of the area under the performance curve as a surrogate *(18–20)*. Pavements in good condition have lower user costs than pavements in poor condition. In addition, the longer the pavement remains in good condition, the longer it provides lower user costs. The basic hypothesis is that user utility (non-costed benefit) is the mirror image of performance *(19)*. The area above the curve indicates loss of user benefits and the area under the curve is the pavement user utility or non-costed benefit. This is illustrated in Figure 1. The PCI can be used for this curve and is already available in the Bay Area PMS, which eliminates the need for an expensive second set of data collection, roughness.

Effectiveness, then, is defined in the Bay Area PMS as the area under the PCI time curve above the minimum analysis condition level, which was identified to be 25 for the Bay Area PMS. This is illustrated as the area under the curve above the PCI level of 25, shown in Figure 1. The PCI of 25 was determined to be the point below which the Bay Area engineers would generally perform major rehabilitation; the degree of condition below 25 has little impact on the rehabilitation treatment to be applied *(7)*.

Effectiveness is calculated automatically in the Bay Area–PMS software budget analysis module using a trapezoidal integration procedure. For the current pavement surface, the area under the PCI time curve adjusted for performance is calculated for each individual management unit of pavement identified as needing maintenance or rehabilitation in the budget-needs module. The effectiveness of the maintenance or rehabilitation is calculated using the PCI time curve for the individual section adjusted for maintenance or rehabilitation applied at the date it is identified in the budget-needs module. This is illustrated in Figure 2 as the area under the second curve designated as $A_3$. The first curve represents the adjusted performance curve of the original pavement. The second represents the increase in the PCI to 100 due to an overlay or reconstruction and the projected performance of that pavement following the application of the treatment.

In the above cases, the treatment is applied when the PCI equals 25, and the effectiveness is the total area under the family curve of the treatment applied, shown in Figure 2. However, if a treatment is applied before the PCI of the original pavement reaches 25, the effectiveness of the treatment is equal to the area under the family curve for the treatment minus the area under the existing family curve from the date of

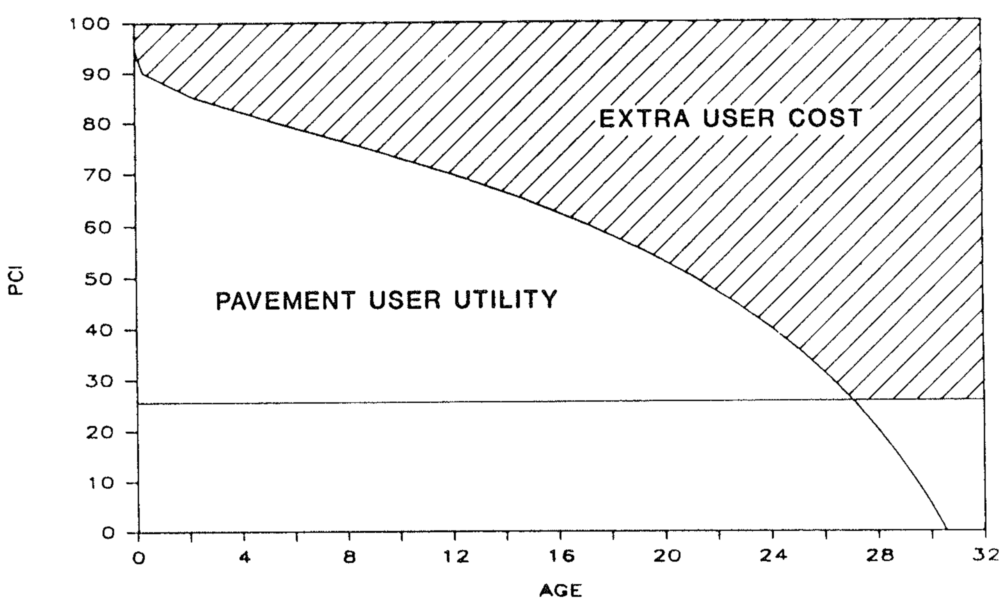


**FIGURE 1 Effectiveness equal to pavement user utility shown as the area under the PCI deterioration curve and used in the Bay Area PMS *(22)*.**

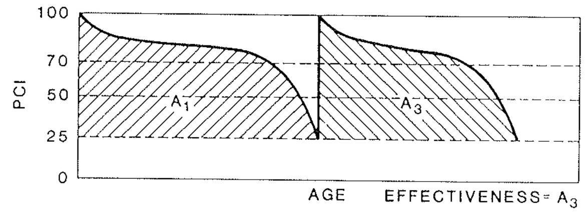


**FIGURE 2 Effectiveness of rehabilitation applied at the end of acceptable pavement life shown as $A_3$.**

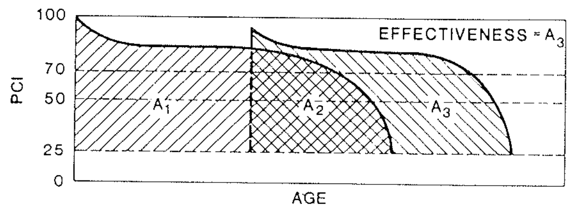


**FIGURE 3 Effectiveness of rehabilitation applied before end of acceptable pavement life shown as $A_3$.**

application to the time when the PCI is projected to reach 25. This is illustrated in Figure 3 with the effectiveness of the rehabilitation designated as $A_3$. The area designated as $A_2$ is a part of the effectiveness of the current pavement surface and is not a part of the effectiveness of the treatment.

As described below, the costs are annualized. In the effectiveness analysis, the effectiveness is divided by the number of years in the life of the treatment needed to annualize the effectiveness as well.

## Cost Calculation

The costs used in the cost-effectiveness analysis are the unit costs determined from the decision trees in the budget-needs module described by Smith *(6)* and Darter *(8)*. To account for the time value of money, the equivalent uniform annual costs (EUAC) are used in the analysis. Both interest and inflation can be used in the equation; however, the user can decide whether only interest or both will be used. To account for the difference in the areas among management units that are being compared, the costs are calculated per square yard.

The effectiveness is an area under the PCI performance curve that is not influenced by the size of the management unit being analyzed. If total cost were used, the management units with the smaller areas would have larger ratios than management units with small areas for the same cost per square yard and same life. Dividing the EUAC by the area normalizes the EUAC for the area. Life extensions of the selected treatments are stored in the data base, with the unit costs for the treatment as default data for use by the PMS software in this calculation of EUAC/yd$^2$. They may be changed by the user.

## Weighting Factors

The ratio of the expected effectiveness per year for the identified maintenance and rehabilitation treatment to the equivalent uniform annual cost/yd$^2$ (effectiveness/yr)/(EUAC/yd$^2$) is calculated for each management unit. The management units could then be ranked from highest to lowest cost-effectiveness ratio. The highest to lowest would then be selected until the available budget was expended. However, generally it is less costly to repair the residential or local streets, and in general they will have longer lives than arterial streets. This would cause the majority of available funds to be allocated to residential or local streets. To counter this problem, the effectiveness ratio would have to be weighted for usage. This weighting is normally a function of traffic. When traffic data are not available, as is the case for most agencies in the Bay Area, the weighting could be based on functional classification as a surrogate for traffic.

Multiple attribute decision-making concepts have been developed to determine the importance of various decision-making attributes when used in a forced choice situation *(21)*. A special set of linear programming procedures, termed goal programming, is used for normative decision making. To determine reasonable weighting factors based on functional classification, a set of pavement management units was described in terms of PCI and functional classification. The pilot agency public works personnel were then required to identify the management unit they would repair first if funds were limited to repairing only one of the two. This provided a set of paired comparisons that were used in the goal-programming procedures to develop the relative importance of the ranking compared with the PCI. The weights could then be multiplied by the scale of the attribute to determine the importance. This has been used experimentally by highway researchers to develop relationships between pavements with several attributes *(22)*. However, it is assumed that the scale of the attribute is known.

The PCI scale is well defined; however, the functional classification scale is not known. In fact, if the location of each classification on a scale were known, the relative importance and weighting needed for the effectiveness would be known. The results of the forced choices are shown in Table 1. Analysis of those results provides the ranking table shown in Table 2, where the number in the box indicates the priority, with the lowest number indicating first priority. By trying different locations on a scale of 0 to 10 for the functional classification and the fixed PCI scale, the priority table in Table 2 was very nearly duplicated from results of the goal-programming techniques, as shown in Table 3, by using arterials as 10, collectors, as 7.25, and residential/locals as 5.5. When normalized, this provides a weighting of 1.0 for arterials, 0.725 for collectors and 0.55 for residential/locals. These were selected as the default weighting factors for the PMS.

The user has the option of changing the weighting factors when using the budget-scenario PMS software. The budget-scenario reports can be run using the PMS software for each functional classification separately. The results can then be checked against the results of all the reports using all types combined to determine if the weighting factors are reasonable. This weighting could vary considerably among different agencies based on the traffic levels for the functional classifications and the distribution of functional classifications maintained by the agency. This results in the following equation, which is used to calculate the weighted effectiveness ratio:

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

where

WER = weighted effectiveness ratio,

TABLE 1 RESULTS OF FORCED-CHOICE DECISIONS

| FUNCTIONAL CLASSIFICATION | PCI | TOTAL CHOICE | | FUNCTIONAL CLASSIFICATION | PCI | TOTAL CHOICE |
|---|---|---|---|---|---|---|
| ARTERIAL | 10-0 | 6 | VS | COLLECTOR | 10-0 | 0 |
| COLLECTOR | 10-0 | 5 | VS | RESIDENTIAL | 10-0 | 1 |
| ARTERIAL | 25-10 | 4 | VS | COLLECTOR | 10-0 | 2 |
| COLLECTOR | 25-10 | 3 | VS | RESIDENTIAL | 10-0 | 3 |
| ARTERIAL | 40-25 | 1 | VS | COLLECTOR | 10-0 | 5 |
| ARTERIAL | 40-25 | 4 | VS | COLLECTOR | 25-10 | 2 |
| COLLECTOR | 40-25 | 1 | VS | RESIDENTIAL | 10-0 | 5 |
| COLLECTOR | 40-25 | 4 | VS | RESIDENTIAL | 25-10 | 2 |
| ARTERIAL | 55-40 | 1 | VS | COLLECTOR | 10-0 | 6 |
| ARTERIAL | 55-40 | 1 | VS | COLLECTOR | 25-10 | 5 |
| ARTERIAL | 55-40 | 4 | VS | COLLECTOR | 40-25 | 2 |
| COLLECTOR | 55-40 | 1 | VS | RESIDENTIAL | 10-0 | 5 |
| COLLECTOR | 55-40 | 1 | VS | RESIDENTIAL | 25-10 | 5 |
| COLLECTOR | 55-40 | 4 | VS | RESIDENTIAL | 40-25 | 2 |
| ARTERIAL | 70-55 | 0 | VS | COLLECTOR | 10-0 | 6 |
| ARTERIAL | 70-55 | 0 | VS | COLLECTOR | 25-10 | 6 |
| ARTERIAL | 70-55 | 2 | VS | COLLECTOR | 40-25 | 4 |
| ARTERIAL | 70-55 | 3 | VS | COLLECTOR | 55-40 | 3 |
| COLLECTOR | 70-55 | 1 | VS | RESIDENTIAL | 10-0 | 5 |
| COLLECTOR | 70-55 | 2 | VS | RESIDENTIAL | 25-10 | 4 |
| COLLECTOR | 70-55 | 0 | VS | RESIDENTIAL | 40-25 | 6 |
| COLLECTOR | 70-55 | 5 | VS | RESIDENTIAL | 55-40 | 1 |

AREA = area under PCI curve described above,
YR = years affected,
WF = weighting factor for usage, described earlier,
EUAC = equivalent uniform annual cost, and
SY = square yards in management unit.

## Budget Allocation

The pavement management units identified for rehabilitation are separated from those identified for preventive maintenance to determine an appropriate split in preventive maintenance versus rehabilitation by the PMS software. Those identified for rehabilitation are ranked from highest- to lowest-weighted effectiveness/cost ratio within the rehabilitation group, as illustrated in Table 4. A second ranking by weighted effectiveness ratio is completed for the management units needing preventive maintenance, as illustrated in Table 5.

The manager selects a budget for the first year of the analysis period (e.g., $100,000) and an expected budget inflation factor for the 5-year analysis period (e.g., 5 percent). The budget inflation factor is applied only to the budget entered. Any budget inflation factor, including 0, can be selected. The manager also identifies the percentage of the budget to allocate to rehabilitation compared with preventive maintenance (e.g., 70 percent rehabilitation and 30 percent preventive maintenance). These are entered when requested by the menu-driven PMS software.

TABLE 2 PRIORITY TABLE BASED ON ANALYSIS OF FORCED-CHOICE DECISION IN TABLE 34

| PCI | ART | COL | RES/LOC |
|---|---|---|---|
| 70 - 55 | 10 | 13 | 15 |
| 55 - 40 | 7 | 11 | 14 |
| 40 - 25 | 4 | 8 | 12 |
| 25 - 10 | 2 | 5 | 9 |
| 10 - 0 | 1 | 3 | 6 |

Note: PCI = pavement condition index, ART = arterial, COL = collector, RES/LOC = residential/local.

TABLE 3 PRIORITY TABLE FROM GOAL PROGRAMMING

| PCI | ART | COL | RES/LOC |
|---|---|---|---|
| 70 - 55 | 10 | 14 | 15 |
| 55 - 40 | 7 | 11 | 13 |
| 40 - 25 | 4 | 8 | 12 |
| 25 - 10 | 2 | 5 | 9 |
| 10 - 0 | 1 | 3 | 6 |

Note: PCI = pavement condition index, ART = arterial, COL = collector, RES/LOC = residential/local.

TABLE 4 MANAGEMENT UNITS NEEDING REHABILITATION RANKING BY WEIGHTED EFFECTIVENESS RATIO

| STREET ID | SECTION ID | RH / PM | WEIGHTED EFFECTIVENESS RATIO |
|---|---|---|---|
| ASTREE | 02 | REHAB | 503.96 |
| DEANST | 02 | REHAB | 317.63 |
| ALICES | 01 | REHAB | 310.91 |
| CLAIRE | 01 | REHAB | 308.99 |
| OPTIMI | AREA01 | REHAB | 293.15 |
| MYRTLE | 01 | REHAB | 230.62 |
| CSTREE | 02 | REHAB | 72.63 |
| CSTREE | 01 | REHAB | 71.77 |
| BSTREE | 01 | REHAB | 70.27 |
| ATHERT | 01 | REHAB | 69.95 |
| WILLIS | 01 | REHAB | 44.78 |
| MYRTLE | 03 | REHAB | 44.78 |
| SUTROS | 01 | REHAB | 44.77 |
| PAMELA | 01 | REHAB | 44.77 |
| FILBER | 01 | REHAB | 44.77 |
| MONTGO | 01 | REHAB | 44.77 |
| DEANST | 01 | REHAB | 39.38 |

Note: RH = rehabilitation, PM = preventive maintenance.

TABLE 5 MANAGEMENT UNITS NEEDING PREVENTIVE MAINTENANCE RANKED BY WEIGHTED EFFECTIVENESS RATIO

| STREET ID | SECTION ID | RH / PM | WEIGHTED EFFECTIVENESS RATIO |
|---|---|---|---|
| DSTREE | 01 | P. MAINT | 702.23 |
| MEEKST | 01 | P. MAINT | 674.14 |
| ALICES | 03 | P. MAINT | 665.39 |
| BURBAN | 01 | P. MAINT | 585.96 |
| ARNOLD | 01 | P. MAINT | 572.40 |
| DOTSON | 01 | P. MAINT | 475.34 |

Note: RH - rehabilitation, PM = preventive maintenance.

The computer software selects projects identified for rehabilitation from highest-weighted effectiveness ratio to lowest until the funds allocated for rehabilitation (e.g., $70,000) are expended. If the entire rehabilitation budget is not expended, the remainder is allocated to preventive maintenance within the same year; it is not reallocated to following years. Those management units identified as needing rehabilitation but not selected are considered in the following year. Deferred rehabilitation costs are based on the needs deferred in that year. Those management units identified as needing rehabilitation but not selected for funding at this point will also have stopgap maintenance fund requirements assessed based on condition level.

This stopgap maintenance fund requirement is based on the concept that those pavements needing rehabilitation will generate maintenance expenditures to patch potholes and other high-severity and safety-related distresses if they are not rehabilitated. The actual amount allocated to stopgap maintenance is based on an analysis of the type of maintenance Bay Area public works personnel would apply to pavement types in each condition level if funds were not available to apply needed maintenance and rehabilitation. The stopgap maintenance funds assessed by this procedure are subtracted from the funds allocated to preventive maintenance. If the stopgap maintenance fund requirements exceed the available preventive maintenance (PM) funds, then all PM funds are exhausted on stopgap needs. The PMS software reports are then used to advise the user that stopgap fund requirements exceed the allocated funding for that analysis year, and no management units are selected for preventive maintenance. In addition, the surplus PM funds will have a negative balance. Those management units identified as requiring rehabilitation but not selected for the initial year are considered in the following years of the analysis period.

The management units identified to receive preventive maintenance will then be selected based on the same type of ordered weighted effectiveness/cost ratio analysis. Those with the highest ratios are selected until the total allocated preventive maintenance funds for that year, minus those expended for stopgap maintenance, are allocated (e.g., $30,000 − $10,000 = $20,000). Those identified as needing preventive maintenance but not selected in the desired year are considered in the following year of the analysis period.

The total budget allocated to rehabilitation, stopgap maintenance, and preventive maintenance is calculated along with the deferred maintenance and rehabilitation costs and the surplus preventive maintenance funds. This process is repeated for each of the 5 years in the analysis period by the software. The results are provided both in a detailed management unit selection analysis for each year and in a summary table, as shown in Tables 6 and 7. This allows an analysis of the capital improvement budget and preventive maintenance budget compared with other classes.

TABLE 6 DETAILED MANAGEMENT UNIT SELECTION ANALYSIS

Sections Selected for M&R in 1988

| Type of M&R | Street ID | Section ID | Total Cost ($) | Rating |
|---|---|---|---|---|
| Rehabilitation | FILBER | 02 | 8,358 | 74.57 |
| | WILLIS | 01 | 19,049 | 43.69 |
| | MYRTLE | 03 | 29,549 | 43.69 |
| Total | | | 56,956 | |
| Preventive maintenance | MEEKST | 01 | 10,524 | 768.22 |
| | DSTREE | 01 | 3,058 | 650.89 |
| Total | | | 13,582 | |

NOTE: Budget = $72,223 and 0% inflation, 90% rehabilitation.

The manager can try other budget splits until the best overall network condition is found. In theory, the split that provides the best overall network condition over the analysis period should be chosen. In reality, other factors often intervene. These include the requirement to keep agency forces gainfully employed, limitations on contractor capabilities, and political considerations. In addition, some agencies are constrained to distribute maintenance and rehabilitation funding equally among the political subdivisions of the city or county.

This provides the manager with an analysis tool with which he can look at the effects of the various budget decisions. In effect it is a higher-level ranking approach *(23)*. The ranking has a number of steps and uses more information than most ranking systems. Trade-offs between maintenance and rehabilitation are considered in building the decision trees. It is used again in the ranking process by comparing the effects of various percentages of funds applied to maintenance and rehabilitation. However, an optimization procedure is not included in the PMS software.

There are a number of optimization tools available that could be used to determine the optional allocation of funds *(12, 23, 24)*. However, several factors have inhibited the use of true optimization tools in the Bay Area PMS. First, several of the participating pilot agency personnel adamantly opposed the use of linear programming, Markov decision analysis, and dynamic programming. They felt these techniques were too complex and provided answers through a process they did not understand. On the other hand, the Bay Area PMS system provides a ranking system based on condition of the pavement over time, cost over time, and importance of the road or street in a procedure they understand, support, and can explain to the elected officials to whom they must justify their budget requests.

Second, most of the decisions are made based on the bare minimum of possible data. Ranking provides feasible solutions with improved decision effectiveness; optimization selects the

TABLE 7 SUMMARY DATA FROM BUDGET SCENARIOS REPORT

| | Budget Allocation by Year ($) | | | | | |
|---|---|---|---|---|---|---|
| Type of M&R | 1987 | 1988 | 1989 | 1990 | 1991 | Total |
| Rehabilitation | 52,826 | 56,956 | 60,068 | 59,063 | 58,599 | 287,512 |
| Preventive maintenance | 0 | 13,582 | 10,069 | 8,634 | 11,288 | 43,573 |
| Stopgap maintenance | 18,312 | 0 | 1,618 | 1,911 | 0 | 21,841 |
| Deferred maintenance | 393,107 | 350,619 | 379,802 | 441,981 | 402,860 | 1,968,369 |
| Surplus preventive maintenance | 1,085 | 1,685 | 468 | 2,615 | 2,336 | 8,189 |

NOTE: Budget = $72,223 and 0% inflation, 90% rehabilitation.

best; however, when the data are incomplete, optimization may provide no better solution than ranking. The efforts involved in optimization really should be spent optimizing solutions based on more complete data.

Finally, the output that comes from the ranking or optimization at the network level will not be used directly. The output provides lists of management units and treatments. These treatments are basically network-level budget planning treatments developed for budgeting purposes that must be reviewed in later project-level analysis. The maintenance and rehabilitation needs of a small network are shown in Figure 4. Note how the treatment numbers are scattered across the network with the rehabilitation year similarly randomly distributed. If this were the complete network, the agency might apply the treatments that way. However, if this were a small portion of a large network, the difficulty of applying treatments scattered across the network in this way can be imagined. To gain efficiencies of scale, an agency will normally apply the same type of treatment to several streets in an area. They will not apply an overlay to two blocks, heater scarify overlay one block, skip two blocks, apply a chip seal to one block, and skip two more blocks before reconstructing three blocks in the same year. If two management units need a treatment in one year and the management unit connecting them is identified as needing the same treatment the following year, the agency will generally apply the treatment to all three in one year. Thus, considerable modification in management unit selection occurs in developing "contract or maintenance packages."

With this much readjustment of management-unit selection occurring at the project-level following the network-level analysis, it is doubtful that true optimization would provide much better final information than ranking until procedures can be developed that will provide contract or maintenance packages from the PMS. More detailed project-level data are required to develop those packages that cost more money to collect than the agencies are willing to expend at the network level. When the data become available over time, the optimization can be added to the system. Additional budget levels or budget inflation rates can also be tried to determine the impact of budget levels on the overall network condition.

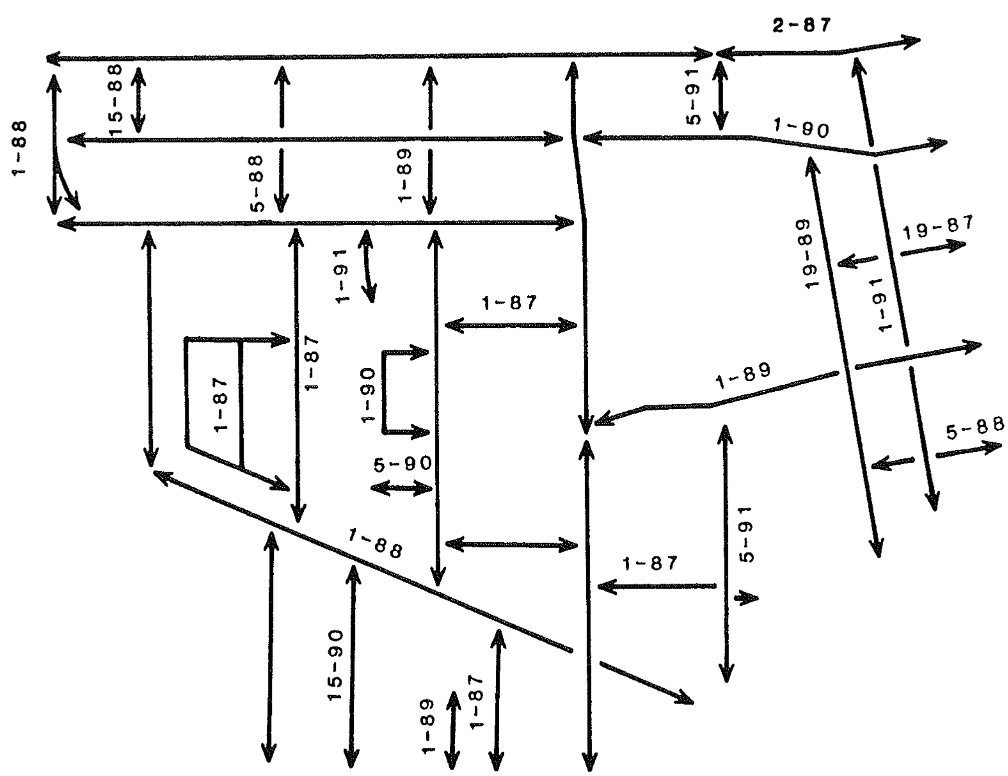


**FIGURE 4 Example network with treatment number and year of application (1–86) from PMS budget scenario output.**

TABLE 8 PROJECTED FUTURE CONDITION

| STREET ID | SECTION ID | LATEST PCI | M & R YEAR | 87 | 88 | 89 | 90 | 91 |
|---|---|---|---|---|---|---|---|---|
| ASTREE | 02 | 67 | 87 | 76 | 74 | 72 | 69 | 67 |
| DEANST | 02 | 67 | 87 | 76 | 74 | 72 | 70 | 68 |
| ALICES | 01 | 65 | 87 | 74 | 72 | 70 | 68 | 66 |
| CLAIRE | 01 | 63 | 87 | 73 | 71 | 69 | 67 | 64 |
| OPTIMI | AREA01 | 64 | 87 | 73 | 71 | 69 | 67 | 65 |
| MYRTLE | 01 | 60 | 87 | 70 | 69 | 67 | 65 | 64 |
| CSTREE | 02 | 51 | 87 | 100 | 93 | 91 | 90 | 89 |
| FILBER | 02 | 55 | 88 | 52 | 100 | 93 | 91 | 90 |
| WILLIS | 01 | 22 | 88 | 17 | 100 | 94 | 92 | 91 |
| MYRTLE | 03 | 25 | 88 | 20 | 100 | 94 | 92 | 91 |
| MEEKST | 01 | 76 | 88 | 75 | 83 | 82 | 80 | 79 |
| DSTREE | 01 | 79 | 88 | 77 | 85 | 83 | 82 | 80 |
| ATHERT | 01 | 43 | 89 | 40 | 37 | 100 | 93 | 91 |
| ARNOLD | 01 | 78 | 89 | 76 | 74 | 84 | 82 | 80 |
| DOTSON | 01 | 89 | 89 | 88 | 87 | 93 | 92 | 91 |
| BURBAN | 01 | 85 | 89 | 84 | 83 | 90 | 89 | 88 |
| PARKST | 01 | 40 | 90 | 36 | 32 | 28 | 100 | 94 |
| PAMELA | 01 | 23 | 90 | 18 | 13 | 7 | 100 | 94 |
| ALICES | 03 | 77 | 90 | 76 | 74 | 73 | 84 | 83 |
| BSTREE | 02 | 73 | 90 | 71 | 70 | 68 | 77 | 75 |
| SUTROS | 01 | 17 | 91 | 13 | 8 | 4 | 0 | 100 |
| MONTGO | 01 | 15 | 91 | 10 | 4 | 0 | 0 | 100 |
| ALICES | 02 | 57 | 0 | 55 | 52 | 50 | 48 | 45 |
| CSTREE | 01 | 45 | 0 | 42 | 39 | 36 | 33 | 30 |
| BSTREE | 01 | 42 | 0 | 39 | 36 | 33 | 29 | 26 |
| MYRTLE | 02 | 37 | 0 | 34 | 30 | 27 | 23 | 19 |
| FILBER | 01 | 27 | 0 | 22 | 17 | 12 | 6 | 0 |
| DEANST | 01 | 28 | 0 | 25 | 23 | 20 | 16 | 12 |
| SOUZAC | 01 | 97 | 91 | 94 | 92 | 91 | 89 | 93 |
| WATKIN | 01 | 98 | 91 | 94 | 92 | 91 | 89 | 93 |
| ASTREE | 01 | 97 | 0 | 89 | 86 | 84 | 82 | 80 |
| GRANDS | 01 | 74 | 0 | 72 | 70 | 67 | 65 | 62 |
| GRANDS | 02 | 74 | 0 | 72 | 69 | 67 | 64 | 62 |
| | Network Mean | 57.9 | | 58.6 | 63.0 | 63.1 | 66.5 | 70.7 |

Note: Budget = $72,223 and 0% inflation, 90% rehabilitation.

## Future Network Condition

The future overall network condition is affected by funding available as well as by the allocation of funds to preventive maintenance versus rehabilitation. Individual management unit conditions are projected into the future, reflecting the performance expected with no maintenance or rehabilitation until they are selected for preventive maintenance or rehabilitation. At the time they are selected, the increase in condition because of maintenance or rehabilitation is reflected in the PCI, and the condition of those management units is projected into the future based on the maintenance or rehabilitation applied. Stopgap maintenance does not generally change the PCI significantly nor does it generally provide a long-term increase; it is not reflected in the PCI increases because of maintenance. A table of management unit condition listings with the mean condition of the group for each year is provided to show these results, as illustrated in Table 8.

## SUMMARY

The budget-analysis concepts selected for use included providing the best network pavement condition for the available funds. This gives the user the greatest relative advantage. A cost-effectiveness procedure was adopted to provide a relative ranking of pavement management units. This offers observable and readily understandable criteria for ranking that decrease complexity and increase compatibility. The area under the PCI-time curve can be easily visualized and presented to public officials to illustrate the quantity used in selecting management units for funding. Weighting the effectiveness ratio for use increases compatibility with expected results and also increases credibility.

The use of stopgap maintenance in the cost analysis makes the results more realistic in terms of actual maintenance expenditures. The replacement cost procedures make the funds invested in the pavement network more readily apparent to the funding agency personnel. The programs were structured to decrease complexity while the reports were developed to enhance the impact of the presented data to the decision makers.

Treatments, costs, life extensions, and strategies are all default but modifiable elements of the PMS software, and were developed for the Bay Area PMS. These are applicable only for the San Francisco Bay Area, and even then represent the mean costs provided by the pilot agencies. They are used to provide an example of how to develop and use the data, and are not presented as the final answer.

## ACKNOWLEDGMENT

This work was funded by the Metropolitan Transportation Commission (MTC), Oakland, California. Wes Wells was the contract manager. It was completed through a contract with ERES Consultants, Inc., Champaign, Illinois, while Roger E. Smith was a member of the ERES staff.

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