dicate that the POD program should produce reasonable results for concrete pavements as well as for flexible pavements.

INSTALLATION AND TRAINING COURSE

The modified and extended version of Idaho PPMIS program has been installed on ITD's computer facilities in Boise, Idaho, after the assessment of the results. Extensive test runs were made to debug the programs and to overcome the problems associated with installation of a software package on a different hardware. A 2-day training course was held to train the ITD personnel in the use of the system. Detailed engineering and software documentations along with user manuals were provided to the potential users in ITD to facilitate ease of use of the system.

The Idaho version of the new PPMIS program is now operational and is being used effectively by ITD personnel for the management of the state's pavement network.

ACKNOWLEDGMENT

We wish to acknowledge Brian Kerr, Kirk Smeaton, and Alan Sadowsky of PMS Ltd; our colleagues in ARE, Inc., specifically, Freddy Roberts and Frank McCullough; and Dean Tisdale, Bill Pardew, and Ruben Manubey of ITD for their invaluable assistance in this project.

REFERENCES

1. Pavement Management Systems International, Inc.; Austin Research Engineers, Inc. Documentation, Modification and Application of the Idaho PPMIS. Idaho Transportation Department, Boise, June 1980.
2. MACS Milepost and Coded Segment System. Idaho Transportation Department, Boise, 1978.
3. Pavement Management Systems International, Inc.; Austin Research Engineers, Inc. Supplementary Report for Comparing Various Dynaflect Units Used in the PPMIS Deflection Inventory Program. Idaho Transportation Department, Boise, Nov. 1979.
4. M.A. Karan, D.H. Kobi, C.B. Bauman, and R.C.G. Haas. Subjective and Mechanical Estimations of Pavement Serviceability for Rural-Urban Road Networks. TRB, Transportation Research Record 715, 1979, pp. 31-36.
5. D.H. Kobi and others. Data Inventory for Pavement Management. Paper presented at Annual Conference, Roads and Transportation Assn. of Canada, Regina, Saskatchewan, Canada, Sept. 1979.
6. D.H. Kobi. ARAN--An Integrated and Automated Road Inventory Tool. Paper presented at American Public Works Assn. International Public Works Congress and Equipment Show, Kansas City, Sept. 1981.
7. Pavement Management Systems International, Inc.; Austin Research Engineers, Inc. Serviceability (PSI)-Roughness Correlation Project for the State of Idaho. Idaho Transportation Department, Boise, Jan. 1981.
8. F.R.P. Meyer and M.A. Karan; Pavement Management Systems International, Inc.; Austin Research Engineers, Inc. Updated Serviceability (PSI)-Roughness Correlation Report. Idaho Transportation Department, Boise, Jan. 1981.
9. B.F. McCullough. A Pavement Overlay Design System Considering Wheel Loads, Temperature Changes and Performance. Univ. of California at Berkeley, Ph.D. Dissertation, July 1969.
10. Pavement Management Systems International, Inc.; Austin Research Engineers, Inc. Modification and Extension of the Idaho PPMIS. Idaho Transportation Department, Boise, June 1981.
11. M. Gutierrez de Velafco and B.F. McCullough. Summary Report for the 1978 Condition Survey in Texas. Center for Transportation Research, Univ. of Texas, Austin, Rept. 177-20, Dec. 1979.

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

Rigid Pavement Network Rehabilitation Scheduling

MANUEL GUTIERREZ de VELASCO AND B.F. McCULLOUGH

The development and application of a scheme, in the form of a computer program, to order the priority and schedule a set of rigid pavements for rehabilitation within a specified time frame and budget constraints are presented. The scheme makes use of a distress index to order the priority of a group of pavement sections and to decide when a pavement has reached its terminal condition. The distress index is calculated by combining into a single number the various distress manifestations that occur in a pavement section. The initial pavement condition is determined from field distress condition surveys and the future condition is determined by means of distress prediction models. The immediate application of the computer program is to generate lists of candidate pavements for rehabilitation; however, the use of the program can be extended to analyze the effect of several different budget policies on the condition of the pavement network.

The need for better management tools to allocate money, staff, equipment, and materials in an efficient manner has become evident with the continuous increment of requirements to maintain and rehabilitate a pavement network.

A relatively small amount of research effort has been placed on restoration as compared with the provision of new facilities because most previous capital investments have been centered on construction of new roads. This trend is reversing, however, and the prime effort is shifting toward the maintenance and rehabilitation of existing pavements.

During the last decade, pavement management systems (PMS) have been applied successfully to improve the management and technology of pavements (1-3). Among the PMS studies, the methods for planning maintenance and rehabilitation in a pavement network have become relevant in recent years. The desired result from a network application is a work program for each year during an analysis period. However, different degrees of complexity can be achieved and, for an agency without PMS experience, starting with a simplified version and progressing in a staged

manner has been suggested (4). The concepts, steps involved in the development, and application of a pavement rehabilitation priority-ordering and scheduling scheme at the network level are presented.

PMS

PMS involves the application of systems engineering to assist decision makers in defining optimum strategies for maintaining pavements in a serviceable condition over a given period of time. The development of PMS is a cyclic procedure that works toward an ideal system. For example, improvements are achieved by continuous upgrading of the network by using the models and the algorithms in the program to predict the rehabilitation needs. An ideal system should be capable of predicting (a) the precise future condition of each project in a given network, (b) the proper timing and type of maintenance required, (c) the date to overlay, (d) the costs, and (e) the consumption of resources.

Management decisions involving pavements can be considered at two different levels: the network and the project. A network consists of a series of projects under the jurisdiction of an agency. A project is a pavement unit that has been defined by the agency for construction and record-keeping purposes. The developments in this paper are confined to those at the network level.

At the network level the management system provides information to help decision makers in the development of agencywide programs of new construction, maintenance, or rehabilitation that will make optimum use of available resources (3). The results of the analysis should provide a program for construction, maintenance, and rehabilitation of pavements within available resources. Several schemes for maintenance and rehabilitation management have been presented in the literature or are currently in use by state agencies (4-11). Each one is different, which is a reflection of the needs of a particular agency.

SYSTEM OUTPUT FUNCTION

Among the important developments required in PMS is an output function that involves the various parameters that affect decision making in pavements, such as riding quality, skid resistance, distress, traffic, and costs. In general, riding quality has been the most important factor considered, primarily because of the influence of the AASHO Road Test, where the concept of present serviceability index (PSI) was developed. Although the PSI equation includes patching and cracking, roughness is the dominating term. From experience with rigid pavements in Texas, distress was found to be a more useful output function for ordering the priority and scheduling a set of pavements for rehabilitation. Thus, sources of information for developing productive algorithms must be used.

Continuously Reinforced Concrete Pavement System Output Function

In a large number of the cases observed the pavement serviceability history does not appear to change with time or traffic; however, the distress condition does change. Figures 1 and 2 indicate how serviceability and distress vary with traffic for Texas pavements. Each point represents a surveyed project (1 to 10 miles) of continuously reinforced concrete pavement (CRCP) in Texas (12,13). The serviceability index was derived from roughness data obtained by using profilometer measurements. The traffic figures were provided by the Texas State Department of Highways and Public Transportation (TSDHPT). The number of failures (punchouts and patches) per mile was obtained from the records of the CRCP condition surveys performed in Texas in 1974 and 1978 (described later in the paper). The figures show that the serviceability index is independent of the traffic; i.e., the serviceability index value does not vary. Unfortunately, only a few of these projects have been monitored over time. For these cases history shows that the pavements remain near the initial PSI. One likely reason for having a constant serviceability is the continuous repair of the highway performed by the district's staff. Hence, although from a structural or economics standpoint the section is approaching its terminal point, the riding quality remains unchanged. Thus, the use of distress measures may be a more realistic way to evaluate a pavement's terminal condition. This observation is contrary to the basic hypothesis of the AASHO guides for rigid pavement (14). However, these concepts, which are based on results of the AASHO Road Test (15), do not consider that deteriorating pavement sections receive maintenance.

Therefore, distress manifestations (in this case failures per mile) appear to be better indicators of the deterioration of CRCP than the serviceability index, as seen by the variability. In other words, with CRCP distress generally appears to be a more significant factor in the decision-making process than the serviceability index.

Figure 1. Serviceability index versus traffic applications (both directions) for Texas CRCP sections surveyed in 1974 and 1978.

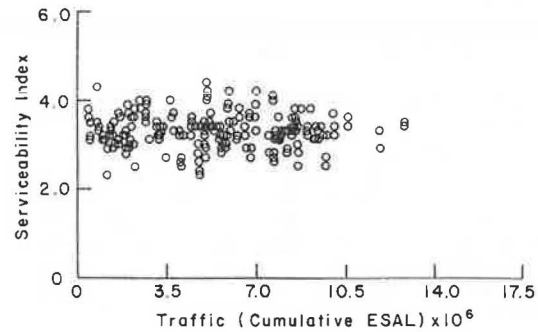
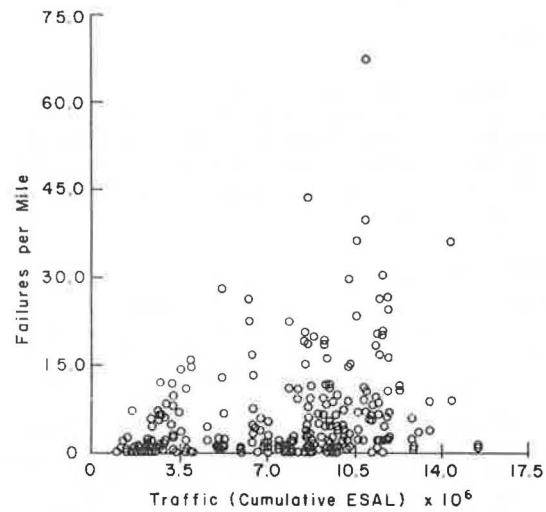


Figure 2. Number of failures per mile (punchouts and patches) versus traffic applications (both directions) for Texas CRCP sections surveyed in 1974 and 1978.



An additional advantage of using distress is that it relates directly to maintenance requirements and measures indirectly other pavement functional indicators such as serviceability. Among the disadvantages of using distress manifestations is the lack of cost equations, because past research has made extensive use of the PSI concept in developing these equations.

Sources of Information for Predictive Algorithms

Field data were collected for CRCP and asphalt concrete (AC) overlaid pavements, and literature information used for jointed pavements.

CRCP

Condition surveys (i.e., field measurements of distress to the pavement condition) have been carried out by the Center for Transportation Research (CTR). The rural districts in Texas were surveyed in 1974, 1978, 1980, and 1982. The urban districts were surveyed in 1976 and 1982. The following manifestations were measured: transverse cracking, localized cracking, spalling, pumping, punchouts, and patches. Detailed information on the condition survey procedures used is given elsewhere (16).

Jointed Pavements

Although jointed pavements [jointed concrete pavement (JCP) and jointed reinforced concrete pavement (JRCP)] are used in the state, this type of pavement has not been monitored on a regular, scheduled basis. Therefore, other sources of information were used in this study. Data used by Carey and Irick (17) to develop the serviceability-performance concept were used to develop some of the distress models (16). Other models have also been adopted from the literature (15,18,19).

Rigid Pavements Overlaid with AC Pavement

The monitoring of overlaid rigid pavements is a recent task; therefore, the existing information does not present extensive time histories of distress occurrence. A project in Walker County on I-45 represents one of the oldest, better monitored asphalt concrete overlays of rigid pavements in the state (i.e., it has a history of approximately 14 years).

DEVELOPMENT OF COMPUTER PROGRAM

Although a PMS is not necessarily a computer program, the amount of calculations necessary render the development of computer programs essential to transform the concepts into a working reality. The key issue of any PMS is to move past the conceptual stage and develop an actual working system.

Program PRP01

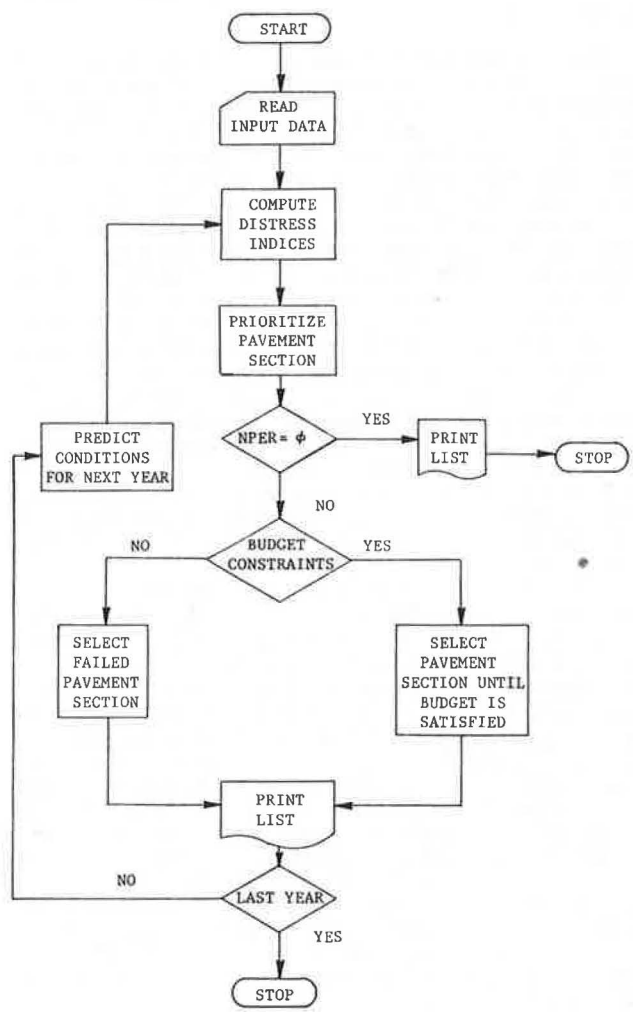
Program PRP01 was developed to schedule rehabilitation of rigid pavements (JCP, JRCP, and CRCP) within a certain design period. The input data are condition survey information on a set of rigid pavements for the same year. The solution is obtained by using distress models (i.e., distress indices and distress prediction equations). All of the distress models were integrated as subroutines in the program to facilitate future modifications.

The program output has several alternatives:

1. A priority-ordered list of pavement sections according to their distress condition at the time of the condition survey;
2. A multiperiod rehabilitation schedule of the pavement sections without consideration of budget constraints; the selection of candidates for each year is made on the basis of the magnitude of the distress index; and
3. A multiperiod rehabilitation schedule of the pavement sections that account for budget restrictions; the selection for each year depends on the magnitude of the distress index and budget availability.

Figure 3 is a simplified flowchart of the computer program. Information on the distress condition of each project is required as input. The program starts by calculating the distress index for each section. Then the priority order of the sections is determined according to the magnitude of their distress indices. The design period is checked at this stage: If the design period is set equal to zero the program prints the priority list and stops. If the design period is larger than zero the program continues. Budget restrictions are checked next by using two different criteria: If no budget constraints are imposed by the user, the rule for selecting the candidates for rehabilitation is that all pavements that reach terminal condition are included in the list for that year. If budget constraints are present the selection of candidates is made on the basis of availability of funds. The

Figure 3. Simplified flowchart of computer program PRP01 developed to order the priority of and schedule rehabilitation.



rehabilitation cost of each project is calculated in order of project priority and this cost is accumulated until the budget constraint is reached. A list of candidate projects is printed for each year of the design period. The program checks to see if the design period has been covered, in which case it exits; otherwise, conditions are predicted for the next year and the program returns to the step in which the distress indices are calculated.

Models in Program PRP01

Distress Index

Several approximate methods for developing a distress index were studied--subjective parameters, regression analysis, factor analysis, and discriminate analysis (16, 20-23). The following conclusions have been obtained from the study of these methods.

1. The equations that have subjective parameters rely heavily on engineering judgment and experience and, therefore, are useful when sufficient information is not available.
2. Factor analysis is difficult to interpret and the assumption used in this approach (i.e., the resulting equations measure structural performance or deterioration of a pavement section) is not supported.
3. Regression analysis and discriminant analysis are feasible techniques for developing distress and decision criteria indices; the selection of one or the other is dependent on the dependent variable selected.

Discriminant analysis was chosen to develop rigid pavement distress indices because it conforms to available data. It is a statistical technique used to classify data into groups; its objective is to construct a boundary (i.e., a discriminant equation) such that the elements of each group can be separated. Once the equation is defined any new element can be assigned to one of the predetermined groups. This technique was applied to develop an equation to discriminate CRCPs that have an acceptable level of distress from pavements that require overlay.

Distress condition surveys of CRCP in Texas were performed in 1974 and 1978. Several distress manifestations were recorded--punchouts and patches per mile, percentage of minor spalling, percentage of severe spalling, and percentage of pumping. Some of the pavements surveyed during 1974 were overlaid before the survey in 1978. These data are used to determine the reasons for the decision to overlay. Data on several variables from two groups (overlaid and nonoverlaid pavements) that describe their difference are used.

The jointed pavement data used in the analysis are those used by Carey and Irick (17) to develop the serviceability-performance concept. The justification for the use of this information is based on the findings of Hutchinson (24) and Weaver (25). Hutchinson found that subjective estimation procedures, typified by Road Test panel ratings, were inappropriate for the task because they tended to measure pavement distortion and deterioration rather than riding quality, which is the essence of serviceability. Weaver reinforces this point in his results to develop a serviceability index for New York. He found that inclusion of experts in the rating panels or inappropriate definition of objectives biases the results of serviceability studies. Therefore, the acceptability or unacceptability of pavement sections in the Road Test was assumed to be influenced by the pavement condition.

Although the outcome of the discriminant analysis is a decision criteria index, its relative magnitude can be used as a distress index. Further details of the application of this technique are presented elsewhere (13,16).

The following discriminant equations were obtained by using the statistical package for the social sciences (SPSS) (20). The discriminant score can be interpreted as follows: If it is positive for a given pavement section then the section is in good condition; if the score is negative (i.e., smaller than zero) the section is considered to have failed. The larger the magnitude of the discriminant score, the better the condition of the pavement. The equation obtained from continuous pavements was of the form

$$Z_c = 1.0 - 0.065FF - 0.015MS - 0.009SS \quad (1)$$

where

Z_c = distress index or discriminant score for continuous pavements,
FF = failures (punchouts and patches) per mile,
MS = percentage of minor spalling, and
SS = percentage of severe spalling.

The equation classified correctly 88 percent of the 224 cases used in the analysis. Of course, the prediction capability of the discriminant equation will need to be checked in the future. The equation obtained for jointed pavements, after algebraic manipulation so that it resembles Equation 1, was

$$Z_j = 1.0 - 0.005C - 0.006S - 0.021P - 0.003F \quad (2)$$

where

Z_j = distress index or discriminant score for jointed pavements,
C = cracks (number per mile),
S = spalling (%),
P = patches (number per mile), and
F = faulting in wheelpath (number per mile).

The equation classifies correctly 92 percent of 49 cases.

Distress Prediction Equations

The initial pavement condition is determined from field distress condition surveys and input into the program. The future condition is calculated internally by means of distress prediction equations. Field data were used to obtain models for CRCP and AC overlaid rigid pavements through regression analysis. The models for jointed pavements have been adopted from the literature (15,18,19). The models derived assume that at some point in time information on the distress of a pavement was collected and used to forecast the future condition of the pavement.

The models developed predict failures (punchouts and patches), minor spalling, and severe spalling for CRCPs and cracking, spalling, and faulting for jointed pavements. Further information on the distress prediction equations and their development is presented elsewhere (16).

The information used for the development of the equations did not come from an experimental design but from data collected primarily with the purpose of evaluating pavement conditions. Future improvements of distress prediction equations should include experimental design techniques. Guidelines exist in the literature (26,27) for that purpose.

Overlay Thickness

The field information collected about overlaid rigid pavements was used to derive an equation for calculating an approximate AC overlay thickness and, from it, to estimate the overlay cost of a pavement section. The thickness design can be explained by using the data in Figure 4; the figure shows the average percentage of distress history for different overlay thicknesses as monitored in the field. The program selects a percentage from the original distress of a pavement section, which corresponds to the failure condition, and an overlay life. An approximate thickness is estimated from two inputs.

Outputs from Program PRP01

Figures 5-7 are partial outputs of sample runs made with the priority-ordering and scheduling program PRP01 and are used to explain the contents of the lists produced by the program for the various available options.

Figure 5 is the type of output generated when the option selected is priority ordering of projects using the condition survey information directly. This option does not involve any type of distress prediction. The program calculates the distress index for each of the sections and sorts them all according to the relative magnitude of the indices, the worst condition first. The output contains four columns. The first column is section identification. The second is the distress index (note that the numbers increase progressively as the condition of the sections improves). The third column is the cumulative equivalent single axle loads (ESALs) that were input by the user. The last column is the ranking of each section as obtained from the distress indices, with the poorest pavement listed first.

Figures 6 and 7 are the type of output obtained for both the second and third options of the program (i.e., multiperiod rehabilitation scheduling with and without budget constraints). Any of these options produces a list of projects that require overlay for each year of the design period (similar to Figure 6) and a summary for the design period (similar to Figure 7). Figure 6 represents a specific year of the year-by-year output, year 1, in six columns. The first three columns and the sixth column are identical to those in Figure 5. The fourth column contains the project lengths in miles, and the fifth column contains the estimated cost of each overlay. At the bottom of the printout the total length and the total cost to overlay the candidate projects for the specific year are printed.

For the second option (scheduling of pavement sections without budget constraints) the distress

Figure 4. Plot of average percentage of distress time history for different overlay thicknesses as monitored in Walker County, Texas.

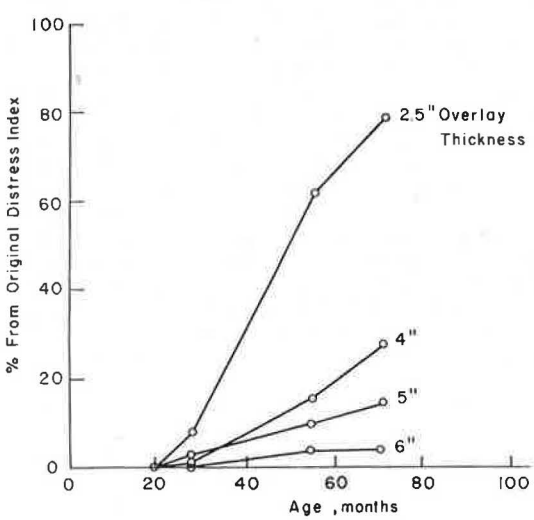


Figure 5. Sample output from program PRP01 by using priority-ordering option.

PRIORITY LIST OF TX CRCP FOR REHABILITATION
INPUT DATA FROM 1980 CONDITION SURVEY

LIST OF PRIORITIZED SECTIONS AT TIME OF CB

SECTION ID	DISTRESS INDEX	CUMULATIVE ESAL (MILLIONS)	RANK
1908EB	-4.076	5.080	1
1908WB	-2.215	5.480	2
1807WB	-2.124	5.830	3
1906EB	-2.041	5.310	4
1814EB	-1.694	5.160	5
1806WB	-1.688	5.940	6
904 SB	-1.652	7.220	7
1801EB	-1.490	5.700	8
1807EB	-1.304	5.830	9
1804WB	-1.194	5.680	10
1303WB	-1.073	2.020	11
2009WB	-1.062	3.160	12
1902EB	-1.057	5.770	13
1906WB	-1.007	5.310	14
1801WB	-.941	5.700	15
2009EB	-.909	3.160	16
1303EB	-.864	2.020	17
1814WB	-.850	5.160	18
1808EB	-.760	4.440	19
1810EB	-.739	5.130	20
1305SB	-.683	1.490	21
1306WB	-.653	1.820	22
1804EB	-.513	5.680	23
907 NB	-.475	5.830	24
1902WB	-.465	5.770	25
1810WB	-.445	5.130	26
1313WB	-.391	1.910	27
1811WB	-.334	4.630	28
108 SB	-.290	3.250	29
1803EB	-.276	5.950	30
1307WB	-.245	1.510	31
1909EB	-.242	6.020	32
1904WB	-.238	6.160	33
1802EB	-.200	5.860	34
1904EB	-.199	6.160	35
1706SB	-.198	5.490	36

Figure 6. Sample output page from computer program PRP01 by using scheduling option.

PRIORITY LIST OF TX CRCP FOR REHABILITATION
INPUT DATA FROM 1980 CONDITION SURVEY

LIST OF PAVEMENT SECTIONS REQUIRING OVERLAY
YEARS AFTER CONDITION SURVEY= 1

SECTION ID	DISTRESS INDEX	CUMULATIVE ESAL (MILLIONS)	SECTION LENGTH (MILES)	OVERLAY COST (DLLS)	RANK
1908EB	-4.037	5.918	9.80	4686232.	1
1908WB	-3.055	5.918	10.00	3629770.	2
1906EB	-2.784	5.629	7.00	2454482.	3
1807WB	-2.617	6.180	5.00	1714050.	4
904 SB	-2.322	7.653	1.80	591402.	5
1814EB	-2.218	5.676	8.20	2651398.	6
1806WB	-2.123	6.296	5.20	1656546.	7
1801EB	-1.749	6.099	4.00	1195507.	8
1807EB	-1.617	6.180	4.80	1399609.	9
	-.094		55.80	19978996.	

Figure 7. Sample output summary from computer program PRP01 by using scheduling option.

PRIORITY LIST OF TX CRCP FOR REHABILITATION
INPUT DATA FROM 1980 CONDITION SURVEY

SUMMARY TABLE

YEAR	AVG. DI	LENGTH (MILES)	BUDGET (DLLS)
1	-.094	55.80	19978996.
2	.032	64.40	18852102.
3	.134	65.10	17574961.
4	.204	75.90	19301323.
5	.347	75.30	17445063.
6	.452	93.40	19739679.
7	.550	99.90	19022178.
8	.699	108.40	19017960.
9	.833	118.70	18582421.
10	.996	0	0
	.415	756.50	169514682.

indices for years other than the first one in the design period are close to zero and of equal value. Therefore, further ranking of the sections can be made in terms of cumulative ESAL.

Figure 7 presents the summary of the year-by-year analysis, which includes the average distress index calculated for the network, the total length of projects recommended for rehabilitation, and the yearly budget. An overall summary is printed in the lower part of the table.

PROGRAM APPLICATIONS

The obvious application of the computer program PRP01 is to generate lists of candidate pavements for rehabilitation. The use of the program can be extended to analyze the impact of several different budgeting policies on the condition of the pavement network. The purpose of this section is to present the effects of different budget policies by using information from the 1980 East Texas CRCP condition survey. The data used for the analysis came from 139 sections, representing 7 districts, with a total length of 756.5 miles and age that ranges from 9 to 18 years.

Analysis Approach

Several computer runs were performed for a 10-year analysis period using several budget levels--$5, $10, $15, $20, and $30 million per year. An additional computer run was developed without considering budget restrictions. The output of the runs was plotted to observe the effect of the various yearly budgets on the distress condition of the pavement network.

The numbers used in the analysis are not definitive because the cost of overlay used was approximate. An accurate figure should include costs such as the costs of handling traffic, materials, equipment, and labor.

Effect of Yearly Budget

Table 1 gives summary information for each budget level considered in the analysis. The second column contains the total number of miles repaired for the design period considered, and the third column contains the total budget used in the design period, in millions of U.S. dollars. The fourth column contains the average overlay cost per mile for each budget level, without considering the time value of money. The average overlay cost per mile was obtained by dividing the total budget by the number of miles repaired. Column five gives the average distress index for each budget level. The poor condition of the network, exemplified by negative average distress index values for the low budget levels, is obvious, along with the improved condition for higher budgets.

Table 1. Summary information for several different budget levels from computer program PRP01 by using Texas CRCP information.

Budget Level ($000,000s/year)	Length Repaired (miles)	Budget Used ($000,000s)	Avg Overlay Cost per Mile ($000s/mile)	Avg Distress Index
Variable	532.2	119.957	225.40	0.628
5	70.8	35.052	495.09	-0.670
10	261.0	91.934	352.24	-0.128
15	506.3	137.974	272.51	0.154
20	756.5	169.515	224.08	0.415
30	756.5	157.850	208.66	0.648

Note: Ten-year analysis period.

Figure 8. Average distress index for network through time for various yearly budgets using Texas CRCP Information.

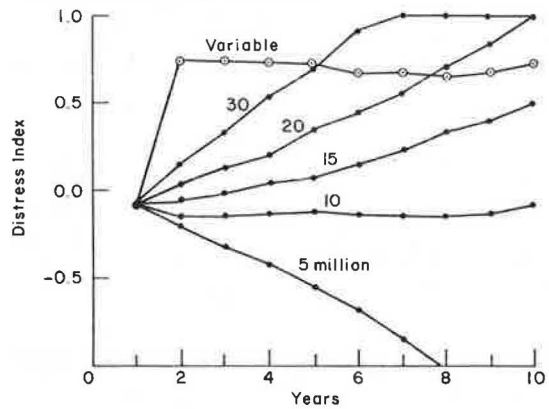


Figure 8 presents information on the average distress index predicted each year within the design period for the network and for the various budget levels. It is apparent from this figure that if a low budget is used (i.e., $5 million/year), the network will continue to deteriorate. The rate of deterioration can be reduced or even reversed, however, if higher budgets are adopted. Also, note the yearly budget (i.e., $10 million) for which the present condition of the network is maintained. This budget level may not be a feasible alternative because of the network's low initial distress condition. The use of a variable budget involves investing an extensive amount of money the first year, about $84 million for the problem in question, to improve the condition of the network, and a yearly budget of about $4 million (lower than the $10 million required if the network is not restored to a better condition) for the rest of the design period. The additional cost incurred by postponing the overlay of a pavement section is given in Table 2.

To help the reader visualize the meaning of the distress index, Figure 9 was produced. A 0.2-mile section is depicted in the figure with several dif-

Table 2. Additional cost incurred by postponing overlay of pavement section, developed from Texas CRCP information.

Year of Overlay	Network Average: Cost per Mile ($000s/mile)	Network Average: Increase (%)	Severely Deteriorated Section: Cost per Mile ($000s/mile)	Severely Deteriorated Section: Increase (%)	Slightly Deteriorated Section: Cost per Mile ($000s/mile)	Slightly Deteriorated Section: Increase (%)
1	247.87		478.16		180.37	
2	265.30	7.03	545.20	14.02	182.22	1.03
3	284.65	14.84	624.59	30.62	184.07	2.05
4	306.22	23.54	718.06	50.17	185.93	3.08
5	330.37	33.28	828.06	73.18	187.96	4.21

Figure 9. Sample distress condition of 0.2-mile CRCP section with different values of distress index.

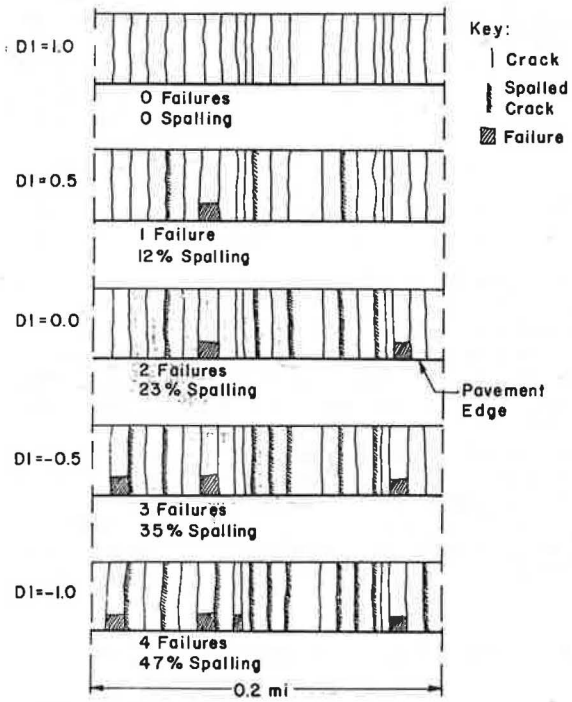
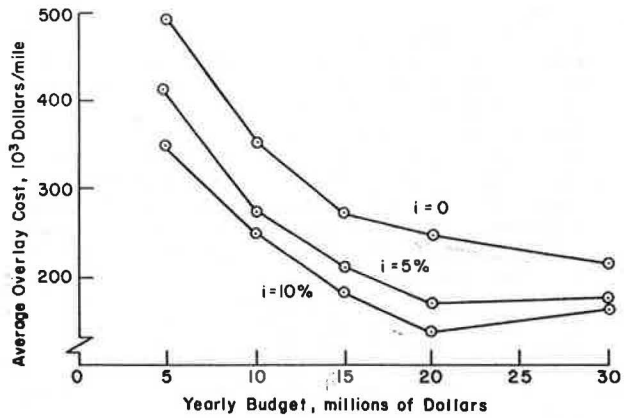


Figure 10. Average overlay cost per mile versus different yearly budgets for various interest rates using Texas CRCP information.



ferent stages of distress. Notice the different stages of deterioration that correspond to various magnitudes of the distress index. If a low budget is used, the deterioration of the pavement follows stages similar to the ones presented in Figure 9.

CONCLUSIONS AND RECOMMENDATIONS

The computer program presented was used to analyze the impact on the future distress history of a pavement network of several different budgeting policies. The program was shown to be a useful tool for selecting an adequate budgeting policy. From the analysis conducted the following additional conclusions were drawn; although they may seem obvious, the program corroborates and provides means to estimate them (see Figure 10).

1. A minimum budget is required to maintain the condition of a pavement network. This minimum is variable, depending on the original condition of the network.
2. If the network is allowed to deteriorate, the amount of money required to upgrade its condition will increase with time; that is, more money will be needed to upgrade the network as time goes by.
3. In addition to the availability of funds and personal preferences, an economic analysis is an important factor in the selection of a budget. User costs are not included in the analysis, however, so detailed consideration should be paid to the initial and the predicted distress condition of the network.

The program estimates, in terms of both dollars and distress predictions, should be verified further to corroborate and improve them. As with any PMS, continuous upgrading is required to achieve optimum management of funds. If the rehabilitation scheduling procedure is to include flexible pavements, similar distress indices need to be developed so as to have a common yard stick to measure both types of pavements (i.e., rigid and flexible).

ACKNOWLEDGMENT

We are pleased to acknowledge the combined efforts and support of the Center for Transportation Research at the University of Texas at Austin and the Texas State Department of Highways and Public Transportation, in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

REFERENCES

1. R.C.G. Haas and W.R. Hudson. Pavement Management Systems. McGraw-Hill, New York, 1978.
2. Pavement Management Guide. Road and Transportation Association of Canada, Ottawa, 1977.
3. W.R. Hudson, R.C.G. Haas, and R.D. Pedigo; Austin Research Engineers, Inc. Pavement Management System Development. NCHRP, Rept. 215, Nov. 1979, 32 pp.
4. R.D. Pedigo and W.R. Hudson. Simplified Pavement Management at the Network Level. ARE, Inc., Austin, Tex., Rept. NA-3/1, 1981.

5. P.J. Weaver and J.M. Newman. The Dream versus the Reality of a PMS. PM Workshop, Tumwater, Wash., FHWA-TS-79-206, 1978, pp. 267-293.
6. T.L. Nelson, D.B. House, H.E. Sandahl, and R.V. LeClerc. Washington Pavement Management System. Washington Department of Transportation, Tumwater, 1977.
7. M.A. Karan and R.C.G. Haas. Urban Pavement Management on a Coordinated Network: Project Basis. Proc., 4th International Conference on Structural Design of Asphalt Pavements, Univ. of Michigan, Ann Arbor, 1977.
8. N.V. Ahmed, D.Y. Lu, R.L. Lytton, J.P. Mahoney, and D.T. Phillips. The Texas Rehabilitation and Maintenance District Optimization System. Texas Transportation Institute, Texas A&M Univ., College Station, Res. Rept. 207-3, Nov. 1978.
9. D.T. Phillips, R.L. Lytton, and C.V. Shanmugham. Rehabilitation and Maintenance System: The Optimization Models. Texas Transportation Institute, Texas A&M Univ., College Station, Res. Rept. 239-1, Jan. 1981.
10. D.T. Phillips, C.V. Shanmughan, F. Ghasemi-Tari, and R.L. Lytton. Rehabilitation and Maintenance System: State Optimal Fund Allocation--Program II (RAMS-SOFA-2). Texas Transportation Institute, Texas A&M Univ., College Station, Res. Rept. 239-2, Jan. 1981.
11. D.T. Phillips, C.V. Shanmughan, S. Sathaye, and R.L. Lytton. Rehabilitation and Maintenance System: District Time Optimization (RAMS-DTO-1). Texas Transportation Institute, Texas A&M Univ., College Station, Res. Rept. 239-3, Sept. 1980.
12. B.F. McCullough and P. Strauss. A Performance Survey of CRCP in Texas. Center for Highway Research, University of Texas at Austin, Austin, Res. Rept. 21-1F, 1974.
13. M. Gutierrez de Velasco and B.F. McCullough. Summary Report for 1978 CRCP Condition Survey in Texas. Center for Highway Research, University of Texas at Austin, Austin, Res. Rept. 177-20, 1979.
14. AASHO Interim Guide for Design of Pavement Structures. AASHO, Washington, D.C., 1972.
15. The AASHO Road Test: Report 5, Pavement Research. HRB, Special Rept. 61E, 1962, 352 pp.
16. M. Gutierrez de Velasco. Rigid Pavement Network Rehabilitation Scheduling Using Distress Quantities. University of Texas at Austin, Austin, Ph.D. Dissertation, Aug. 1982.
17. W.N. Carey, Jr. and P.E. Irick. The Pavement Serviceability Performance Concept. HRB, Highway Research Bull. 250, 1960, pp. 40-58.
18. W. Gulden. Pavement Faulting Study--Extent and Severity of Pavement Faulting in Georgia. Georgia Department of Transportation, Forest Park, Res. Proj. 7104, 1972.
19. M.I. Darter, M.B. Snyder, and R.E. Smith. Nationwide Evaluation of Concrete Pavements--Illinois Demonstration. Proc., 2nd International Conference on Concrete Pavement Design, Purdue Univ., Lafayette, Ind., April 1981, pp. 399-408.
20. N.H. Nie, C.H. Hull, J.G. Jenkins, K. Steinbrenner, and D.H. Bent. Statistical Package for the Social Sciences (SPSS), 2nd ed., McGraw-Hill, New York, 1970.
21. R.L. Lytton, W.M. Moore, and J.P. Mahoney. Pavement Evaluation. FHWA, Final Rept., Phase 1, FHWA-RD-75-78, March 1975.
22. L.T. Oehler and L.F. Holbrook. Performance of Michigan's Postwar Concrete Pavements. Michigan Department of State Highways, Lansing, Res. Rept. 711, June 1970.
23. M.Y. Shahin, M.I. Darter, and S.D. Kohn. Evaluation of Airfield Pavement Condition and Determination of Rehabilitation Needs. TRB, Transportation Research Record 700, 1970, pp. 1-10.
24. B.G. Hutchinson. Principles of Subjective Rating Scale Construction. HRB, Highway Research Record 46, 1964, pp. 60-70.
25. R.J. Weaver. Quantifying Pavement Serviceability As It Is Judged by Highway Users. TRB, Transportation Research Record 715, 1979, pp. 37-44.
26. M.I. Darter. Requirements for Reliable Predictive Models. TRB, Transportation Research Record 766, 1980, pp. 25-31.
27. R.D. Pedigo, W.R. Hudson, and F.L. Roberts. Pavement Performance Modeling for Pavement Management. TRB, Transportation Research Record 814, 1981, pp. 14-21.

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