Network-Level Prioritization of Local Pavement Improvements in Small and Medium-Sized Communities

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Theoretical and pragmatic problems surrounding network-level prioritization of pavement management activities for local communities are examined. Although the principles of pavement management are the same for all agencies, pavement management at the local level is generally somewhat different from that at the state level because of dissimilarities in resources and responsibilities. Instead of creating a new management system a public domain software package, developed by the Metropolitan Transportation Commission of Oakland, California, was used as a framework for the analysis. This is a comprehensive but low-cost system that can be run on a personal computer. Because much of the research on which this system is based has already been published, an overview of only some elements of the system is presented. The focus is on the use of the system for prioritization of treatment for a local community facing budget constraints. This was accomplished through the use of computer-modeled budget scenarios. This type of analysis proved to be a practical tool for conducting multiyear network-level prioritization at the local level. Analysis, however, is more complicated than just printing out a list. The principal finding was that there is a means of incorporating the link between priority assessment and roadway funding into the network-level prioritization process. This was accomplished by varying treatment selection as funding levels changed. Merely ordering a set of alternatives that were found to be optimal at the project level did not maintain a roadway network in acceptable condition when funding was constrained.

A primary purpose of a pavement management system (PMS) is to provide information so that roadway improvements can be priority ranked (*1*). Ideally, prioritization is a consistent and justifiable process. It should involve minimizing life cycle costs subject to minimum levels of serviceability and budget constraints. This is no simple task. Prioritization is a complicated process that requires sound engineering judgment and a good understanding of local conditions.

Bad prioritization decisions can lead to costly future problems. Current fiscal crises and rising roadway improvement costs have made prioritization decisions more important than ever. The pavement management literature, however, provides little prioritization guidance for use at the local level. This paper examines theoretical and pragmatic problems surrounding the prioritization process and includes a methodology for addressing these problems.

PROBLEM STATEMENT

It is not uncommon for a prioritized list of projects generated by a computerized PMS to bear little resemblance to the work that a community's qualified highway official thinks should be done first. Differences are typically most striking in times of severe fiscal crisis, the times when prioritization guidance is most needed. The cause of this deficiency seems to be that the prioritization procedures in many PMSs are simplistic and do not necessarily reflect the views or constraints of decision makers. At the local level, projects are typically ranked by measures such as pavement condition, rideability, or composite ratings that incorporate other factors such as traffic volume and accident history. Prioritization is then accomplished by procedures such as "best first," "worst first," or percentage-based approaches that divide resources between maintenance, rehabilitation, and reconstruction. These methods are based on common roadway management strategies. Little research, however, has been done to verify the actual efficiency of these strategies. Mathematical procedures exist that can be proven to optimize the allocation of resources. These procedures, however, are complicated and have not yet been applied at the local level.

Because the goal of this research was to develop prioritization guidance for use by local and regional agencies, there was a balancing of efficiency and effort. An efficient prioritization scheme is not useful if it requires unrealistic amounts of data, expertise, and time. Pavement management is a continuing activity. A prioritization procedure should therefore provide useful results, and implementation and updating of the procedure should be able to be done in a practical manner. If not, this element of a pavement management system may be of little use to public officials. Simplicity and practicality are therefore stressed in the final recommendations.

ROLE OF PRIORITY ASSESSMENT IN PAVEMENT MANAGEMENT

A primary step in the establishment of a local PMS is to determine a level of funding that is adequate to maintain roadways in acceptable condition at a minimal life cycle cost. When funding is constrained somewhat below this level in the short run (less than 5 years), as often happens in local communities, preventive maintenance, which is relatively inexpensive, becomes especially important, even if not optimal at the project level. When fiscal crises that reduce roadway funding arrive, however, local highway officials are forced to save what pavements they can and let the rest go. The costs in this situation are generally passed on, by default, to motorists in the form of higher user costs. For example, a community facing extreme fiscal constraints may be forced to patch and seal high-volume roadways instead of overlaying them and skip maintenance of residential roadways altogether. Over the long run such strategies probably cost more than proper maintenance and rehabil-

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itation. They also result in higher user costs because of pavement roughness. However, this may be the best option for maintaining a local roadway network if funding is just not available.

Prioritization procedures should reflect this scale of fiscal circumstances and be able to assist a community in spending limited funds in the best way possible. This is especially important in today's fiscal climate.

METHODOLOGY

This section describes methods used to prioritize roadway improvements and outlines the information needed before prioritization can take place.

Prioritization Indexes

Prioritization indexes are used to order needs. The simplest indexes are based on pavement distress or roughness. Composite indexes are formed when more than one serviceability indicator is combined into a single index. An example of a composite index is a pavement condition index (PCI), which combines measures of distress and roughness. Composite indexes may also incorporate variables such as traffic volume, drainage, and accident history. The next level of prioritization indexes is based on pavement performance. Performance is typically estimated through deterioration curves. The area under these curves can serve as a proxy for user benefits (*2*), which is a measure of effectiveness. This approach takes advantage of the deterioration curves that are already required by multiyear analysis procedures for condition projection. This is a higher-order approach that considers future as well as present pavement conditions. It should be noted, however, that the results are only as good as the original deterioration curves.

Any of these indexes may be cast in a cost-benefit framework to provide additional information to decision makers. In the case of a cost-effectiveness rating, this is accomplished by dividing effectiveness by cost of treatment. This cost-effectiveness rating must be weighted by traffic volume. This is necessary because treatment applied to low-volume roadways typically costs less per year than that applied to high-volume roadways. For example, a thin overlay on a residential street may last as long as a thick overlay on a principal collector but will obviously be less expensive per year of life. The weight is a means of ensuring that these lower-cost treatments for low-volume roadways are not necessarily ranked above the higher-cost treatments applied to heavily traveled roadways. It is a means of normalizing the rating to account for the higher number of users. Additional details on weighted effectiveness ratings can be found in research done by Andres (*3*).

Computer-Modeled Budget Scenarios

The most realistic means of assessing near-term (5-year) local roadway treatment priorities appears to be through the use of computer-modeled scenarios. This type of network simulation approach can be superior to mechanical spreadsheet-type approaches in the analysis of complicated problems (*4*). Modeled scenarios also allow preventive maintenance such as sealing to be considered, and penalties (stopgap maintenance such as pothole patching) can be assigned when treatment is delayed.

The Metropolitan Transportation Commission (MTC) of Oakland, California, has developed a pavement management system that uses this type of procedure to evaluate the impacts of alternative funding levels (*5*). The system uses a composite performance-based index to assess priorities. The index is formed by first determining an effectiveness ratio. This is accomplished by dividing "benefits" (areas under deterioration curves after treatment is assigned) by the cost per square yard of treatment. This effectiveness ratio is then weighted by functional class. This measure of the influence of traffic volume on priority assessment can be modified by the user. The details of weight selection are referenced in the user's guide (*5*).

During the scenario procedure percentages of the agency's budget are allocated to rehabilitation and preventive maintenance. The weighted effectiveness ratio is then used to prioritize road segments in each category. Stopgap maintenance can be assigned when treatment is delayed. Ideally, the determination of the split between preventive maintenance and rehabilitation would be derived through the use of an optimization procedure. Unfortunately, true optimization procedures are currently too complex for practical use at the local level. They also typically require unrealistic amounts of long-term data (20-plus years). After true optimization procedures are refined at the state level and better local data are accumulated, such procedures may prove useful to local communities. At present, however, such procedures would most likely be "black boxes" with limited usefulness. For the present analysis the split was determined through trial and error. The goal was to achieve the best overall network condition subject to conditions such as keeping agency forces gainfully employed, limits on contractor capabilities, and political considerations.

Budget scenarios proved to be an excellent format for prioritizing local roadway needs. "What if" experiments with budget levels and treatment selection can be rapidly simulated on a computer instead of on the actual roadway network. It is a powerful tool that allows highway officials to substantiate the results of their engineering judgment. This method of priority assessment is probably the most advanced procedure readily available for use at the local level. It is not as pleasing theoretically as true optimization, but the measure of benefits that are ranked (the areas under deterioration curves) is often the same as that used for true optimization. The effort described here therefore adopted the MTC system as a framework for an analysis of prioritization at the local level, but it is anticipated that the results of this analysis can be applied to other PMSs.

Prerequisite Tasks

This section briefly describes the steps that must be accomplished before prioritization can take place. It should be noted that these steps are similar for many PMSs.

Inventory

During the inventory phase the roadway network is broken into management sections. Data such as length, width, date of construction, pavement type, and functional classification are then obtained for each section.

Condition Survey

Pavement condition can be measured in several ways. Some PMSs use measures of rideability or roughness. This is usually done for high-speed roads such as Interstate highways. Other systems measure pavement deflection under loads. Deflection measurements of

structural capacity are typically used for detailed project-level analyses. Measures of surface distresses, however, are best suited to network-level use on local roads.

The MTC system uses a PCI to measure pavement distress. The PCI is a scale with a range of 100 to 0. A pavement with a PCI of 100 is perfect. The distresses measured were alligator cracking, block cracking, distortions, longitudinal and transverse cracking, patch and utility cut patch, rutting and depression, and weathering and raveling.

The distresses are measured by a sampling approach. This consists of a detailed examination of at least 10 percent of the pavement in each roadway section. This approach is much less expensive than examining the entire segment. An extensive body of literature, documented in the MTC PMS user's guide (*5*), concludes that a sampling approach provides adequate data for a network-level analysis. During the field test sampling was found to give consistent results, especially for pavements in better than fair condition. If excessive variation is found between the conditions of samples on the same management segment the computer flags that segment for additional inspection.

The sampling procedure is more complicated and time-consuming than a "windshield" survey in which pavements are rated while the inspector drives at 5 to 10 mph. During a windshield survey pavements are usually rated qualitatively, that is, excellent, good, fair, and poor. This type of information, however, is not generally adequate for use with deterioration models. The information gathered by sampling is more detailed and accurate. These qualities lead to better estimates of future roadway conditions. Knowledge of the type, severity, and quantity of each distress also allows reasonable network-level estimates of maintenance expenses to be made.

Because manual condition inspection is time consuming, the entire roadway network is not reinspected yearly. The critical pavements to be inspected are those that are anticipated to cross decision thresholds. The MTC software therefore generates a reinspection schedule on the basis of anticipated deterioration.

Condition Projection

Deterioration curves are used to accomplish condition projection. These projections are used to identify when maintenance and rehabilitation will be required, determine future budget needs, and prioritize treatment when funding is constrained.

The MTC system assumes that pavement deterioration takes the form of a reverse S-shaped curve. This choice of form was based on research from Texas A&M University (*6*) and Cornell University (*7*), which used regression analysis to relate pavement condition to age. The reverse S-Shape seems theoretically sound. One would expect that pavements would deteriorate slowly at first and that deterioration would quicken over time. This increase in the rate of deterioration is especially likely in regions that experience abundant precipitation and hard frosts. In these regions a sharp drop off in condition would be expected as winter exacerbates existing defects. If a reverse S-shaped deterioration curve is inappropriate for a region or pavement type, such as overlays, the software could be modified.

The basic functional form of this relationship curve can be expressed as

$$\mathrm{PCI} = 100 - \left[\frac{R}{(\ln A - \ln \mathrm{age})^{1/B}} \right] \tag{1}$$

where

PCI = pavement condition index,
age = age of pavement,
ln = natural logarithm, and
R, A, B = regression coefficients.

The limit to the drop in later years is determined by the A coefficient. Examination of the PCI formula shows that it becomes undefined when age is equal to A. Because pavements rarely, if ever, reach a PCI of 0, the segment of the curve below the designated failure PCI should be disregarded.

Accurate pavement condition projections are dependent on the suitability of the deterioration curve for the pavement being modeled. The choice of a deterioration curve, however, is complicated by the extreme variability of pavement life. This variation is due to differences in factors such as native subgrades, road construction methods and materials, quality control, drainage, traffic loadings, and environmental factors.

This variation is handled in two ways. First, pavements are separated into the categories that were discussed in the data section (functional classification, pavement type). Pavements within these categories are assumed to deteriorate in a similar fashion. Therefore, they are assigned a family deterioration curve. These are typical curves for average pavements in each class.

Second, additional variation within these categories is accounted for by adjusting the family curves. The adjustment procedure acknowledges that there will be variation in pavement condition, but assumes that future deterioration will occur in a fashion similar to that category's family curve. There are two procedures used by the MTC package to adjust the deterioration curves. They are illustrated in Figure 1. The curve either is adjusted up or down or is shifted horizontally. The appropriate procedure will be determined by the observed condition and age of the particular road segment.

If the observed point falls within the confidence limits shown in Figure 1, the deterioration curve is adjusted up or down. The MTC user's guide calls this procedure "adjusting the curve." It is a percentage-based procedure that entails multiplying the deduct value by an adjustment factor. The following equation is used to calculate the adjustment factor:

$$\mathrm{ADJ\ FAC} = \left(\frac{100 - \mathrm{PCI}}{100 - \mathrm{PCI}_f} \right) \tag{2}$$

where

ADJ FAC = adjustment factor,
PCI = observed PCI, and
PCI_f = family PCI.

The adjusted PCI is represented by the following equation:

$$\mathrm{ADJ\ PCI} = \mathrm{ADJ\ FAC} * \left(\frac{R}{(\ln A - \ln \mathrm{age})} \right)^{1/B}$$

The upper and lower confidence limits can be thought of as the best and worst pavement deterioration scenarios. When a specific segment falls in between these ranges its deterioration is interpolated (*8*). The default value of the confidence limits is plus or minus 50 percent of the drop in the PCI. This value for the confidence limits was deemed "reasonable" in the MTC user's guide. It produced good results for this analysis but can be modified if necessary. Eventually, after more deterioration data are gathered for the family of pavements, these limits might be tightened.

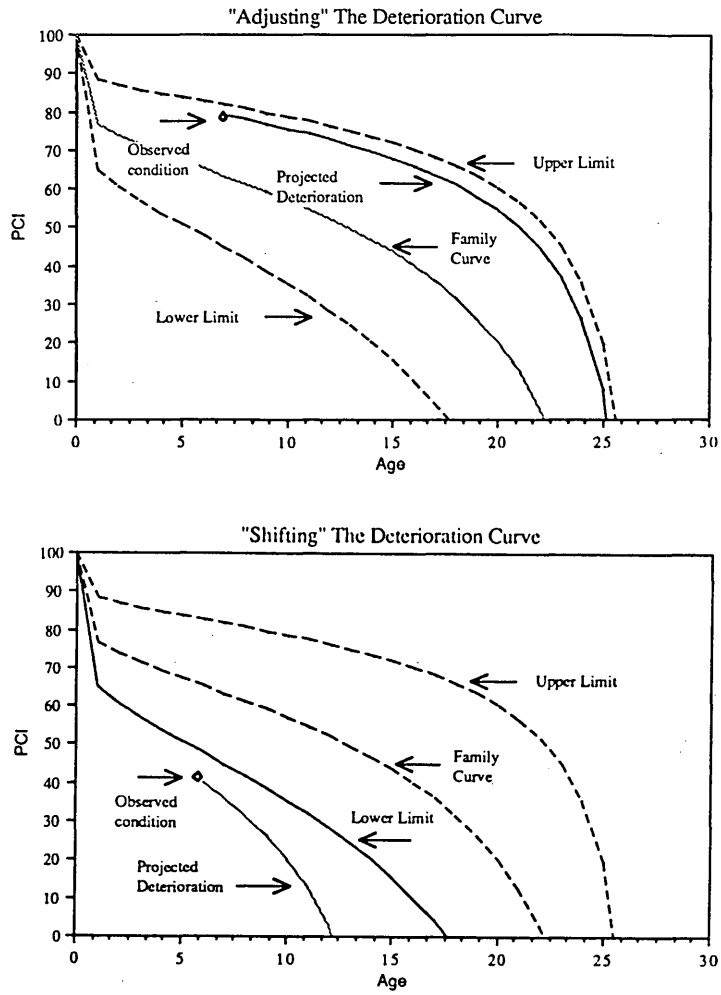

FIGURE 1 Adjustments to family deterioration curves.

If the observed point falls outside these limits the curve is simply shifted horizontally. This procedure is called "shifting the curve." The reason for having two procedures is that adjusting the curve can result in an unrealistic condition projection if the observed point is outside the confidence limits. This could also result in the inability to calculate the area under the deterioration curve. This procedure is equivalent to assuming that the date of construction is wrong or that maintenance or rehabilitation was not recorded.

Rehabilitation and maintenance will affect PCI. Rehabilitation, such as an overlay, will raise the PCI of a segment to 100. Maintenance, such as crack sealing, will turn medium- and high-severity cracks to low-severity cracks. A new PCI is then calculated. The effects of rehabilitation on PCI were calculated through regression analysis of a large sample of actual projects. These default coefficients can be modified by the user, but they appeared suitable for use in the study area.

Treatment Selection

To develop multiyear work plans and examine the effects of various funding levels, future pavement maintenance and rehabilitation actions are modeled. This is accomplished through the use of a set of decision criteria that are triggered by pavement condition. At specified thresholds user-defined treatment is assigned. Treatment is based on pavement type, functional classification, and condition. At this point it should again be stressed that this is network-level analysis. It is only meant to predict probable maintenance for typical pavements to anticipate budget needs. The actual maintenance to be done on specific pavement segments is determined from detailed project-level analyses.

ANALYSIS

This section details the prioritization of local roadway improvements for the town of Eastham, Massachusetts. This network-level analysis was conducted as a pilot project by the Cape Cod Commission, a metropolitan planning organization (MPO). The project was sponsored by the Massachusetts Highway Department and FHWA. This type of technical assistance is continuing at the Cape Cod Commission as well as at other MPOs across the country. These local pavement management efforts by MPOs are supported by the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA).

Budget Needs

Before prioritization can take place budget needs must be determined. This was accomplished through the application of the treat-

ment selection procedure discussed above. Application of this algorithm produces a list of treatments anticipated to minimize the life cycle cost of each management section. The budget needs module of the MTC PMS produces a list of selected treatments and the weighted effectiveness of each selection in the present year. The budget needs analysis was conducted in current dollars. The MTC program, however, does allow the use of a discount rate.

The weighted effectiveness ratings are used to prioritize roadway improvements when funding is constrained. This is accomplished through the use of computer-modeled scenarios. In the future the MTC plans to develop a procedure to calculate current weighted cost-effectiveness for all potential projects in each analysis year rather than just calculating them all in the beginning (Sachs, unpublished data). This improvement will be possible because of the phenomenal increase in microcomputer capability in recent years.

The budget needs analysis indicated that the sample community should spend just over $1 million during the next 5 years to maintain its roadway system adequately. The unconstrained budget needs analysis, however, did tend to "front load" needs. It indicated that the town should spend more in the early years. This is due to having to catch up with maintenance and the fact that repairs become more expensive with time. The budget needs analysis procedure produced the following results:

1991	$311,159
1992	$314,336
1993	$276,699
1994	$99,538
1995	$2,416
	$1,004,148

The unconstrained analysis is an initial cut at determining maintenance and rehabilitation requirements. But fiscal constraints, which tend to favor uniform yearly appropriations, need to be considered. This initial budget option was infeasible for the sample community. The typical skew of an unconstrained budget toward the present, however, suggests the possibility of a road bond issue for long-term improvements as a means of minimizing roadway expenditures.

Budget Scenarios

Budget scenarios are modeled over a 5-year period. Two methods of specifying yearly budgets are available. In the first method an initial budget and optional budget increase factor is selected. The second method entails specifying individual yearly budgets. This allows the analysis of nonuniform allocations such as bonding. In either case a split between preventive maintenance and rehabilitation is specified.

During scenario analysis the computer selects projects on the basis of the weighted effectiveness index until the rehabilitation allotment is exhausted. If rehabilitation expenses are less than the budgeted amount the remainder is allocated to preventive maintenance for that same year. Those sections identified for rehabilitation but not selected are deferred until the next year. Stopgap maintenance costs, such as emergency patching, can be assigned as a penalty for delay. Stopgap repair expenses are subtracted from the preventive maintenance allotment. Management sections identified for preventive maintenance are then selected on the basis of the same weighted effectiveness rating. This process is repeated yearly.

The end results of the scenario procedure are detailed, and summary reports that document assigned treatment, surplus and deferred expenses, and network conditions are prepared. Scenarios can be rerun until, in the highway official's judgment, the best strategies and funding levels are determined. Budget scenarios may be run on any subset of management sections.

Although an infinite number of budget options is possible, only four funding levels are presented. Prioritization was accomplished through somewhat different means at each of these funding levels. These funding levels are a concise format for presenting budget options to decision makers. The presentation of too many options confuses decision makers. Although not presented in this analysis, the development of a road bond option would be straightforward.

Zero Funding

The impacts of zero funding of the roadway maintenance and rehabilitation budget were calculated as a benchmark. This, however, was actually done in the sample community the year that the present study was conducted. The analysis of zero funding required no prioritization decisions. The impacts of this funding level over the next 5 years are illustrated in Figure 2. It can be seen that this strategy will result in the average condition of the sample community's roadway network decreasing from very good (PCI = 75) to good (PCI = 61). Although this average condition may not appear to be too bad, a closer examination reveals that almost 7 percent of the town's roadway network would be in very poor or failed condition (PCI <25) within 5 years under the zero funding scenario. The town would also find that it would have no choice but to incur repair

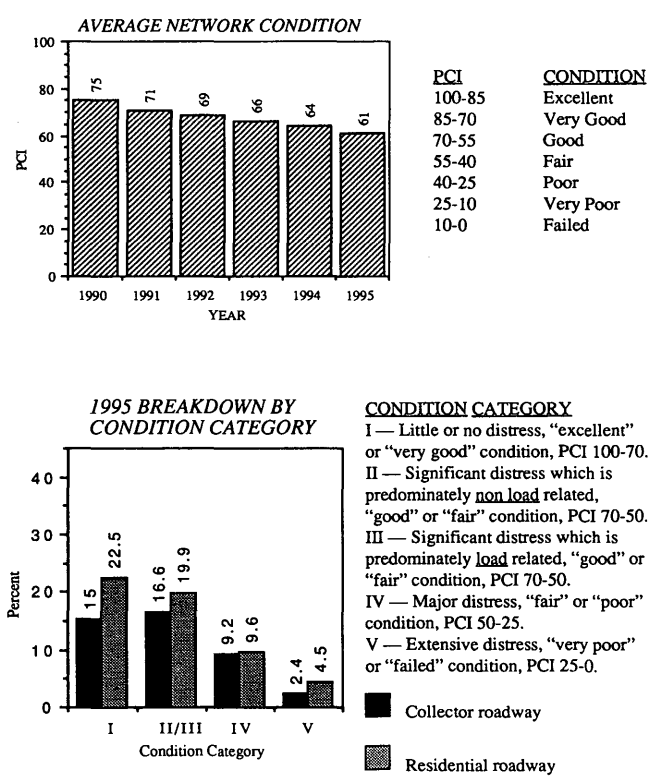

FIGURE 2 Projected roadway conditions with zero funding.

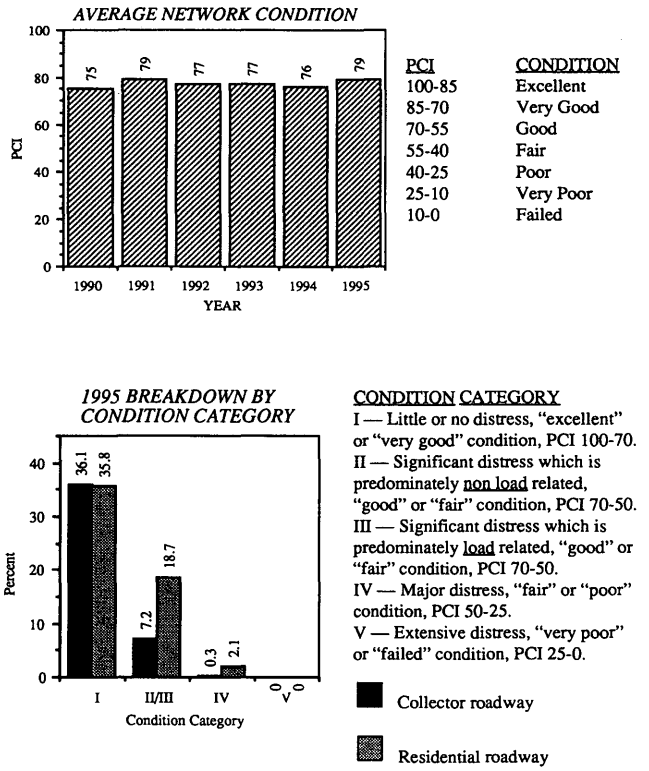

FIGURE 3 Projected roadway conditions with $200,000 annual budget.

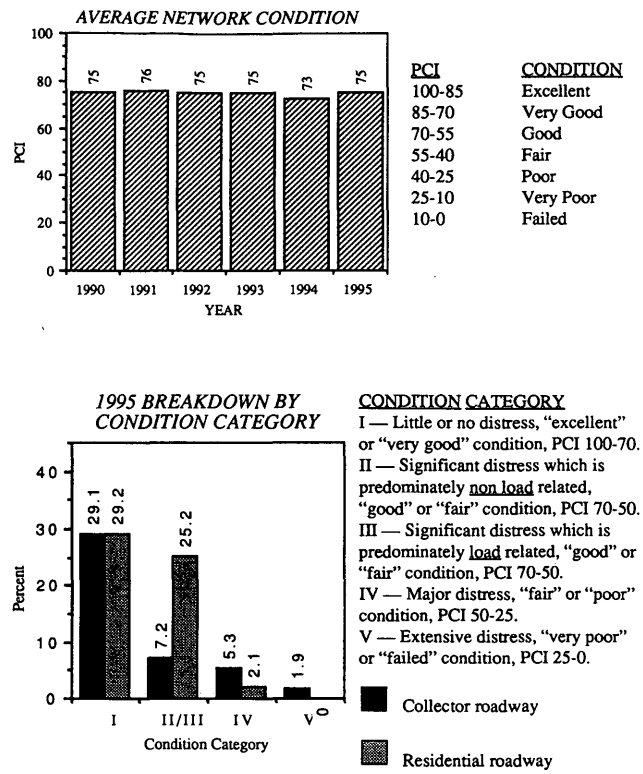

FIGURE 4 Projected roadway conditions with $100,000 annual budget and original treatment selection.

expenses much larger than would have been necessary if it had budgeted timely maintenance.

Full Funding

A uniform maintenance and rehabilitation budget was favored by decision makers in the pilot community. After repeated application of the budget scenario procedure, a $200,000 maintenance and rehabilitation budget was developed as a full funding option. A yearly maintenance and rehabilitation appropriation of this amount would allow for preventive maintenance and annual capital improvements such as upgrading sections of collector roadways from surface treatment to hot mix and the resurfacing of some residential roadways. Figure 3 shows that this level of funding would raise the average condition of the sample community's roadway network. It would also prevent any roadway segment from deteriorating to a poor or failed condition.

Moderate Budget Cuts

This budget level was presented as a compromise. It would allow preventive maintenance such as crack sealing and sand sealing. It is not sufficient, however, to allow for annual capital improvements. The impacts of this level of funding are presented in Figure 4. The end result would be a fairly uniform average network condition, but a percentage of the collector streets would deteriorate into poor or failed condition. The collector roadways were not assigned treatment because the rehabilitation costs for a section of this type of roadway were generally greater than a whole year's rehabilitation budget. No matter what the weighting it is impossible to assign rehabilitation if the total required for these improvements is greater than the whole budget.

Because of the higher user costs resulting from defects on collector roadways, most highway officials would do their best to avoid a situation in which these roadways are failing. The first option examined to prevent this situation was to shift funds from preventive maintenance to rehabilitation. The high effectiveness ratings and low costs for preventive maintenance activities, however, lead to the conclusion that this was an unwise strategy. It creates a cycle of dealing with problems at the point where they are most expensive to fix.

The next option was to assign treatments with lower initial costs. These were treatments that were excluded from consideration initially because of higher life cycle costs. Examples of these types of treatment are wedging or chip sealing a roadway in poor condition instead of reconstruction. Veteran highway officials indicate that they know that such treatment costs more over the long run, but at times they cannot afford to do anything else. These types of treatments can be necessary to prevent the loss of infrastructure investments such as roadway bases. Although they do not make sense at the project level, they can, at times, be the best strategies at the network level. This is especially true at the local level, where user costs because of repeated treatment, such as chip seals, are not as high as user costs on heavily traveled state highways. Local communities typically go through cycles in which funding is constrained. These types of holding strategies can allow a community's roadway investment to be preserved until funding constraints are relaxed.

Modifications to treatment selection were accomplished by first examining detailed budget needs reports to determine what ex-

penses could be eliminated or postponed. That review determined that rehabilitation of residential asphalt concrete roadways was a major expense that would probably be delayed. It was impossible to avoid these selections by modifying the weight assigned to functional classification because by doing so many low-cost but effective selections, such as heavy sand seals for residential surface-treated roadways, would be eliminated. It was therefore necessary to modify the treatment selection procedure. Because none of these pavements was near failure a decision was made to assign "do nothing" instead of rehabilitation. The probable long-term effect of this decision will be higher life cycle costs for these pavements.

The next modifications to treatment selection were changes to the maintenance and rehabilitation strategies for collector roadways. First, maintenance overlays for roadways in "good" condition were eliminated. Second, a staged rehabilitation approach that was successfully used in the past was adopted. This strategy consisted of leveling and placing a 2-in. lift of dense binder, which also served as a wearing surface.

Unfortunately, the consequences of actions such as these, which are contrary to pavement management philosophy, cannot be adequately illustrated with a 5-year analysis. It should be stressed that these strategies are only buying time. Eventually a significantly higher annual funding level or a road bond will be required. The results of these changes in treatment selection are illustrated in Figure 5. It can be seen that although there are higher percentages of pavements in the lower PCI ranges, roadway failures and the associated dramatic increases in user costs are avoided. Again, this is accomplished at the expense of higher future costs for some management segments that are currently in acceptable condition.

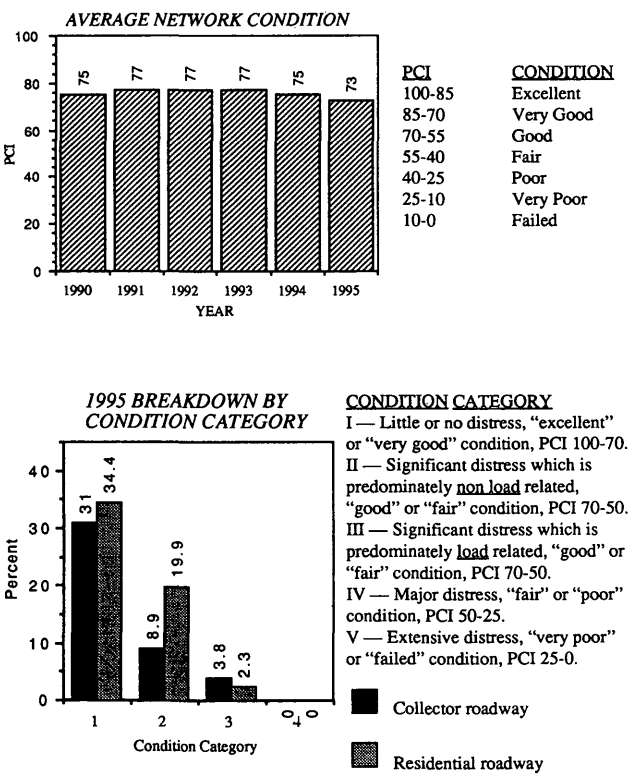

FIGURE 5 Projected roadway conditions with $100,000 annual budget and modified treatment selection.

Calculation of life cycle costs followed by trial-and-error modifications to treatment selection and use of the budget scenario procedure will be required to determine a community's least painful alternatives. User costs such as traffic delays, user inconvenience, and higher operating costs should be considered. These costs, however, are much less significant for low-volume, low-speed local roadways than for state highways. Emphasis should be placed on determining the least-cost holding strategies that minimize increases in future funding requirements. It should be stressed again that this requires extensive engineering judgment. The computer will not make decisions for the highway official, but it is a tremendous tool for examining the consequences of particular strategies. It facilitates the development of a defendable 5-year plan.

Severe Budget Cuts

Prioritization under severe budget cuts is difficult to determine through the use of budget scenario models. In this situation the most effective treatment for the network is generally preventive maintenance. It was found, however, that it took more time to get the model to come up with accurate estimates of preventive maintenance needs than it did simply to use current preventive maintenance budgets and the information contained in the data base to develop a bare-bones preventive maintenance budget.

In the case of the sample community it was determined that the town should, at a minimum, fully fund preventive maintenance actions to preserve its substantial roadway investment. Preventive maintenance includes the sand seal program, the drainage program, and the adoption of a crack sealing program. Collector roadways should be given priority. The following yearly appropriations were recommended:

Sand sealing	$50,000
Crack sealing	$10,000
Drainage	$15,000
	$75,000

This funding strategy will not prevent some roadways from failing, but it will hold most roadways in acceptable condition until adequate funding is available. Additional funding for emergency maintenance, however, will probably be required in the future. Motorists will also pay for deferred maintenance through higher user costs.

RESULTS

This paper documents the results of using the MTC PMS, a personal computer-based software package in the public domain, to conduct a network-level analysis of a local community's roadway system. Prioritization was accomplished through the use of computer-modeled scenarios that employed weighted cost-effectiveness as a prioritization index. The key result is the identification of the prioritization linkage between funding level and treatment selection.

Without budgetary constraints the goal of local pavement management is to provide acceptable pavement at a minimum life cycle cost. Prioritization is not an issue. Network-level funding is determined through the use of a treatment selection algorithm that identifies treatment and timing to achieve these objectives. In times of constrained funding, however, only a limited number of these identified treatments can be selected. Prioritization research has concentrated on selecting the best mix of identified treatments, with the

objective being to choose an optimum combination of projects. This is illustrated in Figure 6. Little attention, however, has been paid to verifying that the items on the list of potential treatments that are being ranked are indeed the best choices for maintaining a roadway network at a given funding level.

To maintain a roadway network in the best possible condition with constrained funding, local highway officials are often forced to make decisions that are, at the project level, suboptiminal. For example, a roadway segment that would ideally receive a thick overlay might, instead, receive a chip seal that will last only 3 years. This may seem to be a waste at the project level. But at the network level it may be possible to treat 10 times the amount of pavement with this strategy. Instead of having one excellent roadway and nine pavement failures the community would have maintained acceptable surface conditions, saved the roadway bases, and bought time in which to accomplish the required work. Holding strategies such as this one, however, are often not in the subset of treatments that are being prioritized. Treatment selection must therefore be modified at lower funding levels to include alternatives that may be optimal only at the network level. If project-level decisions are allowed to routinely override network-level suggestions, a PMS is not serving its best use.

An alternative that must be considered when funding is constrained is to delay treatment. This can be accomplished by assigning "do nothing" as treatment. For example, a residential reconstruction job may have to wait until it is projected to cross the next threshold before treatment is assigned. This option would not be considered by a prioritization procedure if the linkage between treatment selection and prioritization was not examined.

Ideally, modifications in treatment selection would be based on a network optimization model. At present, however, engineering judgment, life cycle cost analysis, and repeated application of the budget scenario procedure will have to suffice at the local level.

In times of severe fiscal crises the goal of local pavement management is to save those pavements that can be saved. This triage is best accomplished through an emphasis on preventive maintenance on selected pavements. Examination of weighted effectiveness ratios for preventive maintenance confirms this. Extensive manipulations of computer scenarios are generally not necessary to assign preventive maintenance or determine funding levels under these circumstances.

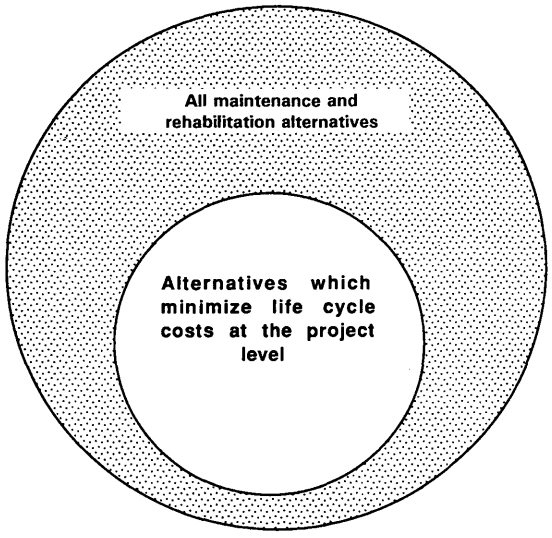

FIGURE 6 Sets of alternatives.

SUMMARY AND CONCLUSIONS

The central element of this paper was a network-level analysis of a local community's roadway network. The analysis was conducted with computer-modeled scenarios that employed a weighted cost-effectiveness ratio as a prioritization index. The areas under pavement deterioration curves served as proxies for user benefits.

This type of network simulation procedure proved to be a practical framework for conducting network-level prioritization of pavement improvements at the local level. The procedure had to be modified, however, to reflect local conditions. This customization requires an investment of time and funding to produce valid results. When there is a commitment to maintaining a PMS, this is a well-spent effort. If a community cannot make such a commitment, it should adopt and maintain a simpler system. Commitment to a good record-keeping system will make it relatively easy to graduate to a higher-order PMS in the future.

The principal finding was a means of incorporating the link between priority assessment and funding level into the network prioritization process. This was accomplished by varying the treatment selection process as funding levels changed.

It was found that at full funding the goal of pavement management was to assign those actions that were optimal at the project level. These are the actions that minimize life cycle costs. Prioritization is not an issue. When funding was constrained, as is often the case at the local level, the goal of network-level prioritization was to maintain a roadway network in the best possible condition at a minimum long-run cost. This involved some decisions that, at the project level, appeared to be suboptimal. If, however, a prioritization procedure is ordering only the subset of actions that minimize life cycle costs at the project level, no amount of mathematics will produce an optimum network-level strategy. Changes must therefore be made in the treatment selection procedure as funding levels ebb.

The greatest strides in network-level prioritization can be made by determining more accurate estimates of the lives and costs of pavements and pavement maintenance treatments in localized situations (*9*). This entails a commitment to keeping records. Eventually good record keeping will allow efficient pavement maintenance strategies to be developed through better performance prediction, life cycle cost analysis, and optimization techniques. When funding is constrained, computer-modeled scenarios will offer a practical means of assessing the future impacts of alternate strategies, establishing priorities, and convincing local decision makers to support adequate funding levels before roadway investments are compromised.

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