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# Development and Implementation of Alberta's Pavement Information and Needs System

M.A. KARAN, T.J. CHRISTISON, A. CHEETHAM, AND G. BERDAHL

**Alberta Transportation initiated a project in November 1980 to develop and implement a pavement management system (PMS) for the province of Alberta, Canada. A comprehensive project plan was developed in the first phase of the project, which commenced in November 1980 and was completed in January 1981. Carried out as a preplanning project, the first phase identified six successive stages for the overall total PMS development and implementation project. Stage 1 of the project, the development and implementation of a pavement information and needs system (PINS), was initiated in May 1981 and scheduled to be completed in September 1982. A major element of PINS is a set of models that predict performance and various data processing and analysis components that take the individual field meansurements; calculate the performance measures in terms of pavement quality index, riding comfort index, structural adequacy index, and visual condition index; apply the performance prediction models; and identify both current and future needs. The major features of the PINS system and how the system fits into Alberta's overall PMS development and implementation are described. Specific attention is given to the details of performance prediction modeling and development of a pavement quality index concept.**

Alberta Transportation is responsible for the management of a large network of provincial highways that consists of approximately 7,000 miles of paved primary highways and about 2,000 miles of paved secondary roads. In addition, approximately 200 miles of new pavement are added to the highway system annually. This represents a substantial investment of many millions of dollars. To preserve this investment and maintain an acceptable level of serviceability for the total highway network, an additional investment of approximately $50 million is required annually for the maintenance and rehabilitation of deteriorating highway sections.

The department's engineers and administrators are concerned that the rehabilitation and maintenance programs make the best possible use of available funds on an overall basis as well as ensure an equitable allocation between the regions in the province. To establish an objectively based rehabilitation program several questions must be answered:

1. What is the current status of the network?
2. What are the expected needs during the programming period?
3. What rehabilitation alternatives can be considered for sections that require action within the programming period?
4. What are the performance and cost implications associated with the possible rehabilitation alternatives?
5. What is the effect of delaying or advancing a rehabilitation project within the programming period?
6. What are the effects of maintenance on the rehabilitation alternative selection?
7. What is the optimum total program of work for each year in the programming period based on the previous questions for a given level of funding?
8. What are the effects of the funding level used on the network as a whole?
9. What level of funding is required to maintain or increase the average serviceability of the network during the programming period?

Pavement management is the process by which answers to these questions can be obtained; Alberta Transportation initiated a project in November 1980 to develop and implement a pavement management system (PMS) for the province of Alberta.

A comprehensive plan was developed in the first phase of the project, which started in November 1980 and was completed in January 1981 (1). Carried out as a preplanning project, the first phase identified six successive stages for the overall total PMS development and implementation project. These stages, which are briefly summarized in Figure 1, were designed specifically for Alberta Transportation's needs and requirements considering its goals and objectives, organizational structure, current

Figure 1. Proposed stages of project.

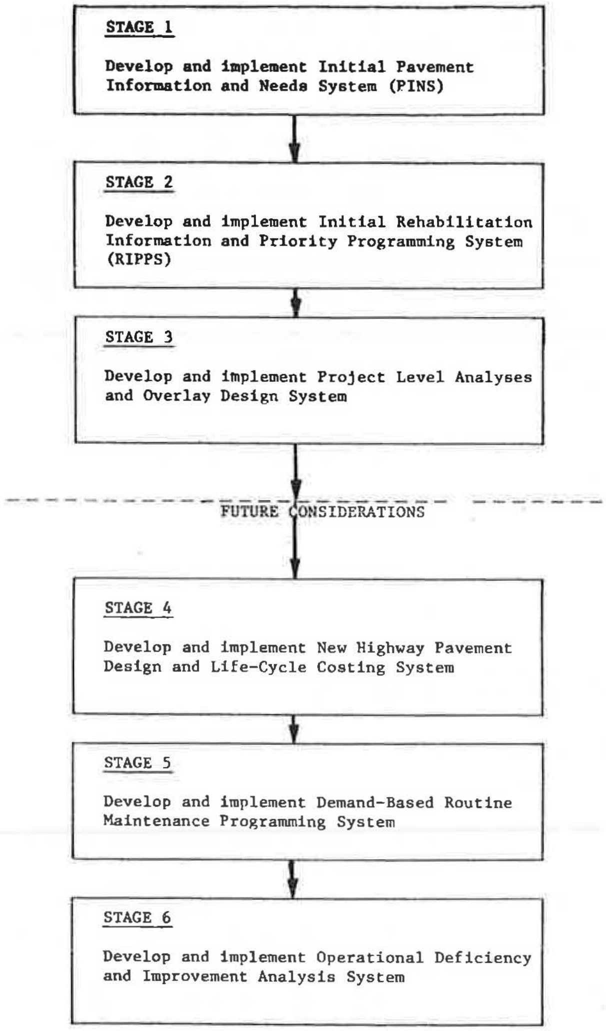
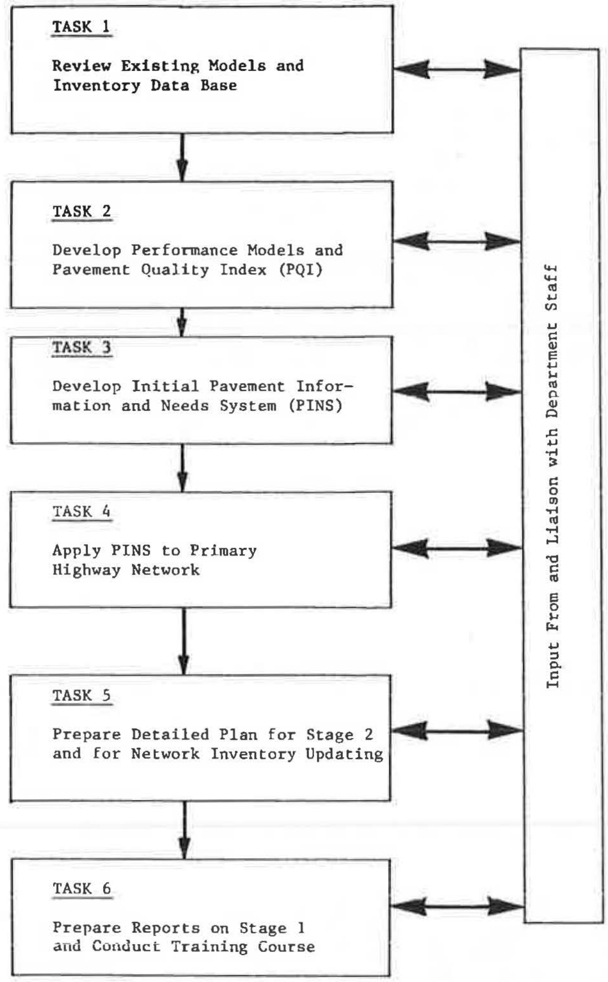



Figure 2. Major tasks in stage 1.




practices, staff and equipment resources, and financial constraints.

Stage 1 of the project, the development and implementation of a pavement information and needs system (PINS), was initiated in May 1981 and scheduled to be completed in September 1982. The main objective of this paper is to summarize the development of the PINS system with specific attention to the details of performance prediction modeling and development of a pavement quality index (PQI) concept.

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: PINS. The preplanning project produced a work plan for stage 1 using a series of tasks and subtasks. The end product of each task was also identified. The major tasks and their interrelationships are shown in Figure 2; the subtasks involved in stage 1 are shown in Figure 3.

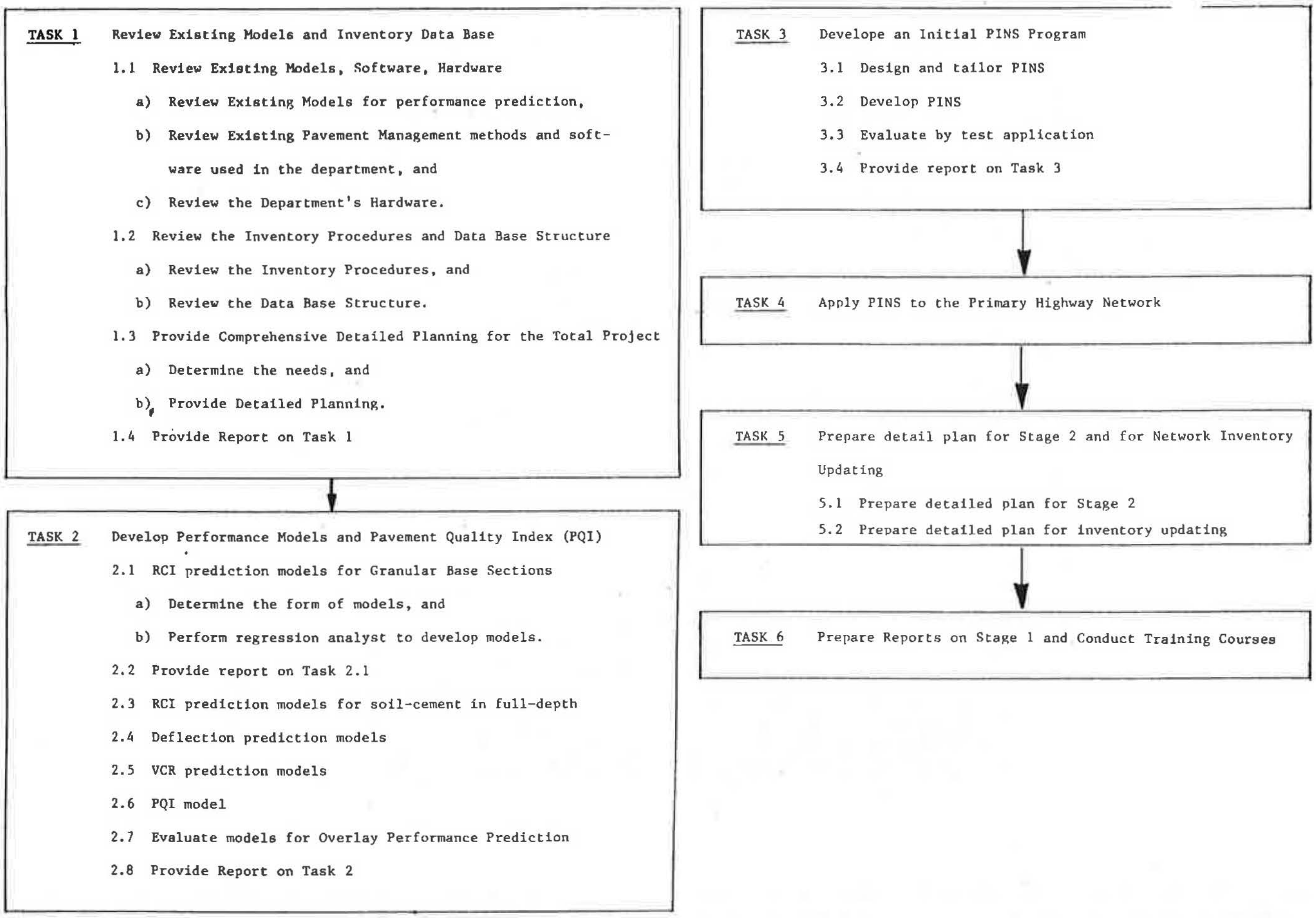
## TASK 1: REVIEW EXISTING MODELS AND INVENTORY DATA BASE

The first task undertaken in stage 1 was (a) to review Alberta Transportation's existing methodologies, information, and hardware and (b) to assess these in terms of the requirements of the overall system. The overall objective of this task was to make the best possible use of the province's existing data, hardware, and methods.

The review process revealed the following.

1. Some significant work had been done toward the development of performance prediction models. Although these models are not directly applicable to PINS, some valuable concepts were available.
2. The pavement management methodology that exists in Alberta Transportation is based on a comprehensive pavement sectional system, which provides structural, geometric, and performance data that are relatively detailed for use at the project level of pavement management (i.e., design).
3. A serious need exists for an objective, systematic, and computerized method for determining and programming pavement rehabilitation projects.
4. Alberta Transportation's computer facilities are suitable for the software packages that will be developed in the project.
5. The primary highway network of the province has been the subject of one of the most extensive (in terms of both time and information content) pavement inventories in North America. Historical field data are, therefore, available in a computerized data bank format to develop prediction models for various pavement parameters.
6. Alberta Transportation currently uses six Benkelman beams and one Dynaflect for measuring deflection, usually at a rate of 10 tests/mile,

**Figure 3. Tasks and subtasks in stage 1.**




although this is increased to 26 tests/mile for sections that approach the terminal level. The department also uses two Portland Cement Association (PCA) car roadmeters for measuring roughness. Since 1976 the visual condition rating (VCR) procedures have been used by department personnel.

7. The department has an effective method of sectioning the highway system, which involves control sections defined by major intersections along a highway and these, in turn, are composed of homogeneous subsections. A total of 3,014 subsections are currently in the primary highway network.

## TASK 2: DEVELOP PERFORMANCE MODELS AND PQI

Task 2 was directed toward the development of the pavement performance models required by the proposed PMS. Originally it was thought that approximately 27 performance models would be required. These models included three dependent variables [riding comfort index (RCI); deflection, and VCR] for each of three pavement types (granular base, soil-cement, and full-depth) in each of three climatic zones (southern, central, and northern). A PQI model was also needed as a means of combining RCI, deflection, and VCR into a single index for comparison of highway sections.

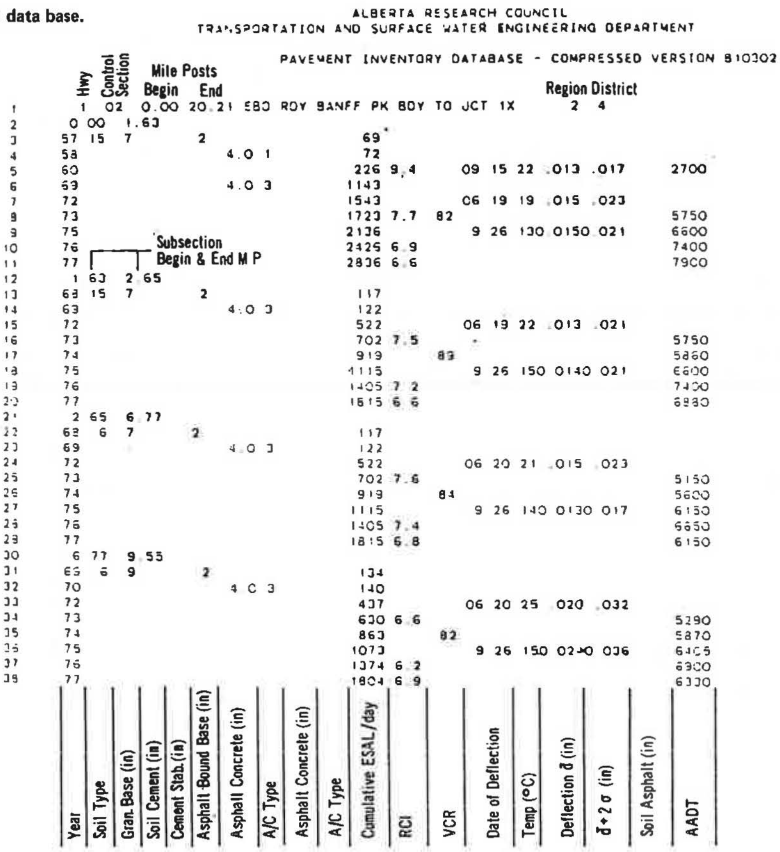
### Performance Prediction Models

The performance models were expected to be recursive (i.e., the future RCI is a function of the present RCI), with terms that relate to age, traffic, soil type, and structural thickness used as independent or explanatory variables. The starting point for the model development was the department's performance data base, which had previously been computerized by the Alberta Research Council. This data base includes (for every section in the primary network) periodic measurements of RCI, Benkelman beam rebounds, VCR, and structural composition, traffic, soils, and rehabilitation data (see Figure 4). For some sections the data base dates as far back as the 1950s.

Separate models were thought to be necessary for different types of pavement structure; therefore, the first step involved extraction of the RCI, deflection, and VCRs and all relevant data [e.g., soil type, layer thicknesses, cumulative equivalent single axle load (ESAL)/day, and year] for each type of structure from the historical data base. During this process certain conversions were performed to make the data compatible with the types of models required. For example, years were converted to ages, with an age of zero corresponding to the year of surfacing, and cumulative ESAL/day for the age of zero were also set to zero. The resulting data files were then screened to eliminate extremely short sections (0.5 mile or less) and sections for which all data points are similar.

To analyze the possible effects of soil type, the soil types given in the data base were divided into three classes (good, fair, and poor). Two indicator variables were then defined--soil D1 and soil D2. Similarly, to test for possible effects of climate, two indicator variables (climate D1 and climate D2)

Figure 4. Sample of historical data base.




were defined. The 15 districts in the province were separated into three approximate climatic zones (south, central, and north), and the indicator variables were assigned values that corresponded to the climatic zones and districts.

To compare the effects of structural layer thicknesses within structure types, the variable Equivalent Granular Thickness (EGT) was defined by using granular equivalency factors in the Roads and Transportation Association of Canada Pavement Management Guide (2).

## RCI Prediction Models

Separate analyses were conducted for different pavement types by using explanatory variables related to age, traffic, layer thicknesses, soil type, and climate. As many as nine models (one for each combination of three climatic zones and three pavement types) were thought to be required. However, the results of the analyses indicated that only two models were required to predict RCI performance adequately for evaluation purposes under the conditions that exist in Alberta. The two models include one for granular base sections and one for the other structure types (full depth, soil cement, and cement stabilized). Both models are recursive in nature (i.e., RCI now is a function of the previous RCI). The analyses also showed that age was the major influence on RCI performance.

The major findings of the development analyses of the RCI model are summarized as follows.

1. Reliable RCI predictions cannot be obtained without the use of a recursive model in which the RCI at time t is a function of a previous RCI at time t - 1.

2. Regression analyses showed that the traffic, structural thickness, and soil type do not affect RCI performance significantly.

3. Climate has an effect on RCI performance only when a full-depth section is constructed in the northern climatic zone, in which case performance decreases significantly.

4. Although these parameters (traffic, soil, structural thickness, and climate) do not play a major role in affecting RCI performance, this does not mean that they have no effect on overall pavement performance.

5. The granular base sections perform significantly better (with respect to RCI) than the other structure types.

6. Two RCI prediction models were developed for use in the PINS system that require only Δ AGE and a starting value of RCI. The accuracy of the predictions are therefore dependent on the accuracy of the starting value. These two models include one for granular base sections and another for all other structure types. The value for Δ AGE that should be used in both models is 4 years. For predictions between the 4-year intervals linear interpolation should be used.

The two models discussed in detail by Cheetham and Christison (3) are described below:

$$RCI = -5.998\ 75 + 6.870\ 09 \times LOG_e (RCI_B) - 0.162\ 42 \times LOG_e (AGE^2 + 1) + 0.184\ 98 \times AGE - 0.084\ 27 \times AGE \times LOG_e (RCI_B) - 0.092\ 60 \times \Delta AGE \quad (1)$$

with $R^2$ = 0.838 and a standard error of estimate = 0.38.

For soil-cement, full-depth, and cement-stabilized pavements:

$$RCI = -4.288 + 5.802 \times LOG_e (RCI_B) - 0.1744 \times \Delta AGE - 0.1846 \times FDN \quad (2)$$

with $R^2 = 0.845$ and a standard error of estimate = 0.29

where

$RCI_B$ = previous RCI,
AGE = present age of pavement,
$\Delta$ AGE = 4 years, and
FDN = 1 for full-depth sections in the northern climatic zone
= 0 otherwise.

## Deflection Prediction Models

Similar analysis conducted for predicting average pavement deflection as measured by Benkelman beam resulted in three models for the three major types of pavement in Alberta. Unlike the RCI models, it was found that separate models were needed for predicting average deflection for soil-cement, cement-stabilized, and full-depth pavements. However, as with RCI models, the effect of climatic zones was not significant and, therefore one model for each major pavement type was sufficient for predicting average deflection in the context of PINS.

The models for the different pavement structure types are as follows:

For granular base pavements,

$$LOG_e \bar{d} = 0.428\,47 + 0.916\,46 \times LOG_e \bar{d}_B + 0.041\,04 \times SD_2 \ldots \quad \text{with } R^2 = 0.87 \quad (3)$$

where $\bar{d}_B$ is the previous mean deflection and $SD_2$ is the soil district parameter.

For soil-cement and cement-stabilized pavements,

$$LOG_e \bar{d} = [0.688\,4 + 0.926\,38 \times LOG_e \bar{d}_B + 0.115\,44 \times (AGE + 1)] \div [(AGE_B + 1) + 0.025\,14 \times LOG_e \times \text{cumulative daily ESALS} \ldots] \quad \text{with } R^2 = 0.86 \quad (4)$$

where AGE is the present age of pavement and $AGE_B$ is the previous age of pavement.

For full-depth pavements,

$$\bar{d} = 1.728\,41 + 1.209\,73 \times \bar{d}_B \ldots \quad \text{with } R^2 = 0.86 \quad (5)$$

After the development of deflection-prediction models, a structural adequacy index (SAI) concept was necessary to convert deflections into a more meaningful engineering measure that would indicate directly the ability of the pavement structure to withstand the traffic loadings. The SAI concept provides a means of converting the deflection (measured or predicted) to a scale of 0 to 10 (with 10 being perfect) and thus enables one to know the structural condition from a single number.

The SAI models were derived from the measured pavement deflection and an empirical relationship involving a maximum tolerable deflection (MTD) and the traffic volumes.

The SAI models developed are as follows:

For granular base pavements,

$$\text{Log } SAI = 1.222\,51 + 0.003\,2\,(SAL + 1.65)^{1.39} - 0.012\,538\,\bar{d} - 0.000\,157\,\bar{d}\,(SAL + 1.10)^{1.44} \quad (6)$$

When $\bar{d} \leq 18$, set SAI = 10.

For full-depth pavements,

$$\text{Log } SAI = 1.269\,62 + 0.000\,267\,(SAL + 7.6)^{2.086} - 0.011\,885\,\bar{d} - 9.88 * 10^{-6}\,d(SAL + 7.6)^{2.14} \quad (7)$$

When $\bar{d} \leq 13.5$, set SAI = 10.

where

$\bar{d}$ = mean fall rebound as measured by Benkelman beam x $10^3$,
SAL = cumulative ESAL/$10^5$, and
MTD = deflection at 1980 cumulated ESALs that correspond to SAI = 3.0 for each of the three types of pavement.

## VCR Prediction Models

The performance of a pavement in terms of its surface distress was modeled and predicted by using a visual condition index (VCI) concept, which is calculated from VCR and is based on a scale of 0 to 100 by dividing by 10. This was done to make the surface condition scores compatible with the RCI and SAIs, which are based on a scale of 0 to 10.

Extensive regression analysis conducted by using the VCR data in the data bank revealed no need to develop nine models (combinations of three pavement types and three climatic zones) as originally expected. One model for each pavement type was sufficient for predicting VCIs in the context of PINS evaluation.

The VCI prediction models developed are as follows:

For granular base pavements,

$$VCI = 1/10 \times (8.959\,66 + 0.875\,1 \times VCR_B - 3.046\,95 \times CD_2 - 2.921\,35 \times LOG_e (AGE + 1) \ldots \quad \text{with } R^2 = 0.74 \quad (8)$$

where

$VCR_B$ = previous visual condition rating,
$CD_2$ = climatic district indicator, and
AGE = present age of the pavement.

For soil-cement and cement-stabilized pavements,

$$VCI = 1/10 \times (33.094 + 0.006\,67 \times VCR_B^2 - 1.252\,8 \times LOG_e (AGE^2 + 1) \ldots \quad \text{with } R^2 = 0.8 \quad (9)$$

For full-depth pavements,

$$VCI = 1/10 \times \exp\left\{-0.645\,84 + 1.122\,23 \times LOG_e VCR_B - 0.059\,73 \times CD_2\right\} \ldots \quad \text{with } R^2 = 0.73 \quad (10)$$

## Development of PQI

The three performance prediction models just described aid in determining future needs for rehabilitation in terms of the individual parameters. Needs are thus determined for RCI that relate to the roughness of the pavement as it affects the highway user, for VCI in terms of the amount and severity of surface distress, and for SAI as the structural ability to withstand the expected traffic loadings.

The individual prediction of each of the preceding performance parameters discussed allows the determination of rehabilitation needs based on each parameter; however, the ability to determine needs based on the overall quality is also necessary. The use of PQI allows RCI, VCI, and SAI to be combined into a single number that represents the overall quality of the pavement. PQI encompasses all of these aspects of the pavement performance and provides a single index for comparing the performance of pavement sections and their relative rehabilitation needs.

The PQI model was developed considering the overall performances of different pavement sections for which RCI, SAI, and VCI were known. The overall performance was defined by a subjective panel rating procedure. Forty pavement sections were selected for the PQI rating sessions. The sections were selected to cover a wide range of the three basic performance parameters (RCI, VCI, and SAI) for each of the three major pavement types (granular base, full depth, and soil cement).

Two station wagons of similar ride and size (a 1978 Plymouth and a 1977 Ford) were used in October 1981 to carry two panels of four raters each on a visual inspection and ride on 5 of the 40 sections. During the following 2 days the remainder of the sections were rated but only by six raters. On the last day replicate ratings were made on five sections by five raters.

The panel members were trained before the rating sessions. The purpose of the project was explained and the pavement quality concept discussed. A sample rater's guide used in the training can be found elsewhere (4). Pavement quality rating forms were provided for each section, a sample of which is shown in Figure 5. These forms also contained information on traffic and deflection magnitudes as well as RCI, VCI, and SAI.

PQI rating data were first analyzed to check for systematic errors. Leniency error, halo effects, and central tendency effects, which are the most common types of systematic errors in rating procedures, were found to be insignificant. Therefore, no adjustment of the data was necessary, and the raw data were used in subsequent analyses.

Analysis of variance (ANOVA) techniques were then used to test for sources of variation in the data. A panel comparison was made that tested between panels and among each panel as sources of variation. However, neither of these factors was found to be significant as a source of variation. Next a location comparison ANOVA was conducted on the data. This ANOVA tested the effects of drivers versus others and among others for location comparisons. Again, these effects were found to be insignificant as sources of variation.

In both the panel comparison and location comparison, the only truly significant source of variation was due to sections. The replicated sections were then analyzed to determine the short-term repeatability of the PQI ratings. The replication ANOVA indicated that the raters could repeat their ratings reasonably well. However, this should not be taken as a generalization because the replications were done within a short time period (i.e., 2 days). The details of the preceding data analyses are given by Cheetham and Karan (4).

No systematic errors were found; therefore, the raw data were used in regression analyses to develop a PQI model. Several transformations of the data were evaluated; however, the final model that resulted from the analyses is

$$PQI = 1.1607 + 0.0596 \cdot RCI \cdot VCI + 0.5264 \cdot RCI \cdot \log_{10} SAI \quad (11)$$

This model has a standard error of estimate of 0.79 ($R^2 = 0.76$).

The regression analyses that result in this model are discussed elsewhere (4).

Figure 5. Sample PQI rating form.

SECTION NUMBER:

LOCATION: 21:22 MP 5.36 (8.63 km) to MP 6.36 (10.23 km)

MILEAGE TIE: MP 0.0 = Jct. 53

PAVEMENT TYPE: GB

LAYER THICKNESS: 4 AC, 2 ABB, 6 BASE

Age: 18 DTF: 4.8 ESAL ($x10^5$): 2.4

d: 0.039 MTD: 0.056 RCI: 5.5

VCI: 6.5 SAI: 5.2

PAVEMENT QUALITY

Excellent (Pavement Like New)

Good (Many years of service life)

Fair (Close to or needing rehabilitation)

Poor (Should have been rehabilitated in the last couple of years)

Extremely Poor (Should have been rehabilitated many years ago)

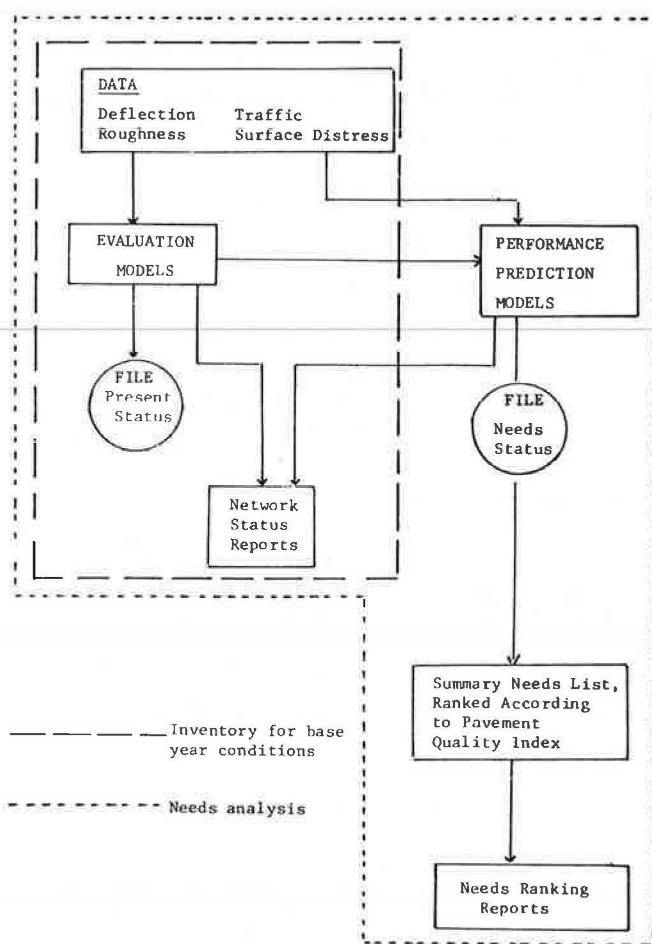
Is Pavement of Acceptable Quality? ____Yes

____No

____Undecided

COMMENTS: ____________________

Figure 6. General structure of PINS.



An analysis of the acceptance of the pavement quality was also conducted based on the acceptable-unacceptable responses of the rater for each section. This analysis showed that, based on the raters involved, a minimum acceptable level of PQI is about 4.7. This is not to be taken as an absolute level but is an indication of the rater's responses. The details of the minimum acceptable PQI analysis are also given elsewhere (4).

TASK 3: DEVELOP INITIAL PINS

The main function of the PINS program is to process pavement management data (i.e., deflection, RCI, VCR, and traffic) from the pavement data base and to generate for immediate and future use of department personnel the following:

1. Current status of the network in terms of PQI and its components of structural adequacy, SAI, ride quality, RCI, and visual condition, VCI;
2. Remaining service life (in structural and serviceability terms) of each section in the network, based on the performance prediction models 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 current status of the highway network and improvement needs for each region in Alberta.

The PINS programs developed for Alberta has the capability of determining the current status of a section in terms of its RCI, SAI, VCI, and PQI parameters (see Figure 6). These analyses can be conducted for every section in the network, in a region, or on a highway. Once the analyses are completed for every section the program produces detailed output for every section as well as a status report for the network, region, or highway.

The next step in the analyses is to predict performance for each performance parameter (i.e., RCI, SAI, VCI, and PQI). As with analysis of the current status, performance prediction and needs analyses can be conducted for every section in the network, in a region, or on a highway. The program produces graphical outputs (i.e., performance curves) for every section as well as the year in which a parameter will reach its minimum acceptable level. A sample output of this type is shown in Figure 7.

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 RQI) 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 is produced by PINS. Figures 8 and 9 show sample ranking lists based on RCI and PQI, respectively. Similarly, a three-dimensional histogram similar to the one shown in Figure 10 is also produced so that comparisons can be made of regions, districts, or highways in Alberta.

Figure 7. Sample sectional PINS output.

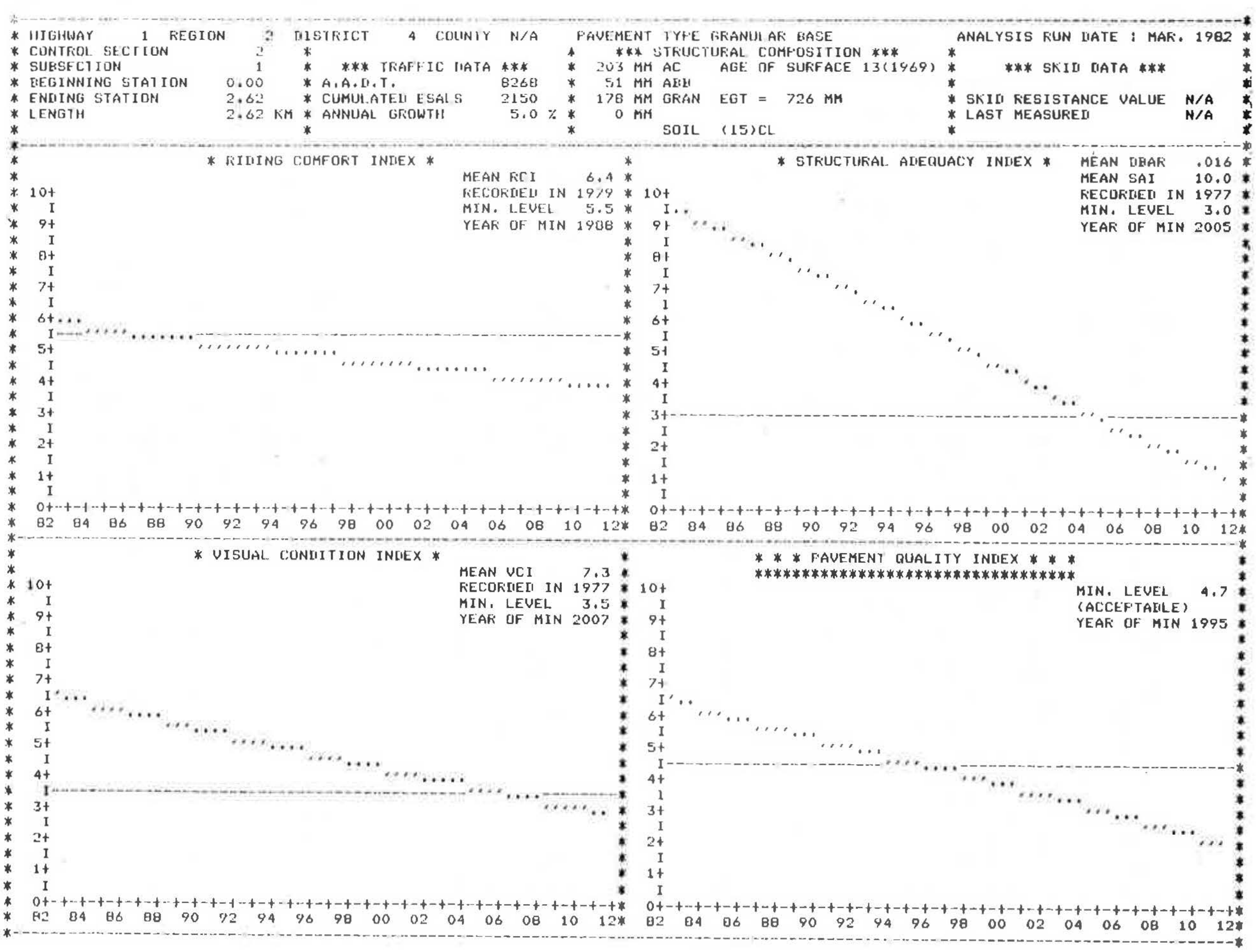


**Figure 8. Sample RCI ranking list produced by PINS.**

* PAVEMENT INFORMATION AND NEEDS SYSTEM *

* SECTIONAL SUMMARY TABLE *

* RCI RANKING FOR REGION 2 *

| 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 | 2.7 | 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 | SCL 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 | 1.9 | 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 | 2 | 7.96 | 9.17 | 3.2 | 4.3 | 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 | 25.26 | 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 940 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 | 1.03 | 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 | 1.4 | 3.5 | 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 23 | 4 | 21.54 | 21.77 | 3.6 | 4.4 | 2.2 | 2.8 | N/A |

**Figure 9. Sample PQI ranking list produced by PINS.**

* PAVEMENT INFORMATION AND NEEDS SYSTEM *

* SECTIONAL SUMMARY TABLE *

* PQI RANKING FOR REGION 2 *

| 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 | 3.1 | 4.3 | 1.2 | N/A |
| 2 | 3 | 10-08 | ECL DRUMHELLER TO EAST COUL | 1 | 0.00 | 5.79 | 0.1 | 2.3 | 3.0 | 1.2 | N/A |
| 3 | 3 | 10-08 | ECL DRUMHELLER TO EAST COUL | 3 | 6.92 | 10.23 | 0.4 | 2.8 | 3.2 | 1.3 | N/A |
| 4 | 4 | 1A-06 | JCT 940 TO 16 AVE NW CALGAR | 1 | 0.00 | 3.35 | 4.5 | 1.2 | 0.1 | 1.5 | N/A |
| 5 | 4 | 2A-12 | JCT 2 TO DIDSBURY | 3 | 9.48 | 9.75 | 4.3 | 0.9 | 1.1 | 1.5 | N/A |
| 6 | 3 | 21-14 | JCT 9 TO JCT 27 | 21 | 39.47 | 41.05 | 4.1 | 2.2 | 0.1 | 1.7 | N/A |
| 7 | 3 | 21-14 | JCT 9 TO JCT 27 | 22 | 41.05 | 42.64 | 4.0 | 2.5 | 0.5 | 1.7 | N/A |
| 8 | 3 | 21-14 | JCT 9 TO JCT 27 | 20 | 38.54 | 39.47 | 4.2 | 2.7 | 0.3 | 1.8 | N/A |
| 9 | 3 | 21-16 | JCT 27 TO JCT 42 | 1 | 0.00 | 2.48 | 4.2 | 2.6 | 0.4 | 1.8 | N/A |
| 10 | 3 | 21-16 | JCT 27 TO JCT 42 | 2 | 2.48 | 3.07 | 4.1 | 2.6 | 0.7 | 1.8 | N/A |
| 11 | 4 | 1-14 | JCT 21 TO JCT 956 | 1 | 0.00 | 11.44 | 2.8 | 2.7 | 1.9 | 2.0 | N/A |
| 12 | 4 | 1A-06 | JCT 940 TO 16 AVE NW CALGAR | 3 | 12.16 | 13.63 | 4.4 | 3.3 | 1.0 | 2.0 | N/A |
| 13 | 4 | 2A-04 | JCT 2 TO JCT 23 | 1 | 0.00 | 18.78 | 3.2 | 1.1 | 2.4 | 2.0 | N/A |
| 14 | 3 | 21-14 | JCT 9 TO JCT 27 | 23 | 42.64 | 44.05 | 4.0 | 3.4 | 0.3 | 2.0 | N/A |
| 15 | 3 | 21-14 | JCT 9 TO JCT 27 | 19 | 36.36 | 38.54 | 4.7 | 2.5 | 1.2 | 2.1 | N/A |
| 16 | 3 | 10-08 | ECL DRUMHELLER TO EAST COUL | 6 | 14.50 | 21.27 | 2.3 | 2.9 | 3.5 | 2.2 | N/A |
| 17 | 4 | 2A-10 | S.CROSSFIELD TO N.CROSSFIEL | 1 | 0.00 | 2.04 | 3.6 | 1.8 | 2.5 | 2.3 | N/A |
| 18 | 4 | 1A-04 | JCT 1X TO JCT 940 | 2 | 27.34 | 29.64 | 4.2 | 2.4 | 2.0 | 2.4 | N/A |
| 19 | 4 | 1A-06 | JCT 940 TO 16 AVE NW CALGAR | 2 | 3.35 | 12.16 | 4.6 | 1.6 | 2.2 | 2.4 | N/A |
| 20 | 3 | 21-16 | JCT 27 TO JCT 42 | 4 | 4.09 | 14.53 | 5.0 | 2.5 | 1.5 | 2.4 | N/A |
| 21 | 4 | 22-16 | JCT 1 TO CREMONA | 7 | 9.28 | 10.93 | 4.2 | 5.1 | 0.7 | 2.4 | N/A |
| 22 | 4 | 2A-04 | JCT 2 TO JCT 23 | 3 | 20.74 | 21.54 | 5.0 | 4.7 | 0.4 | 2.5 | N/A |
| 23 | 3 | 21-16 | JCT 27 TO JCT 42 | 3 | 3.07 | 4.09 | 4.9 | 2.9 | 1.6 | 2.5 | N/A |
| 24 | 4 | 9-04 | JCT 21 TO SCL DRUMHELLER | 1 | 0.00 | 0.39 | 3.2 | 1.7 | 4.6 | 2.6 | N/A |
| 25 | 4 | 22-16 | JCT 1 TO CREMONA | 4 | 7.88 | 8.09 | 4.6 | 5.3 | 0.4 | 2.5 | N/A |
| 26 | 4 | 22-16 | JCT 1 TO CREMONA | 5 | 8.09 | 8.50 | 4.5 | 5.1 | 1.1 | 2.6 | N/A |
| 27 | 4 | 1-08 EBD | JCT 22 TO WCL CALGARY | 1 | 0.00 | 3.81 | 4.8 | 4.4 | 1.3 | 2.7 | N/A |
| 28 | 4 | 1-08 EBD | JCT 22 TO WCL CALGARY | 2 | 3.81 | 7.63 | 4.7 | 4.9 | 1.2 | 2.7 | N/A |
| 29 | 4 | 1-08 EBD | JCT 22 TO WCL CALGARY | 3 | 7.63 | 13.07 | 4.8 | 5.2 | 1.1 | 2.7 | N/A |
| 30 | 4 | 1-10 EBD | BLACKFT TR(CAL) TO JCT 9 | 6 | 19.28 | 26.61 | 4.4 | 4.9 | 1.3 | 2.7 | N/A |
| 31 | 4 | 1A-06 | JCT 940 TO 16 AVE NW CALGAR | 8 | 24.63 | 29.53 | 4.7 | 5.2 | 0.9 | 2.7 | N/A |
| 32 | 3 | 21-14 | JCT 9 TO JCT 27 | 5 | 9.98 | 13.95 | 4.3 | 4.6 | 1.5 | 2.7 | N/A |
| 33 | 4 | 22-16 | JCT 1 TO CREMONA | 2 | 0.63 | 3.02 | 4.9 | 5.3 | 0.8 | 2.7 | N/A |
| 34 | 4 | 22-16 | JCT 1 TO CREMONA | 3 | 3.02 | 7.88 | 5.0 | 5.3 | 0.7 | 2.7 | N/A |
| 35 | 4 | 27-06 | ECL SUNDRE TO JCT 2 | 3 | 25.20 | 26.26 | 4.3 | 5.8 | 0.4 | 2.7 | N/A |
| 36 | 3 | 56-10 | JCT 9 TO S.JCT 589 | 3 | 12.97 | 13.35 | 4.2 | 4.3 | 1.7 | 2.7 | N/A |
| 37 | 4 | 1-06 EBD | E.MORLEY TO JCT 22 | 3 | 16.56 | 20.42 | 4.4 | 5.4 | 1.2 | 2.8 | N/A |

Figure 10. Sample three-dimensional histogram produced by PINS.

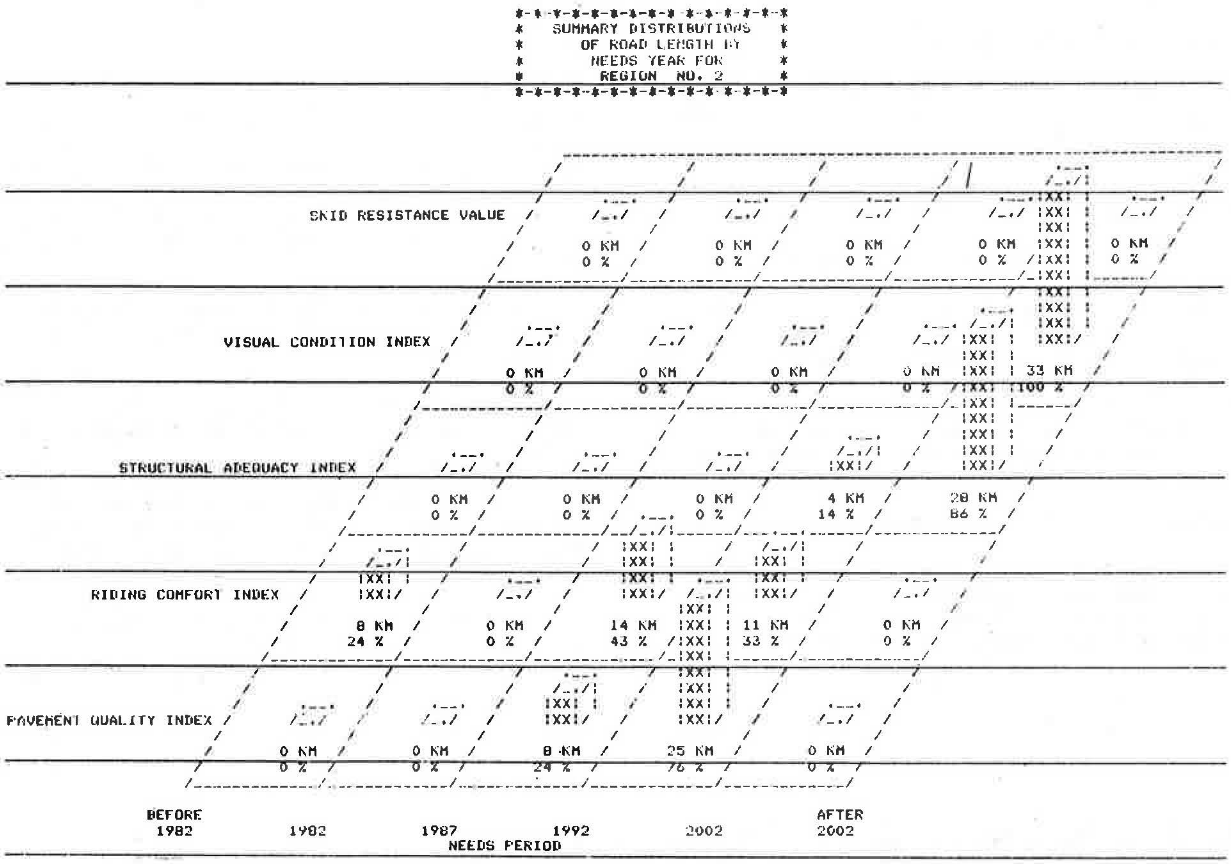



Figure 11. Sample needs list produced by PINS.

* PAVEMENT INFORMATION AND NEEDS SYSTEM *

* NEEDS IDENTIFICATION LIST *
BY VCI
* FOR HIGHWAY 1 *
FOR ALL SECTIONS OF THIS HIGHWAY

| DISTRICT | HWY - CONTROL SECTION | CONTROL SECTION DESCRIPTION | INV. SECTION | BEGIN KM. | END KM. | PAVEMENT QUALITY INDEX | RIDING COMFORT INDEX | STRUCTURAL ADEQUACY INDEX | NEEDS * * * VISUAL CONDITION INDEX | SKID RESISTANCE VALUE |
|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 1- 2 | EBD BANFF PK BDY TO JCT 1X | 1 | 0.00 | 2.62 | 2.9(1995) | 4.2(1988) | 2.3(2005) | 3.5(2007) | N/A |
| 4 | 1- 2 | EBD BANFF PK BDY TO JCT 1X | 2 | 2.62 | 4.26 | 2.5(1997) | 4.1(1989) | 1.7(2006) | 3.5(2010) | N/A |
| 4 | 1- 2 | EBD BANFF PK BDY TO JCT 1X | 3 | 4.26 | 10.89 | 2.7(1999) | 4.2(1992) | 2.1(2008) | 3.5(2010) | N/A |
| 4 | 1- 2 | EBD BANFF PK BDY TO JCT 1X | 4 | 10.89 | 15.37 | 2.1(1988) | 3.5(1982) | 1.3(1999) | 3.5(2007) | N/A |
| 4 | 1- 2 | EBD BANFF PK BDY TO JCT 1X | 5 | 15.37 | 18.60 | 2.7(1992) | 3.6(1982) | 2.6(2006) | 3.4(2007) | N/A |
| 4 | 1- 2 | EBD BANFF PK BDY TO JCT 1X | 6 | 18.60 | 21.79 | 2.5(1997) | 3.9(1989) | 1.8(2007) | 3.4(2011) | N/A |
| 4 | 1- 2 | EBD BANFF PK BDY TO JCT 1X | 7 | 21.79 | 32.52 | 2.8(2000) | 4.0(1993) | 2.4(2010) | 3.5(2011) | N/A |

Needs tables are also produced for each performance parameter and for each year in the programming period. Figure 11 shows a sample needs table.

In summary, the PINS program developed for Alberta analyzes the data base first to determine the present status and second to predict performance and 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 and graphical format for every section. Network summary information is also produced in tabular and graphical formats.

## TASK 4: APPLY PINS TO PRIMARY HIGHWAYS IN ALBERTA

PINS has been applied to all of the primary highways in each of the six regions in Alberta. These results, which are described in detail by Kerr and Karan (5), included the predicted performance over a 30-year period (1982 to 2012) for each inventory section; the existing status of the primary highways in each region in terms of PQI, RCI, SAI, and VCI; and the needs lists for selected periods of time, again for each of the four evaluation indices.

Alberta Transportation's headquarters and regional personnel have gone through the results in detail and assessed their reasonableness. Extensive field trips and discussions indicated that the results are reasonable and that they provided useful information for pavement management purposes. A few comments were made about program structure and formats to make the overall program performance more efficient and results more directly useful to the department's engineers. In overall terms, however, the PINS was generally accepted as a valuable tool within the department.

TASKS 5 AND 6: CONTINUING WORK PLAN

The following tasks were conducted to complete stage 1 by September 1982 and provide a good base for stage 2:

1. Refine PINS program based on the feedback received from Alberta Transportation in terms of input and output formats,
2. Prepare model and system documentation,
3. Prepare user manual,
4. Install PINS program on Alberta Transportation's computer facilities,
5. Conduct training courses for the users of PINS at Alberta Transportation,
6. Prepare a detailed work plan for stage 2, and
7. Carry out the actual work in stage 2 according to the plan prepared in step 6 above and the preplanning report.

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# Predicting Reductions in Service Life of Surface-Treated Pavements under Oil Field Traffic

THOMAS SCULLION, JOHN M. MASON, JR., AND ROBERT L. LYTTON

**One adverse effect of the recent oil field boom in Texas has been the accelerated physical deterioration of many of the thin pavements that service the oil fields. To study this problem the Texas State Department of Highways and Public Transportation sponsored a research project the ultimate aim of which is to quantify the additional costs to the highway department associated with the drilling of a single well and the total costs for any impacted area. One key phase of the study has been the development of pavement distress and performance equations for thin pavements that relate pavement damage to traffic loading. These equations have been developed by regression analysis using pavement condition data collected during a seven-year period on thin pavements in Texas. Initial results demonstrate that these regression equations are better predictors of long-term pavement performance than the AASHTO equation. A case study is presented to outline how these predictions were used to calculate reductions in pavement life and increases in life-cycle costs associated with the oil field development. This study predicted that the oil field development reduced the remaining life of a typical thin pavement from 46 to 16 months and increased the rehabilitation costs tenfold from $0.50 to more than $5.00/yd$^2$.**

During the late 1970s and early 1980s, several Texas counties experienced a rapid expansion of oil field exploration and development work. A majority of the pavements in these rural areas are surface-treated pavements, which typically have a 6-in. flexible base. These pavements were not designed to carry the high intensity of loads associated with oil field traffic, and subsequently many severe pavement failures occurred. The Texas State Department of Highways and Public Transportation (TSDHPT) found that the oil-related activity caused considerable additional demand for their maintenance and rehabilitation funds. This aroused an interest in providing a means of accurately predicting the additional life-cycle costs incurred. Questions such as the following became the subject of a research project (1) with the Texas Transportation Institute: What traffic loads are associated with the development of an oil well? How much damage do they do? What additional costs are associated with the drilling of a single well? What are the total costs associated with an impacted area? The long-term objectives of this project are as follows.

1. Identify the type and duration of loads associated with the development of a single oil well. Convert these loads into 80-kN (18-kip) equivalent single-axle-loads (ESALs).
2. Develop a procedure to predict the reduction in pavement life and increases in rehabilitation costs associated with these oil-related loads.
3. Perform a life-cycle cost analysis to identify total additional costs associated with the development of a single well and total costs for an oil-impacted area.

The first objective has been met and is reported elsewhere (1). This paper concentrates on describing the development of the predictive procedure used for calculating the reductions in pavement life associated with oil field traffic and presents the initial results of a life-cycle cost analysis.