Development and Implementation of a New Rehabilitation Information and Priority Programming System (RIPPS)

M. A. KARAN, R. C. G. HAAS, A. CHEETHAM, T. J. CHRISTISON, and S. M. KHALIL

ABSTRACT

In November 1980 the province of Alberta (Alberta Transportation) initiated a project to develop and implement a pavement management system. Stage 1 involved the design and implementation of a pavement information and needs system (PINS), which was completed in October 1982. Stage 2 involved the design and implementation of a rehabilitation information and priority programming system (RIPPS), which was completed in June 1983. PINS includes the use of recursive performance models for predicting future riding comfort index, structural adequacy index, and visual condition index. These parameters are also combined into a pavement quality index to provide an overall measure of performance. The performance predictions are used to identify the current and future needs for rehabilitation improvements for each inventory section in the network. RIPPS involves the selection of candidate rehabilitation alternatives for each section, so that economic and performance analyses of each alternative for each possible implementation year can be conducted. A heuristic procedure has been developed as a priority programming model that employs marginal cost-effectiveness analyses. The model can be operated in two modes: (a) cost minimization (given performance constraints), and (b) effectiveness maximization (given annual budget constraints). The cost minimization method produces a program of rehabilitation improvements and the required annual budgets that will meet the desired level of network performance. The effectiveness maximization method produces a program of rehabilitation improvements and the resulting network performance that meets the available funds. In this paper an overview of PINS is given, and the major components of RIPPS and its development are described. Sample outputs are provided to illustrate the results obtained from the two modes.

One of the larger highway networks among states and provinces in North America is in Alberta. It has approximately 7,000 miles of paved primary highways and approximately 2,000 miles of paved secondary roads. Over the past decade the system has been expanding at an average rate of 200 miles per year. This represents a substantial investment of many millions of dollars, and like any other investment, it requires good management.

Realizing that pavement management is the process by which this investment can properly be managed, Alberta Transportation initiated a project in November 1980 to develop and implement a pavement management system (PMS) for the province.

In the first phase of the project a comprehensive plan for the project was developed (1). This was carried out as a planning project and it identified six successive, stand-alone stages for the overall, total PMS development and implementation project. These stages, which are briefly summarized in Figure 1, considered Alberta Transportation's goals and objectives, organizational structure, current practices, manpower and equipment resources, and financial constraints.

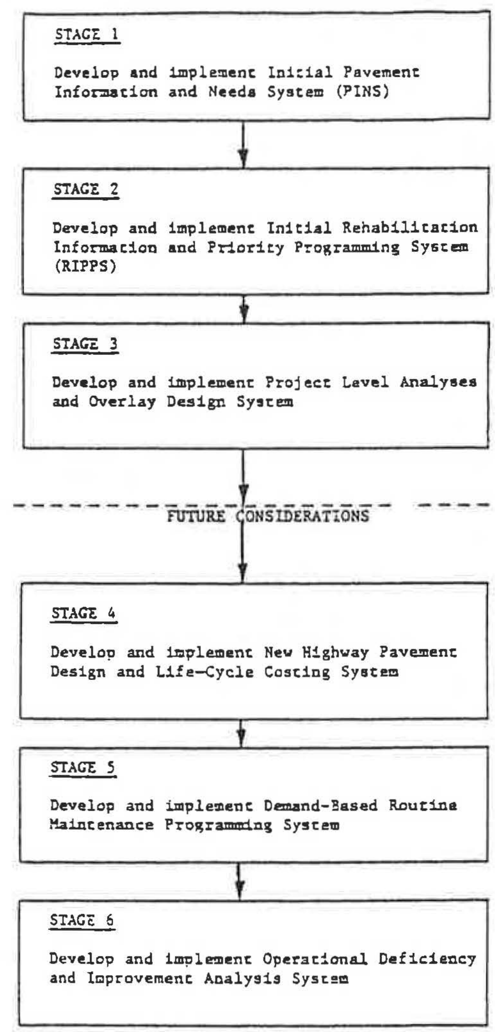


FIGURE 1 Staging of the project.

Stages 1 and 2 of the project, which were identified as the development and implementation of a pavement information and needs system (PINS) and a rehabilitation information and priority programming system (RIPPS), have been completed and implemented. In this paper an overview of PINS, which is described in detail elsewhere (2,3), is given, and the major components of RIPPS, including its subsystems and outputs, are described.

STAGE 1: PINS

The overall objective of Stage 1 was to produce a computerized system for determining the status of the highway network as well as pavement rehabilitation needs. This is the PINS.

PINS processes pavement management data from the pavement data base currently available in Alberta Transportation and generates for immediate and future use of department personnel the following items:

1. Present status of the network in terms of pavement quality index (PQI) and its components of structural adequacy index (SAI), riding comfort index (RCI), and visual condition index (VCI);
2. Remaining service life (in structural or serviceability terms or both) of each section in the network, based on the performance prediction models that have been developed;
3. Pavement improvement needs ranked with respect to PQI and the individual components of RCI, SAI, and VCI; and
4. Summary statistics (in tabular and graphical forms) of the present status of the highway network and improvement needs for each region.

The PINS program has the capability of first determining the present status of a section in terms of its RCI, SAI, VCI, and PQI parameters, as shown in Figure 2. These analyses can be conducted for every section in the network or in a region or on a highway. Once the analyses are completed for every section, the program produces detailed output for every such section as well as a status report for the network, region, or highway.

The next step in the analysis is to predict the performance for each performance parameter (i.e., RCI, SAI, VCI, and PQI). Prediction models specifically calibrated to Alberta conditions are used in the analysis. The development of these models is described in detail elsewhere (4,5).

Similar to present status analysis, performance prediction and needs analyses can be conducted for every section in the network or in a region or on a highway. The program produces graphical outputs (i.e., performance curves) for every section; it also gives the year in which the parameter will reach its minimum acceptable level. A sample output is shown in Figure 3.

The needs analysis can be conducted over a predetermined programming period, which can be 5, 10, 20, or 30 years. Thus pavement improvement needs (based on RCI, SAI, VCI, or PQI) are established for each year in 5-, 10-, 20-, or 30-year programming periods.

Although PINS does not establish a true priority program (this requires economic analysis and optimization), it does have the capability of ranking the sections in the order of their improvement needs and in terms of each performance parameter. This constitutes the network summary information that PINS produces. Figure 4 shows an example ranking list based on RCI. Also, three-dimensional histograms, like the one shown in Figure 5, are produced so that regions, districts, or highways in Alberta can be compared.

Needs tables are also produced for each performance parameter and for each year in the programming period. Figure 6 shows an example needs table.

In summary, the PINS program developed for Alberta analyzes the data base to (a) determine the present status, (b) predict performance, and (c) establish needs for each performance parameter for each year in the programming period of 5, 10, 20, or 30 years. The results are detailed in tabular form and graphical format for every section. Network summary information is also produced in tabular and graphical formats.

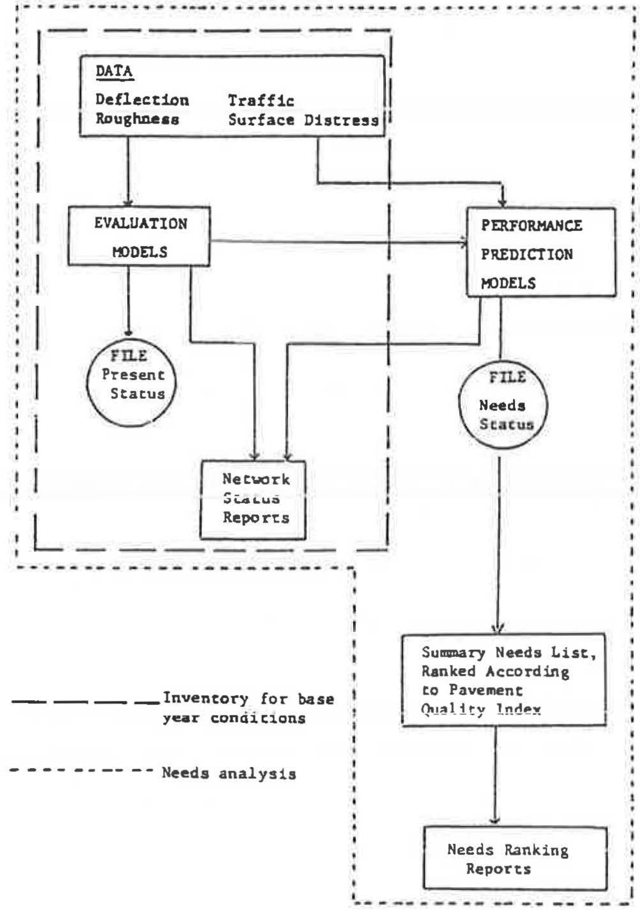


FIGURE 2 General structure of PINS.

The PINS program has been installed on Alberta Transportation's computer facilities and is now fully operational and is being used on a day-to-day basis.

STAGE 2: RIPPS

System Overview

The overall objective of Stage 2 was to produce a computerized system to analyze alternative rehabilitation strategies for the needs identified in PINS and to produce an optimum program of projects to be implemented over the programming period of up to 10 years. This is the RIPPS.

RIPPS basically processes the output of PINS and generates the following for department personnel:

1. Complete engineering and economic evaluation of alternative rehabilitation strategies for every needs section identified in PINS,
2. For a given set of annual budgets it produces an optimum (based on effectiveness maximization) priority program of pavement improvements for a programming period of up to 10 years, and
3. For a given set of annual performance standards it produces an optimum (based on cost minimization) financial plan (i.e., annual budgets required) for a programming period of up to 10 years.

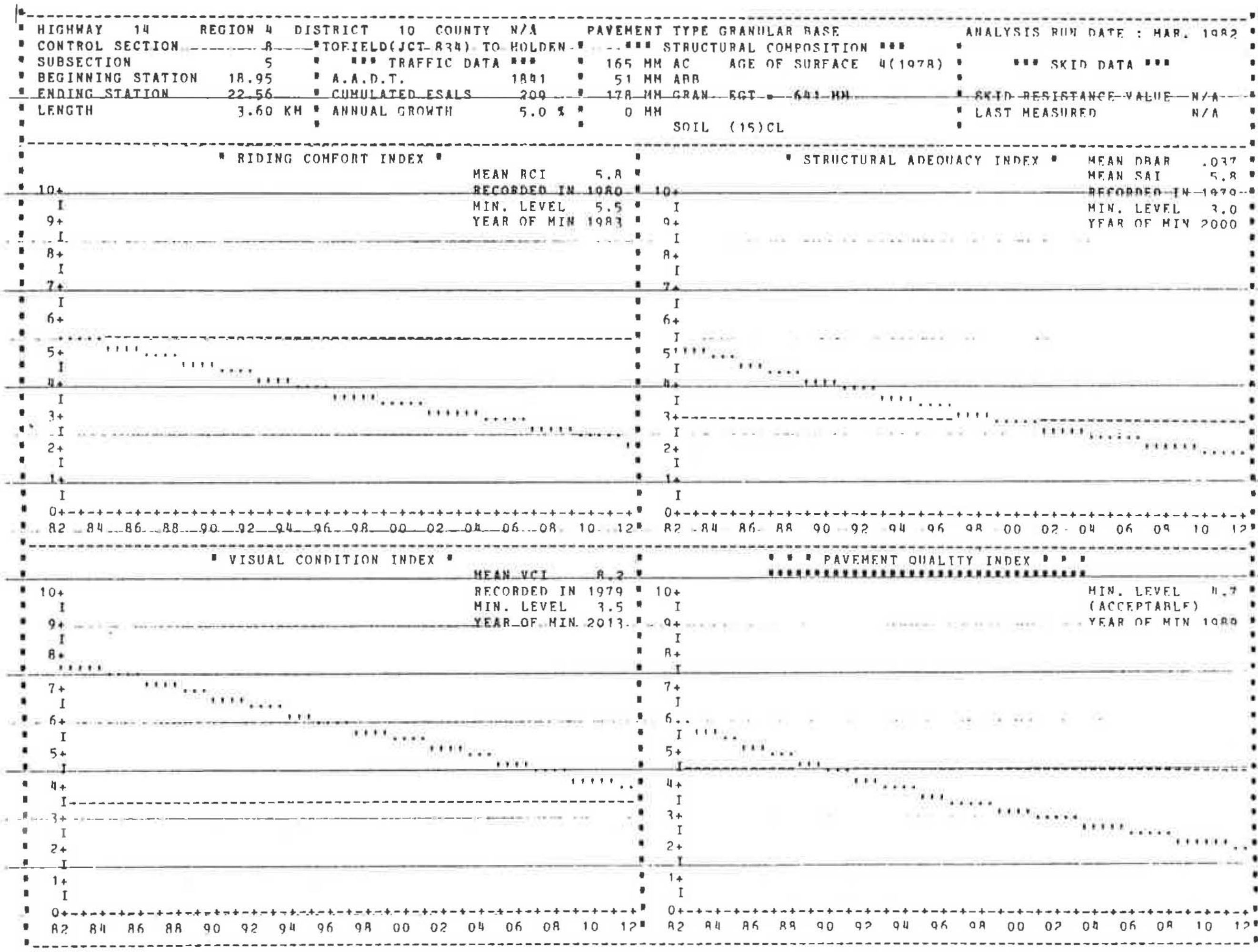


FIGURE 3 Sample of sectional PINS output.

RANK	DISTRICT	CONTROL SECTION		CONTROL SECTION DESCRIPTION	INVENTORY SECTION	BEGIN STATION	END STATION	RCI	VCI	SAI	PQI	SKID
1	4	1-12		JCT 9 TO JCT 21	1	15.48	18.76	0.0	2.7	2.8	1.2	N/A
~~2~~	~~3~~	~~10-08~~		~~ECL DRUMHELLER TO EAST COUL~~	~~1~~	~~0.00~~	~~5.79~~	~~0.0~~	~~1.9~~	~~3.3~~	~~1.2~~	~~N/A~~
3	3	10-08		ECL DRUMHELLER TO EAST COUL	3	6.92	10.23	0.0	2.4	2.5	1.2	N/A
4	3	10-08		ECL DRUMHELLER TO EAST COUL	6	14.50	21.27	0.8	2.5	2.7	1.5	N/A
5	3	10-08		ECL DRUMHELLER TO EAST COUL	2	5.79	6.92	1.2	4.6	3.2	1.8	N/A
6	4	1-14		JCT 21 TO JCT 956	1	0.00	11.44	1.3	2.3	1.1	1.4	N/A
7	4	9-04		JCT 21 TO SCL DRUMHELLER	1	0.00	0.39	1.7	1.4	3.6	1.8	N/A
~~8~~	~~3~~	~~10-08~~		~~ECL DRUMHELLER TO EAST COUL~~	~~4~~	~~10.23~~	~~11.71~~	~~1.8~~	~~4.7~~	~~1.4~~	~~1.8~~	~~N/A~~
9	3	21-14		JCT 9 TO JCT 27	12	25.74	28.32	1.8	5.0	3.9	2.2	N/A
10	4	2A-04		JCT 2 TO JCT 23	5	21.77	22.35	2.5	5.1	4.8	2.8	N/A
11	3	21-14		JCT 9 TO JCT 27	22	41.05	42.64	2.6	1.8	0.1	1.4	N/A
12	3	21-14		JCT 9 TO JCT 27	23	42.64	44.05	2.6	2.6	0.1	1.6	N/A
13	4	2A-04		JCT 2 TO JCT 23	1	0.00	18.78	2.7	0.8	2.0	1.7	N/A
~~14~~	~~3~~	~~21-14~~		~~JCT 9 TO JCT 27~~	~~21~~	~~39.47~~	~~41.05~~	~~2.9~~	~~1.6~~	~~0.0~~	~~1.4~~	~~N/A~~
15	3	21-16		JCT 27 TO JCT 42	2	2.48	3.07	2.9	1.9	0.2	1.5	N/A
16	3	21-16		JCT 27 TO JCT 42	1	0.00	2.48	3.0	1.9	0.1	1.5	N/A
17	4	22-16		JCT 1 TO CREMONA	7	9.28	10.93	3.0	4.2	0.2	1.9	N/A
18	4	2A-10		S.CROSSFIELD TO N.CROSSFIEL	1	0.00	2.04	3.1	1.4	1.9	1.7	N/A
19	3	21-14		JCT 9 TO JCT 27	20	38.54	39.47	3.1	2.0	0.1	1.5	N/A
~~20~~	~~4~~	~~1-10~~	~~WBD~~	~~BLACKFT TR(CAL) TO JCT 9~~	~~3~~	~~7.96~~	~~9.12~~	~~3.2~~	~~4.8~~	~~1.4~~	~~2.4~~	~~N/A~~
21	4	1A-08		ECL CALGARY TO JCT 1	2	13.39	14.64	3.2	5.4	0.2	2.2	N/A
22	4	2-12	SBD	DEWINTON INTERCHANGE	1	27.51	28.40	3.2	5.4	0.6	2.2	N/A
23	3	21-14		JCT 9 TO JCT 27	5	9.98	13.95	3.2	3.7	0.6	1.9	N/A
24	4	27-06		ECL SUNDRE TO JCT 2	3	25.20	26.26	3.2	4.8	0.1	2.1	N/A
25	4	1-12	EBD	JCT 9 TO JCT 21	1	0.00	0.37	3.3	4.2	0.9	2.0	N/A
~~26~~	~~4~~	~~1A-06~~		~~JCT 2A0 TO 16 AVE NW CALGAR~~	~~3~~	~~12.16~~	~~13.63~~	~~3.3~~	~~2.5~~	~~0.3~~	~~1.6~~	~~N/A~~
27	3	21-14		JCT 9 TO JCT 27	10	24.14	24.46	3.3	5.5	4.3	3.3	N/A
28	4	1-10	EBD	BLACKFT TR(CAL) TO JCT 9	6	19.28	26.61	3.4	3.9	0.3	1.9	N/A
29	4	1-12	EBD	JCT 9 TO JCT 21	2	0.37	6.05	3.4	4.2	1.6	2.4	N/A
30	4	22-16		JCT 1 TO CREMONA	6	8.50	9.28	3.4	4.2	0.7	2.0	N/A
31	4	1-12	WBD	JCT 9 TO JCT 21	4	1.83	2.99	3.5	4.0	0.9	2.0	N/A
~~32~~	~~4~~	~~1A-02~~		~~JCT 1 E. CANMORE TO JCT 1X~~	~~4~~	~~18.41~~	~~26.95~~	~~3.5~~	~~5.5~~	~~4.4~~	~~2.5~~	~~N/A~~
33	3	9-06		NCL DRUMHELLER TO JCT 27	2	2.43	2.67	3.5	5.9	4.7	3.6	N/A
34	3	21-14		JCT 9 TO JCT 27	11	24.46	25.74	3.5	5.4	2.8	3.1	N/A
35	4	22-16		JCT 1 TO CREMONA	5	8.09	8.50	3.5	4.2	0.3	2.0	N/A
36	4	1-10	EBD	BLACKFT TR(CAL) TO JCT 9	5	17.36	19.28	3.6	4.9	0.4	2.2	N/A
37	4	1-10	WBD	BLACKFT TR(CAL) TO JCT 9	5	14.01	19.08	3.6	5.3	0.5	2.3	N/A
~~38~~	~~4~~	~~2A-04~~		~~JCT 2 TO JCT 2A~~	~~4~~	~~21.54~~	~~21.77~~	~~3.6~~	~~4.4~~	~~2.2~~	~~2.0~~	~~N/A~~

FIGURE 4 Sample RCI ranking list produced by PINS.

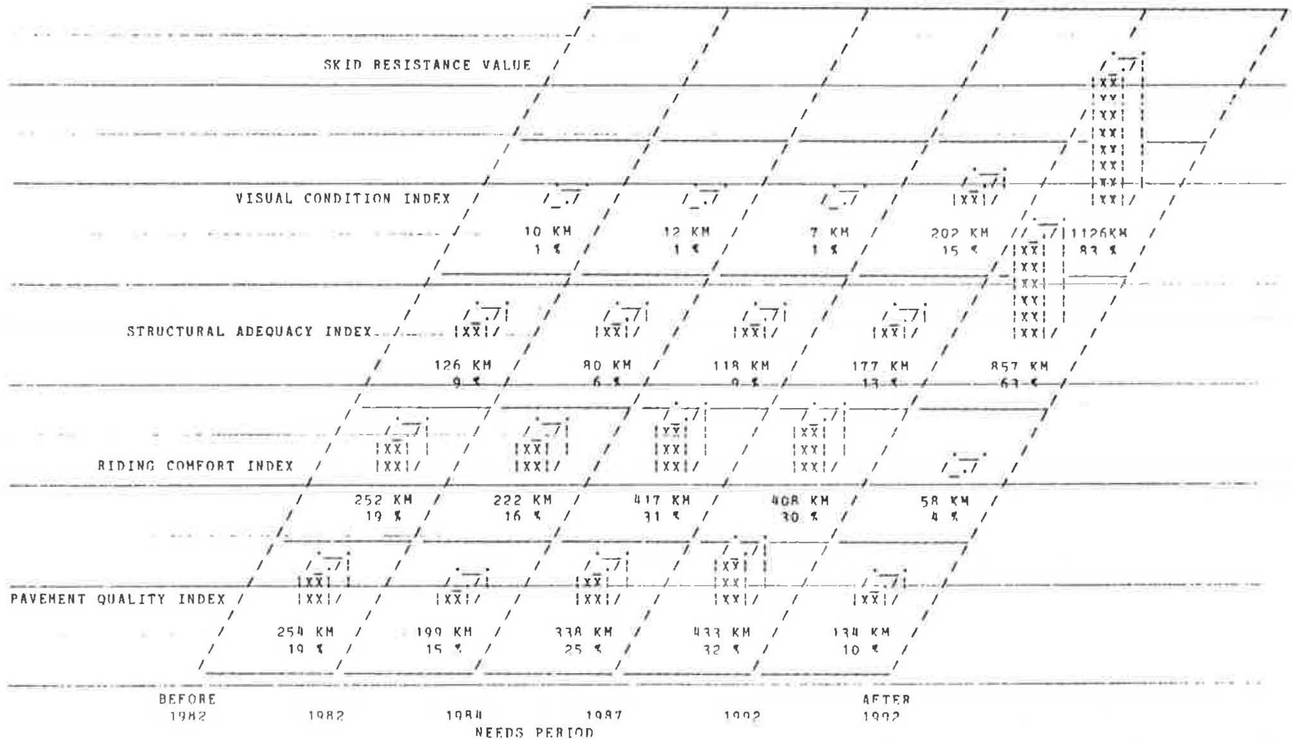


FIGURE 5 Sample three-dimensional histogram produced by PINS.

RIPPS, which is described in more detail by Cheetham et al. (6), is shown in outline form in Figure 7. It has two main subsystems: rehabilitation analysis (REHAB) and priority programming (PRIORITY), also shown in outline form in Figures 8 and 9.

The REHAB subsystem (Figure 8) performs rehabilitation analyses for each section and involves generation of rehabilitation alternatives, performance prediction of the alternatives, economic analyses, and effectiveness analyses.

The PRIORITY subsystem (Figure 9) uses the output files from REHAB and conducts priority or financial

NEEDS

DIST	HWY CONTROL SECTION	CONTROL SECTION DESCRIPTION	INV. SECTION	BEGIN KM.	END KM.	PAVEMENT QUALITY INDEX	RIDING COMFORT INDEX	STRUCTURAL ADEQUACY INDEX	VISUAL CONDITION INDEX	SKID RESISTANCE VALUE
10	14-14	JCT 870 TO JCT 41	4	25.18	29.33	4.6(1985)	5.4	5.7(2000)	3.9(1990)	N/A
10	14-16	JCT 41 TO SASK BDY	11	42.06	44.36	4.4(1984)	5.4	4.3(1995)	4.5(1993)	N/A
10	14-16	JCT 41 TO SASK BDY	12	44.36	44.88	5.0(1987)	5.4	5.3(2002)	5.5(1999)	N/A
10	14-16	JCT 41 TO SASK BDY	13	44.88	44.99	5.0(1987)	5.4	5.3(2002)	5.5(1999)	N/A
10	15- 8	JCT 45 TO JCT 16	1	0.00	6.11	4.7(1985)	5.5	5.9(2004)	4.0(1990)	N/A
10	15- 8	JCT 45 TO JCT 16	6	21.03	22.06	5.2(1989)	5.5	3.5(1990)	7.6(2013)	N/A
10	15- 8	JCT 45 TO JCT 16	7	22.06	25.42	5.1(1987)	5.4	4.3(1998)	6.8(2003)	N/A
10	16-22	ELK ISLAND ACCESS TO JCT 15	4	7.42	8.48	5.1(1988)	5.5	6.4(1998)	4.9(1999)	N/A
10	16-24	JCT 15 TO JCT 36	34	18.09	18.63	6.0(1993)	5.4	7.7(2004)	7.1(2013)	N/A
10	16-30	JCT 41 TO SASK BDY	4	4.28	5.89	4.3(1984)	5.5	3.2(1986)	5.4(1998)	N/A
10	16-30	JCT 41 TO SASK BDY	14	39.68	46.29	4.1(1983)	5.4	3.3(1986)	4.4(1993)	N/A
10	16-30	JCT 41 TO SASK BDY	18	53.63	57.51	5.4(1990)	5.4	6.5(1998)	6.0(2006)	N/A
11	28-10	JCT 36N TO JCT 28A	3	5.34	7.02	3.6(1981)	5.4	2.5(1983)	4.0(1990)	N/A
11	28-16	JCT 41 TO JCT 28A	3	3.04	4.88	4.5(1984)	5.5	2.5(1982)	6.6(2003)	N/A
11	28-16	JCT 41 TO JCT 28A	5	7.61	10.81	4.7(1985)	5.5	3.0(1986)	6.5(2003)	N/A
11	28-16	JCT 41 TO JCT 28A	7	14.46	23.76	5.2(1988)	5.5	4.3(1996)	6.7(2004)	N/A
11	28-20	ARDMORE TO JCT 55 @ COLD L.	16	31.62	32.49	5.3(1989)	5.4	5.4(1999)	6.2(2000)	N/A
11	8A- 4	JCT 28 TO JCT 28	2	15.61	17.22	4.4(1984)	5.4	4.0(1990)	4.7(1995)	N/A
11	8A- 4	JCT 28 TO JCT 28	4	18.99	20.13	4.8(1986)	5.5	5.3(1994)	4.7(1995)	N/A
11	8A- 4	JCT 28 TO JCT 28	12	36.69	40.00	4.3(1984)	5.4	3.3(1987)	5.2(1997)	N/A
10	36-20	JCT 16 TO JCT 45	3	16.54	20.93	4.1(1984)	5.4	2.2(1983)	6.0(1999)	N/A
11	41-22	JCT 45W TO JCT 28	4	21.80	22.98	4.4(1984)	5.4	2.7(1983)	6.2(2002)	N/A
10	45- 4	JCT 15 TO ANDREW ACCESS	4	10.99	14.34	5.2(1988)	5.5	8.1(2006)	4.2(1992)	N/A
10	45- 4	JCT 15 TO ANDREW ACCESS	5	14.34	15.56	5.1(1987)	5.4	7.9(2006)	4.2(1992)	N/A
10	45- 4	JCT 15 TO ANDREW ACCESS	6	15.56	16.49	5.3(1989)	5.4	8.7(2013)	4.5(1997)	N/A
10	45- 6	ANDREW ACCESS TO TWO HILLS	5	5.25	6.98	4.1(1984)	5.5	1.9(1983)	6.4(2000)	N/A
10	45- 6	ANDREW ACCESS TO TWO HILLS	12	23.88	24.36	3.7(1981)	5.4	1.7(1979)	5.8(2000)	N/A
10	45- 8	TWO HILLS TO JCT 41	4	10.51	13.71	4.7(1985)	5.4	3.9(1994)	5.7(1999)	N/A
11	55-12	JCT 63 TO JCT 36	12	11.70	11.91	5.5(1989)	5.4	6.3(2007)	6.4(2002)	N/A
11	55-12	JCT 63 TO JCT 36	17	19.65	21.45	5.3(1988)	5.4	6.1(2004)	5.8(1999)	N/A
11	55-12	JCT 63 TO JCT 36	18	21.45	23.43	5.1(1987)	5.5	5.3(2001)	5.6(1999)	N/A
11	63- 2	W.ATHORE TO N WANDERING R.	6	10.36	11.26	3.9(1982)	5.4	2.1(1981)	5.6(1998)	N/A
11	63- 2	W.ATHORE TO N WANDERING R.	7	11.26	12.12	4.1(1983)	5.4	2.5(1983)	5.6(1998)	N/A
11	63- 2	W.ATHORE TO N WANDERING R.	8	12.12	12.95	2.8(1978)	5.5	0.9(1978)	5.0(1997)	N/A
11	63- 2	W.ATHORE TO N WANDERING R.	9	12.95	13.81	4.3(1984)	5.5	3.3(1987)	5.1(1997)	N/A

...CONTINUED

FIGURE 6 Example output of needs report by PINS.

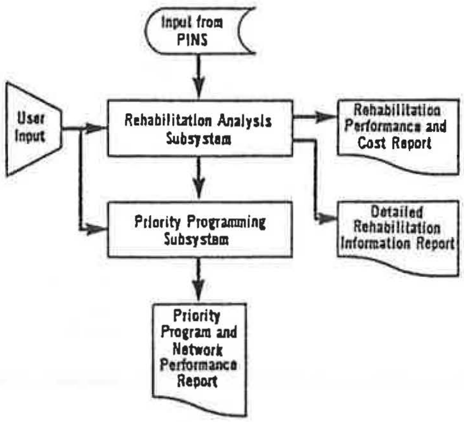


FIGURE 7 Outline of RIPPS.

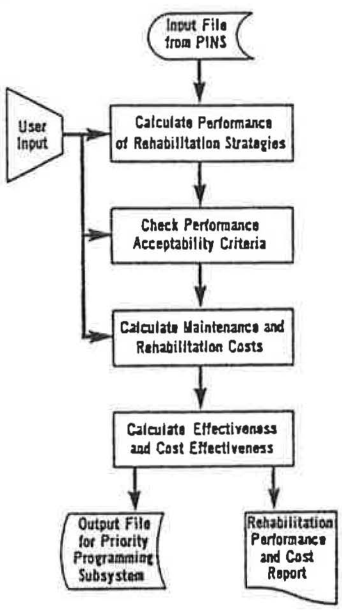


FIGURE 8 REHAB subsystem.

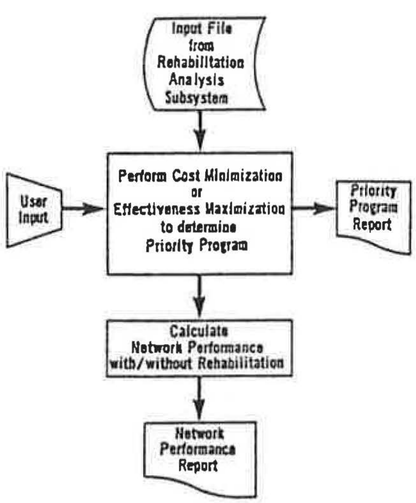


FIGURE 9 PRIORITY subsystem.

planning analysis by using a heuristic optimization procedure employing marginal cost-effectiveness analyses. The priority analysis can either be run in cost minimization or effectiveness maximization modes.

REHAB Subsystem

Alternative Selection

The subsystem allows for the analysis of up to five different types of alternatives for each inventory section analyzed. The alternative types from which the five can be selected are as follows: overlay, milling, milling plus overlay, recycle, recycle plus overlay, recycle plus seal coat, widening plus surfacing, widening plus overlay, heater plane plus overlay, heater plane plus seal coat, and reconstruction.

The selection of the five alternatives for each section using this master list can be accomplished by using one of the four methods built into the subsystem:

1. Defining a fixed set for the network;
2. Specifying different alternative sets for different sections, with default to the fixed set for unspecified sections;
3. Using an automatic alternative type set selection procedure; and
4. Specifying different alternative sets for different sections, with default to the automatic selection procedure for unspecified sections.

Performance Prediction

The performance of the alternatives is predicted by using the same recursive models used in PINS. For some of the alternatives, the models have been modified to reflect the difference in performance expected from these alternatives. The performance prediction models used in PINS and RIPPS are described in detail elsewhere (2,4).

Economic and Effectiveness Analyses

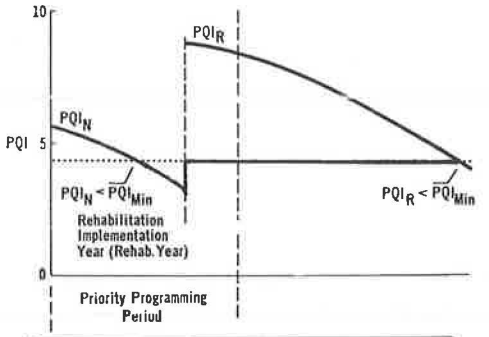
Each rehabilitation alternative that meets the minimum life constraints is subject to an economic analysis. This involves calculation of the capital cost and expected annual maintenance cost streams for a 25-year period from the start of the priority programming period. Inflation of the rehabilitation and maintenance costs can also be considered through the input of an inflation rate. The present worth of the total costs (rehabilitation plus maintenance) is calculated for use in determining the cost-effectiveness of the strategy.

The effectiveness of each rehabilitation alternative is also calculated. It is related to the difference between the rehabilitated PQI performance curve and the nonrehabilitated performance curve, as shown in Figure 10. The difference between the two curves in each year is weighted by annual average daily traffic (AADT) and section length and summed over time to determine the total effectiveness of the alternative.

The total effectiveness is used to calculate the cost-effectiveness for the alternative. This is similar to a benefit-cost ratio, except that the benefits (total effectiveness) are not in terms of dollars.

Output Reports

The REHAB subsystem, in the network mode, produces a rehabilitation information report for each section



$$\text{EFFECTIVENESS} = \sum_{\text{Rehab. Year}}^{PQI_R < PQI_{Min}} (PQI_R - PQI_N^{*}) \bullet \text{AADT} \bullet \text{Length} - \sum_{PQI_N < PQI_{Min}}^{\text{Rehab. Year}} (PQI_{Min} - PQI_N) \bullet \text{AADT} \bullet \text{Length}$$

* where PQI_N is the non-rehabilitation index value or the critical value, which ever is greater

FIGURE 10 Effectiveness calculation.

analyzed, as shown in Figure 11. This report consists of an information matrix of 5 columns of rehabilitation alternative types and 10 rows of implementation years, which represent a maximum of 50 strategies (alternative/implementation year combinations) that can be analyzed for a section. For each information cell in the table the alternative description, rehabilitation capital cost, present worth of the maintenance costs, and the cost-effectiveness are given for the strategy.

In each implementation year the alternative with the highest cost-effectiveness is highlighted with a line of dashes above and below the information cell. The strategy with the overall highest cost-effectiveness for the section is highlighted with a line of asterisks above and below the information cell.

In the detail mode a rehabilitation performance report is produced for each section, rehabilitation alternative, and implementation year combination analyzed. Figure 12 shows an example rehabilitation information report from a detailed analysis. In this analysis mode the output consists solely of a report of this type for each section, alternative, and implementation year specified for detail analysis.

```
* HIGHWAY    16      REGION 5  DISTRICT    8  COUNTY  N/A      PAVEMENT TYPE GRANULAR BASE                 ANALYSIS RUN DATE : MAR. 1
* CONTROL SECTION          6    JCT 47 TO JCT 32           *    *** STRUCTURAL COMPOSITION ***           *
* SUBSECTION               6    *   *** TRAFFIC DATA ***   *  406 MM AC     AGE OF SURFACE  9(1974)   *      *** SKID DATA ***
* BEGINNING STATION    11.10    * A.A.D.T.          4980   *  102 MM ABD                              *
* ENDING STATION       11.50    * CUMULATED ESALS   1950   *  406 MM GRAN   EGT = 1504 MM             * SKID RESISTANCE VALUE   N/A
* LENGTH             0.40 KM    * ANNUAL GROWTH    5.0 %   *    0 MM                                  * LAST MEASURED           N/A
* PAVEMENT WIDTH         N/A    *                          *           SOIL   (15)CL                  *
*------------------------------------------------------------------------------------------------------------------------------
* NEEDS YEAR WITHOUT REHABILITATION : PQI : 1983   RCI : 1981   SAI : 1990   VCI : 1990
*------------------------------------------------------------------------------------------------------------------------------
*   ------------------------  *                          *                          *                          *
* 1 60 MM OVERLAY             *  MILL 20 & 60 MM O/L     *                          *                          *
* 9 REHAB COST      17123.    *  REHAB COST     18753.   *                          *                          *
* 8 MAINT COST       5752.    *  MAINT COST      5752.   *                          *                          *
* 3 COST-EFF.          3.7    *  COST-EFF.         3.6   *                          *                          *
*   ------------------------  *                          *                          *                          *
* 1 60 MM OVERLAY             *  MILL 20 & 60 MM O/L     *                          *                          *
* 9 REHAB COST      17123.    *  REHAB COST     18753.   *                          *                          *
* 8 MAINT COST       5643.    *  MAINT COST      5643.   *                          *                          *
* 4 COST-EFF.          4.1    *  COST-EFF.         3.9   *                          *                          *
*   ------------------------  *                          *                          *                          *
* 1 60 MM OVERLAY             *  MILL 20 & 60 MM O/L     *                          *                          *
* 9 REHAB COST      17123.    *  REHAB COST     18753.   *                          *                          *
* 8 MAINT COST       5552.    *  MAINT COST      5552.   *                          *                          *
* 5 COST-EFF.          4.1    *  COST-EFF.         3.9   *                          *                          *
*   ------------------------  *                          *                          *                          *
* 1 60 MM OVERLAY             *  MILL 20 & 60 MM O/L     *                          *                          *
* 9 REHAB COST      17123.    *  REHAB COST     18753.   *                          *                          *
* 8 MAINT COST       5479.    *  MAINT COST      5479.   *                          *                          *
* 6 COST-EFF.          4.5    *  COST-EFF.         4.3   *                          *                          *
*   ------------------------  *                          *                          *                          *
* 1 60 MM OVERLAY             *  MILL 20 & 60 MM O/L     *                          *                          *
* 9 REHAB COST      17123.    *  REHAB COST     18753.   *                          *                          *
* 8 MAINT COST       5427.    *  MAINT COST      5427.   *                          *                          *
* 7 COST-EFF.          4.9    *  COST-EFF.         4.6   *                          *                          *
*   ------------------------  *                          *                          *                          *
* 1 60 MM OVERLAY             *  MILL 20 & 60 MM O/L     *                          *                          *
* 9 REHAB COST      17123.    *  REHAB COST     18753.   *                          *                          *
* 8 MAINT COST       5391.    *  MAINT COST      5391.   *                          *                          *
* 8 COST-EFF.          5.2    *  COST-EFF.         4.9   *                          *                          *
*   ------------------------  *                          *                          *                          *
* 1 60 MM OVERLAY             *  MILL 20 & 60 MM O/L     *                          *                          *
* 9 REHAB COST      17123.    *  REHAB COST     18753.   *                          *                          *
* 8 MAINT COST       5377.    *  MAINT COST      5377.   *                          *                          *
* 9 COST-EFF.          5.6    *  COST-EFF.         4.7   *                          *                          *
*   ------------------------  *                          *  ----------------------  *                          *
* 1 60MM O/L & 20 MM LEV      *  MILL 20 & 60 MM O/L     *  RECYC.50 & 60 MM O/L    *  RECYC.50 & SEAL COAT    *
* 9 REHAB COST      22830.    *  REHAB COST     18753.   *  REHAB COST     28538.   *  MIN. LIFE CONSTRAINT    *
* 9 MAINT COST       5382.    *  MAINT COST      5382.   *  MAINT COST      5203.   *  NOT MET FOR             *
* 0 COST-EFF.          4.3    *  COST-EFF.         5.0   *  COST-EFF.         5.9   *  PRI  SAI                *
*                             *                          *  ********************    *                          *
* 1 60MM O/L & 20 MM LEV      *  MILL 20 & 60 MM O/L     *  RECYC.50 & 60 MM O/L    *  RECYC.50 & SEAL COAT    *
* 9 REHAB COST      22830.    *  REHAB COST     18753.   *  REHAB COST  [illegible]  *  MIN. LIFE CONSTRAINT    *
* 9 MAINT COST       5412.    *  MAINT COST      5412.   *  MAINT COST  [illegible]  *  NOT MET FOR             *
* 1 COST-EFF.          4.5    *  COST-EFF.         5.3   *  COST-EFF.  [illegible]   *  PRI  SAI                *
*                             *                          *  ********************    *                          *
* 1 60MM O/L & 20 MM LEV      *  MILL 20 & 60 MM O/L     *  RECYC.50 & 60 MM O/L    *  RECYC.50 & SEAL COAT    *
* 9 REHAB COST      22830.    *  REHAB COST [illegible]  *  REHAB COST  [illegible]  *  MIN. LIFE CONSTRAINT    *
* 9 MAINT COST       5466.    *  MAINT COST [illegible]  *  MAINT COST  [illegible]  *  NOT MET FOR             *
* 2 COST-EFF.          4.8    *  COST-EFF.  [illegible]  *  COST-EFF.         6.0   *  PRI  SAI                *
```

FIGURE 11 Rehabilitation information report.

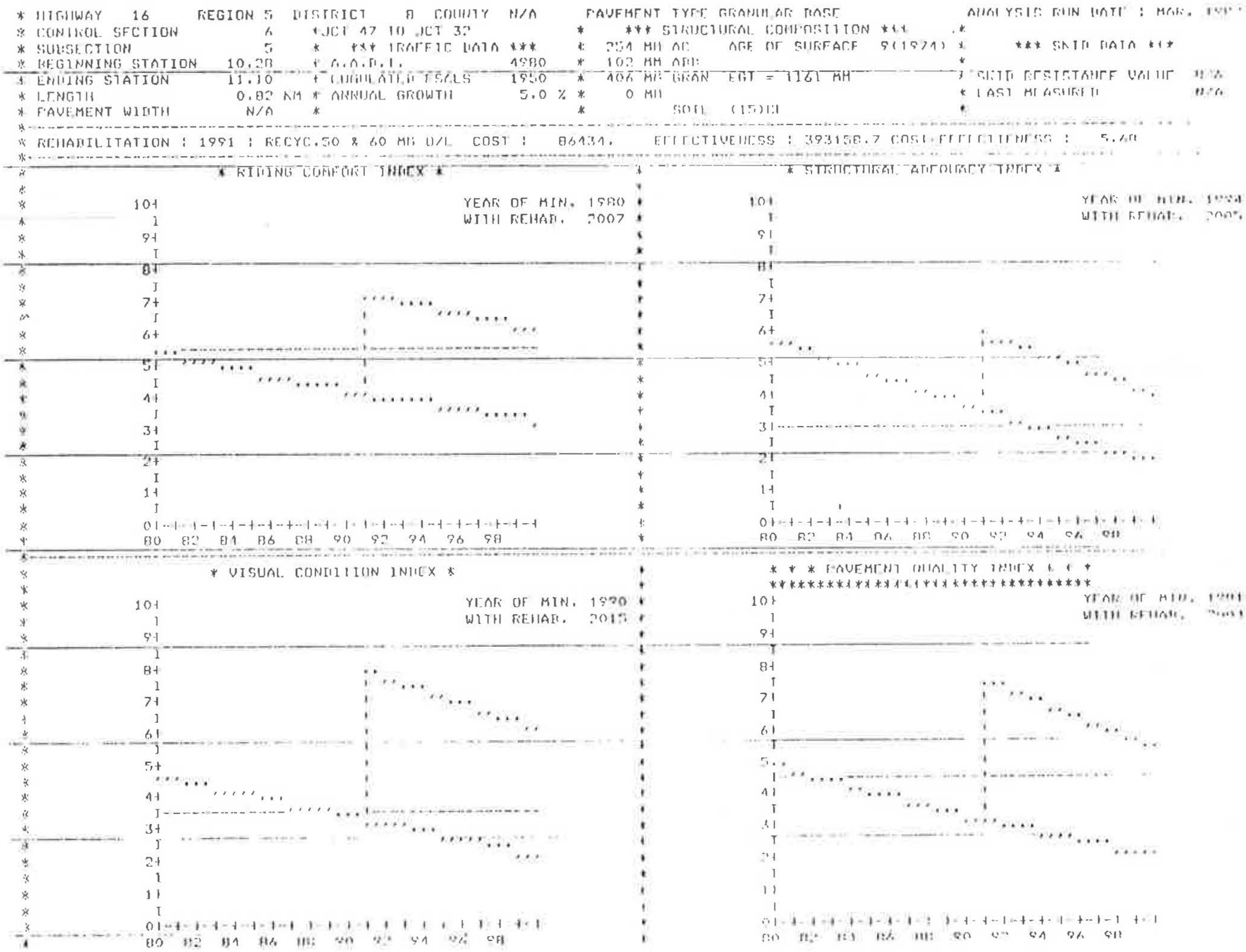


FIGURE 12 Detailed rehabilitation information report.

The report consists of four performance plots similar to those produced by the PINS system. Each plot shows the performance with and without rehabilitation and the needs years with and without rehabilitation. A detailed description of subsystem REHAB and its outputs is given elsewhere (7).

PRIORITY Subsystem

The PRIORITY subsystem forms the priority or financial planning analysis part of the RIPPS system. A heuristic procedure has been developed specifically for RIPPS for the purpose of optimizing investments. The procedure uses the marginal analysis concept and can be employed for either cost minimization or effectiveness maximization purposes or both.

The heuristic procedure developed eliminates the problems related to solving large networks by using linear or integer programming techniques while producing close-to-optimum solutions in an efficient way, as subsequently discussed in the paper. It is believed that this new procedure is a distinct advance over the mathematical programming techniques previously used by the authors of this paper, and others, for optimization and priority analyses.

Cost Minimization Method

Cost minimization is based on highest cost-effectiveness and marginal cost-effectiveness analyses. Strategies are selected on an annual basis because the implementation of an alternative in a given year affects the performance in all subsequent years. When a strategy is selected for a section, the marginal cost-effectiveness is calculated for any other strategy available for that section for that year. Strategies in other years for the section are then eliminated from further consideration. The following performance constraints are built into the procedure (others can easily be incorporated):

1. Annual average network PQI level specified, and
2. Annual percentage of network allowed to be below the minimum acceptable PQI level.

Cost minimization is a budgeting tool because the annual expenditures required to achieve a desired performance level are produced. The program can be rerun with different performance constraints to test the effects of desired performance levels on the required funding level.

Effectiveness Maximization Method

The effectiveness maximization method is also based on highest cost-effectiveness and marginal cost-effectiveness analyses. In this method, however, all of the implementation years are treated simultaneously because the implementation of an alternative affects only the budget for the implementation year. When a strategy is selected for a section, the marginal cost-effectiveness is calculated for all other strategies available for the section. The constraints imposed on this analysis method are simply the annual available rehabilitation budgets.

This method is not a budgeting tool, but rather it is a programming tool for determining rehabilitation programs. The end result of this method is a program of rehabilitation strategies to be implemented that will provide the maximum effectiveness for the available funding levels. The program can be rerun with different budget levels to test the effects of funding levels on the resulting network performance.

The marginal analysis optimization procedure briefly described in the preceding paragraphs has been compared with the linear programming (LP) technique (using MPSX package) by using three different data sets that were available from other projects. The pavement networks involved were the region of Waterloo--rural (23 sections) and urban (66 sections)--and the borough of Scarborough (63 sections). In the effectiveness maximization mode the marginal analysis procedure was 93.1 percent of the LP for the Waterloo rural, 96.7 percent of the LP for the Waterloo urban, and 97.4 percent of the LP for the Scarborough project. The resulting priority lists were almost identical, with the exception of one or two projects. Most of the difference was caused by the fractional solutions that LP produced.

Similarly, in the cost minimization mode, the one test conducted using Waterloo rural data resulted in better effectiveness using marginal analysis, but the total dollars spent was higher. This is simply because of the way the marginal analysis procedure is set up, where effectiveness is also being considered while trying to minimize the cost, which was not the case in the LP formulation. Hence marginal analysis in the test run spent more, but the return for the dollars spent was higher.

These marginal analysis tests were conducted by using a PDP-11-34 minicomputer, and in the maximization mode the following CPU times were observed:

1. Waterloo rural (23 sections, 2 alternative strategies per year, 5-year period): 0.22 min;
2. Waterloo urban (66 sections, 2 alternative strategies per year, 5-year period): 0.89 min; and
3. Scarborough (63 sections, 2 alternative strategies per year, 10-year period): 1.42 min.

Drs. Moore and Magazine of the University of Waterloo, who have been involved in the assessment of the marginal analysis approach, both believe that this procedure is appropriate for the purposes of optimizing pavement investments within the context of pavement management. (Note that this information is from correspondence from Dr. J.B. Moore to Dr. M.A. Karan, July 7, 1983.)

Output Reports

Three types of output reports can be obtained from the PRIORITY subsystem:

1. Priority programming report by highway,
2. Priority programming report by year, and
3. Performance summary report.

REG	DIST	HWY - CONTROL SECTION	CONTROL SECTION DESCRIPTION	INV. SECT.	BEGIN KM.	END KM.	PCI NEED YEAR	REHAB YEAR	REHABILITATION ALTERNATIVE	COST	EFFECT	COST-EFF
5	8	16- 2	JASPER PK BDY TO OBED	1	0.00	4.26	1983	1989	MILL 20 & 60 MM O/L	267647	149.5	5.72
				2	4.26	13.44	1985	1986	MILL 20 & 60 MM O/L	498227	203.5	3.64
				3	13.44	25.87	1995	N/A				
				4	25.87	54.03	1994	N/A				
				5	54.03	54.98	1996	1992	60 MM OVERLAY	63086	21.1	4.12
5	8	16- 4	OBED TO JCT 47	1	0.00	3.22	1997	N/A				
				2	3.22	8.05	1992	N/A				
				3	8.05	15.03	1996	N/A				
				4	15.03	24.79	1997	N/A				
				5	24.79	28.35	1987	1991	60 MM OVERLAY	225150	165.7	8.16
				6	28.35	31.54	1995	1989	MILL 20 & 60 MM O/L	200421	78.6	4.07
				7	31.54	34.19	1997	N/A				
				8	34.19	36.04	1994	N/A				
				9	36.04	41.67	1994	N/A				
				10	41.67	41.99	1991	1990	60 MM OVERLAY	19274	6.4	3.57
				11	41.99	42.65	1990	1983	MILL 20 & 60 MM O/L	30942	6.1	1.51
				12	42.65	45.78	1990	N/A				
				13	45.78	49.24	1990	1983	MILL 20 & 60 MM O/L	162216	42.2	1.99
5	8	16- 6	JCT 47 TO JCT 32	1	0.00	1.19	1992	1990	60 MM OVERLAY	71677	27.8	4.30
				2	1.19	8.27	1989	1985	60 MM OVERLAY	334133	122.7	3.08
				3	8.27	10.09	1980	1991	100 MM OVERLAY	191841	99.1	6.49
				4	10.09	10.28	1980	1992	100 MM OVERLAY	21028	10.7	6.36
				5	10.28	11.10	1981	1990	RECYC.50 & 60 MM O/L	82318	37.3	5.39
				6	11.10	11.50	1983	1991	RECYC.50 & 60 MM O/L	42162	20.9	6.19
				7	11.50	13.95	1987	1990	60 MM OVERLAY	147570	61.2	4.57
				8	13.95	25.76	1984	N/A				
				9	25.76	42.25	1995	N/A				
5	8	16- 6	EB EDSON ONE-WAY COUPLET	10	6.07	11.25	1989	1992	MILL 20 & 60 MM O/L	413113	397.2	12.42
5	8	16- 8	JCT 32 TO CHIP LAKE	1	0.00	7.69	1990	1988	60 MM OVERLAY	420127	195.2	4.67
				2	7.69	8.05	1985	1989	60 MM OVERLAY	20651	6.3	3.13
				3	8.05	8.61	1987	1991	60 MM OVERLAY	35416	12.4	4.01
				4	8.61	9.85	1988	1984	MILL 20 & 60 MM O/L	61041	14.5	1.92
				5	9.85	10.72	1985	1987	60 MM OVERLAY	45267	14.4	2.96
				6	10.72	10.97	1986	1990	60 MM OVERLAY	15058	5.3	3.81
				7	10.97	12.20	1987	1985	MILL 20 & 60 MM O/L	63577	17.4	2.31
				8	12.20	13.55	1988	1983	MILL 20 & 60 MM O/L	63292	14.6	1.76
				9	13.55	14.53	1988	1984	MILL 20 & 60 MM O/L	48242	11.1	1.86
				10	14.53	16.65	1988	1985	60 MM OVERLAY	100051	28.2	2.36
				11	16.65	19.55	1987	N/A				
				12	19.55	23.33	1989	N/A				
				13	23.33	27.40	1992	N/A				
				14	27.40	35.88	1990	1984	60 MM OVERLAY	381148	103.9	2.16
5	8	16-10	CHIP LAKE TO JCT 22	1	0.00	1.90	1981	1987	60 MM OVERLAY	98859	32.4	3.00
				3	3.51	6.85	1981	1982	100 MM OVERLAY	289641	112.5	3.97

FIGURE 13 Priority program report by highway.

REG	DIST	HWY CONTROL SECTION	CONTROL SECTION DESCRIPTION	INV. SECTION	BEGIN KM.	END KM.	REHABILITATION ALTERNATIVE	COST	EFFECT	COST EFF
5	8	16- 4	OBED TO JCT 47	10	41.67	41.99	60 MM OVERLAY	19274	6.4	[illegible]
5	8	16- 6	JCT 47 TO JCT 32	1	0.00	1.19	60 MM OVERLAY	71677	27.8	4.30
5	8	16- 6	JCT 47 TO JCT 32	5	10.20	11.10	RECYC.50 & 60 MM O/L	82318	37.3	[illegible]
5	8	16- 6	JCT 47 TO JCT 32	7	11.50	13.95	60 MM OVERLAY	147570	61.2	[illegible]
5	8	16- 8	JCT 32 TO CHIP LAKE	6	10.72	10.97	60 MM OVERLAY	15058	5.3	3.81
5	8	16-10	CHIP LAKE TO JCT 22	6	10.84	11.55	100 MM OVERLAY	71275	27.5	[illegible]
5	8	16-10	CHIP LAKE TO JCT 22	7	11.55	12.45	100 MM OVERLAY	90349	34.9	4.56

FIGURE 14 Priority program report by year.

These three reports can be obtained for different levels of the network (i.e., for the province, sorted by region, and sorted by district).

Figure 13 shows an example of a priority programming report by highway. This report lists the sections in the order they appear in the input file and gives the rehabilitation strategies selected for implementation. This report can be produced for each separate district or for each separate region or for the whole network.

Figure 14 shows an example of a priority programming report by year. This type of report is repeated for each year in the programming period. Only those sections that have a rehabilitation strategy selected appear in this type of report. This report can also be produced for each separate district or for each separate region or for the whole network.

Figure 15 shows an example of a performance summary report. This report is produced for the network and can also be produced for each district or for each region. The annual costs shown in this report and the percentage budget usage have different meanings, depending on the mode of operation and the report level. For district and region reports, the annual costs are the total cost for the region or district and the percent budget usages are the annual costs as a percentage of the total annual network costs. For the network report in the effectiveness maximization mode, the costs are the total costs for the network and the budget usages are the annual total costs as a percentage of the input annual budget limitations. For the network report in the cost minimization mode, the costs are the total costs for the network and the budget usage has no meaning and is therefore not written in this case. Figure 16 shows an example output for the cost minimization mode.

The average annual PQIs and annual percentage below the minimum acceptable PQI are weighted by traffic volumes (AADT) and section lengths. These values are also plotted in the performance plots to give a visual representation of the performance trends with and without rehabilitation. A detailed description of the PRIORITY subsystem and its outputs is given elsewhere (8).

Application of RIPPS to Primary Highways in Alberta

RIPPS has been applied to portions of the primary network in Alberta. These test runs have been

YEAR	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
NETWORK COST	490459	490433	497762	498227	470711	484777	488719	497523	494572	497228
BUDGET USAGE (%)	98	98	99	99	94	96	97	99	98	99
NETWORK AVG PQI (WITH REHAB)	6.0	5.9	5.8	5.7	5.6	5.6	5.5	5.4	5.4	5.3
NETWORK AVG PQI (WITHOUT REHAB)	5.9	5.7	5.5	5.3	5.1	4.9	4.8	4.6	4.4	4.2
PERCENT < MIN PQI (WITH REHAB)	11	17	20	18	18	19	23	20	18	17
PERCENT < MIN PQI (WITHOUT REHAB)	12	19	19	22	26	29	36	43	52	55

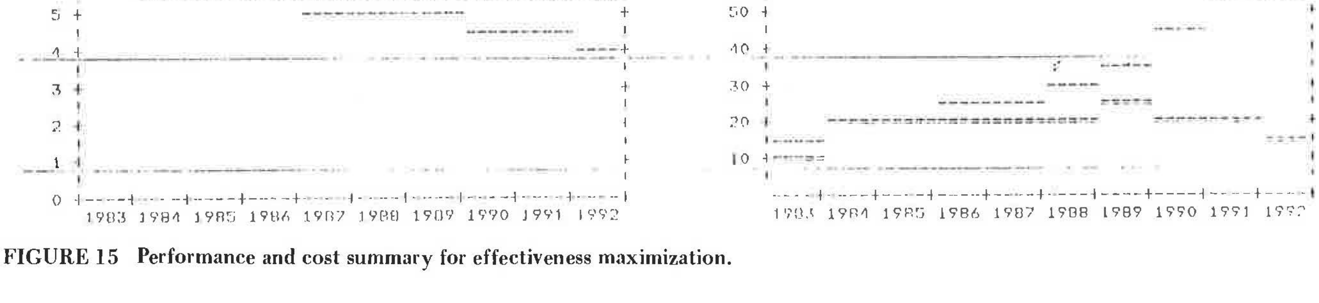
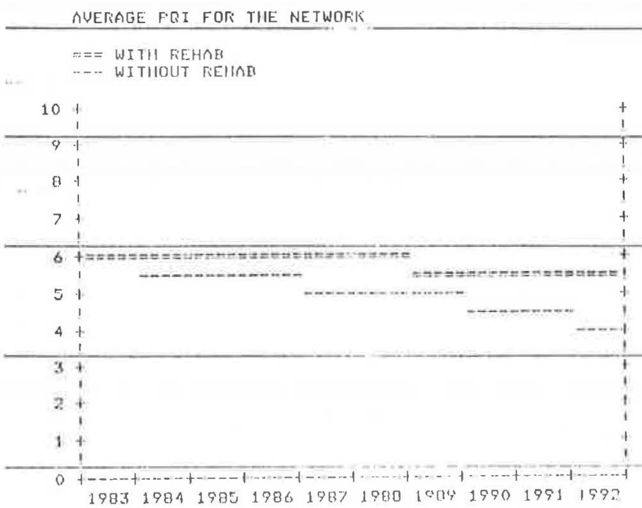


FIGURE 15 Performance and cost summary for effectiveness maximization.

YEAR :	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
NETWORK COST :	614007	1414944	365956	875969	1401206	0	0	0	1588823	1017509
NETWORK AVG PQI : (WITH REHAB)	6.0	6.1	6.1	6.0	6.1	5.9	5.7	5.5	5.6	5.6
NETWORK AVG PQI : (WITHOUT REHAB)	5.9	5.7	5.5	5.3	5.1	4.9	4.8	4.6	4.4	4.2
PERCENT < MIN PQI : (WITH REHAB)	11	10	11	11	13	13	16	16	17	17
PERCENT < MIN PQI : (WITHOUT REHAB)	12	19	19	22	26	29	36	43	52	55



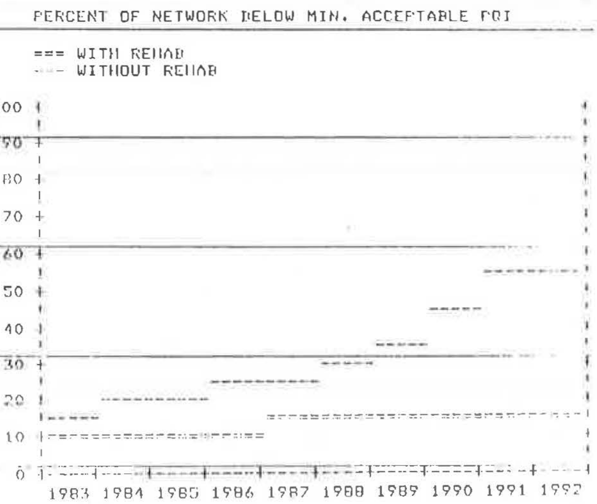


FIGURE 16 Performance and cost summary for cost minimization.

thoroughly evaluated and have resulted in some modifications that are now completed.

The computer programs for RIPPS have now been installed on Alberta Transportation's computer facilities in Edmonton. RIPPS is expected to be fully operational in late 1983 and used on a day-to-day basis along with PINS.

ACKNOWLEDGMENTS

The authors wish to acknowledge Brian Kerr and Alan Sadowsky of Pavement Management Systems, Ltd.; Gordon Berdahl, Robert White, and George Nicol of Alberta Transportation; and Brian Shields of the Alberta Research Council for their invaluable assistance in this project.

REFERENCES

1. A. Cheetham, M.A. Karan, R.C.G. Haas, and F. Meyer. Development and Implementation of a Pavement Management System for the Province of Alberta. Alberta Transportation, Edmonton, Alberta, Canada, Jan. 1981.
2. M.A. Karan, T.J. Christison, A. Cheetham, and G. Berdahl. Development and Implementation of Alberta's Pavement Information and Needs System (PINS). In Transportation Research Record 938, TRB, National Research Council, Washington, D.C., 1983, pp. 11-20.
3. A. Cheetham and M.A. Karan. A Pavement Quality Index (PQI) Model for Primary Highways in Alberta. Alberta Transportation, Edmonton, Alberta, Canada, Jan. 1982.
4. A. Cheetham and T.J. Christison. The Development of RCI Prediction Models for Primary Highways in the Province of Alberta. Alberta Transportation, Edmonton, Alberta, Canada, April 1981.
5. J.B. Kerr and M.A. Karan. Pavement Management System Development and Implementation Project Interim Report for the Province of Alberta--Stage 1. Alberta Transportation, Edmonton, Alberta, Canada, March 1982.
6. A. Cheetham, M.A. Karan, and A.J. Sadowsky. Summary Report on the Rehabilitation Information and Priority Programming System--Stage 2. Alberta Transportation, Edmonton, Alberta, Canada, March 1983.
7. A. Cheetham and A.J. Sadowsky. User's Manual for Program REHAB. Alberta Transportation, Edmonton, Alberta, Canada, March 1983.
8. A. Cheetham and A.J. Sadowsky. User's Manual for Program PRIORITY. Alberta Transportation, Edmonton, Alberta, Canada, March 1981.

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