Combined Priority Programming of Maintenance and Rehabilitation for Pavement Networks

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Total expenditures for maintenance and rehabilitation of a pavement network should represent an optimum combination of the two types of activities. Under the usual situation of budget constraints, this requires the establishing of priorities. An integrated method for programming maintenance and rehabilitation for paved road networks for any chosen program period is described. It begins with a common inventory of condition, serviceability, structural adequacy, traffic, unit costs, and other information. The maintenance programming subsystem evaluates alternative treatments for different types, densities, and severities of distresses and produces a demand-based budget by using a maximization of cost-effectiveness. The rehabilitation programming subsystem similarly evaluates alternatives, and a priority list of year-by-year projects over the program period, based on benefit maximization, is produced. The total of maintenance and rehabilitation costs for any given year does not exceed the total budget limit. A case application is provided to illustrate the method. It uses the arterial street network of a small city, subdivided into 100 sections. The outputs include section-by-section, year-by-year, recommended programs of maintenance and rehabilitation work. An additional feature of the method is a capability for evaluating the long-term effect of various budget options on average network serviceability. Two rehabilitation budget levels, representing the expected funding and a zero budget, have been tested for the case application. As expected, average network serviceability was estimated to decrease significantly over the 10-year programming period for the zero budget case. Finally, it is recommended that year-by-year updates be carried out on the inventory and the maintenance and rehabilitation programs.

Should we be spending more money on maintenance and less on rehabilitation, or vice versa? What is the optimal combination of expenditure for maintenance and (capital) rehabilitation to get the best possible value for the total available funds?

The overall objective of a public agency should be to obtain such a total best value. However, it is common practice to separately determine maintenance and rehabilitation needs and prepare separate budgets that are separately administered. Coordination between the two is on a judgment basis. Quantitative answers to whether the individual programs and budgets for each represent the best balance cannot easily be answered with present methodology.

A better approach is one that starts with a coordinated or combined inventory and inspection to establish the present status of the network. Maintenance needs and rehabilitation needs can then be identified by comparing this present status with policy variables such as minimum acceptable levels of serviceability and maximum levels of surface distress, and initial, "demand-based" budgets can be established. However, because the required funding is not usually available, various maintenance and rehabilitation alternatives, including deferral of the work, should be considered for each need and their cost and benefit implications should be analyzed. Then a final priority set of maintenance and rehabilitation alternatives and their timing are chosen by varying the individual budgets, within a total budget limit, to determine which combination gives the highest average serviceability for the network as a whole.

The purpose of this paper is to describe a working procedure for obtaining coordinated priority programs of maintenance and rehabilitation for a paved road network. An example application to the arterial network of a small city is provided to illustrate the procedure.

FRAMEWORK FOR COORDINATING BUDGETING AND PROGRAMMING

Maintenance and rehabilitation expenditures should be programmed simultaneously to avoid incompatibilities in an operational sense and to approach a truly optimum allocation of available funds. Figure 1 shows an ideal framework for accomplishing this in a coordinated manner.

Three levels of budgeting and programming have been identified in this framework. The first level represents a "first cut" at the programming of pavement investments. The starting point is to conduct an inventory and to establish the present status of the system and the needs by considering policy variables such as acceptable levels of service. From these needs, it is possible to establish a "demand budget" that can then be compared with the total available funds.

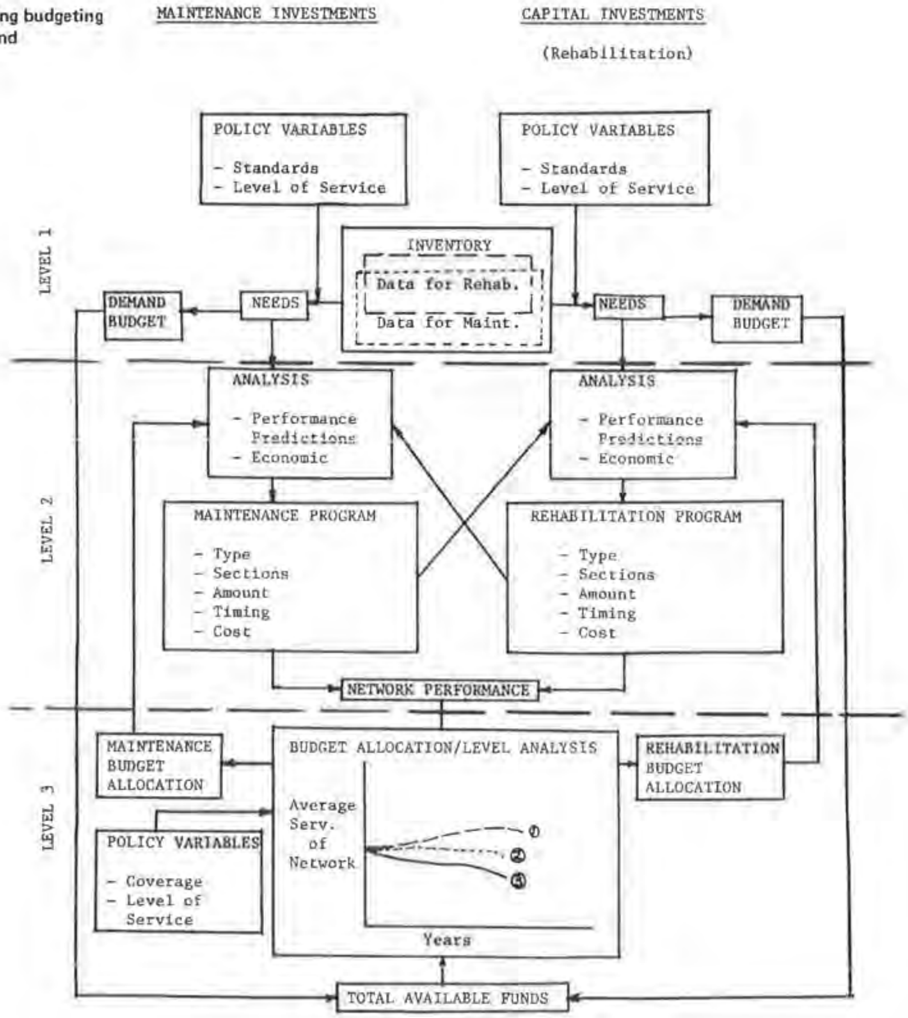
The types of inventory information required are simply categorized as to maintenance or rehabilitation use in Figure 1 and are listed in more detail in Figure 2. Some of this information is specific to the type of programming. For example, structural adequacy is not usually considered in programming maintenance, since maintenance does not normally deal with strengthening operations per se. Although there is considerable overlap in the types of information acquired, the intensity of the data or the specific parameters of concern may be different. For example, programming rehabilitation may require an indication of the overall condition of a pavement surface in the form of, say, a condition rating or index; on the other hand, programming maintenance requires specific details of the type, amount, and severity of distress, since this has a bearing on the type of maintenance activities that may apply.

The second level of programming involves the establishment of programs for maintenance and rehabilitation based on the needs identified in the first level plus analyses of the performance and economics of various strategies for fulfilling these needs. These strategies include not only the rehabilitation and maintenance alternatives but also the timing of these alternatives.

The determination of the budget allocations for maintenance and rehabilitation programs as well as the overall pavement budget levels for each year in the programming period are considered in the third programming level. By varying the total funds available in each year and also by altering the allocation ratio between maintenance and rehabilitation budgets, the analyses of level 2 can be iterated under different budget constraints to produce different profiles of average overall network serviceability with time. This allows policy planners to study the effect of budget levels and allocations on the performance of the pavement network and, by considering another set of policy variables as decision criteria, arrive at the most suitable budget allocations.

The relation of most current maintenance management systems to the framework of Figure 1 should be noted. Although these systems have generally achieved a high state of development, they only really take over after the programming has been done--i.e., they represent a "production control"

Figure 1. Framework for coordinating budgeting and programming for maintenance and rehabilitation.



type of process. The current methodology for programming of maintenance investments consists essentially of establishing maintenance needs and developing the associated demand budget as shown in level 1. The establishment of needs is based on attaching average unit volumes, weights, rates of application, times, (depending on type of maintenance activity) for different types of surfaces and road classes and then working out the total volumes or weights of materials and equipment and person hours required. These average volumes, weights, rates, etc., are themselves based on past maintenance management records.

WORKING METHOD

The following sections present a working method for the framework shown in Figure 1.

Pavement Inventory and Maintenance Alternatives

Good inventory information (Figure 1), both acquired (such as traffic and unit costs) and field measured (such as roughness), is the foundation for effective programming of maintenance and rehabilitation. Of these, the surface condition survey (Figure 2) is perhaps the key item for maintenance. With information from the survey on the types, extent, and severity of surface distresses, the most cost-effective maintenance alternatives can be identified.

One of the most up-to-date approaches for accomplishing this has been developed by the Ontario Ministry of Transportation and Communications (1-3). This approach has the following major elements: (a) a condition survey to identify the types, severity, and density of distresses; (b) the alternative maintenance treatments available and their expected lives for each combination of type, severity, and density of distress; and (c) an economic analysis to determine the most cost-effective treatments. Such an analysis makes it possible to prepare a direct demand budget.

Figure 3 (2) shows how alligator cracking (one of the 12 types of example distresses in the Ontario method) is described and how its severity is established and its density is determined. Photographs (not included in this paper) are provided in the method to assist field personnel in getting the right answers and being consistent.

Table 1 gives the alternative treatments available and their expected effective lives. These lives, of course, apply to Ontario conditions and would have to be calibrated for other regions. Performance standards, available elsewhere (3), have also been developed for the treatment alternatives.

With cost information on the various items in the performance standards, plus the amount of maintenance to be performed, unit cost calculations can first be performed for each treatment alternative:

$$\text{Unit cost} = (\text{manpower} + \text{equipment} + \text{materials})/\text{accomplishment per day} \quad (1)$$

Figure 2. Types of inventory information required for maintenance and rehabilitation use.

Then equivalent annual cost calculations can be made:

$$\text{Equivalent annual cost} = \text{unit cost/expected life of alternative in years} \quad (2)$$

The most cost-effective alternative is the one with the least equivalent annual cost.

A quantitative end-product illustration of the foregoing procedures is provided later in this paper.

Pavement Inventory and Rehabilitation Alternatives

The inventory information for rehabilitation programming includes the acquired data items in Figure 2 (such as traffic and unit costs), the condition survey previously noted for maintenance programming, and several additional key items from field measurements. These include structural adequacy, riding comfort and skid resistance, and structural composition (from coring) if construction records are inadequate.

Although information on the individual data items should be retained, a composite "pavement quality index" (PQI), on a scale of 0-10, has been found quite useful for rehabilitation programming (4). This uses the Canadian riding comfort index (RCI), a structural adequacy rating (SAR) from deflection survey measurements, and a condition index (CI) from the condition survey measurements. RCI, SAR, and CI are all based on a scale of 0-10.

Rehabilitation alternatives may include overlays of varying thickness, full or partial reconstruction (including recycling), and surface treatment. The set of alternatives available will vary with the network considered and the jurisdiction involved.

Figure 3. Example of distress-type description, severity, and density.

Alligator Cracking

Description:	Cracks form a network of multi-sided (polygon) blocks resembling the skin of an alligator. The block size can range from 5 to 10 cm to about 50 cm. The alligatored area may or may not be accompanied by distortion in the form of depression, and may occur anywhere on the pavement surface.	
Possible causes:	1. Insufficient pavement strength. 2. Poor base drainage and stiff or brittle asphalt mix at cold temperature.	
Severity:	**Class.**	**Guidelines** (Base on appearance and surface distortion)
	Slight	Alligator pattern established with corners of polygon blocks fracturing
	Moderate	Alligator pattern established with spalling of polygon blocks
	Severe	Polygon blocks begin to lift; may or may not involve potholes.
Density:	*Local:*	Less than 30% of pavement surface affected; distress spotted over localized areas only.
	General:	More than 30% of pavement surface affected; distress spotted evenly over entire length of pavement section.

Maintenance-Rehabilitation Programming System

The general structure of the maintenance-rehabilitation programming system is shown in Figure 4, including the two main subsystems. The entire process has been computerized, and a detailed description, including the various subsystems, is given by Cheetham (5).

The first step in operating the system is to collect the previously noted inventory data. Together with the available maintenance and rehabilitation alternatives and their associated unit costs, analyses are then performed to select the most cost-effective maintenance alternatives. In addition, through analyses of performance and a benefit maximization model, an optimized priority program of rehabilitation is determined. This priority programming method for rehabilitation has been extensively applied and is described by Karan and others (6-9). Typical outputs of the system are provided in the case illustration given later in this paper. As an alternative, Cheetham (5) has developed a ranking method, based on cost-effectiveness analysis, for selecting a network priority program of rehabilitation. Although it represents an approximation, it is very efficient with respect to computer time and gives essentially the same results as the optimization method (6-9). But it should be periodically calibrated with an optimization run.

The maintenance programming subsystem analyzes the pavement network one section at a time. Figure 5 outlines the subsystem, which has separate subroutines for the different types of pavements.

The network inputs include the available maintenance alternatives for each pavement type and their associated unit costs, the number of sections in the network, and the year of analysis. The sectional inputs that are read in the main line include the section number, pavement type, PQI, average annual daily traffic (AADT), traffic growth rate, number of lanes, lane width, section length, surface thickness, and drainage condition.

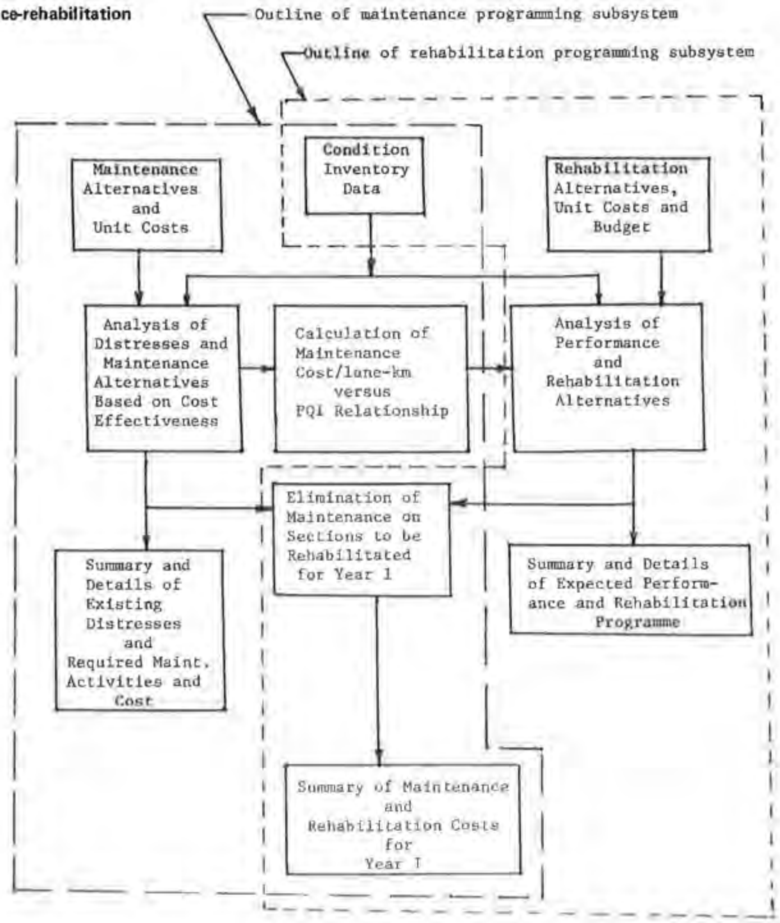
Each section can be analyzed as a whole or, for ease of condition inventory data collection, broken into subsections of constant length called "stations". Once all of the sections in the network have been analyzed, total costs are calculated for

Table 1. Example of treatment alternatives for particular distress type: alligator cracking.

Evaluation		Recommended Maintenance Treatment Alternative	Maintenance Function Classification		Expected Effective Life (years)
Severity	Density		Routine Patrol	Nonpatrol	
Slight	Local	No action			
	General	No action but monitor closely for future development			
Moderate	Local	Spray patch	1004		1
		Cold-mix patch	1001		1
		Hot-mix patch	1001 1002	1002	4
		Hot-mix patch for multilanes		1002	4
	General	Same as above but notify district office of situation and maintain close monitoring			
Severe	Local	Cold-mix patch	1001		0,5
		Hot-mix patch	1001 1002	1002	3
		Excavate, granular and hot-mix patch	1002	1002	7
		Improve drainage (additional)	-[a]	-[a]	
	General	Hot-mix patch for highways with AADT < 2000 and notify district office	1002		2
		Mulching for AADT < 2000		1014	3
		Granular lift and surface treatment for highways with AADT < 2000		1017	4
		Hot-mix patch over selected areas and notify district office for further action for highways with AADT > 2000	1002	1002	3

[a] Contract only.

Figure 4. General structure of maintenance-rehabilitation programming system.



each of the maintenance activities and a summary of the network costs is produced. A maintenance cost versus serviceability relation is then calculated by using regression analysis.

An outline of the maintenance subroutine for flexible pavements is shown in Figure 6. The inputs from the main line include the available maintenance alternatives and their associated unit costs, AADT, number of stations and station length, number of lanes in each station, number of lanes in the section, lane width, and surface thickness. The distress inputs that are read into the subroutines

Figure 5. Basic structure of maintenance programming subsystem.

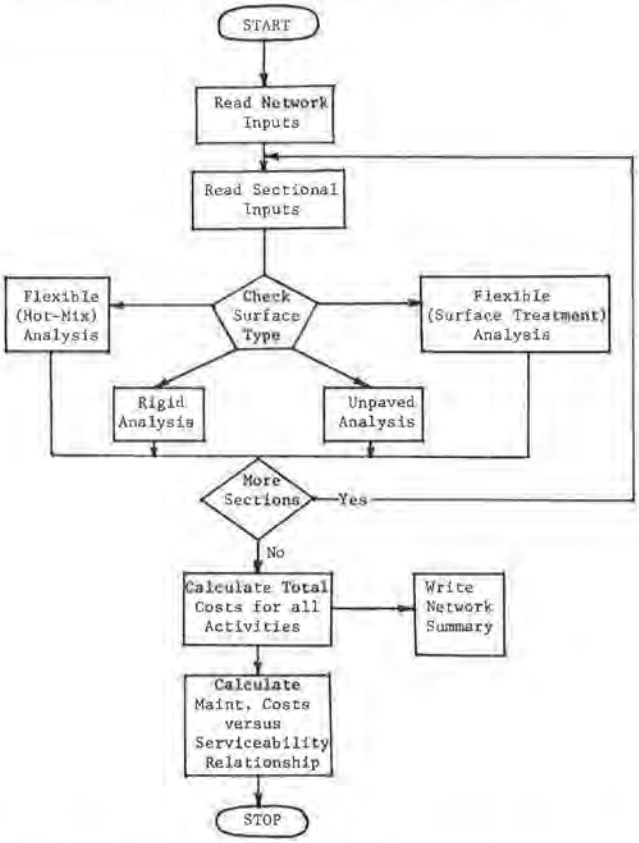
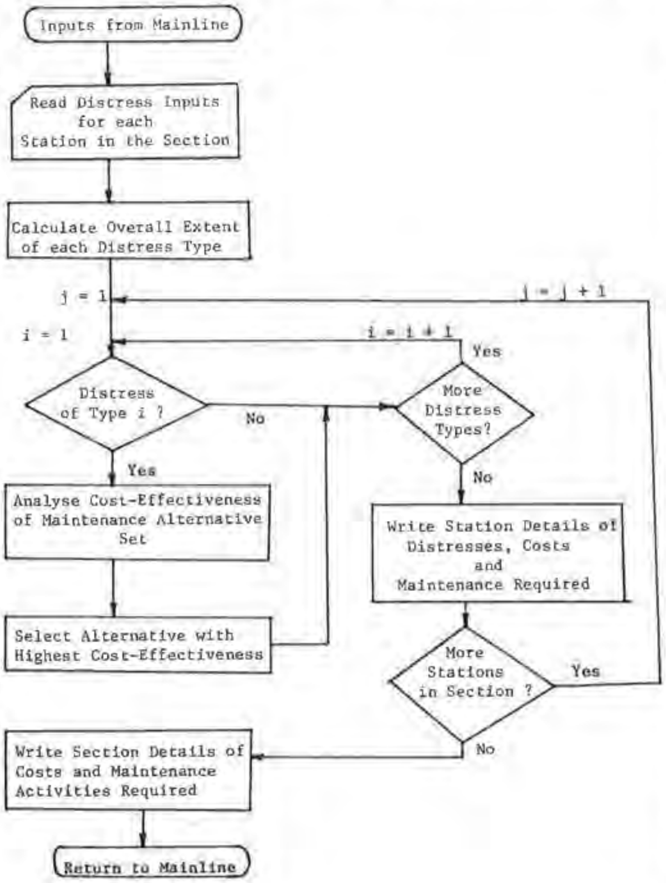


Figure 6. Outline of subroutines for maintenance analysis of flexible pavements.



include two vectors for each station: one that indicates the severity of each distress type and one that gives the extent of each type of distress in terms of an areal percentage.

The stations are then analyzed one at a time, and the most cost-effective alternative is selected for each distress in each station. Details of distresses, required maintenance, and costs are written for each station for the section.

The program considers 12 distinct types of distress for both flexible pavement subroutines (hot mix or asphalt concrete surface and surface treatment). These 12 distresses are subsequently listed in the case example. The areal units used for extent of distress are either percentage area or percentage length, depending on the distress type. Severity codes are also subsequently listed in the case example.

Subroutines for rigid pavements and for unpaved roads are included in the maintenance programming subsystem but are not covered in this paper.

The number and type of maintenance treatment alternatives to be considered vary with pavement type and distress type. These are described in detail elsewhere (3,5); an example of the alternatives available for alligator cracking has been given in Table 1.

The rehabilitation programming subsystem uses a rationally based ranking factor for prioritization but retains the performance prediction method described by Karan and others (6-9). The ranking factor was developed from a "calibration" procedure that used the optimization results of various network analyses carried out for Canadian and U.S. jurisdictions according to the method of Karan and others (6-9). This method includes benefit maximization through a linear programming formulation. The ranking factor is a function of minimum acceptable serviceability level, initial serviceability level, AADT, and length of section. It maximizes average network serviceability over the program period. Figure 7 shows the general structure of the rehabilitation programming subsystem.

The rehabilitation subsystem uses a Markov chain model of order 1 (8) to model the performance. The model describes the pavement as existing in a current "state", and subsequently the pavement undergoes transitions to lower states during successive time periods. The state is defined by the level of serviceability, and the time increment used is one year. Since the transition from one state to another is a stochastic process, the model requires transition probability matrices to function.

The model also requires the definition of pavement classes in order to include factors that affect performance, such as pavement thickness, subgrade strength, and traffic volume. The program defines 18 pavement classes, each of which requires a different transition probability matrix. The 18 classes are defined by three levels of pavement thickness (equivalent granular thickness for the structure), three levels of traffic (AADT), and two levels of subgrade type (strong and weak). The transition probability matrices have been developed under the assumption that "routine" maintenance is applied to the pavement.

Transition probability matrices are also required for each of the rehabilitation alternatives.

The rehabilitation programming subsystem has the capability of analyzing six different rehabilitation alternatives. These include three thicknesses of overlay, reconstruction, upgrading, and surface treatment. In addition, the program has the capability of analyzing sections with paved or unpaved shoulders and the addition of paved shoulders to sections that do not have them. The program allows

Figure 7. General structure of rehabilitation programming subsystem.

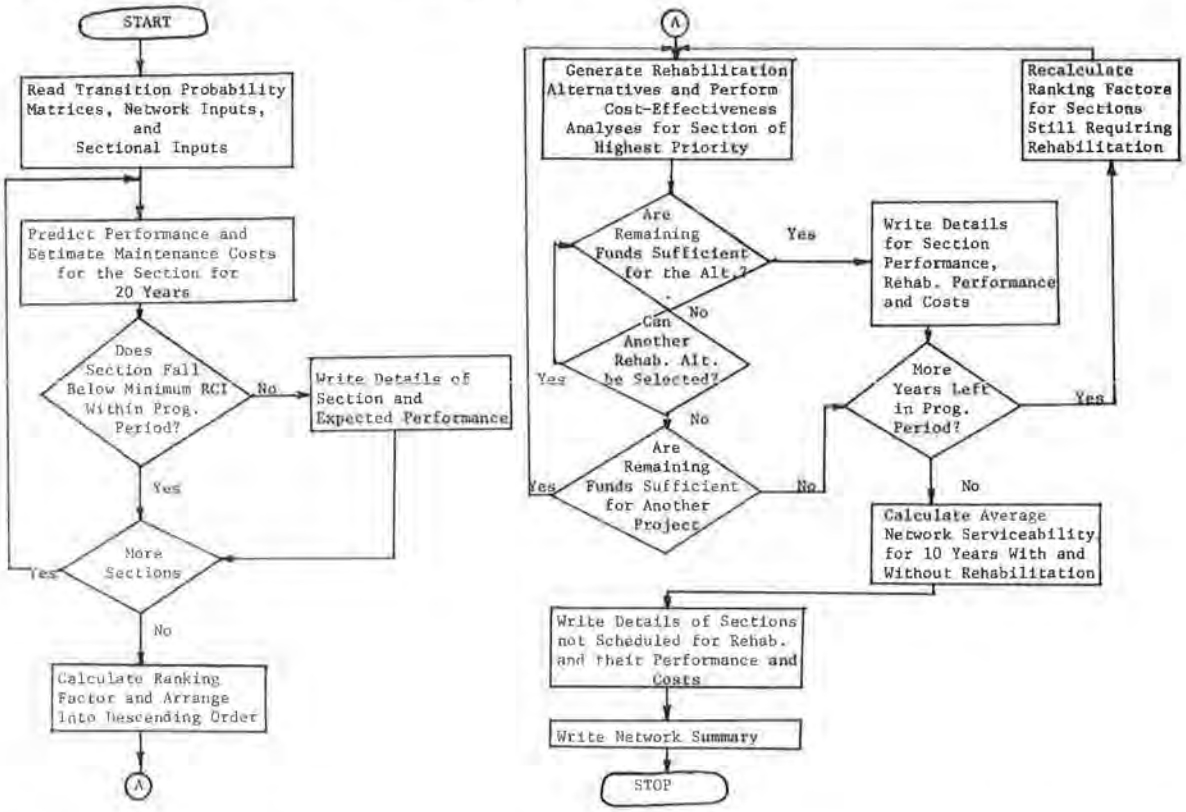
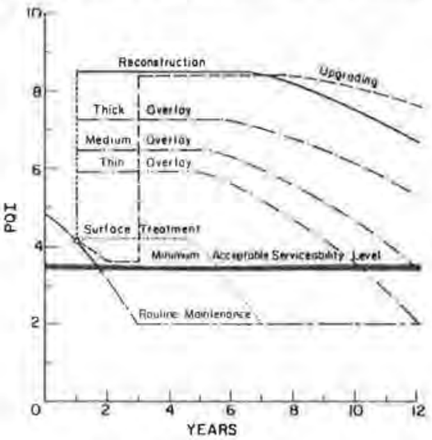


Figure 8. Typical performance curves for rehabilitation alternatives.



three reconstruction designs for different levels of traffic.

The upgrading alternative is a relatively new innovation and is based on the idea of "betterments" used in some agencies. This is a form of staged rehabilitation that, because of various constraints, can only be done on certain sections. Some agencies use a form of upgrading on certain rural sections that have a low level of serviceability but cannot be rehabilitated by using one of the usual alternatives because of limited funds. The upgrading or betterment strategy involves work over approximately three years, the first two of which are relatively low cost. This strategy involves shoulder and drainage work in the first year, the application of a few inches of granular material and a surface treatment in the second, and an overlay in the third year. Since so much new material is added to the structure, this alternative can only be considered on sections that do not have height limitations due to curbs or utility services.

The sectional inputs to the program indicate which alternatives are to be considered for that section. Each desired strategy is then analyzed, and its subsequent performance and associated costs are predicted. Figure 8 shows typical performance curves for the six basic alternatives.

After the performance analysis of each rehabilitation alternative, the cost-effectiveness is determined. This is done by calculating the present worth of all of the costs involved with each alternative; i.e., the maintenance costs plus capital costs of rehabilitation. Then the area between the two performance curves (performance for the rehabilitation and performance for only routine maintenance) is calculated as a measure of the associated benefits. The cost-effectiveness of a given alternative can then be calculated by dividing the area between the curves by the present worth of the costs. The alternative with the highest cost-effectiveness is then selected for implementation since it makes the best use of the available funds.

In the case where insufficient funds remain in the budget to complete the project, other alternatives are compared with the remaining funds. Since budget estimates are usually approximate, a project will still be programmed for implementation if the remaining funds cover 95 percent of the cost. If sufficient funds remain to complete a rehabilitation project on a different section but not on the section being considered as top priority at the time, then other sections are considered and the process is repeated.

The programming subsystem can operate in one of two modes, depending on the number of budgets used by the particular agency. If two separate budgets are used (one for maintenance and one for rehabilitation), then the maintenance costs, although used in the cost analyses, are not subtracted from the total budget. In the case of a single budget, the maintenance costs are subtracted from the budget.

Two modes of operation are also available for the use of any remaining funds in the budget after projects are scheduled for rehabilitation in a given year. Since fractional projects are not considered in the system (as in linear programming), there is usually some amount of money remaining for a given year's budget. One mode of operation allows the remaining funds to be added to the budget for the following year, and the other mode simply leaves the remaining funds as extra. This choice of mode again depends on the agency involved and exists because of the approximate nature of future budgets.

CASE ILLUSTRATION OF THE SYSTEM

The City of Cambridge in Ontario provides a good case illustration for the maintenance-rehabilitation programming system. The arterial street network was subdivided into 100 sections (see Figure 9 for typical listings), and a condition survey was conducted according to Ontario procedures (1). Other field measurements included a deflection survey, using a Dynaflect, at an average of 6 tests/km, a roughness survey using the ARAN unit (10), and cores, at a minimum of one per section, for structural composition and subgrade characteristics. In addition, data were acquired on traffic volumes, unit costs for the various maintenance and rehabilitation alternatives, etc. Figure 10 shows an example of the input data, and the two tables below provide unit cost data used in the analysis:

Activity	Unit Cost ($/unit)
Spray patch	1.15/m^2
Sand or chip seal	1450.0/lane-km
Hot-mix patch	
Manual	1.75/m^2
Machine	1.20/m^2
Cold-mix patch	
Manual	2.35/m^2
Machine	1.65/m^2
Deep patch	6.80/m^2
Crack seal	0.60/linear m
Surface treatment	1574.50/lane-km

Alternative	Design	Unit Cost ($/lane-km)
Overlay		
1	19-mm dense AC	7 686.00
2	38-mm HL3 AC	8 198.40
3	51-mm HL4 AC	8 820.60
Reconstruction	38-mm HL3 AC, 51-mm HL6 AC, 152-mm granular A, 305-mm granular B	56 766.60
Surface Treatment	Single application, 6-mm stone, emulsion binder	1 574.50

The system requires only entry of the inventory data and selection of various options (i.e., budget

Figure 9. Section identification.

SEC.NO.	NAME	FROM	TO	LENGTH M
5	AVENUE ROAD	1 MILE EAST OF FRANKLIN BLVD.	TOWN LINE ROAD	1060
6	AVENUE ROAD	FRANKLIN BLVD.	1 MILE EAST OF FRANKLIN BLVD.	1620
|	|	|	|	|
|	|	|	|	|
|	|	|	|	|
54	GLENMORRIS ST.	FIFTH AVE.	CULHAM DR.	200
55	GLENMORRIS ST.	CULHAM DR.	CITY LIMITS	1020
59	FIRST AVE.	GLENMORRIS ST.	BORDEN ST.	500
|	|	|	|	|
|	|	|	|	|
|	|	|	|	|
403	NORFOLK AVE.	BROCKLYN RD.	JARVIS ST.	400
404	NORFOLK AVE.	BROCKLYN RD.	SAMUELSON ST.	730
405	ELGIN ST. NORTH	SAMUELSON RD.	AVENUE RD.	1020

Figure 10. Section input data for analysis.

SECTION NO.	PVT. THK.[1]	SUBG. TYPE[2]	AADT	TGR[3]	LANES	LENGTH (M)	PQI[4]	MINPQI[5]
5	28	1	600	1.05	2	1060	4.3	4.0
6	30	1	770	1.05	2	1620	5.9	4.0
|	|	|	|	|	|	|	|	|
|	|	|	|	|	|	|	|	|
|	|	|	|	|	|	|	|	|
54	38	1	1700	1.01	2	200	6.0	4.0
55	28	1	1700	1.01	2	1020	5.8	4.0
59	20	1	610	1.005	2	500	3.7	4.0
|	|	|	|	|	|	|	|	|
|	|	|	|	|	|	|	|	|
403	20	1	2660	1.01	2	400	6.0	4.0
404	25	2	2090	1.01	2	780	4.3	4.0
405	20	1	6880	1.02	2	1020	7.0	4.0

NOTES:
1 : Pavement thickness: total equivalent granular thickness of structure (cm.)
2 : Subgrade Type: 1 = strong; 2 = weak
3 : Traffic Growth Rate: i.e. 1.05 means 5 percent
4 : Pavement Quality Index: Scale of 0 to 10 (Ref. 4)
5 : Minimum Acceptable PQI

limits); operation of the entire system is automated and includes the following output reports:

1. Section-by-section summary of maintenance and rehabilitation costs--Figure 11 shows the final results for the case application, for 1980, where the most cost-effective maintenance program would cost \$22 444 and the optimum rehabilitation program would cost \$100 969. This latter number represents the maximum budget available for rehabilitation.
2. Overall network maintenance summary--Figure 12 shows the results for the case application, for 1980, for the situation of no rehabilitation expenditures. It may be noted for this situation that the cost of the most cost-effective maintenance program would rise to \$27 667 compared with the \$22 444 in Figure 11. The larger sum is of course due to maintenance being required in 1980 on all sections.
3. Detailed record of section distresses and maintenance requirements--Figure 13 shows an example for section 55 in the network of the case application. The record of distresses comes directly from the condition survey, and the maintenance shown is the most cost-effective. The recording of distresses and costs by station, within the section, allows persistent problem areas to be identified and simplifies the collection of distress data in the condition survey.
4. Detailed record of section rehabilitation--Figure 14 shows an example for section 404. The optimum rehabilitation alternative is overlay 3 (51 mm), in 1981, for the budget level used. It should be noted that rehabilitation may be performed when the section reaches its minimum acceptable PQI level (i.e., in the year of need) or it may be accelerated or delayed. This timing is determined through use of the optimization model, which also determines the particular alternative. Both depend on the budget level specified for the optimization. Figure 14 also lists the expected PQI for 10 years for the section for two situations: (a) rehabilitation carried out according to schedule and with the alternative specified and (b) no rehabilitation (i.e., application of regular maintenance only). The latter case, as expected, would result in the section deteriorating to a PQI level of 2.5 at the end of 10 years. These expected performances are based on the performance prediction models incorporated in the system.

A summary of the five-year recommended priority program of rehabilitation, by section and rehabilitation type, is provided in Table 2.

Figure 15 compares the recommended sections of Table 2 with the needs (i.e., when the sections reach or fall below the minimum acceptable PQI level). For example, section 404 has been "accelerated" for rehabilitation (i.e., rehabilitation does not become a need until 1982 but the section is

Figure 11. Maintenance-rehabilitation cost summary for 1980.

```
THE SECTION TYPES ARE      1 :  FLEXIBLE (HOT-MIX SURF.)
                           2 :  FLEXIBLE (SURFACE-TREAT. SURF.)
                           3 :  RIGID (PORTLAND CEMENT CONCRETE)
                           4 :  UNPAVED (GRAVEL)

SECTION        TYPE        PQI        MAINT. COST       REHAB. COST
-------        ----        ---        -----------       -----------
   5             2         4.3           122.
   6             2         5.9           508.
   |             |          |             |
   |             |          |             |
  54             1         6.0           546.
  55             1         5.8          1644.
  59             1         3.7           723.
   |             |          |             |
   |             |          |             |
 403             1         6.0            70.
 404             1         4.3          1303.
 405             1         7.0           758.
 406             1         7.0             0.
 407             1         2.2                             9879.
 408             1         5.0            15.
 409             1         4.4                            10938.

                     TOTAL COSTS         22444.           100969.
```

Figure 12. Network maintenance cost summary for 1980 for no rehabilitation.

```
NO. OF SECTIONS =  100        ( 53.6 KM  )

NO. OF SECTIONS BY SECTION TYPE :
     FLEXIBLE, HOT-MIX SURFACE :             93         46.3 KM
     FLEXIBLE, SURFACE-TREATMENT SURF.  :  7             7.3 KM

TOTAL EXPECTED MAINTENANCE COST =  27667.59

NOTE : THIS TOTAL INCLUDES ONLY ROUTINE MAINTENANCE PERFORMED ON
       THE PAVEMENT SURFACE.  IT DOES NOT INCLUDE WINTER, BRIDGE,
       SIGNS OR OTHER MAINTENANCE ACTIVITIES.

MAINTENANCE COST SUMMARY BY ACTIVITY FOR THE NETWORK :

          ACTIVITY                              EXPECTED COST

 -------------------------------------------------------------
    SPRAY PATCH                                    4282.70
    SAND- OR CHIP-SEAL                              788.80
    HOT-MIX PATCH (MANUAL)                        18959.87
    HOT-MIX PATCH (MACHINE)                        2197.77
    COLD-MIX PATCH (MANUAL)                         428.85
    CRACK SEAL                                     1009.80
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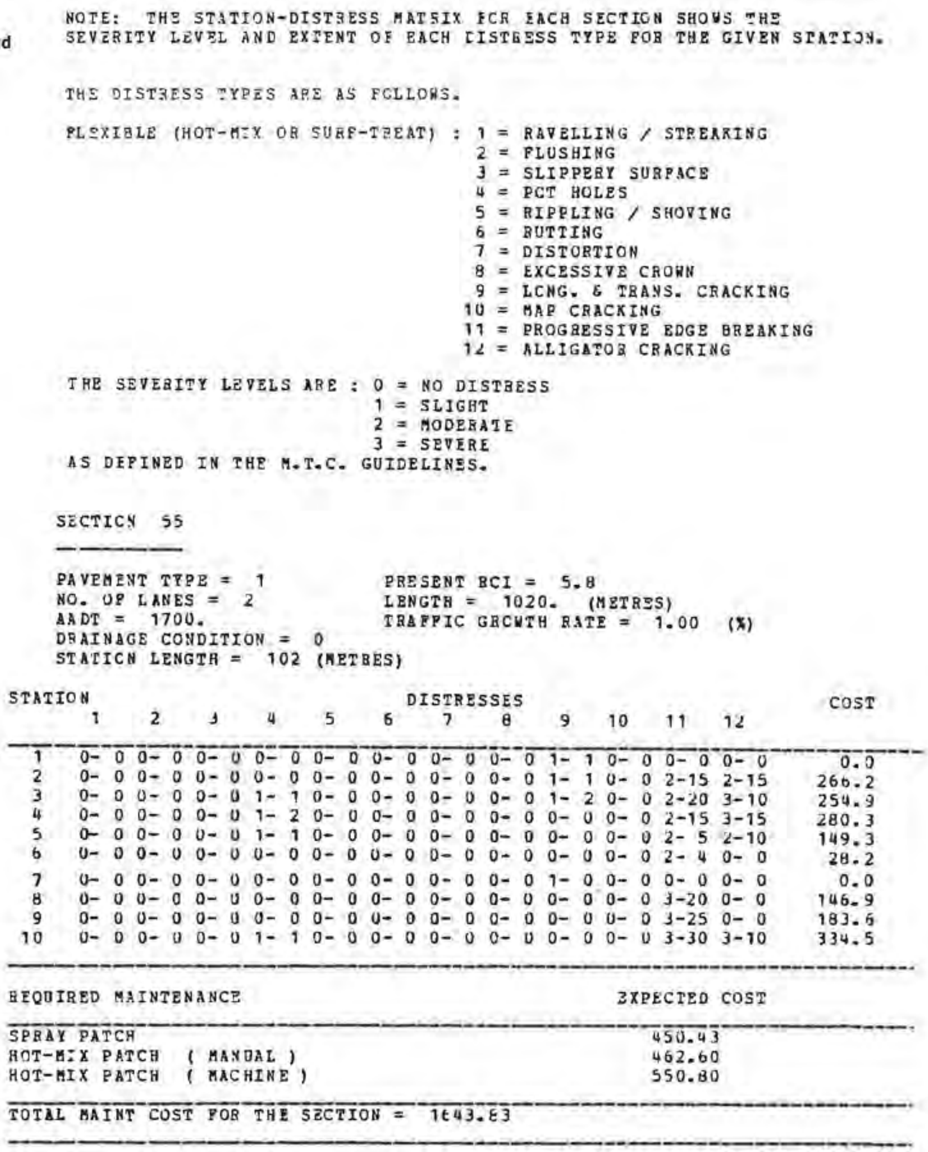
Figure 13. Example of detailed record of section distresses (from condition survey) and maintenance required for 1980.



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NOTE:  THE STATION-DISTRESS MATRIX FOR EACH SECTION SHOWS THE
SEVERITY LEVEL AND EXTENT OF EACH DISTRESS TYPE FOR THE GIVEN STATION.

THE DISTRESS TYPES ARE AS FOLLOWS.

FLEXIBLE (HOT-MIX OR SURF-TREAT) :  1 = RAVELLING / STREAKING
                                    2 = FLUSHING
                                    3 = SLIPPERY SURFACE
                                    4 = POT HOLES
                                    5 = RIPPLING / SHOVING
                                    6 = RUTTING
                                    7 = DISTORTION
                                    8 = EXCESSIVE CROWN
                                    9 = LONG. & TRANS. CRACKING
                                   10 = MAP CRACKING
                                   11 = PROGRESSIVE EDGE BREAKING
                                   12 = ALLIGATOR CRACKING

 THE SEVERITY LEVELS ARE : 0 = NO DISTRESS
                           1 = SLIGHT
                           2 = MODERATE
                           3 = SEVERE
 AS DEFINED IN THE M.T.C. GUIDELINES.

SECTION  55
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PAVEMENT TYPE =  1                PRESENT RCI =  5.8
NO. OF LANES =  2                 LENGTH =  1020.  (METRES)
AADT =  1700.                     TRAFFIC GROWTH RATE =  1.00  (%)
DRAINAGE CONDITION =  0
STATION LENGTH =  102 (METRES)

STATION                           DISTRESSES                              COST
        1     2     3     4     5     6     7     8     9    10    11    12
------------------------------------------------------------------------------
   1   0- 0  0- 0  0- 0  0- 0  0- 0  0- 0  0- 0  0- 0  1- 1  0- 0  0- 0  0- 0    0.0
   2   0- 0  0- 0  0- 0  0- 0  0- 0  0- 0  0- 0  0- 0  1- 1  0- 0  2-15  2-15  266.2
   3   0- 0  0- 0  0- 0  1- 1  0- 0  0- 0  0- 0  0- 0  1- 2  0- 0  2-20  3-10  254.9
   4   0- 0  0- 0  0- 0  1- 2  0- 0  0- 0  0- 0  0- 0  0- 0  0- 0  2-15  3-15  280.3
   5   0- 0  0- 0  0- 0  1- 1  0- 0  0- 0  0- 0  0- 0  0- 0  0- 0  2- 5  2-10  149.3
   6   0- 0  0- 0  0- 0  0- 0  0- 0  0- 0  0- 0  0- 0  0- 0  0- 0  2- 4  0- 0   28.2
   7   0- 0  0- 0  0- 0  0- 0  0- 0  0- 0  0- 0  0- 0  1- 0  0- 0  0- 0  0- 0    0.0
   8   0- 0  0- 0  0- 0  0- 0  0- 0  0- 0  0- 0  0- 0  0- 0  0- 0  3-20  0- 0  146.9
   9   0- 0  0- 0  0- 0  0- 0  0- 0  0- 0  0- 0  0- 0  0- 0  0- 0  3-25  0- 0  183.6
  10   0- 0  0- 0  0- 0  1- 1  0- 0  0- 0  0- 0  0- 0  0- 0  0- 0  3-30  3-10  334.5
------------------------------------------------------------------------------

REQUIRED MAINTENANCE                                   EXPECTED COST
------------------------------------------------------------------------------
SPRAY PATCH                                            450.43
HOT-MIX PATCH   ( MANUAL )                             462.60
HOT-MIX PATCH   ( MACHINE )                            550.80
------------------------------------------------------------------------------
TOTAL MAINT COST FOR THE SECTION =  1643.83
------------------------------------------------------------------------------
```
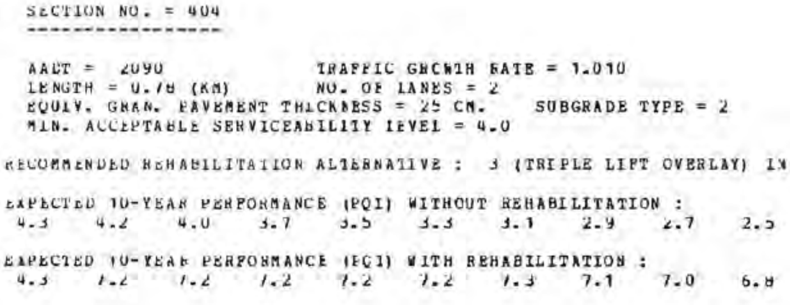

Figure 14. Example of detailed section rehabilitation requirements for 1981.



```
  SECTION NO. = 404
  -----------------

  AADT =  2090                 TRAFFIC GROWTH RATE = 1.010
  LENGTH = 0.78 (KM)           NO. OF LANES = 2
  EQUIV. GRAN. PAVEMENT THICKNESS = 25 CM.    SUBGRADE TYPE = 2
  MIN. ACCEPTABLE SERVICEABILITY LEVEL = 4.0

RECOMMENDED REHABILITATION ALTERNATIVE :  3 (TRIPLE LIFT OVERLAY) IN 1981

EXPECTED 10-YEAR PERFORMANCE (PQI) WITHOUT REHABILITATION :
 4.3    4.2    4.0    3.7    3.5    3.3    3.1    2.9    2.7    2.5

EXPECTED 10-YEAR PERFORMANCE (PQI) WITH REHABILITATION :
 4.3    7.2    7.2    7.2    7.2    7.2    7.3    7.1    7.0    6.8
```

scheduled for rehabilitation in 1981). By comparison, other sections, such as section 59, have had their rehabilitation delayed. These accelerations or deferrals, and the actual rehabilitation type specified in Table 2, are a function of the budget level used, among other factors such as traffic volume, and are determined by the optimization model in the system. Higher budget levels would result in fewer deferrals, to some point where all the needs could be satisfied in the year in which they occur. Most, if not all, highway agencies, however, are faced with limited budgets.

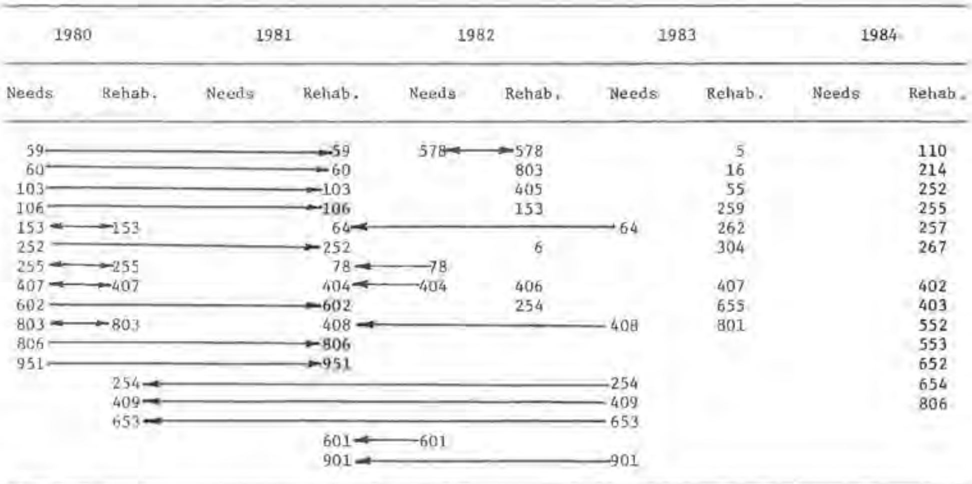
Figure 16 shows the results of a budget analysis for the case illustration. Two budget levels have been chosen: $100 000/year for rehabilitation and $0/year for rehabilitation. The first level represents that used in the analysis and would result in the program given in Table 2. With such a budget, the network would remain at a nearly constant PQI of 7 over the first 5 years and this would drop only marginally over the last 5 years. However, with no funds available at all for rehabilitation, the average PQI of the network will drop to near 5 at the end of 10 years. A histogram of the distribution of

Table 2. Recommended sections and rehabilitation alternatives for Cambridge, Ontario, network.

1980		1981		1982		1983		1984	
Section	Alternative	Section	Alternative	Section	Alternative	Section	Alternative	Section	Alternative
153	3	59	3	6	3	5	3	110	3
254	1	60	3	153	3	16	3	214	3
255	3	64	3	254	3	55	5	252	3
407	3	78	3	405	1	259	3	255	3
409	3	103	3	406	1	262	5	257	5
653	3	106	1	578	3	304	3	267	3
803	3	252	3	803	3	407	3	402	3
		404	3			655	3	403	5
		408	3			801	5	552	3
		601	3					553	3
		602	3					652	5
		806	3					654	3
		901	3					806	3
		951	3						

Note: Alternative 1 = 19-mm dense AC overlay, alternative 3 = 51-mm HL4 AC overlay, alternative 5 = surface treatment (single application, 6-mm stone, emulsion binder).

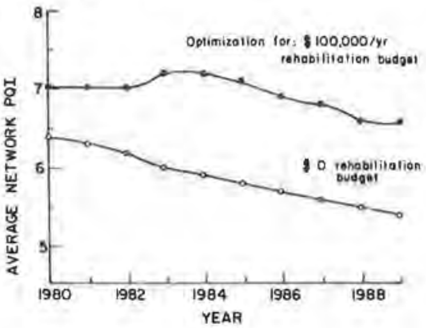
Figure 15. Comparison of recommended sections and needs.



NOTES:

Needs: sections which fall below minimum acceptable PCI level.
Rehab: sections recommended for rehabilitation.
→: rehabilitation action delayed
←: rehabilitation action advanced
↔: rehabilitation action same year.

Figure 16. Analysis of rehabilitation budget level for 53.6-km network in Cambridge, Ontario.



PQIs at the end of 10 years would show 38 sections, or about 35 percent of the mileage, at or below the minimum PQI level of 4.0. The use of computer graphics to illustrate quickly the effects of various budget options (such as the two shown in Figure 16) and the associated accumulation of deficient mileage (i.e., at or below the minimum PQI level) is a part of the rehabilitation subsystem and is more adequately illustrated elsewhere (4).

PERIODIC UPDATING

Although the system described in this paper can produce a 5- or 10-year program of work, periodic updating, preferably on an annual basis, is recommended. This is especially relevant for the maintenance program, whereas the rehabilitation update could be biannual.

Such updating involves two major aspects: update of the inventory and update runs of the maintenance and rehabilitation programs. The basic reasons for updating the inventory include the variations possible in predicting performance. The magnitude of uncertainty in predicting performance of course increases further along in the program period. Even next year's predictions of serviceability can be in considerable error if some unusual weather has occurred and/or if traffic volumes are significantly different from those estimated. Similarly, updates of the maintenance and rehabilitation programs are necessary (a) if the inventory reveals significant differences from earlier predictions, (b) if there have been unexpected changes in unit costs, and (c) if the actual prices for last year's projects resulted in substantially more or less work being done than originally programmed.

SUMMARY AND CONCLUSIONS

This paper is based on the premise that maintenance and rehabilitation programming for pavement networks should be integrated in order to achieve the best possible total value for total funds available. A working method for accomplishing this objective has been presented and illustrated with a case study.

The working method starts with a common inventory of field measurements (e.g., condition survey, roughness, and structural adequacy) and acquired data (e.g., traffic and unit costs). Separate subsystems for maintenance programming and rehabilitation programming are included. These subsystems evaluate various maintenance treatment alternatives, for different distress types, densities, and severities, and rehabilitation alternatives for the various sections for the various years of the program period. The outputs are optimized programs of maintenance and rehabilitation whose total cost does not exceed the budget limit.

The case example, which uses the arterial street network of a small city, provides a quantitative illustration of the method. It also shows how the method can be used to test the effects of different budget levels on the future average serviceability of the network.

Finally, it is recommended that periodic updates of the maintenance and rehabilitation programs be carried out. This includes updating of the inventory.

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Arizona Pavement Management System: Phase 2--Verification of Performance Prediction Models and Development of Data Base

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A pavement management system has been defined as "the systematic development of information and procedures in optimizing the design and maintenance of pavements". Research conducted to verify and adjust performance prediction models (equations) developed during the course of research on a pavement management system in Arizona is described. The verification process involved testing models against real data and determining the correlation. Appropriate adjustments were made to enhance the final predictions. Results of this work indicate that the prediction models can reasonably predict the future ride and cracking condition for newly constructed, in-service, and overlaid asphaltic concrete pavements. The ability to predict future ride and cracking gives Arizona a powerful planning and programming tool.

A pavement management system (PMS) has been defined as "the systematic development of information and procedures necessary in optimizing the design and maintenance of pavements" (1). Implementation of a PMS within the Arizona Department of Transportation (ADOT) has involved three phases:

1. Phase 1--Develop a program to optimize the design of new construction and major maintenance completed by Woodward-Clyde Consultants in 1976 (1);
2. Phase 2--(a) Verify prediction models with actual data and create a computerized data base, and (b) develop a functional PMS within ADOT (accomplished by ADOT staff by March 1981); and
3. Phase 3--Develop a network optimization system (developed by Woodward-Clyde Consultants and tested by ADOT staff).