A Prioritization Scheme for the Micro PAVER Pavement Management System

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The ultimate aim of any pavement management system is to get an optimal return from the available resources. The culmination of a research effort to improve the prediction, optimization, and budget allocation abilities of the Micro PAVER pavement management system is a prioritization scheme capable of taking in available budget estimates for any number of years and outputting the sections recommended for repair and the type and cost of repair to be applied. The scheme uses as its base the effectiveness/cost ratios obtained from a dynamic programming module. These ratios are then modified by weights that are related to section characteristics by each individual pavement manager. This enables a customized output to be obtained for each database. The available budget for repair is determined as the actual budget less the cost of routine and stopgap repairs on every section. This budget is then allocated to the highest-scoring (in terms of weighted effectiveness/cost ratio) sections until the budget is exhausted. Deterministic Pavement Condition Index (PCI) versus age curves are used to predict each section's condition in the following year, and the process is then repeated. A completed example is included to illustrate the working of the program logic.

There is an ongoing effort to improve the prediction and optimizing capabilities of the Micro PAVER pavement management system (*1,2*). Papers presented and published at past Transportation Research Board (TRB) annual meetings have outlined the progression in thought and development from the early stages of this effort (*3–5*). This paper outlines the logic and use of the prioritization schema developed for use in Micro PAVER. It takes inputs from the new Pavement Condition Index (PCI) prediction models developed at the U.S. Army Construction Engineering Research Laboratory (USA-CERL), both deterministic (*3*) and Markovian probabilistic (*4*). It also uses the outputs from the dynamic programming package developed at USA-CERL (*5–7*) and additionally accepts user inputs of budgets available for as many years as is desired. The output from this program is a list of prioritized sections to be repaired within the given budget in every year desired along with the recommended M&R treatment and the estimated cost for each section. A summary of the previous work performed at USA-CERL is not contained in this paper. There is a brief synopsis in an accompanying paper (*8*), and of course the references quoted above deal with each of the related topics in a detailed way.

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INTRODUCTION TO PRIORITIZATION

There would be no need for prioritization if unlimited financial, temporal, and manpower resources were available. Unfortunately, this is seldom the case. Consequently, decisions must be made as to which sections it is most advantageous to repair and which must be left unrepaired at the moment. In the most common case, pavement managers are constrained by the budget allocated to them. A decision must be made as to which sections it is "best" to repair for this budget.

Of course, the problem lies in deciding upon the definition of "best" or "optimal." Dynamic programming yields an optimal solution for every family/state combination over a given life-cycle length. However, this solution is unconstrained by budgetary restrictions. If it were possible to perform the recommended treatment on every section, this would be a truly network-optimal solution. As this is unrealistic in most cases, further analysis must be performed to determine which sections should be repaired within the given budget to yield a network-optimal solution.

Network Optimality

The issue of network optimality must be discussed before progressing further in the prioritization algorithm. Basically, what needs to be decided is which properties of the network are deemed to be most important by the pavement manager. These properties may include

1. Servicing the most important routes first,
2. Attempting to keep the entire network functionally operational,
3. Placing emphasis on some pavement uses over others,
4. Attempting constantly to improve the overall network condition, and
5. Attempting to maintain a uniform network condition.

Many other possible goals can also be included. It can quickly be seen that some of these goals impinge directly upon one another, and all cannot be addressed. Some, indeed, are directly contradictory.

Only the pavement manager can decide which properties to emphasize on the particular network that he or she is managing. There is no universal "best" set of goals applicable to all networks. Many factors, including size of network, diversity of users, available budget, age of network, and others, will all bear upon the manager's decisions and priorities. As the Micro PAVER system is designed for implementation on a large range of networks across the United States and abroad, it is doubly obvious that a single set of goals cannot be universally optimal.

Given that this is the case, a tool must be provided that has the flexibility built in to reflect the different priority schemes possible. A set of weighting factors that are user-defined can be used to customize the prioritization scheme for the individual manager. The particular types of weights and categories to be used are discussed subsequently in the specific details of the prioritization program proposed. It is sufficient at this stage to point out the need for such a scheme.

Thus, the skeleton of a prioritization scheme can be glimpsed. It should take inputs of available budget, candidate sections for repair (in the most general network case, all sections are candidates), and a means whereby the optimal attributes that the network should have are represented. Each candidate section is then judged against all others on the basis of how well it can improve or maintain the network attributes if chosen for repair. Sections should be chosen until the available budget is exhausted. With this background in mind, a detailed description of the proposed prioritization plan now follows.

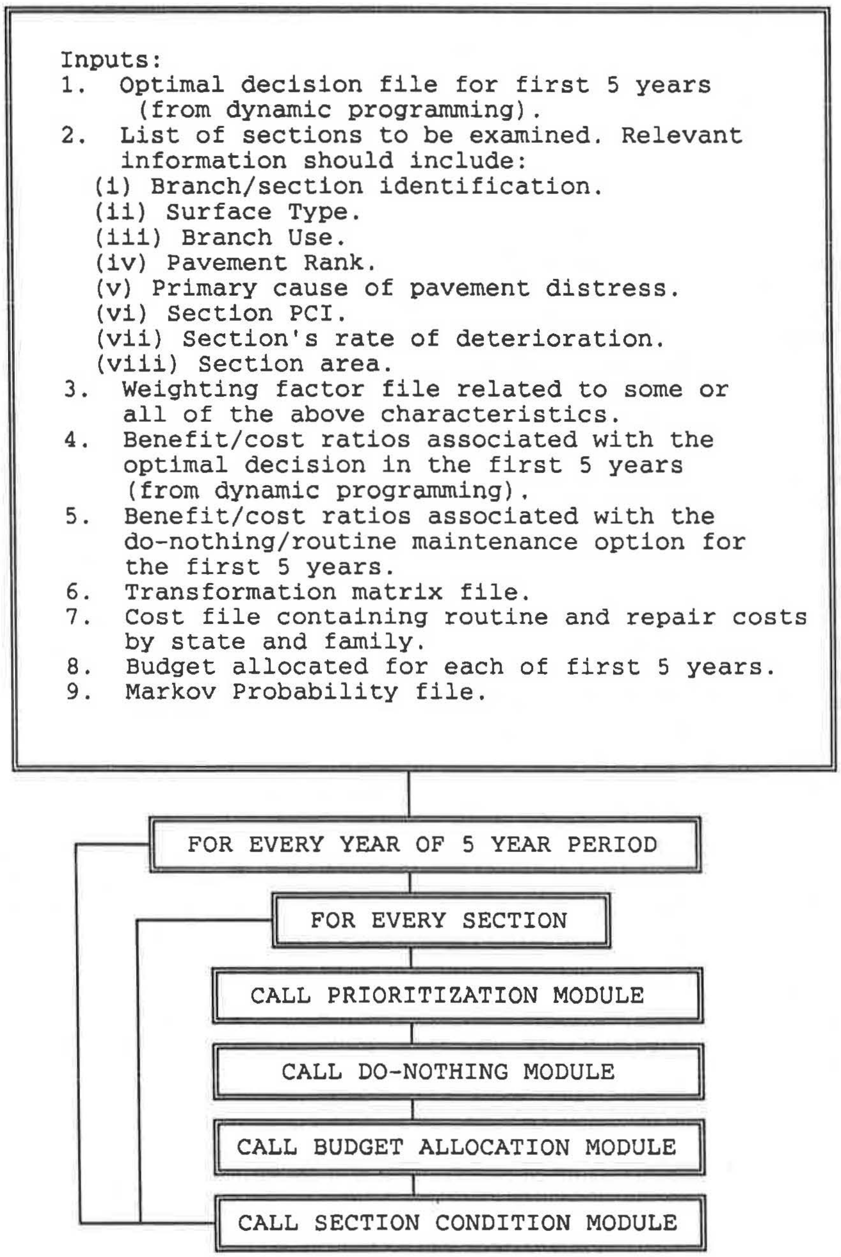

FIGURE 1 Prioritization using dynamic programming.

PRIORITIZATION AND BUDGET ALLOCATION FOR PAVER

The most important step in designing a prioritization program is knowing what type of output is required. In the present case, for the purposes of network planning, it is required that an optimized 5-year plan be output. The plan should consist of a list of sections to be repaired in each of the 5 years for a given annual budget. The annual budget can vary from year to year. Obviously, there will be less confidence in the schedule devised for 5 years before the present time because of the uncertainty in prediction of condition, future costs, and other factors. As the years go by, updated and revised 5-year plans will yield greater confidence in the schedule proposed, just as there is much confidence in the schedule proposed for the first year of the current 5-year plan.

There are a number of tools available, both existing and recently developed, that can be used in constructing a useful prioritization and budget allocation plan. The dynamic programming output (*5*), which contains a list of optimal decisions for every family/state combination in every year of a given life-cycle analysis, is a crucial input to the prioritization scheme. The constrained least squares (LSI) best-fit program (*3*), used to fit predicted PCI versus age curves to the available data, also provides an extremely useful tool.

PRIORITIZATION USING DYNAMIC PROGRAMMING

The overall flowchart outlining this prioritization algorithm is shown in Figure 1. The process consists of four main modules.

1. Prioritization module,
2. Do-nothing/routine maintenance module,
3. Budget allocation module, and
4. Section condition prediction module.

Each of these is described in detail subsequently. Figure 1 also shows all the input data required to allow proper functioning of the prioritization and budget allocation process. While at first glance it may appear that substantial information is required, in fact most of this information has already been provided for the dynamic programming program (*5*).

The optimal decision file contains the optimal decision for every family/state combination considered in dynamic programming for the first 5 years of the life cycle analyzed. This is a direct output from dynamic programming that can be fed straight into prioritization. The list of sections to be evaluated is obviously a user input. The default situation would be to consider all sections in the network; if a manager has earmarked funds for sections with particular characteristics, however, he or she may want to allocate these funds among the qualifying sections only.

The section-related information required is already stored in each network's database and is easily extractable. The use to which each piece of information is put will be outlined in the following module descriptions. The weighting factors used are again user-defined. These weights allow the manager to express the particular goals of the network in a physical way.

The effectiveness/cost ratios for the first 5 years are again direct outputs from dynamic programming. The dynamic programming has also been modified to allow the user to "force" the program to accept routine maintenance as the only viable option in the first few years, the number of years to be determined by the user. Thus, the default budget that calculates the cost and subsequent effectiveness/cost ratio if only routine maintenance is allowed in year 1 can be calculated. This should be the absolute minimum budget allowable. The implications of this approach are discussed further in the do-nothing and budget allocation modules. The transformation matrix, cost, and Markov probability files are all exactly as used in dynamic programming.

The only other input required is the budget allocated for each of the first 5 years. Again, these values must be entered by the pavement manager. It should be possible to enter a number of different combinations of budget values and evaluate their respective impacts upon the overall network condition and upon individual sections. Through playing out these "what-if" scenarios, the manager can seek justification for increased funding or for improved funding in earlier or later years. A description of the four modules constituting the overall program is now presented.

Prioritization Module

An overall flowchart of this module is shown in Figure 2. The first step in the prioritization module is to identify which section is currently being dealt with. Once this is clear, the section characteristics are obtained and the family to which the section belongs is identified. The definition of "family," as used throughout the whole development of the Micro PAVER packages, is a group of sections having common section characteristics (e.g., pavement type, traffic loading, surface thicknesses). On the basis of the section's PCI, the state it belongs to is identified. A state is defined as a 10 PCI-wide bracket in each family. For example, sections having a PCI of 90 to 100 are defined to be in state 1. Thus, it is possible to assign a family/state identification to the section.

The reason for performing this assignment is that the dynamic programming output of effectiveness/cost (E/C) ratio is in terms of family/state combinations. The E/C ratio corresponding to the section's family and state is located. This is a "raw" score, not taking into account any of the section's characteristics, such as branch use, pavement rank, or rate of deterioration. If these characteristics are not considered, all sections in a particular state of a given family will have exactly the same E/C ratio.

If branch use and pavement rank are incorporated into the family definition, then it is still possible that all sections in each state of that family will have the same E/C ratio. To differentiate further between these sections, it is necessary to use another criterion, one that is specifically related to the section's PCI.

The candidate criteria that were considered were

1. Sections with a lower PCI in a state to be repaired first,
2. Sections with a higher PCI in a state to be repaired first,
3. Older sections in a state to be repaired first,
4. Newer sections in a state to be repaired first, and
5. Sections with higher rates of deterioration to be repaired first.

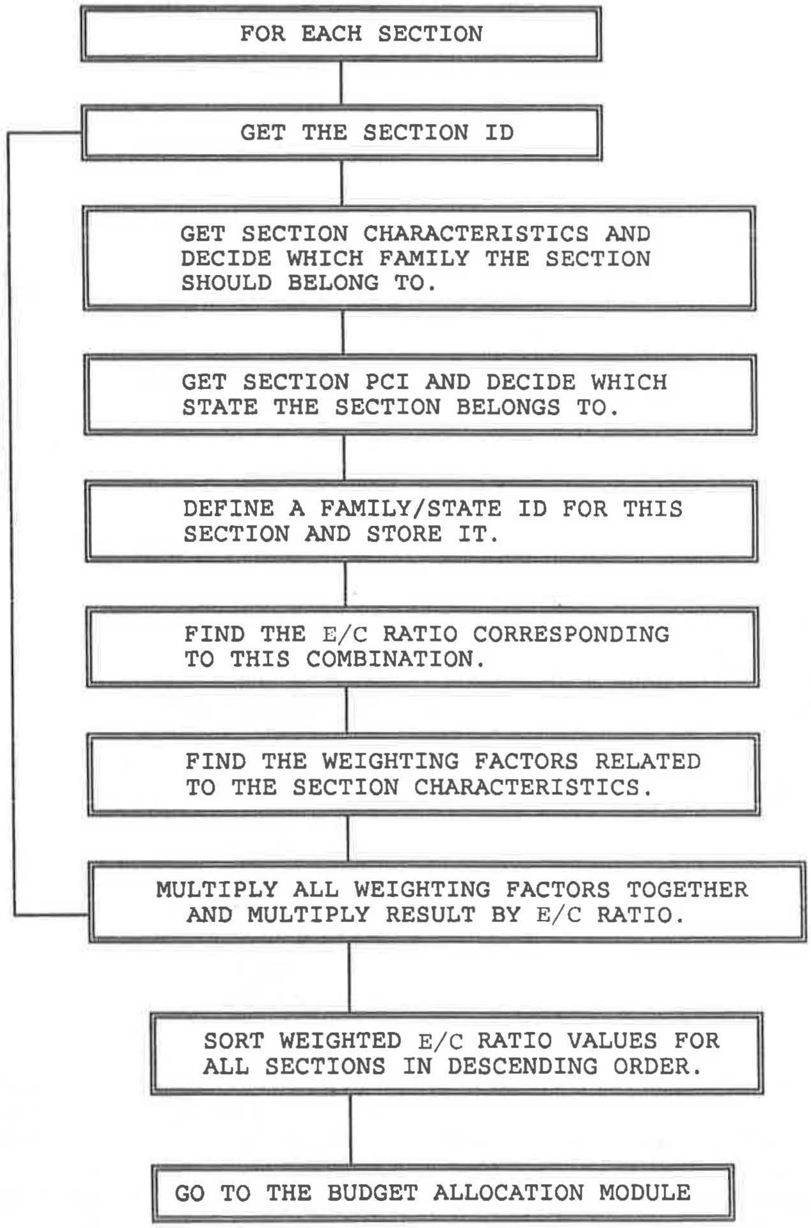

FIGURE 2 Prioritization module.

The justifications for selecting each of these potential criteria follow.

1. Sections with a lower PCI are more likely to transit to the next state, where it will cost more to repair, and thus should be repaired as soon as possible.
2. Life-cycle analysis has shown that preventive maintenance is more cost-effective than after-the-fact repair. Thus, sections with a higher PCI should be repaired first.
3. Older sections are more deserving of repair than newer sections and may be nearer the end of their design life, necessitating major repair if not repaired first.
4. Newer sections usually have higher rates of deterioration than older sections with the same PCI and should be repaired first.
5. Sections with higher rates of deterioration should be repaired first. Using rate of deterioration as a criterion combines the idea of using PCI with that of using age together into a rational decision mechanism. This criterion was chosen as the most suitable.

The weighting factors corresponding to each section's characteristics are then extracted and multiplied by the "raw" effectiveness/cost ratio to give a weighted E/C ratio. This whole process is repeated for every section. All of the candidate sections are then sorted in descending order of weighted E/C ratio. This is the output from the prioritization module, a prioritized list of candidate sections for repair, with prioritization based upon weighted effectiveness/cost ratio.

Routine Maintenance Module

The routine maintenance module is very simple and easily understood. Figure 3 shows a flowchart of the algorithm. The

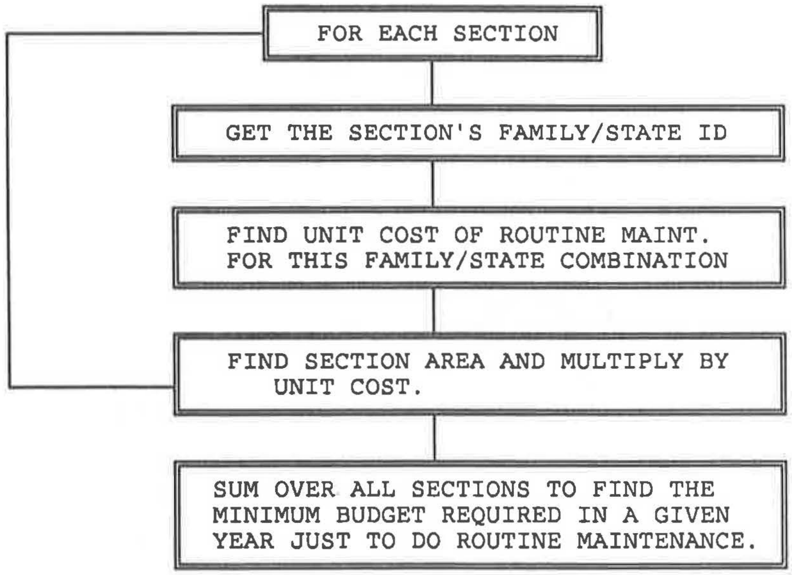

FIGURE 3 Routine maintenance module.

purpose of this module is to determine the absolute minimum budget required just to apply routine maintenance to every section considered. It should be noted that the budget allocated is at least as large as the value obtained from the routine maintenance module; otherwise, many sections will not have any maintenance whatsoever performed. By identifying the surplus of actual budget over minimum allowable budget, it should be possible to calculate how much is actually available for repair activities. Further discussion of this point is contained in the budget allocation module.

Basically, what the routine maintenance module does is locate the unit cost of routine maintenance for each section, multiply this cost by the section area, and sum over all candidate sections. The cost information is contained on a state-by-state basis, so the section's family/state identification is sufficient to locate this cost. The output from this module is the cost of routine maintenance for each section in the given year and the total of these costs over all candidate sections.

Budget Allocation Module

The budget allocation module is run yearly. It takes in the prioritized list of sections from the prioritization module and yields a list of sections to be repaired in that year for a given budget. The advantage of using the modular approach is that the prioritized list is obtained independently of the budget, so changes in proposed budget can be handled easily in the budget allocation module without requiring recalculation in other modules.

Figure 4 shows the module flowchart. The family/state identification associated with the section at the top of the prioritized list is obtained. This is then used to locate the recommended treatment for this family/state combination in the optimal decision file obtained from dynamic programming. The unit cost (cost per square yard) is obtained from the cost file for this repair option and is then multiplied by the section's total area to get the cost of repair.

This repair cost is then subtracted from the allowable budget if the allowable budget is for repair only. If the allowable budget is the total that can be spent on both repair costs and routine maintenance costs for the entire network, however, a different approach is necessary. The do-nothing/routine maintenance module gives the total cost of performing routine maintenance over the network. The surplus between this amount and the amount allocated as budget is the amount available for repair costs.

The section repair cost is subtracted from this figure, and the cost of routine maintenance that would have accrued if repair had not been carried out is added to the repair budget. This whole cycle is repeated until the available repair budget is exhausted. A search is continued until as much of the budget as possible is used up. Thus, a section with a large area and a high potential E/C ratio may be rejected because of insufficient funds. However, another section with a lower E/C ratio but with a smaller area (and, hence, lower total costs) may be chosen because it still is affordable within the available budget.

The output from the budget allocation module is a list of sections to be repaired in the year considered, the type of treatment to be performed on each section, the cost on a section-by-section basis, and the total cost. The expected network PCI to be obtained as a consequence of carrying out this repair schedule can also be computed. The budget allocation process is performed for each year of the 5-year plan being formulated.

Section Prediction

As a part of the analysis performed to obtain PCI prediction curves on a family-by-family basis, deterministic, constrained polynomial curves are fitted to each family's (PCI, age) data, as outlined in other research (*3*). These curves are then used here on a section-level basis to predict the future PCI of each section.

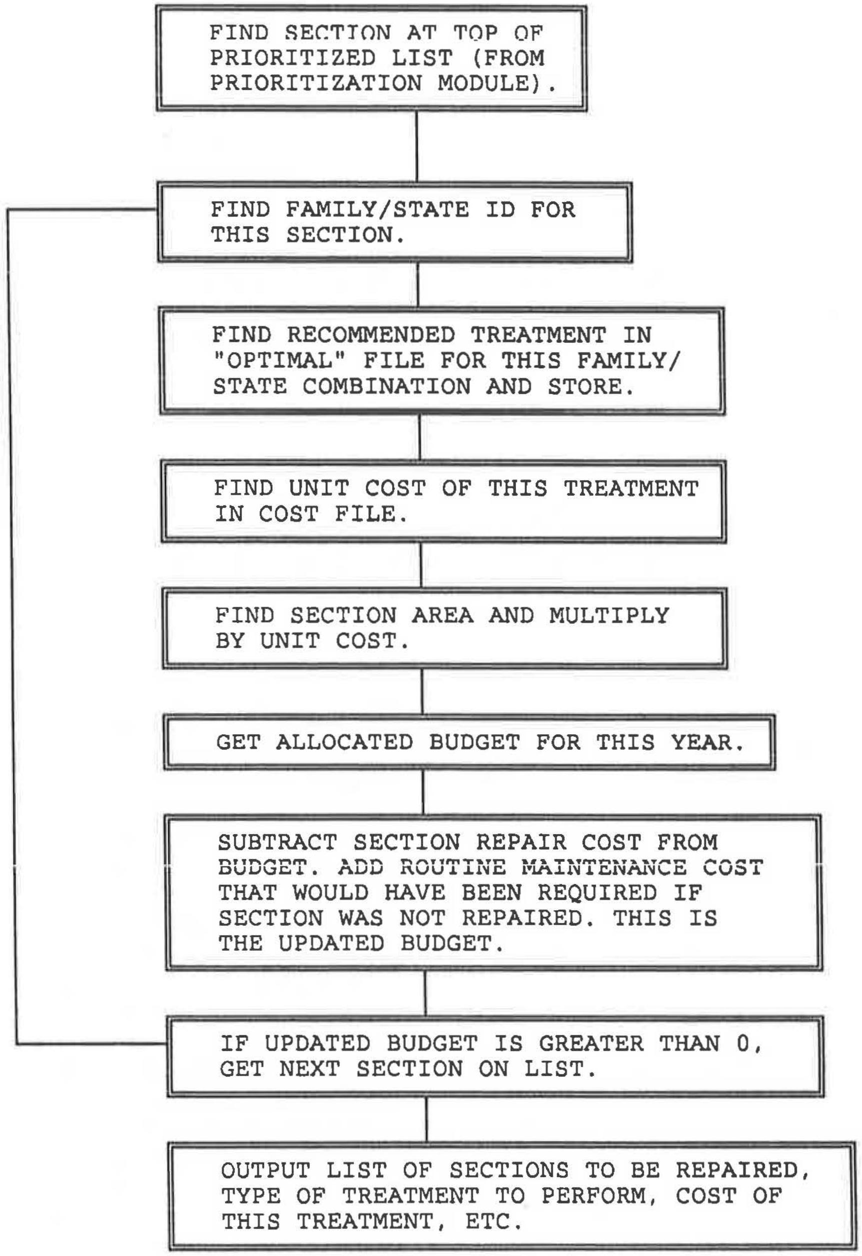

FIGURE 4 Budget allocation module.

If a section is chosen for nonroutine repair in budget allocation, it is assumed that the PCI is returned to 100. If routine maintenance is recommended, the PCI versus age family curves can be used and adjusted directly to predict the section's future PCI in the following year. The flowchart for the section condition in following year module is shown in Figure 5.

PRIORITIZATION EXAMPLE

This section uses a brief example to illustrate the working of the prioritization program. To make it as simple as possible to follow, only five sections in a network are analyzed. The functioning of the program proceeds just as easily, however, when more sections are included. The prioritization program uses the Markov probabilities, costs by state, and dynamic programming outputs described earlier.

Table 1 contains the section information for each of the five sections. These properties were formulated hypothetically. The lowest PCI, 55, occurs in section 5. This relatively high value occurs because it was previously specified in the dynamic programming and simulation routines that the minimum allowable state would be state 5, with PCI values of 50 to 60. It can also be seen from this table that numerous and variable properties are represented among the five sections included.

Table 2 illustrates the weighting factors used in the example. It can be seen that there are four possible surface types: asphalt concrete, surface treatment, thin overlay, and structural overlay. There are three possible branch uses: roadway,

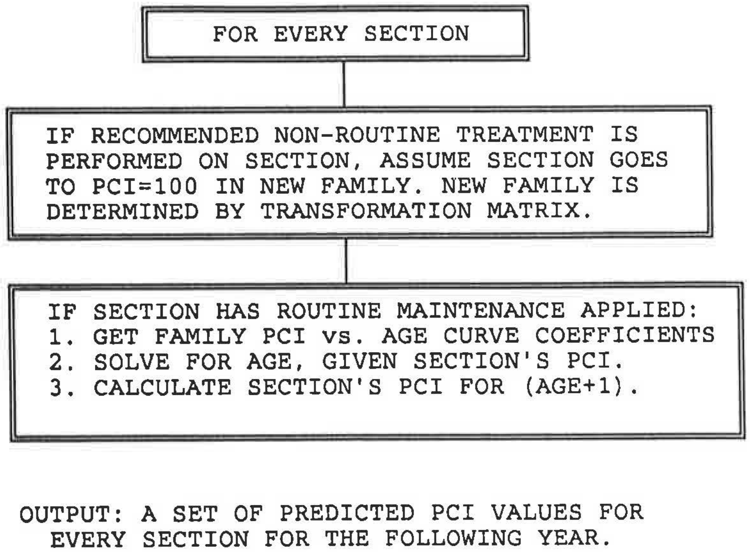

FIGURE 5 Section condition in following year module.

TABLE 1 SECTION INFORMATION

Section Number	Branch Use	Surface Type	Pavement Rank	Cause of Deterioration
1	RO	AC	P	LOAD
2	PA	ST	S	CLIMATE
3	PA	ST	S	LOAD
4	RO	ST	T	CLIMATE
5	RO	TO	S	OTHER

Section Number	PCI	Section Area (sy)	Pavement Family	Rate of Deterioration
1	80	2000	1	2.0
2	65	4000	2	3.0
3	75	5000	3	5.0
4	89	10000	4	5.0
5	55	4500	2	2.5

AC = ASPHALT CONCRETE
ST = SURFACE TREATMENT
TO = THIN OVERLAY
SO = STRUCTURAL OVERLAY

RO = ROADWAY
PA = PARKING

P = PRIMARY
S = SECONDARY
T = TERTIARY

TABLE 2 WEIGHTING FACTORS USED

Category	Surface Type	Branch Use	Pavement Rank	Pavement State
1	.9 (AC)	.6 (RO)	1.0 (P)	.5 (ST 1)
2	.5 (ST)	.7 (PA)	.6 (S)	.6 (ST 2)
3	.7 (SO)	.4 (OTH)	.3 (T)	.7 (ST 3)
4	.3 (TO)			.8 (ST 4)
5				.9 (ST 5)

AC=ASPHALT CONCRETE
ST=SURFACE TREATMENT
TO=THIN OVERLAY
SO=STRUCTURAL OVERLAY

RO=ROADWAY
PA=PARKING
OTH=OTHER

P = PRIMARY
S = SECONDARY
T = TERTIARY

TABLE 3 SAMPLE COSTS ($1/SQ YD)

FAMILY 1

STATE	ROUTINE MAINT.	SURFACE TMT.	THIN OVL.	STRUCT. OVL.	RECONST.
1	0.1	1.1	3.31	4.53	11.8
2	0.1	1.4	3.49	4.68	11.8
3	0.1	1.7	3.67	4.83	11.8
4	0.15	1.86	3.76	4.95	11.8
5	0.2	1.89	3.79	5.05	11.8

FAMILY 2

STATE	ROUTINE MAINT.	SURFACE TMT.	THIN OVL.	STRUCT. OVL.	RECONST.
1	0.05	0.8	3.44	4.5	12
2	0.1	1.2	3.56	4.7	12
3	0.3	1.6	3.68	4.9	12
4	0.4	2.1	4.16	5.45	12
5	1.4	2.7	4.99	6.35	12

FAMILY 3

STATE	ROUTINE MAINT.	SURFACE TMT.	THIN OVL.	STRUCT. OVL.	RECONST.
1	0.05	1.43	3.54	4.59	11.85
2	0.1	1.58	3.66	4.71	11.85
3	0.2	1.73	3.79	4.84	11.85
4	0.3	2.1	4.26	5.24	11.85
5	0.35	2.7	5.09	5.92	11.85

FAMILY 4

STATE	ROUTINE MAINT.	SURFACE TMT.	THIN OVL.	STRUCT. OVL.	RECONST.
1	0.05	1.3	3.15	4.29	11.85
2	0.1	1.5	3.45	4.51	11.85
3	0.2	1.7	3.75	4.74	11.85
4	0.33	2	4.16	5.08	11.85
5	0.6	2.4	4.69	5.53	11.85

FAMILY 5

STATE	ROUTINE MAINT.	SURFACE TMT.	THIN OVL.	STRUCT. OVL.	RECONST.
1	0.1	1.1	3.31	4.53	11.8
2	0.1	1.4	3.49	4.68	11.8
3	0.1	1.7	3.67	4.83	11.8
4	0.15	1.86	3.76	4.95	11.8
5	0.2	1.89	3.79	5.05	11.8

TABLE 4 FAMILY MARKOV PROBABILITIES

FAMILY	STATE 1	STATE 2	STATE 3	STATE 4	STATE 5	STATE 6	STATE 7	STATE 8	STATE 9	STATE 10
1	0.7825	0.8656	0.8717	0.8752	0.0006	0.4144	0.2845	0.6346	0.3548	1
	0.0001	0.5021	0.5015	0.5014	0.0013	0.0001	0	0	0	1
	0.001	0.5	0.4999	0.4999	0.4765	0.1364	0.037	0.0112	0.0025	1
	0.1374	0.6502	0.5021	0.5003	0.0001	0.0361	0.001	0.0001	0.0005	1
2	0.8481	0.407	0.2631	0.4502	0.6058	0.4976	0.5	0.4996	0.859	1
	0.1821	0.4714	0.4736	0.4815	0.0615	0.0029	0.0016	0	0.0442	1
	0	0.5001	0.5	0.5	0.0012	0.0001	0	0	0	1
3	0.7764	0.8579	0.8627	0.8631	0.0007	0.4767	0.5376	0.4954	0.6414	1
	0	0.5	0.5	0.5	0.0001	0.0302	0.0336	0.0008	0.0007	1
	0.6862	0.874	0.6205	0.306	0.001	0.0001	0	0	0	1
4	0.8136	0.7798	0.7829	0.7832	0.0038	0.0001	0.7491	0.2284	0.7604	1
	0.001	0.5	0.4999	0.5	0.0022	0.0006	0.0001	0	0.26	1
	0.9853	0.5002	0.5	0.4999	0.0001	0.0122	0.0327	0.0006	0.0003	1
5	0.7825	0.8656	0.8717	0.8752	0.0006	0.4144	0.2845	0.6346	0.3548	1
	0.0001	0.5021	0.5015	0.5014	0.0013	0.0001	0	0	0	1
	0.001	0.5	0.4999	0.4999	0.4765	0.1364	0.037	0.0112	0.0025	1
	0.1374	0.6502	0.5021	0.5003	0.0001	0.0361	0.001	0.0001	0.0005	1

FAMILY 1: AC PAVEMENTS
FAMILY 2: ST PAVEMENTS
FAMILY 3: AC THIN OVERLAYS
FAMILY 4: AC STRUCTURAL OVERLAYS
FAMILY 5: AC RECONSTRUCTION

YEAR	SECTION NUMBER	MAINT. ALT.	COST	STATE	E/C RATIO
1	1	1	200	2	36.68
	2	2	8400	4	22.95
	3	1	1000	3	20.39
	5	2	12150	5	16.94
	4	1	1000	2	9.34
2	1	1	200	2	34.78
	3	2	10500	4	21.08
	2	1	200	1	19.54
	5	2	5400	2	16.14
	4	1	2000	3	8.21
3	1	1	200	2	32.82
	2	1	200	1	17.96
	3	1	250	1	17.96
	5	1	225	1	15.39
	4	1	2000	3	7.79
4	1	1	200	2	30.82
	2	1	200	1	16.12
	3	1	250	1	16.12
	5	1	225	1	13.82
	4	1	2000	3	7.6
5	1	1	200	2	28.76
	2	1	200	1	16.09
	3	1	250	1	16.09
	5	1	225	1	13.79
	4	1	2000	3	7.33

	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5
REQUIRED BUDGET	22750	18300	2875	2875	2875
AVERAGE PCI	81	89	89	89	85
AVG. PCI WEIGHTED BY AREA	79	86	86	86	81

FIGURE 6 Available annual budget of $25,000.

YEAR	SECTION NUMBER	MAINT. ALT.	COST	STATE	E/C RATIO	
1	1	1	200	2	36.68	
	2	1	1600	4	22.95	#
	3	1	1000	3	20.39	
	5	1	6300	5	16.94	#
	4	1	1000	2	9.34	
2	1	1	200	2	34.78	
	2	1	1600	4	21.08	#
	3	1	1500	4	21.08	#
	5	1	6300	5	15.33	#
	4	1	2000	3	8.21	
3	1	1	200	2	32.82	
	2	1	1600	4	19.33	#
	3	1	1500	4	19.33	#
	5	1	6300	5	14.08	#
	4	1	2000	3	7.79	
4	1	1	200	2	30.82	
	2	1	1600	4	17.35	#
	3	1	1500	4	17.07	
	4	1	2000	3	7.6	
	5	1	7650	6	0.02	#

	YEAR 1	YEAR 2	YEAR 3	YEAR 4
REQUIRED BUDGET	10100	11600	11600	12950
AVERAGE PCI	69	69	67	65
AVG. PCI WEIGHTED BY AREA	69	69	67	65

Budget Required in Year 5 is Insufficient
Min. Budget Required is $16950

FIGURE 7 Available annual budget of $15,000.

parking, and other. The three pavement rank categories are primary, secondary, and tertiary, whereas there are five possible pavement states as defined by the ten PCI point brackets. Again, the weighting factors assigned are purely arbitrary. It is envisaged that the user would determine these on a location-specific basis, thus bringing about a customized prioritization. The values used in the example are intended solely to illustrate the working of the program.

It was decided not to weight on the basis of primary cause of deterioration, rate of deterioration, or pavement family for this example. The capacity does exist within the program to deal with weights assigned on the basis of any of these variables. Table 3 contains the repair costs on the dollar-per-square-yard basis used in the example. There are five possible repair options to be considered: routine maintenance, surface treatment, thin overlay, structural overlay, and reconstruction. The costs are given on a state-by-state basis within each pavement family.

Table 4 contains the Markov probability values used in the analysis. The values for all five options are given on a state-by-state basis for states 1 to 10. The Markov zoning approach was used, as detailed elsewhere (*4,7*), and options 1 and 5 had four zones, while options 2, 3, and 4 used three zones to model the deterioration process accurately. The probability values for original AC pavements and reconstructed AC pavements are identical. This is because the usual assumption made in the absence of substantive data is that reconstructed pavements will behave in the same manner as the original AC pavements. The Markov values and cost figures are actually those obtained from the Tulsa database (*9*).

The Tulsa transformation matrix and optimal decision and effectiveness/cost ratio files from dynamic programming were also used in the analysis. It was decided to run the prioritization package for a 5-year analysis period, with output reports in every year. Three sets of budget figures were used: (1) $25,000 available in each year, (2) $15,000 in each year, and (3) $18,000 in the first 2 years and $13,000 in the last 3 years. The figures for option 3 were chosen to total $75,000 for direct comparison with option 2.

The output from the program for these three sets of budgetary inputs is shown in Figures 6, 7, and 8. In Figure 6, it can be seen that sufficient money was available in every year to perform the optimal treatments. Without discounting the expenditures in any year to present worth values, the total money required to be spent over the 5-year period is $49,675. It can be seen that in the last 3 years, relatively little expenditure is required. The PCI for the network after 5 years is 85 compared to an original value of 73 if section PCIs unweighted by area are used. If the network PCIs weighted by area are compared, there is still a rise from 76 in the present to 81 in 5 years' time.

Figure 7 contains the results for a budget of $15,000 in each of the 5 years. The # signs in the rightmost column indicate that routine maintenance is being performed, even though that is not the optimal alternative for that family/state combination. This is confirmed in referring back to Figure 6, where surface treatments (alternative 2) are chosen for sections 2 and 5. A similar pattern is seen in the succeeding years. In this case, the budget is sufficient to perform routine or holding maintenance only.

By year 5, the section's conditions have deteriorated to such an extent that the $15,000 allotted is not even sufficient to cover the routine and short-term maintenance required; hence, the message output at the bottom of Figure 7. It is interesting to note that a total of $63,200 in undiscounted dollars is required over the 5 years, significantly more than the $49,675 required earlier. Meanwhile, the PCIs after 5 years are much lower, 65 for both unweighted and weighted, compared with 85 and 81 seen in Figure 6.

Figure 8 has the output for the third set of budgetary inputs. Again, some # signs are seen, indicating a deferment of the optimal strategy due to a lack of money. The total expenditure over the 5 years in undiscounted dollars is $48,250. For this outlay, the network PCI remains the same in unweighted terms but drops from 76 to 70 when each section's PCI is weighted by its area in calculating the network average. Note that there is a severe drop in PCI from year 4 to year 5, and if the available budget in year 5 were increased a little over $13,000, the PCI would probably improve appreciably. These are the type of "what if" games it is possible to play easily with this program. Figure 9 illustrates the performance of the network over time under each of the budget scenarios. The program executes almost instantaneously on an IBM AT or compatible.

SUMMARY

A prioritization program that takes the outputs from dynamic programming and combines them with budgetary constraints to produce a prioritized list of sections for repair with the recommended type of treatment and cost has been produced

YEAR	SECTION NUMBER	MAINT. ALT.	COST	STATE	E/C RATIO	
1	1	1	200	2	36.68	
	2	2	8400	4	22.96	
	3	1	1000	3	20.39	
	5	1	6300	5	16.94	#
	4	1	1000	2	9.34	
2	1	1	200	2	34.78	
	3	1	1500	4	21.08	#
	2	1	200	1	19.54	
	5	2	12150	5	15.33	
	4	1	2000	3	8.21	
3	1	1	200	2	32.82	
	3	1	1500	4	19.33	#
	2	1	200	1	17.96	
	5	1	450	2	14.28	
	4	1	2000	3	7.79	
4	1	1	200	2	30.82	
	3	1	1500	4	17.07	
	2	1	200	1	16.12	
	5	1	1350	3	13.98	
	4	1	2000	3	7.6	
5	1	1	200	2	28.76	
	3	1	1500	4	17	#
	2	1	200	1	16.09	
	5	1	1800	4	14.57	#
	4	1	2000	3	7.33	

	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5
REQUIRED BUDGET	16900	16050	4350	5250	5700
AVERAGE PCI	75	81	79	77	73
AVG. PCI WEIGHTED BY AREA	73	79	77	75	70

FIGURE 8 Variable available annual budget.

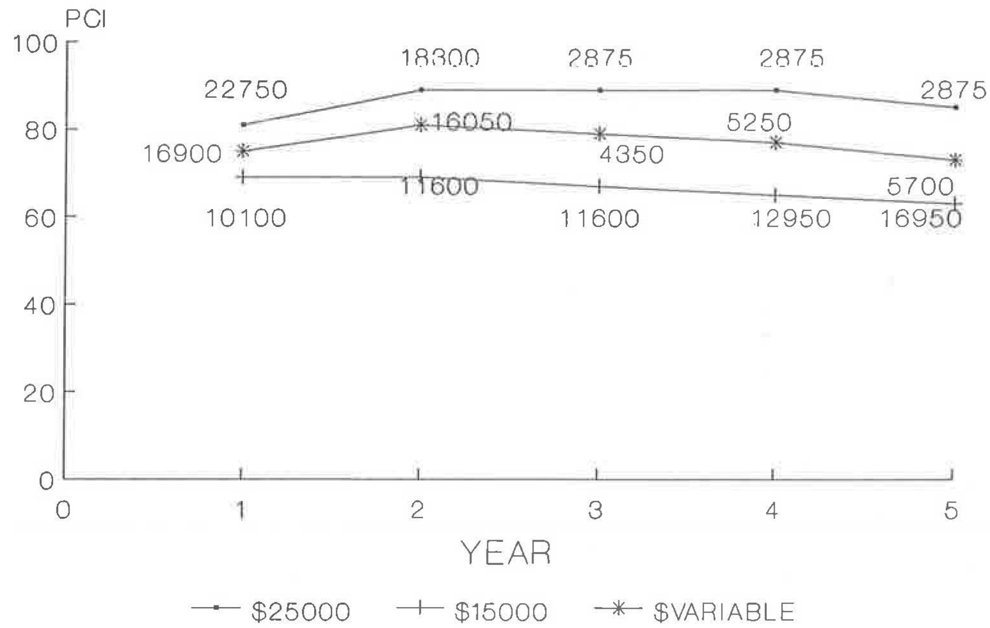

FIGURE 9 Network performance.

for the Micro PAVER pavement management system. The network PCI, calculated both with and without weighting by section area, is also output. It is possible to determine at a glance which sections are being forced to use suboptimal treatments because of budgetary constraints. These programs provide the final link in a chain that goes from extracting raw PCI versus age data out of the Micro PAVER databanks to producing network and semi-project-level recommended maintenance alternatives, costs, and projected network PCI levels within specified budgetary constraints at the microcomputer level.

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