Alternative methods for pavement network rehabilitation management
Mohseni, Alaeddin
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Alternative methods for pavement network rehabilitation management

Mohseni, Alaeddin, Ph.D.

University of Illinois at Urbana-Champaign, 1991

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ALTERNATIVE METHODS FOR PAVEMENT NETWORK REHABILITATION MANAGEMENT

BY

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M.S., Oregon State University, 1985

THESIS

Submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy in Civil Engineering
in the Graduate College of the
University of Illinois at Urbana-Champaign, 1991

Urbana, Illinois

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Committee on Final Examination†

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Dedication

I dedicate this thesis to my late mother, Sareh Bigum Alemzadeh, for her support and encouragement throughout my life and my education, and for all human values that she taught me.

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1 Introduction

1.1 Problem Description

The Illinois Interstate system includes approximately 500 different pavement sections, totaling 3500 one directional centerline miles and having a pavement replacement cost of over 7 billion dollars. The majority of these sections were built during the 1960's and early 70's and have experienced severe climatic conditions and much higher traffic loadings than those for which they were designed. About half of the network has already been rehabilitated and the rest either is currently in need of rehabilitation or will be within the next 10 years. It is estimated that by the year 2000 nearly all of the sections in the network will be rehabilitated at least once and about half will need another rehabilitation (Figure 1.1).

Unfortunately, the funds available for rehabilitation of the Interstate pavement sections are limited. Therefore, not all of the sections in the network that need rehabilitation can be funded. The rest of the sections must be deferred until funding becomes available. By that time, however, not only are the deferred projects further deteriorated, but more projects are added to the backlog, thus requiring a much higher budget to maintain the network condition at an acceptable level. Increased routine and emergency maintenance costs are also incurred as the backlog increases.

The Illinois Department of Transportation (IDOT) has not had available the required data or accurate procedures for estimating funding needs and pavement conditions over future years. In addition, subjective methods which

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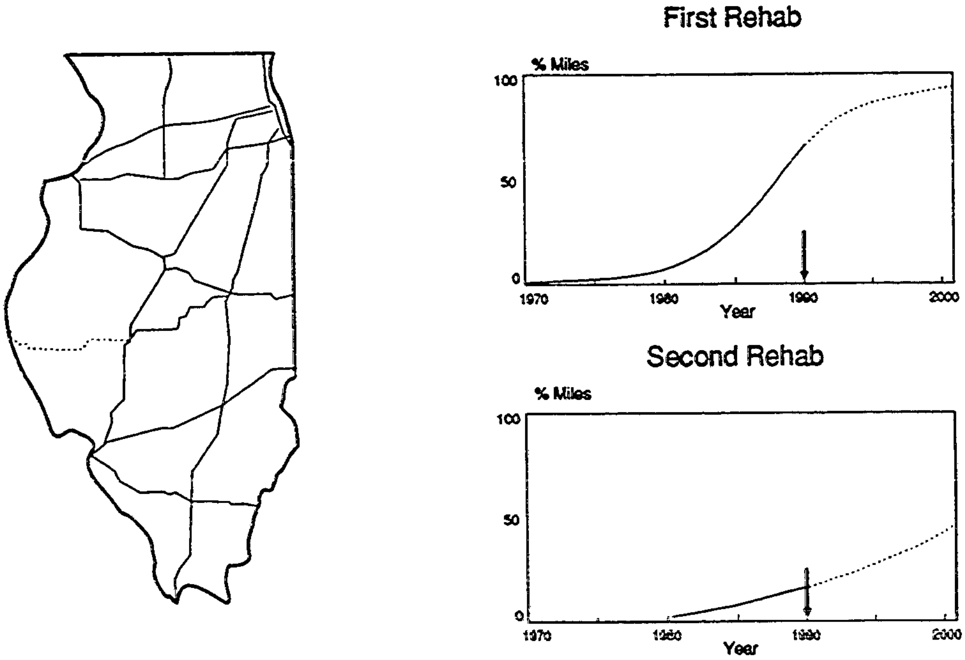

Figure 1.1- Illinois Interstate Highway Rehabilitation Needs Until Year 2000.

have been used to allocate funding for rehabilitation projects do not insure that the condition of the Interstate network is maintained in the most cost-effective manner possible.

1.2 Research Objective

The objective of this research is to develop a network pavement rehabilitation management program called ILLINET to aid IDOT districts and central offices in pavement management decision making for the Illinois Interstate highway network. This program helps the user to analyze data regarding pavement design, condition, traffic, climate, and other factors to provide answers to critical questions often asked about the network at the planning and administration levels before budget allocations are made. These questions are mainly regarding the selection of sections to receive rehabilitation, rehabilitation

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type and timing. Another question is the effect of different rehabilitation and funding policies on the pavement network.

ILLINET provides IDOT with a wide variety of project-level rehabilitation selection routines, network-level analysis algorithms, and benefit functions to identify which projects in the pavement network should receive funding, what treatments are best for those sections, and when the treatments should be applied. As a part of this research, different project-level and network-level methods are analyzed to recommend the most appropriate for use by IDOT.

The development of ILLINET includes the use of available predictive models and development of other models needed. Specifically, systems are developed to:

1. Provide a variety of methods to generate feasible pavement rehabilitation strategies (treatments and timings) for each pavement section in the Illinois Interstate network over a period of up to 10 years.

2. Provide several network management algorithms ranging from pure judgement, to ranking, to different levels of optimization.

3. Provide several ways of defining "benefits."

4. Determine the overall rehabilitation program for a selected budget, or the budget required to maintain the network condition at a desired level.

5. Determine the optimum rehabilitation program for a given budget, and also the minimum budget required to maintain the Illinois Interstate network in the desired condition.

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6. Provide answers for a variety of "what if" questions which are asked before a rehabilitation policy is adopted or budgets are allocated for the rehabilitation of pavements.

7. Analyze the consequences of different project-level rehabilitation selection methods, network-level algorithms, and choices of benefit functions on network performance and budget.

This document outlines a pavement management program developed for IDOT which has been designed to provide these capabilities, and also to meet the current FHWA policy on pavement management.

1.3 Organization of Thesis

This document is organized into three main sections including ten chapters (Table 1.1). The first section, consisting of Chapters One and Two, characterize the research objectives, organization, general description of the problem, available data, and concepts used to approach the problem. The second section, consisting of Chapters Three through Seven, describes the components of the ILLINET program. These include prediction models, pavement rehabilitation, pavement benefit, and alternate network algorithms. The third section, consisting of Chapters Eight through Ten, includes the results of application of ILLINET to a sample database, a sensitivity analysis of the program, and discusses conclusions from the research and recommendations for future work.

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Table 1.1 - Organization of Thesis.

Chapter	Heading	Subjects
1	INTRODUCTION	Background Objectives Report Organization
2	PAVEMENT MANAGEMENT SYSTEMS	PMS Components Alternate Algorithms IDOT Programming Process IPFS Overview ILLINET Overview
3	MODELS	ILLINET Distress Models Variability of Models Calibration of Models ILLINET Condition Models
4	REHABILITATION	Definition Rehab. vs. Maintenance Rehab. Alternatives Consequence of Rehab. Rehab. Costs
5	PROJECT-LEVEL	ILLINET Approach Condition Evaluation Rehab. Selection Strategy Generation
6	BENEFITS	Elements of Pavement Benefit Pavement Use vs. Performance ILLINET's Benefit Functions
7	NETWORK-LEVEL	Annual Network-level Management Multi-year Network-level Management
8	APPLICATION TO A SAMPLE DATABASE	Description of Sample Database Presentation of Results Discussion of Results
9	SENSITIVITY ANALYSIS	Sensitivity of MCRS, Benefit, Project- level, and Network-level ILLINET's Computational Efficiency
10	CONCLUSIONS AND RECOMMENDATIONS	Conclusions Recommendations

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2 Managing Pavements at the Network Level

This chapter describes the components of a Pavement Management System (PMS) with emphasis on the network-level analysis. Current IDOT pavement surveys and planning policies are also discussed here. An overview of the Illinois Pavement Feedback System (IPFS) and ILLINET is also given.

2.1 Pavement Management System

A Pavement Management System (PMS) is "a set of tools or methods that assist decision makers in funding cost-effective strategies for providing, evaluating, and maintaining pavements in a serviceable condition." (36) The key elements of a PMS are:

1. Pavement inventory,
2. A database system, and
3. Data analysis and reporting capabilities (Figure 2.1).

The main component of any PMS is its pavement inventory, since all pavement evaluations and recommendations for rehabilitation and other pavement analyses are made based on various data collected for pavement sections in the network. These data consist of design, condition, traffic, climate, and many other types of information. Naturally, more detailed data concerning pavements allow more comprehensive analyses.

A database system is an "effective, automated system for storage and retrieval of roadway inventory, condition, and traffic data." (36) An automated

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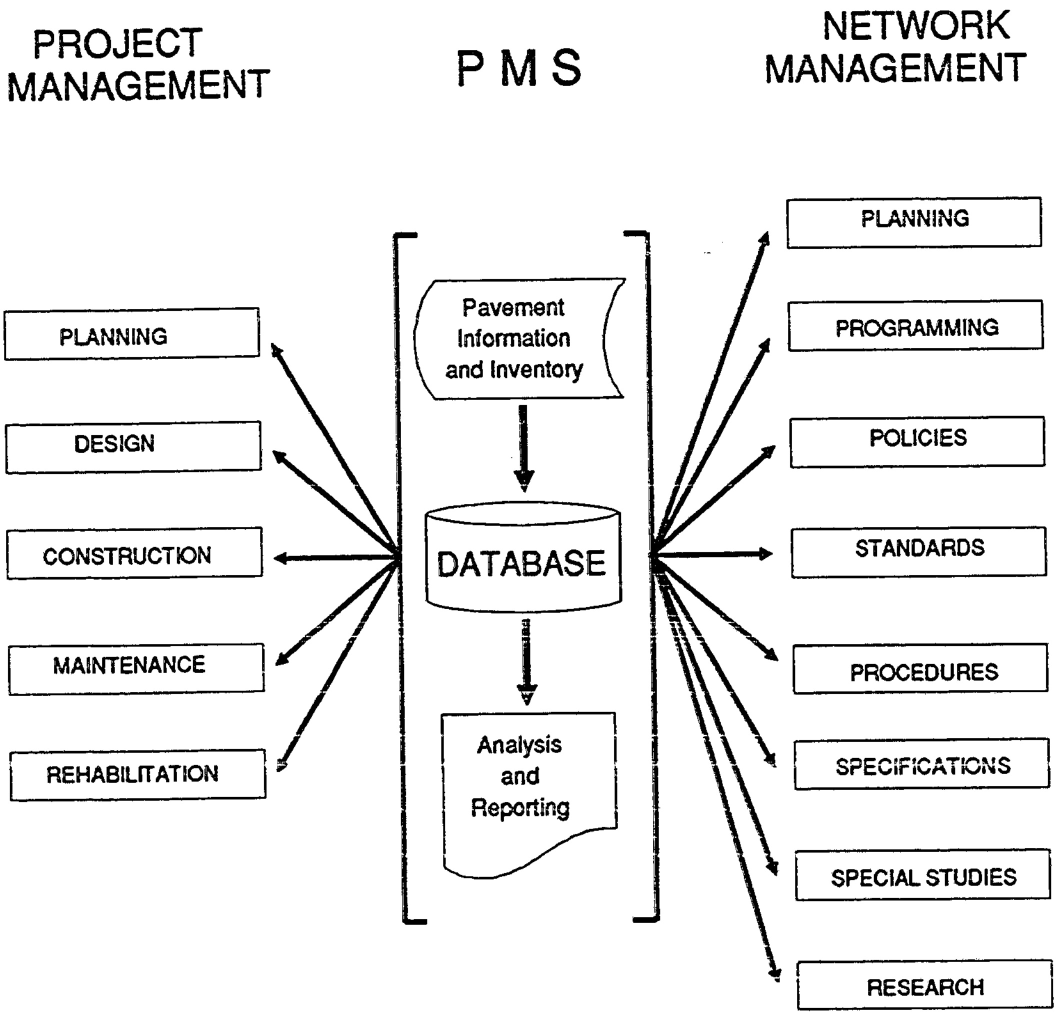

Figure 2.1 - Information Flow and Analysis in Pavement Management System.

database is essential to a PMS since the amount of data collected for a pavement network can be so large that any manual data retrieval and reduction might take weeks or months to complete.

The PMS component that makes it useful is data analysis and reporting. The data analysis and reporting capability of a PMS is its ability to utilize the collected data and other available knowledge to provide answers to a variety of

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questions. The main areas of data analysis are:

1. Future condition prediction models,
2. Project-level rehabilitation needs analysis,
3. Network-level optimization analysis, and
4. Other special analysis.

Prediction models are included to determine objectively the current condition of pavements and their future trends. Prediction models provide very useful information on how a pavement section is expected to perform in the future. This is an essential part of any pavement rehabilitation needs forecasting and budget planning. Prediction models are developed for pavement roughness, key distresses, overall condition, and other pavement parameters.

Project-level analysis involves the use of data concerning a pavement section together with other information to evaluate the pavement's condition, identify deficiencies, and recommend treatments that will correct the deficiencies. The use of prediction models in project-level analysis allow the timing and type of future pavement treatment to be planned. Prediction models that estimate the future life of treatments also provide the ability to conduct life-cycle cost analyses of treatment options to identify the most cost-effective alternative. There are several ways these project-level strategies can be generated. These methods range from judgment in the form of a decision tree, to benefit and cost analysis, or optimization.

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Network-level analysis deals with the problem of rehabilitating several pavement sections at the same time. A network-level analysis should be able to answer the following questions about a pavement network:

1. Which sections should be rehabilitated?
2. When should each of the sections be rehabilitated?
3. How should the sections be rehabilitated?

The network-level analysis can become very complicated when resource constraints (i.e. yearly budget limits) and performance constraints (i.e. minimum average network condition) are also considered.

The database system may also be used for a variety of research programs and special studies. These may include improving pavement design, setting standards, research on material properties, and so on. Finally, the results of the data analysis must be communicated to the engineers and managers of the agency. This makes the reporting capability of PMS an important part of the system. The combination of both tabular data summaries and graphical data presentation can provide a very unique and helpful communication medium.

2.2 Alternate Algorithms for Rehabilitation Programming

Pavement management at the network level should be capable of identifying which sections in the pavement network should receive funding, what treatments are best for those sections, and when the treatments should be applied. All this must be performed within various constraints (e.g. yearly funding limitations). This "which, when, and what" information is referred to as the

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rehabilitation program. In addition, the cost of rehabilitation for each section, the total rehabilitation cost for the network, and the measurable impact of the rehabilitation program on network performance or benefit should also be determined in a network analysis.

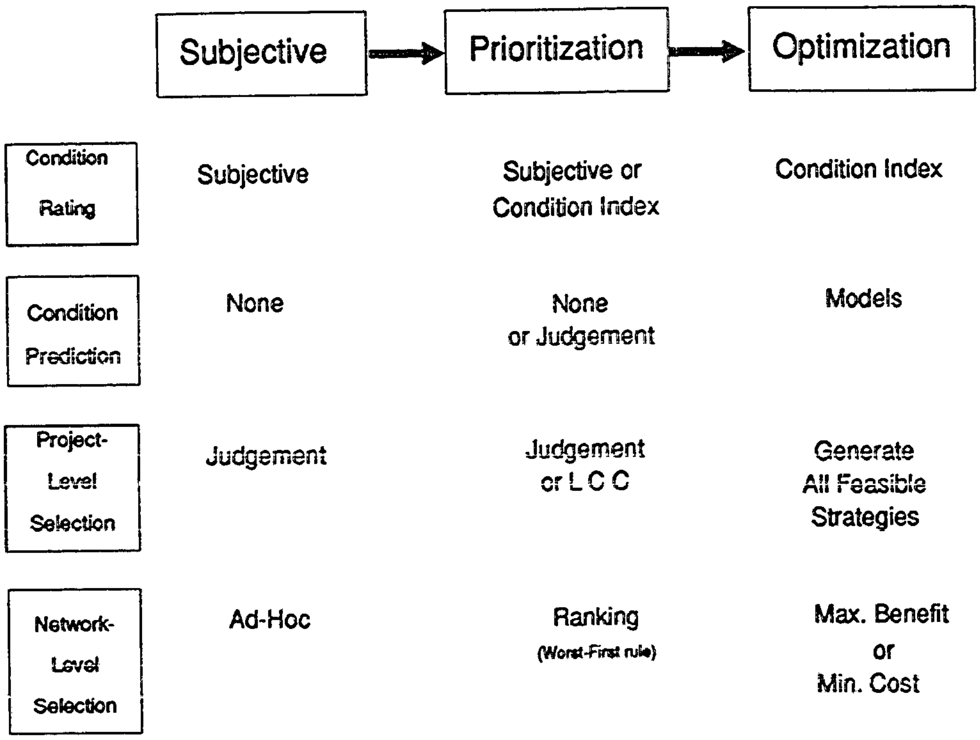

Figure 2.2 - Alternative Network-Level Algorithms.

There are several ways that a rehabilitation program can be generated (see Figure 2.2). The simplest way to arrive at a rehabilitation program involves a subjective inspection of the pavement network (rating each pavement on some scale), identification of pavement sections in need of treatment including a time estimate of when it is needed, and treatment type recommendations. A rehabilitation program is then developed by considering the pavement rating and

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other data such as traffic and functional classification and with regard to budget constraints and other social and political factors.

Subjective procedures such as this have proved to be inefficient and sometimes infeasible for management of larger pavement networks and for consideration of wider varieties of designs, pavement condition, distresses, and traffic levels. Also, since the rehabilitation program (treatment type and timing) is determined subjectively, the involvement of experienced engineers in the whole process is very important as many errors can occur. The major disadvantage of subjective pavement management is that such expertise might not be available at all times, due to typical high turnover rates.

To provide more accurate network programming, ranking procedures have been developed. The main feature of a ranking procedure is the rating of each pavement section in the network. Pavement ratings can be based on several factors such as visible distresses, roughness, structural capacity, or friction. Other factors such as traffic and functional classification are often used with the pavement rating to compute a ranking index. With this approach, pavement sections with the lowest ranking index are included in the rehabilitation program first. Although ranking is able to analyze a larger pavement network more objectively than subjective management, it still has some deficiencies:

1. Factors used for ranking relate to present pavement condition only; future conditions are not considered (or only estimated subjectively).

2. Decisions about project-level rehabilitation must be made prior to ranking; as a result, trade-offs among project-level alternatives cannot be considered.

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3. Inclusion of too many factors in ranking may result in an excessively complex ranking index.

4. Benefits of pavement rehabilitation are not considered in ranking. This may result in selection of alternative which are not very cost-effective.

A benefit-cost analysis may also be employed to rank pavements based on the benefit-cost ratio (B/C) of the rehabilitation alternative selected for each pavement. This is an improvement over simple ranking since future rehabilitation performance and benefits are realized.

Information handling and processing technology improves the analytical capabilities of pavement management systems. Operations research techniques are used to answer the three main network-level questions (i.e., where, when, and what). Operation research techniques (also referred to as "optimization") can provide the best possible solutions to network-level problems.

The first step in using optimization is the mathematical modeling of the problem. This means defining the objective function (OF) and a set of constraints. The general formulation of optimization is to maximize (or minimize) the objective function in the presence of several constraints. In network-level pavement management analysis this formulation translates into either maximization of pavement investments (benefits) considering budget limitations, or minimization of network rehabilitation costs considering network performance standards.

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Optimization can consider several alternative strategies (treatment types and timings) for every section in the network; thus trade-offs among projects are considered. Currently, the general trend is toward a network-level management system that uses heuristic rules (engineering judgement) and deterministic knowledge (prediction and condition models) together with optimization methods in solving the network-level problems.

2.3 Current IDOT Pavement Rehabilitation Programming Process

Each year all IDOT districts submit their lists of candidate projects for pavement rehabilitation, accompanied by their priority of repair, to the Office of Planning and Programming. The central office is then responsible for selecting the specific pavement sections that are in need of rehabilitation for inclusion in the multi-year program.

2.3.1 IDOT Pavement Surveys

Rehabilitation decisions are based on pavement need as recommended by IDOT districts, and also on data collected by different survey teams that inspect the Interstate network at various intervals:

The Pavement Review Team (PRT) visually surveys Interstate highways every two years. The objective is to identify pavement sections that are in need of rehabilitation and determine appropriate rehabilitation strategies. Each section is placed within one of the following four time frames (also called "priorities"):

PRT 1-2 : Pavements that are in immediate need of rehabilitation within one or two years.

PRT 3-5 : Pavements that will need rehabilitation in three to five years.

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PRT 5-10 : Pavements that will need rehabilitation in five to ten years.

PRT >10 : Pavements that will not need rehabilitation within the next ten years.

PRT evaluation of the pavements is based entirely upon the judgment of the experienced engineers on the team. Visible distress information is collected and is an important factor in time frame placement and strategy. This survey and priority has recently been eliminated by IDOT.

The Condition Rating Survey (CRS) is a subjective visual rating (1 to 9 scale) of pavement structural condition based on the judgment of a joint central office/district team of experienced engineers. CRS is conducted every two years for all Interstate pavement sections. A subjective rating of pavement roughness is also conducted. Additionally, some distresses are identified during the CRS survey.

Roughness measurements are conducted with the BPR roughometer during the years of PRT survey for all pavement sections in the network. Additionally, all new pavements and resurfacings are surveyed upon job completion. Friction measurements are performed in high-accident areas as necessary and as required for Federal-Aid Interstate (FAI) system funding during the years of PRT survey.

2.3.2 Project Rehabilitation Selection

Based on the CRS and PRT surveys, maintenance observations, accident reports, and other informal inspections, IDOT districts prepare a list of sections in need of rehabilitation, as well as the type of rehabilitation and their priorities for improvement. Although districts are expected to consider alternate

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rehabilitation options for a section and perform economic analysis, practically the only rehabilitation alternative used is a 3.25-inch asphalt overlay.

2.3.3 Network Budget Allocation

Since there is never enough funding to satisfy all recommended rehabilitation strategies in all districts, the Office of Planning and Programming decides which pavement sections will be included in the program. This is accomplished by ranking all projects recommended for rehabilitation from all districts by their need for rehabilitation, as indicated by the CRS, timing priority, and ADT. Those sections with CRS values less than the minimum acceptable CRS receive funding first.

After other commitments such as deficient structures, safety improvements, and rest areas are met, the remaining funds are allocated to the prioritized projects until the funding runs out. The Office of Planning and Programming, in cooperation with the districts, also decides which projects should be delayed and what their future time frame for improvement should be.

2.3.4 Discussion of IDOT Rehabilitation Programming Process

The function of IDOT pavement rehabilitation programming is mainly to determine the timing of rehabilitation since treatment types are already selected by IDOT districts. This is accomplished by ranking all pavement sections by their needs as indicated by CRS, PRT, and ADT on a year-to-year basis. Since the Interstate Review Team is no longer functioning, this timing determination is no longer made available.

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The objective is then to enter into the rehabilitation program those pavement sections that are in most need of rehabilitation as long as funding can be provided. A five-year program is developed based on the present need and estimated future need. To accomplish this, pavement condition is projected based on the judgment of experienced engineers (priorities by PRT). Rehabilitation timing within the multi-year program is decided subjectively.

Several different questions often arise during this programming and budgeting period, including the following:

1. How large a budget is required to maintain the network condition at a certain level over 5 or 10 years?
2. What are the consequences of different budget levels to the highway network and to the travelling public?
3. What are the consequences of adopting different rehabilitation and maintenance policies?
4. What is the optimum selection of projects for funding?
5. What is the consequence of delaying certain projects?

These questions and several others which are imperative to pavement management decision making have gone largely unanswered because of the lack of a database and available procedure. Pavement performance over the long range has not been considered and prediction models have not been used to predict pavement condition objectively.

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2.4 Illinois Pavement Feedback System Overview

A joint team of University of Illinois and IDOT personnel was formed to develop the Illinois Pavement Feedback System (IPFS) in 1985. The objective of IPFS is "to provide a formalized data processing structure and process which will collect, store, retrieve, and analyze design, materials, traffic, condition, and performance data for existing pavements." (2) A major part of the IPFS project is the development of the IPFS database which will provide IDOT districts and central offices with the information needed for a variety of pavement management purposes. The IPFS project also includes development of analysis routines and reporting capabilities for purposes such as special studies, research, prediction models, and answers to "what if" questions to help improve management strategies (Figure 2.3). The IPFS database is intended to provide all the information required for the analysis routines. The research effort described in this document, with specific objectives pertaining to network-level management of the Illinois Interstate System, is an integral part of the IPFS project.

2.5 ILLINET Overview

The objective of the Illinois network pavement rehabilitation management program (ILLINET) is to provide the Illinois Pavement Feedback System (IPFS) with network analysis and reporting capabilities to aid IDOT personnel in developing multi-year rehabilitation plans and in providing answers to several "what if" questions regarding network-level planning of pavement rehabilitation activities. Currently, IDOT utilizes a subjective ranking procedure based on CRS to allocate pavement rehabilitation funding.

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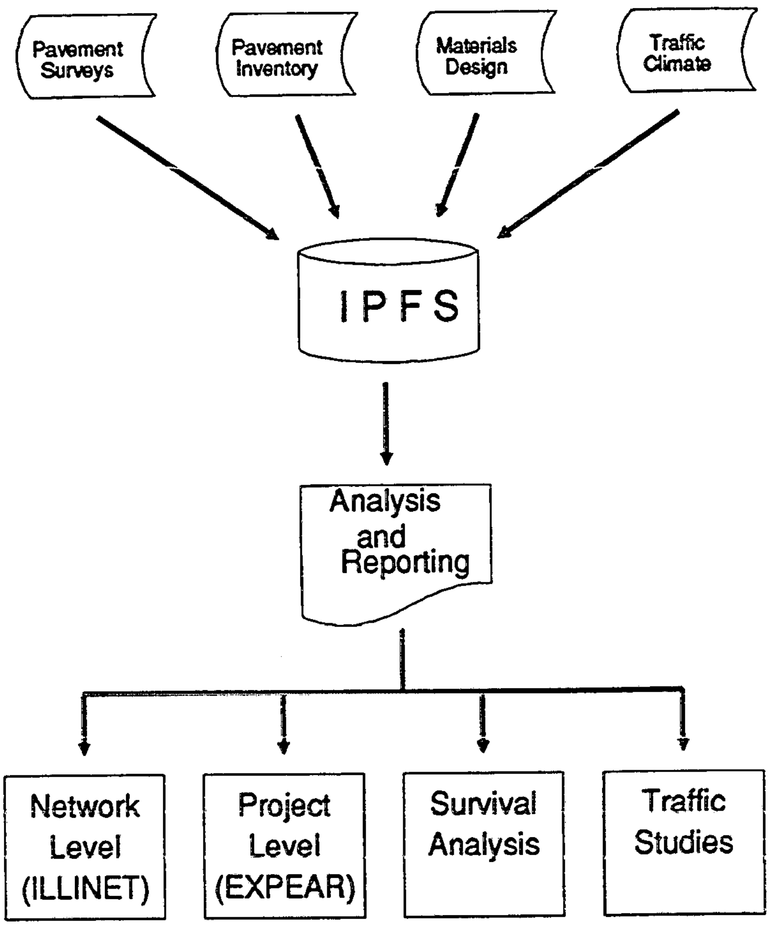

Figure 2.3 - IPFS Information Flow.

As discussed in previous sections, there are several ways to manage pavements at the network level. ILLINET provides several network management algorithms, ranging from judgement-based to different ranking methods to benefit-cost ratio comparison and finally optimization (Figure 2.4). In addition, several ways of defining benefits are provided using benefit as the criteria for management, and several project-level rehabilitation selection procedures are programmed. All these provide ILLINET broad capabilities in managing pavements at the network level.

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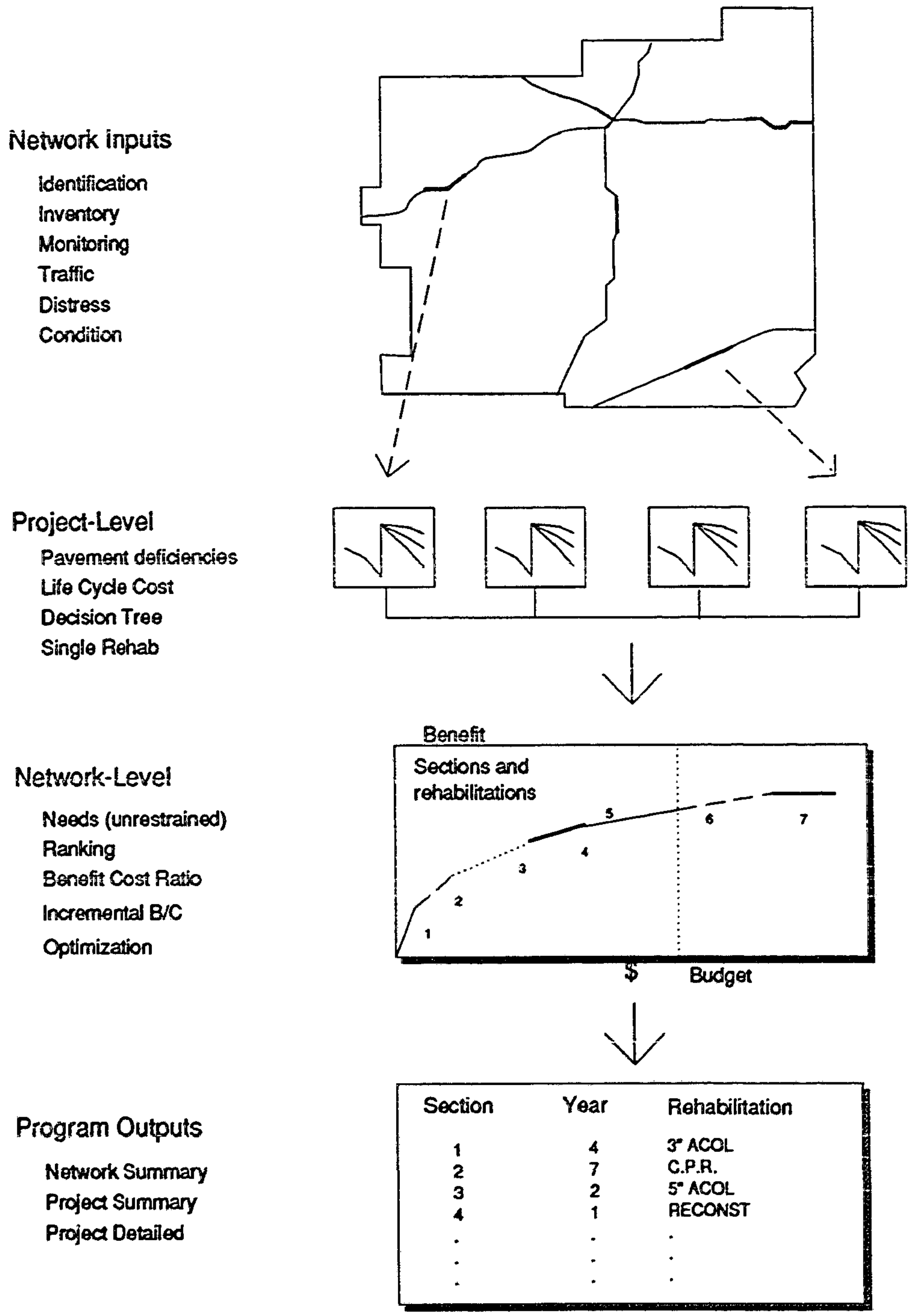

Figure 2.4 - Illustration of ILLINET Components and Options.

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One key aspect of the network-level analysis which has not been addressed before is the effect of each network-level algorithm on the network rehabilitation plan and subsequent performance. Each agency has simply adopted one of the procedures without any consideration of the consequences. The identification of network performance parameters to be used for comparison of alternate network-level methods is required. Questions that often arise in regard to network-level analysis include the following:

1. How does ranking compare to optimization?
2. What are the benefits of optimization?
3. Are these benefits significant?
4. What are the significant differences among different benefit functions and which benefit function provides the best rehabilitation plan?

A major objective of this research is to apply the various network-level decision algorithms available to ILLINET and compare the results. The purpose of this work is to identify the best network-level algorithm for use in developing a multi-year rehabilitation plan.

2.5.1 The ILLINET Computer Program

The ILLINET computer program, which is developed for IBM-compatible personal computers, consists of an analysis module written in Microsoft FORTRAN ANSI 77 language (32) plus an interactive and user-friendly presentation module written in Microsoft Quick BASIC language (33), with menus to enter data and run different options. The analysis module is transportable to other computer systems that support FORTRAN ANSI 77. ILLINET runs on any

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IBM-compatible personal computers with a math coprocessor, at least 640 kilobytes of random access memory (RAM), and more than one Megabyte of storage capacity. A color enhanced graphics adapter (EGA) monitor or better is required to run the interactive program. To run ILLINET efficiently, however, a 80286 or 80386 IBM compatible with standard configuration is recommended.

2.5.2 ILLINET User Friendly Features

Extensive efforts were made to provide IDOT personnel with a very user friendly and easy to use software program. There are several menus and user input screens built into ILLINET that makes it very easy for the user to select an option and to enter and modify data. Users are also able to run different options available in ILLINET and view the output in the form of reports and graphics. The output of the program is organized into three different reports ranging from the "big picture" to the "most detailed." The information in outputs are also charted into several graphs. ILLINET also provides the capability to graphically show the network and to select and view the output for different sections in the network. Following is a brief discussion of different user-friendly features in ILLINET. For more detailed discussion of the features available in the program refer to user's manual in Appendix B.

<u>Menus and Input Fields</u>: Several menus and input fields facilitates the selection of an option and data input such that very little or no computer knowledge is required to run the program. The first item of the main menu allows entering and modifying user input data as well as most of the data in the database (see Figure 2.5). The second item in the main menu includes several sub-menus that allows the user to choose a network-level, project-level, and

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benefit option and to run the program (Figure 2.6). From the same menu user can enter yearly constraints (either budget or performance). Help is also provided for each menu to provide more information for every item and input field in the menu.

Mapping: ILLINET is capable of drawing the map of the network being analyzed (see Figure 2.7). Every section in the network is identified and can be related to for data entry or for project-level charts. In this case, the network map serves as a menu for selection of a specific section. Maps are also used for demonstrating sections attributes like condition, traffic, and etc. Different categories of each attribute is shown using a distinct color. Maps for all nine IDOT districts are available in ILLINET.

Output Reports and Graphs: The results of ILLINET runs are output into three different reports. The network summary report contains yearly network statistics. The project summary report includes the network multi-year rehabilitation program and costs. The detailed project report includes section multi-year CRS, distresses, rehabilitation plan, and cost for every project in the network (refer to Appendix D for sample ILLINET outputs). All reports can be viewed and printed directly from the program. The information in ILLINET reports are also charted in different graphs. The network-level graph contains some of the data in network summary report (see Figure 2.8). The project-level graph shows some of the data in the project detailed report for every section. Project-level graphs are accessed from the network mapping menu facility (see Figure 2.9).

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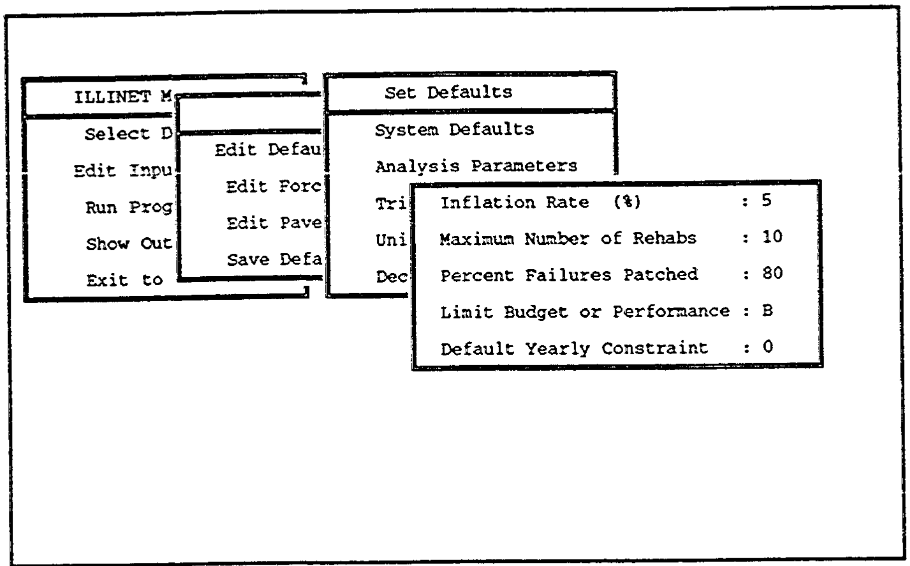

Figure 2.5 - Sample Input Data Menu and Input Screen.

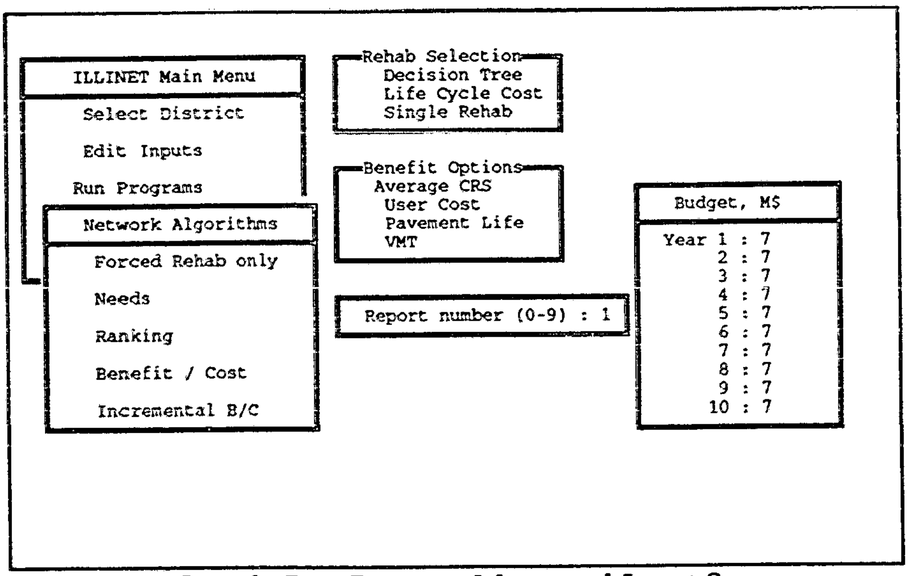

Figure 2.6 - Sample Run Program Menu and Input Screen.

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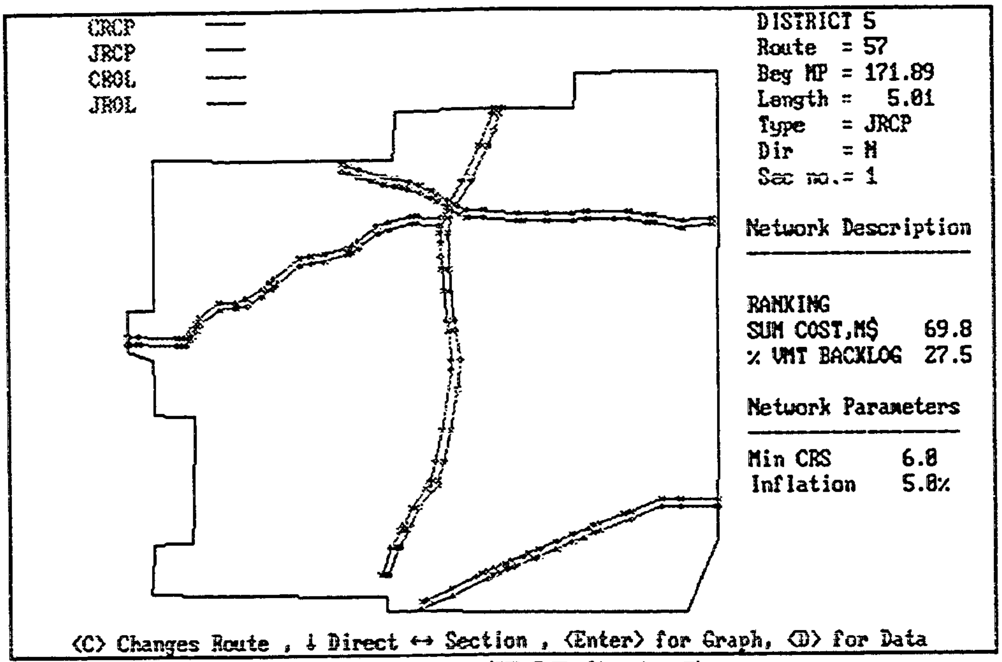

Figure 2.7 - Sample ILLINET Map (IDOT district 5).

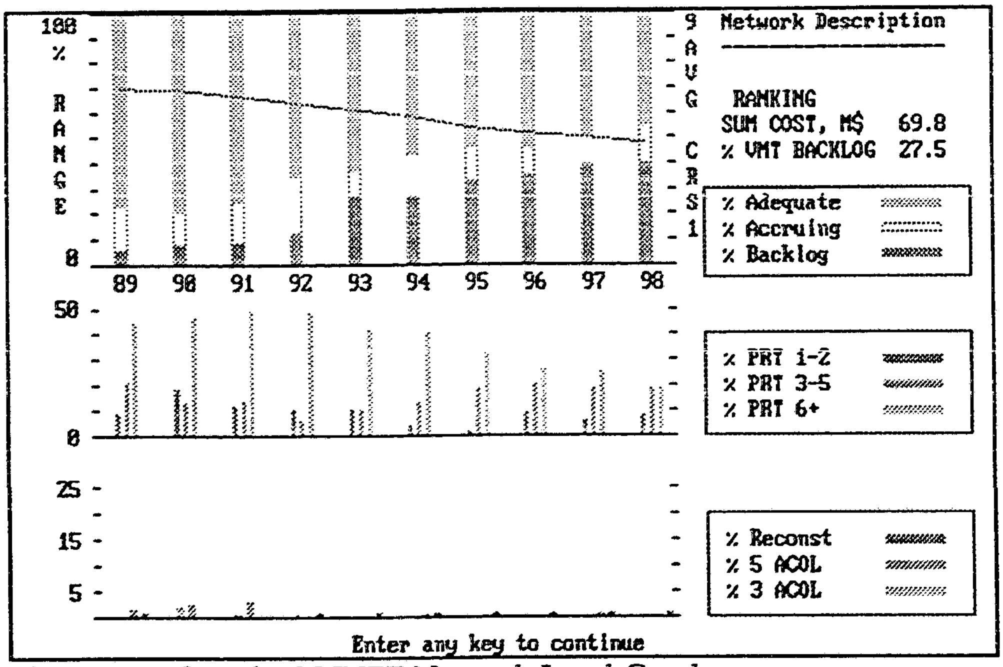

Figure 2.8 - Sample ILLINET Network-Level Graph.

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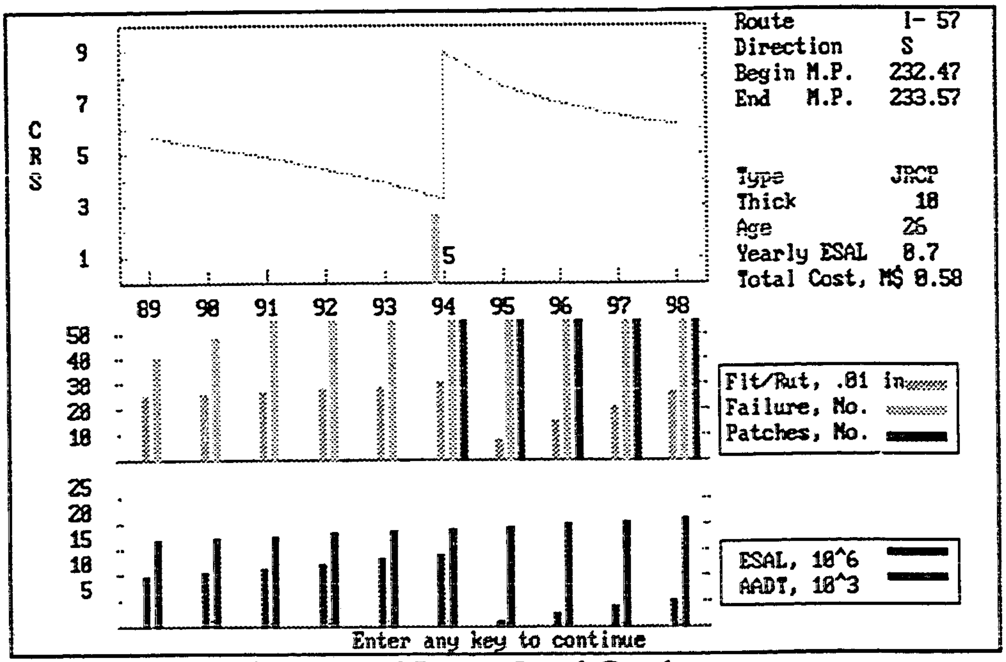

Figure 2.9 - Sample ILLINET Project-Level Graph.

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3 Pavement Deterioration Prediction Modeling

3.1 General

Pavement prediction models are an essential part of any comprehensive network-level pavement management system. Prediction models provide an estimate of future pavement behavior based on data available on past performance, which is an invaluable tool in project-level forecasting and network-level planning. Without prediction models an effective long-term network-level analysis is not possible.

Based on how models are developed, they are either deterministic or probabilistic. A deterministic model predicts the mean value of a predicting (dependent) variable, while a probabilistic model predicts the distribution of a dependent variable. Least squares regression is often used to develop deterministic prediction models, while survivor curves or Markovian or semi-Markovian models are used to develop probabilistic models.

Prediction models can also be mechanistic, empirical or mechanistic-empirical, depending on the formulation and whether mechanistic variables are used in the model. Lastly, there are project-specific or network models. Project-specific models predict pavement attributes as functions of several key pavement factors and can be used for a variety of pavement sections within their limit, while network-level models predict the average condition of a pavement group (for example a group of 3-inch asphalt overlays in a certain climatic condition and under a certain traffic loading).

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Regardless of how models are developed or what type of variables enter into the models or their formulation, the key element in developing prediction models is the pavement inventory. Without well-defined and well-prepared data and an efficient database system, developing reliable prediction models might not be possible.

3.2 Current Prediction Models in Use

Several prediction models have been developed by different agencies around the world to predict pavement serviceability, overall condition, and distresses. Among early prediction models developed for pavements are the AASHO Road Test models (38). These models predict the present serviceability index, which is a measure of a pavement's functional capability to provide a safe and comfortable ride, as a function of the number of 18-kip equivalent single-axle load (ESAL) applications the pavement receives. The empirically based AASHO Road Test models are widely used in pavement design and rehabilitation.

Other models are specifically developed for network-level analysis. Among the early network-level models is the Arizona model (37). One hundred and twenty different condition states based on different roughness, cracking levels and rate of cracking were defined, and probability transition matrices (a matrix containing the probability that a pavement moves from one condition state into a lower condition state) were developed for different networks defined by climatic condition and traffic levels.

Some models predict overall pavement condition as a function of major pavement parameters. Among these models are the PARS models (8). The PARS

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models predict pavement PCR (Pavement Condition Rating) which is a subjective rating of pavement serviceability, as a function of pavement age, thickness, traffic level, environmental factors and soil properties. The PARS models are also adjusted according to the existing pavement condition.

Another category of prediction models are site-specific models. In this type of model, which is currently in use in the State of Washington's PMS (24), future pavement condition is projected from past performance. This involves fitting a curve through the past condition data, while giving more weight to the most recent pavement ratings.

Models have also been developed to predict individual pavement distresses, rather than overall condition. Several such distress models were developed using the Concrete Pavement Evaluation System (COPES) database (5). The COPES database contains data for jointed plain concrete pavements (JPCP) and jointed reinforced concrete pavements (JRCP) from six states distributed among the various climatic regions of the United States. Following the development of the COPES database, non-linear regression models were developed that predicted key pavement distresses (pumping, faulting, cracking, and joint deterioration), as well as serviceability, as a function of several pavement parameters such as thickness, age, and traffic loading.

3.3 ILLINET Prediction Modeling Approach

ILLINET has capabilities for predicting major pavement distresses (Figure 3.1). The distress models used in ILLINET are project-specific since they are adjusted for the existing distress level on a specific project. Project-specific

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distress prediction models allow more accurate project-level prediction. Since the distress prediction from the ILLINET models provide the capablility of predicting the amount of rehabilitation work needed (e.g., patching quantities), this can result in more accurate pavement treatment cost estimations.

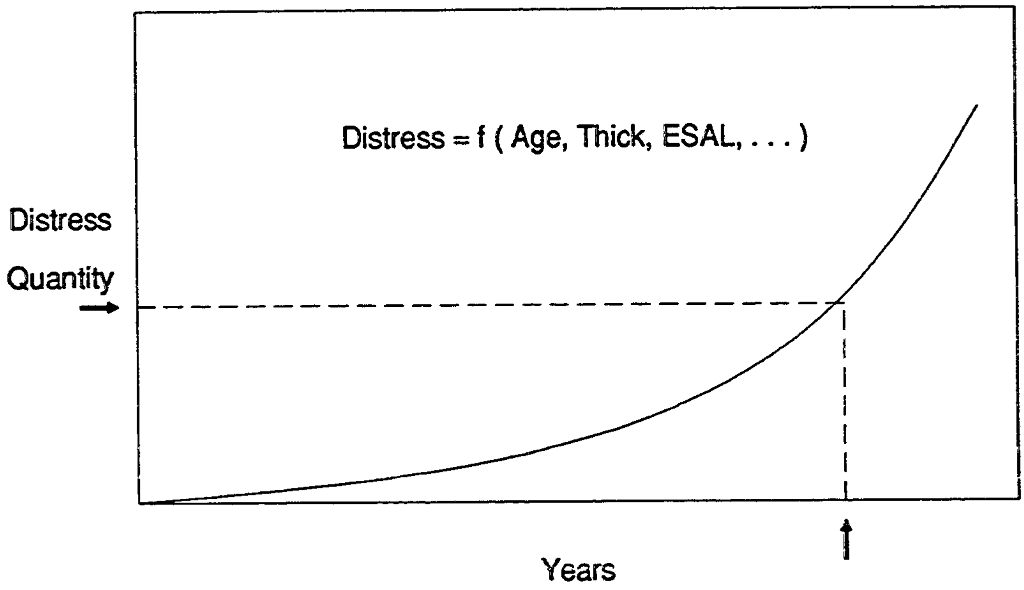

Figure 3.1 - Graph Illustrating General Form of ILLINET's Distress Models.

In addition to predicting major pavement distresses, an overall pavement condition rating called CRS (Condition Rating Survey) is also computed from the existing distresses. The computed CRS is developed to estimate the subjective CRS assigned in the field. CRS is used as a trigger value for pavement rehabilitation, trigger value for life, and for a measure of effectiveness of pavement treatments.

Several models are used to predict major pavement distresses for concrete and composite (asphalt over concrete) pavements (Table 3.1). Some of these

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models are developed under other research studies while others are developed as a part of this research effort. Specifically, models are utilized for faulting, cracking, and joint deterioration of jointed reinforced concrete pavement (JRCP), punchouts on continuously reinforced concrete pavement (CRCP), and reflective cracking and rutting of asphalt concrete (AC) overlays of concrete pavements. Following is a discussion of the models for each pavement type considered. Detailed descriptions of the distresses are given in Reference 39. Appendix A contains a description of each model for all pavement types considered.

Table 3.1 - Distress Models Used in ILLINET.

Pavement Type	Distress Type	Variables in Model
JRCP	Faulting	ESAL, Thickness, Freezing Index, Dowel diameter
	Cracking	Age, ESAL, Steel quantity, Freezing Index
	Joint Deterioration	Age, ESAL, Steel quantity, Freezing Index, 'D' Cracking
CRCP	Punchouts + Steel rupture + Full depth repairs	ESAL, Steel quantity, Base Type, Reinforvement Type
AC overlays of JRCP	Reflective Cracking	Age, ESAL, AC Overlay Thick
	Rutting	Age, ESAL, AC Overlay Thick
AC overlays of CRCP	Reflective Cracking	Age, CRCP Thick, AC Overlay Thickness
	Rutting	Age, ESAL, AC Overlay Thick

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3.4 JRCP Models

Several models that were developed under the NCHRP project 1-19 project (5) are used here to predict three major pavement distresses (faulting, cracking, and joint deterioration) for JRCP. A brief explanation of each distress follows.

Faulting of transverse joints is defined as the difference in elevation across a joint. This distress is mainly caused by the depression of leave slab (e.g. in the case of pumping) and or the buildup of material under the approach slab. Faulting is also caused by the lack of sufficient load transfer. Transverse cracking of JRCP is a major structural distress caused by load and/or climate. Cracking can be caused by fatigue cracking of concrete due to heavy traffic loadings and or cracking of the slab due to temperature gradient. Joint Deterioration (spalling of joints) is the cracking, breaking, or chipping of the slab edges. It is mainly caused by the excess stress buildup on the joint. Many factors including poor load transfer across the joint, presence of incompressibles in the joint, or 'D' cracking of the joint contribute to the joint deterioration.

These distresses are the most commonly observed JRCP distresses in Illinois; therefore, when considered collectively, they should provide a reasonable assessment of pavement condition. Non-linear regression equations were used in NCHRP 1-19 to develop models with the general form of:

$$\text{Distress} = (\text{Traffic or Age})^{a}\ (b\ \text{Design} + d\ \text{Climate} + \dots)$$

Where: a, b, c, d, e, ... are constants to be determined

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3.4.1 Faulting Model

The faulting model is sensitive to accumulative ESAL since construction, pavement thickness, dowel diameter, joint spacing, and Freezing Index (see Appendix A). Figure 3.2 illustrates faulting of a 10-inch JRCP as a function of pavement age since construction for four different levels of yearly ESAL. Dowel diameter of 0.5 inch, 100 feet joint spacing, and Freezing Index of 500 was assumed for this graph. From Figure 3.2 it can be observed that this pavement, under low levels of traffic loading (less than 0.5 million ESAL per year), does not develop a critical amount of faulting (0.25 inches) for more than 20 years. At higher traffic loadings (0.75 to 1 million ESAL per year), however, the age to critical faulting level is much shorter (11 to 14 years). As Figure 3.2 shows, there is a significant increase in faulting for increase in yearly ESAL, which indicates the rapid deterioration of pavement due to increased traffic loadings.

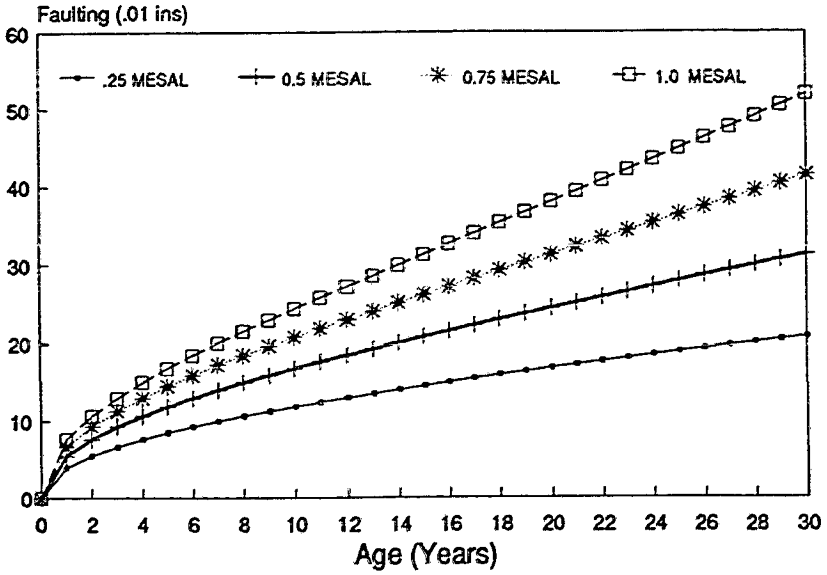

Figure 3.2 - Sample Performance Curve for Faulting.

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3.4.2 *Cracking Model*

The variables that enter into the cracking model are thickness of pavement, area of reinforcement steel, age of pavement since construction, joint spacing, and pavement base type (granular or stabilized) (see Appendix A). The cracking deterioration curve for a 10-inch JRCP with a stabilized base, 100-foot joint spacing, and area of steel of 0.5 in^2/foot is shown in Figure 3.3. As this figure shows, significant amount of cracking develops in the pavement after more than 20 years for low traffic loadings. However, for higher traffic loadings (1 million ESAL per year) the same cracking occurs in less than 10 years. The rate of cracking substantially increases for loadings more than 0.5 million ESAL per year. This is because of the fact that this type of pavement is only designed for moderate traffic loadings and cannot withstand higher ESAL's for a long period of time.

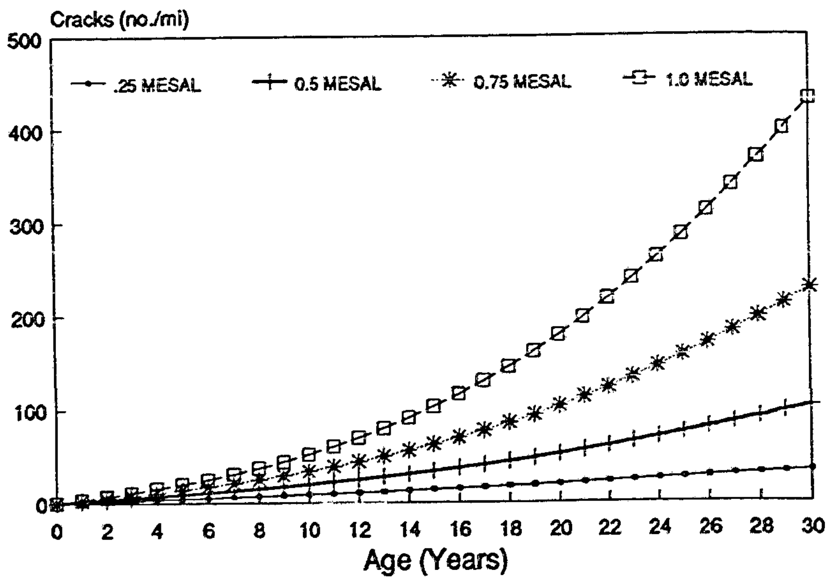

Figure 3.3 - Sample Performance Curve for Cracking.

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3.4.3 *Joint Deterioration Model*

This model predicts the number of deteriorated joints in a JRCP pavement as a function of pavement age, ESAL since construction, Freezing Index (FI), joint spacing, joint seal condition, and whether or not the pavement is 'D' cracked (see Appendix A). A prediction curve that shows the deteriorated joint versus age for traffic loadings of 0.5 million ESAL per year, 100-feet joint spacing, and for different climatic conditions (as denoted by FI) is illustrated in Figure 3.4. Figure 3.4 shows that a deteriorated joint is not significant for low FI levels and FI of over 1000 degree-days is necessary before an appreciable quantity of joint deterioration is developed for this type of pavement.

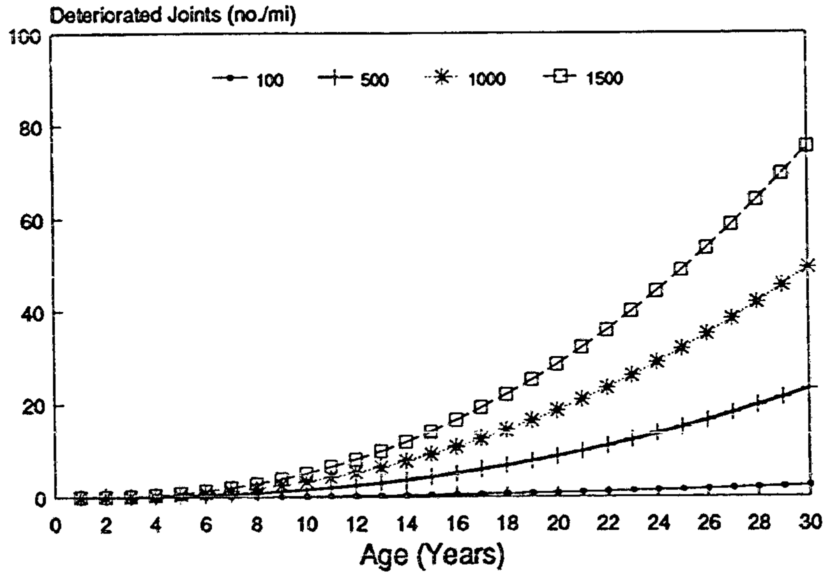

Figure 3.4 - JRCP Deteriorated Joint Model for Different Freezing Degree-Days.

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3.5 CRCP Model

Punchouts are the most commonly observed distress on CRCP in Illinois. Early formation of punchouts is mainly due to the rupture of reinforcing steel in the pavement, which results in a transverse crack in the concrete. When two cracks form close together, there is a potential for a punchout of the concrete between the two cracks.

A model was developed to predict failures (punchouts plus steel ruptures) of CRCP pavement as a function of variables such as pavement thickness, traffic loadings (ESAL since construction), base type, and type and amount of reinforcement. This model was developed from a database of Illinois CRCP sections as a part of a different research project (6). A complete description of the model is given in Appendix A.

Figure 3.5 shows the graph of number of failures developed in a CRCP pavement versus age of the pavement for one million ESAL per year and for different pavement thicknesses. As Figure 3.5 demonstrates, the age of pavement before significant quantities of failures develop in the pavement is: 10 years for a 7-inch, 14 years for 8-inch, 18 years for 9-inch, and 23 years for 10-inch CRCP. This depicts poor performance of 7-inch and excellent performance of 10-inch CRCP under relatively high traffic loadings of 1 million ESAL.

Figure 3.6 includes the graphs of failures versus age for an 8 inch CRCP and for different levels of ESAL per year. As this figure shows, an 8 inch CRCP can easily handle low and moderate levels of traffic loadings, but rapidly fails under higher loadings.

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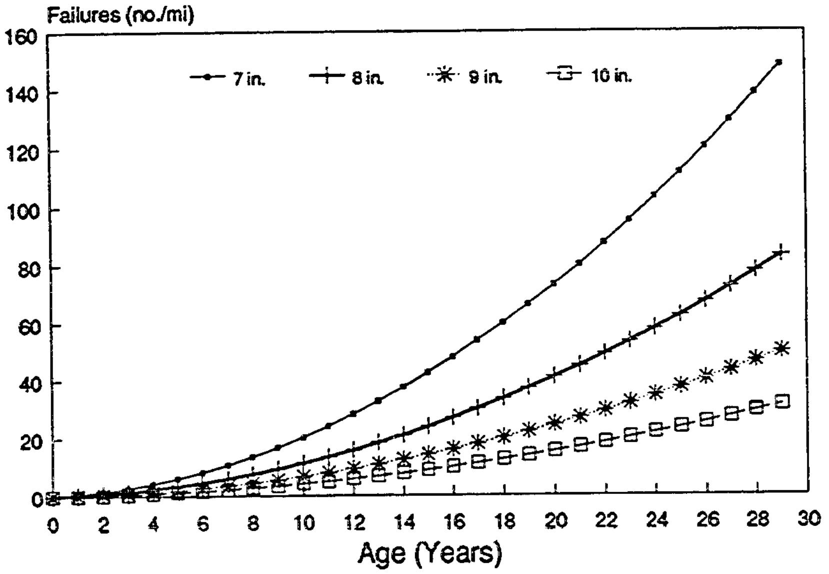

Figure 3.5 - Failures of CRCP for Different Thicknesses.

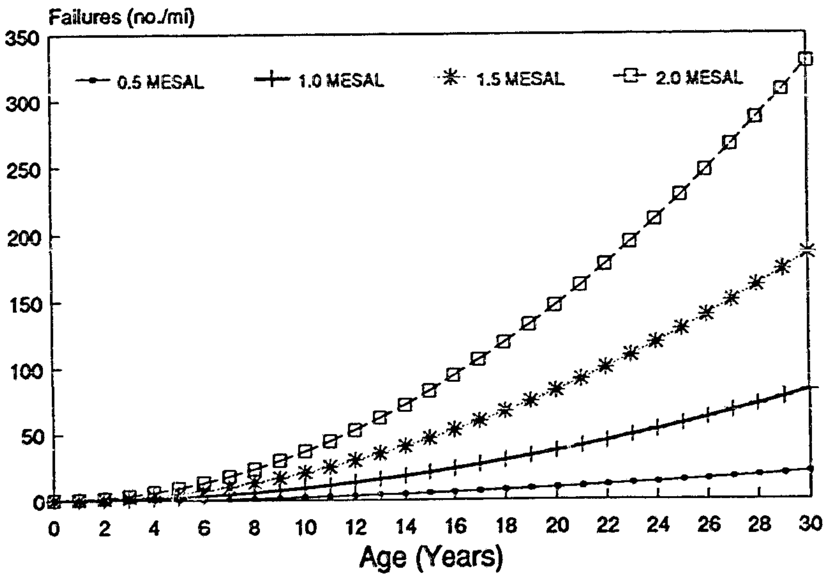

Figure 3.6 - Sample CRCP Failure Curve for Different Annual ESALs.

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3.6 Composite Pavements Models

The major distresses observed on AC overlays of JRCP and CRCP in Illinois are rutting and reflective cracking. Prediction of these distresses seems to provide a good indication of the pavement condition.

Rutting, or permanent deformation, which is a major safety problem, develops as a result of repeated application of heavy wheel loads on an AC overlay. (A complete description of rutting is given in Appendix A). Thus, the number of wheel applications, weight of loads, overlay thickness , and quality of the AC mix are typically the major factors used in predicting rutting. The model used for the prediction of rutting in ILLINET is described in Appendix A. The factors used in this model to predict rutting are age, traffic loading, and overlay thickness. This model represents rutting observed in the AC mix used on Illinois Interstates (IDOT Class I mix). Since the development of rutting is independent of the type of pavement overlaid, the same model was used for AC overlays of both JRCP and CRCP.

Reflective cracking of AC overlays is cracking of the AC layer due to a working joint or crack in the underlying concrete pavement. It is both climate and load associated. Because of the different modes of distress observed in CRCP and JRCP, the reflective cracking models used are different for the AC overlay of each pavement type.

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3.6.1 Rutting Model

Rutting of AC-overlaid concrete pavements is predicted as a function of age, traffic loadings (ESAL) since overlay construction, and thickness of overlay. Figure 3.7 shows rutting development in a 3.25-inch AC overlay for different levels of traffic loadings and for a 5.0-inch AC overlay with high traffic loadinds. For a low level of traffic loading, it takes at least 10 years before a substantial amount of rutting (.25 inch) is developed in the overlay. Higher traffic loadings develop the same amount of rutting between 3 to 6 years. The rate of rutting development is the highest between 0.5 and 1 million ESAL per year. At 2 million ESAL per year, 0.5 inch of rutting is developed in a period of 6 years. Another major factor in rutting is overlay thickness. For an overlay thickness of 5 inches and high traffic loading, a critical amount of rutting (0.25 inch) is developed in 2 years and 0.5 inch of rutting is developed in only 5 years.

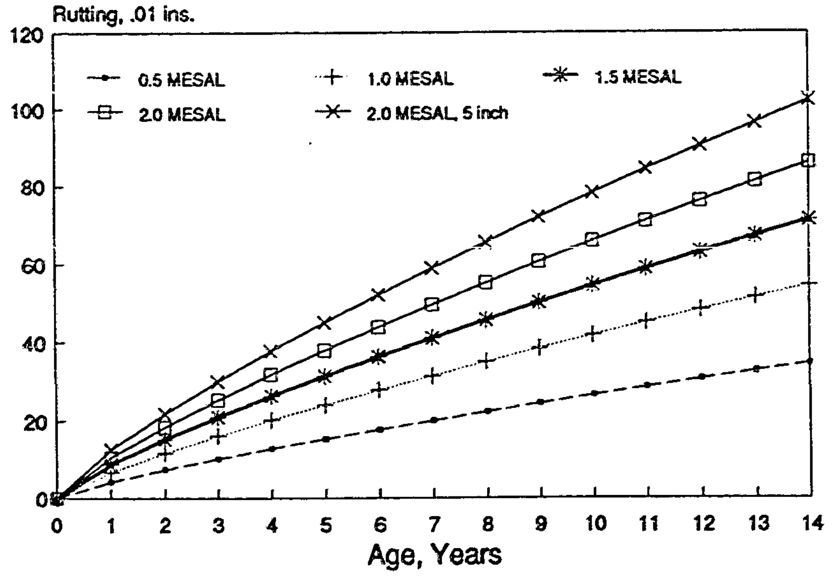

Figure 3.7 - Sample Rutting Performance Curve for Different Annual ESALs.

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3.6.2 *Reflective Cracking of JRCP Overlays*

The main variables in this prediction model are age and ESAL since overlay construction, number of working joints in the overlaid pavement, and overlay thickness. A 3.25-inch overlay with at least 50 working joints prior to overlay was chosen for the sensitivity analysis. The reflected cracking prediction curves for this overlay and for different levels of traffic loadings is shown in Figure 3.8. As Figure 3.8 depicts, within 2 to 3 years almost all working joints are reflected through the AC overlay. After this period, however, the rate of cracking decreases. In 12 years, 80 cracks for low traffic loadings and 110 cracks for high traffic loadings are observed. For a 5.0-inch overlay shown in Figure 3.8 however, 90 cracks develop for high traffic loadings during the same time period.

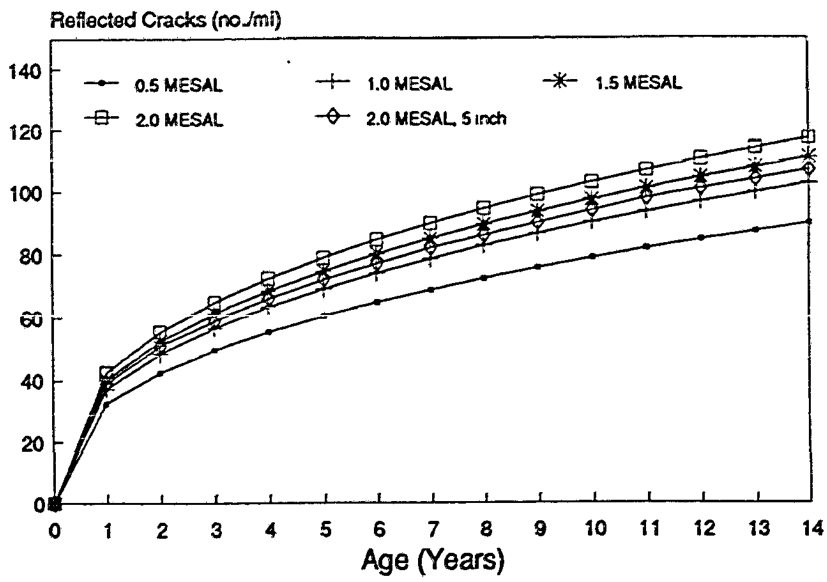

Figure 3.8 - Sample Reflective Cracking Model for AC Overlays of JRCP.

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3.6.3 Reflective Cracking of CRCP Overlays

Reflected cracking of CRCP overlays is predicted as a function of overlay age since construction, thickness of underlying CRCP, and AC overlay thickness. A 3.25-inch AC overlay was considered for the sensitivity analysis and reflected cracks versus age is graphed for different thicknesses of underlying CRCP (see Figure 3.9). After 14 years of service, very few cracks (only 8 or less) develop for 8 inch and thicker CRCP. For 7-inch CRCP however, a substantial number of cracks develop over the same time period (about 20 cracks). The reason AC overlays of 7 inch CRCP do not last very long is mainly that the early development of 'D' cracking in 7 inch CRCP's in the State of Illinois. The overlaid 'D' cracked sections soon after placement developed signs of failure on the AC surface.

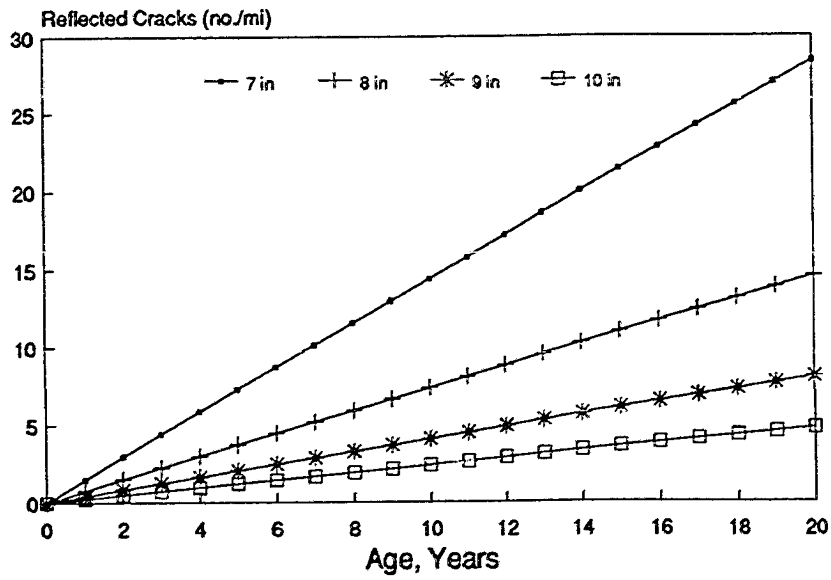

Figure 3.9 - Sample Reflective Cracking Model for AC Overlays of CRCP.

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3.7 Variability of Models

The models used in ILLINET are deterministic models since they predict the mean values of distresses rather than the distribution of values. In reality there is variability associated with the predicted value, as shown in Figure 3.10, and the amount of variability is different for each model. This variability is related to the variability in the data used for regression as well as the appropriateness of the model form, which dictates the relative ability of the model to explain the variability in the data. For each distress model presented in Appendix A, the standard error of estimate (SEE= sum of squared deviation of predicted values from actual data divided by number of observations) is also given as a measure of variability in the model. The mean predicted value, which corresponds to 50 percent probability, is shown in Figure 3.10. Higher degrees of reliability can be achieved by shifting the curve up or down. However, throughout ILLINET mean values (50 percent probability) are used for prediction.

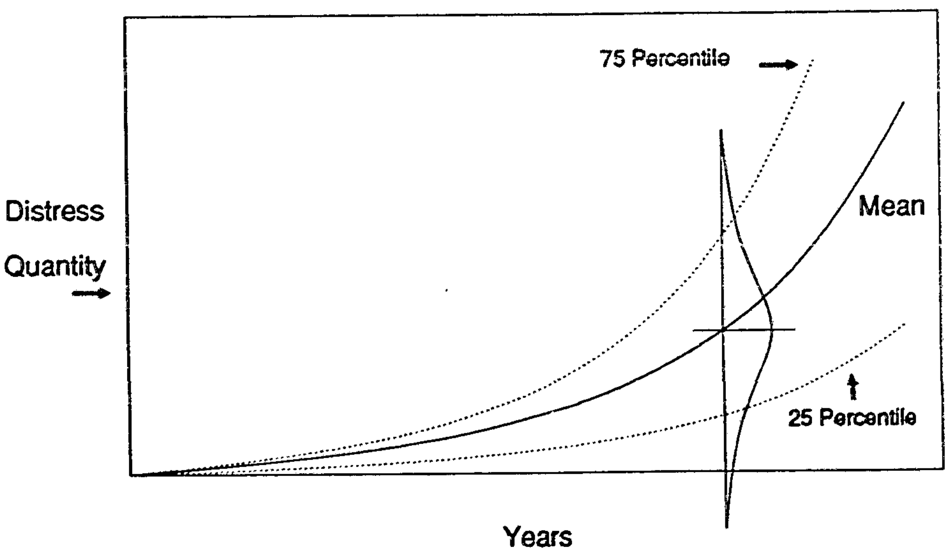

Figure 3.10 - Variability of Models.

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3.8 Calibration of Models

The variability inherent in the predicted distress values causes some degree of uncertainty about the predicted value. This is because other variables beside the ones used in the model may have some effect on the pavement performance. To remove some of the uncertainty about the predicted value, models can be adjusted for the existing distress data. Referring to Figure 3.11, if the mean estimated value from the prediction model at year x is point P with value p, because of uncertainty with regard to point P, there is a chance that the true mean lies at some point away from P. If the actual measured distress at year x is point A the prediction model can be adjusted for this piece of information. The approach taken in this research is to adjust the predicted value by adding the difference (p-a) to the predicted value at other years. This allows the calibration of the general model to the existing pavement condition. Other methods of calibration are possible and should be explored in the future.

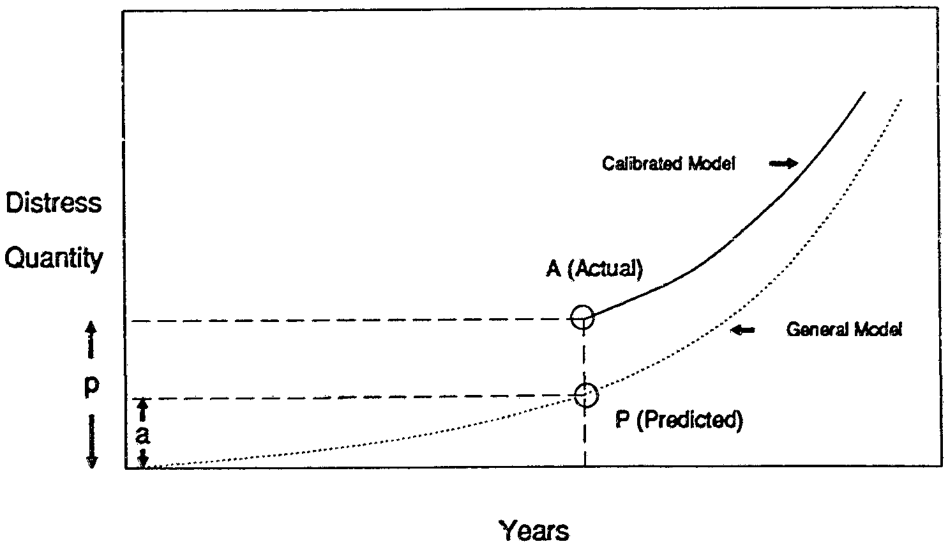

Figure 3.11 - Calibration of Models.

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3.9 Overall Pavement Condition Models

An overall condition index on a 1-to-9 scale was developed for each pavement type to estimate the CRS surveyed in the field as a function of various existing or predicted pavement distresses. The computed CRS is used for a variety of project-level and network-level trigger values (i.e. triggering rehabilitation, pavement life, or a certain rehabilitation type) and also for measuring the effectiveness of a pavement rehabilitation strategy, which is a crucial part of any network-level economic analysis.

Since the predicted distresses discussed in the previous section are the most common distresses observed for each pavement type, it is expected that they can be combined in some way to correlate to the subjective rating of an experienced engineer (CRS). The approach taken to develop a condition index is based on the concept of deduct values. For each type and severity of distress, a number is deducted from the pavement condition index (computed CRS) (Figure 3.12). The maximum value for computed CRS is 9, which is reserved for pavements with no major distresses. For each unit of distress predicted for a pavement, a certain value is deducted from the maximum CRS of 9. The model is linear with the general form of:

$$\text{Computed CRS} = 9 - \text{SUM}(a_i \times dist_i)$$

Where: a_i are deduct values for unit distress quantity

Initially, linear equations were developed based on experience to estimate CRS from major distresses. Multiple linear regression techniques were subsequently

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utilized to correct the coefficients of these equations so that more accurate estimates could be made. The linear CRS equations used in ILLINET are listed in Appendix A.

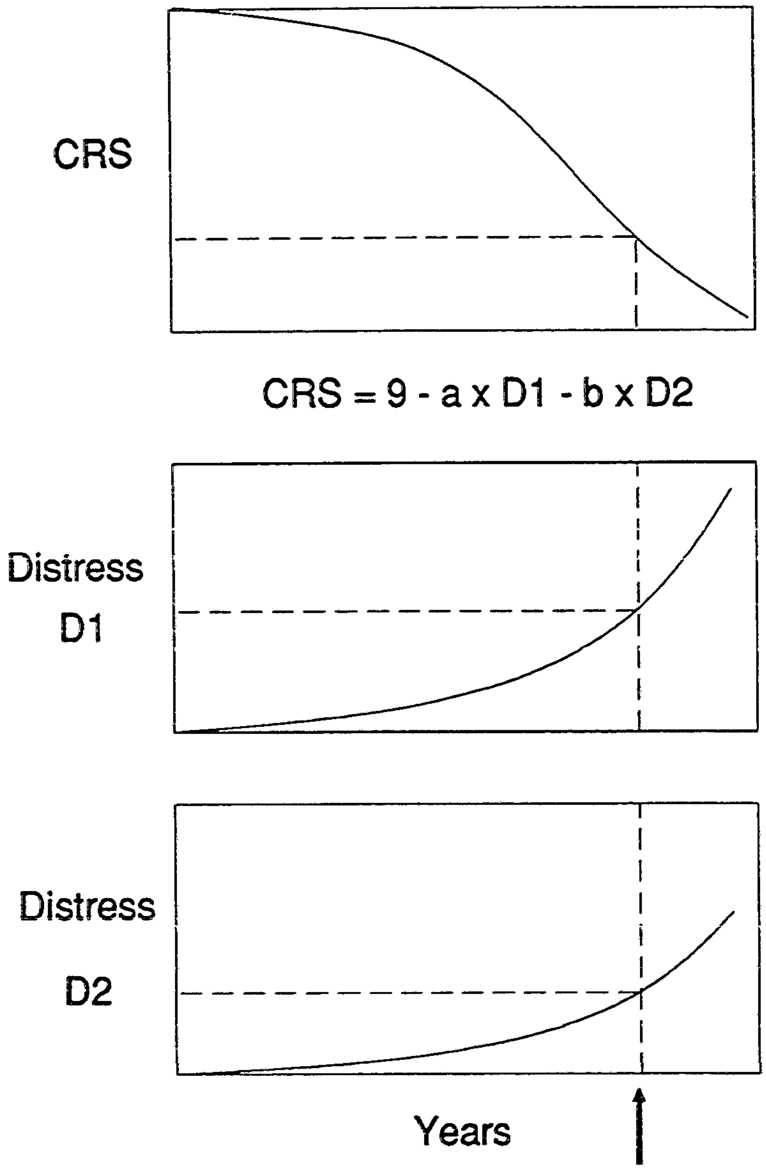

Figure 3.12 - Computed CRS from Distress Quantities.

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3.9.1 Examples of Pavement Condition

Examples of the condition model for JRCP, CRCP, and ACOL are in Figure 3.13, Figure 3.14, and Figure 3.15 respectively. Moderate traffic loading of about one million ESAL per year is considered for all cases. A 10-inch JRCP with the default variables the same as before was used for the example. Figure 3.13 shows that this pavement develops 0.3 inch of faulting and about 60 failures (cracks plus deteriorated joints). For this level of distress a CRS of about 4.5 is computed from the condition models. The example for CRCP shows the performance of an 8 inch pavement (see Figure 3.14). Figure 3.15 shows the example for a 3.25-inch AC overlay over an 8-inch CRCP. This pavement develops 0.4 inches of rutting and about 10 reflected cracks per mile in 9 years. This level of distress corresponds to a CRS of 6, which is the lower limit of an adequate (good) pavement.

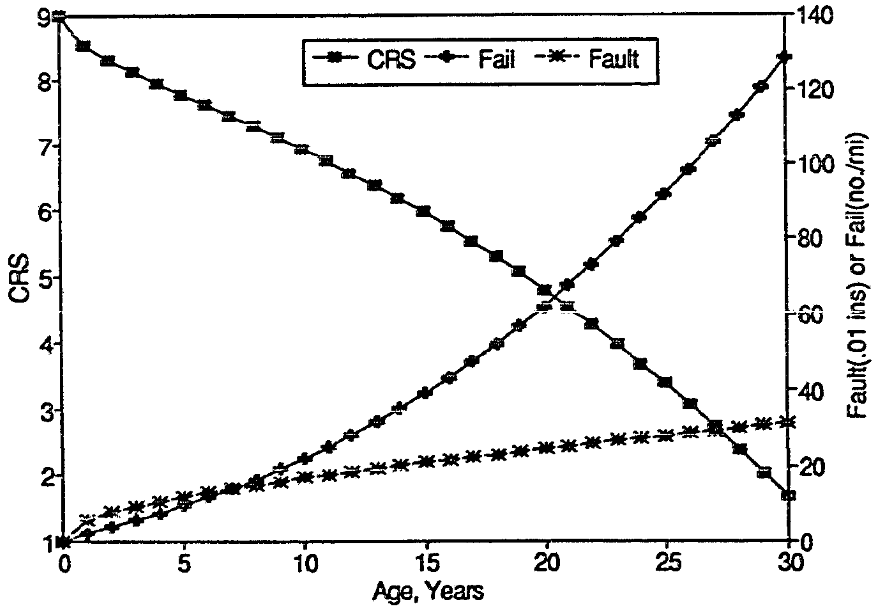

Figure 3.13 - JRCP Condition as a function of distresses.

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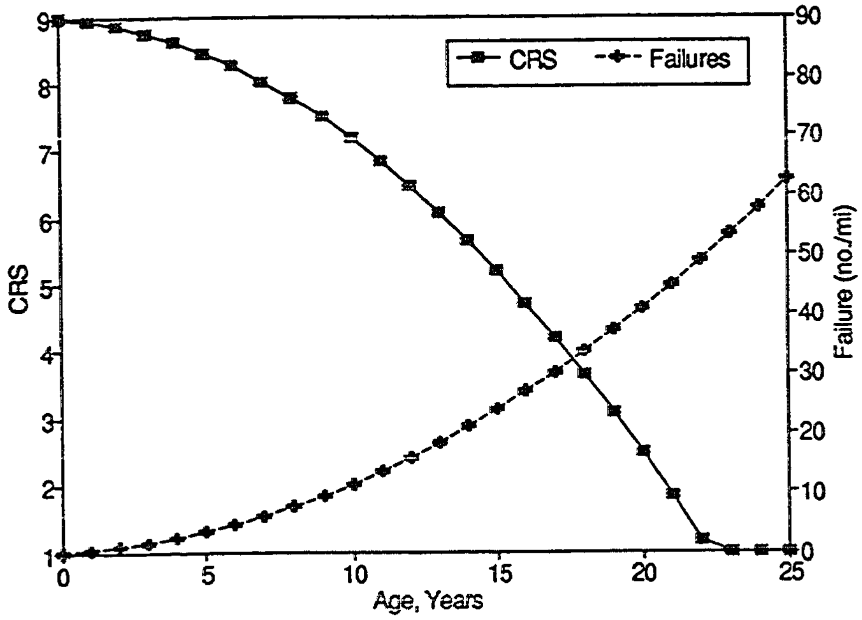

Figure 3.14 - CRCP Condition as a function of distresses.

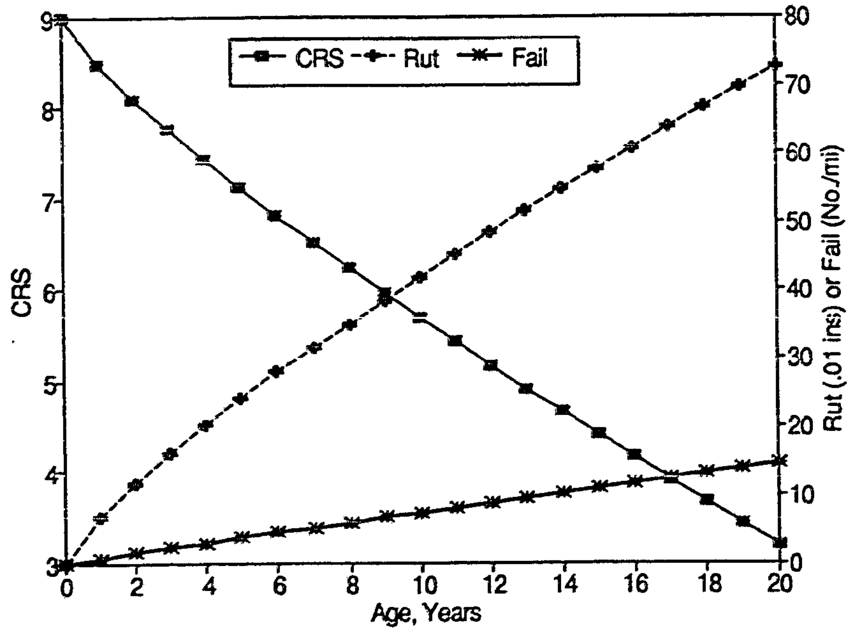

Figure 3.15 - AC overlay of CRCP Condition as a function of distresses.

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4 Pavement Rehabilitation

The term "pavement rehabilitation" refers to corrective measures applied to an in-service pavement to improve its structural capability and/or functional adequacy. Pavement rehabilitation differs from a new pavement design in the fact that the existing pavement structure is salvaged to different degrees. Since all or some part of the existing pavement remains in place, an evaluation of the existing pavement is essential to recommendation for future rehabilitation.

4.1 Rehabilitation vs. Maintenance

Pavement maintenance is routine repair performed on a pavement to ensure its safe and efficient utilization. Pavement maintenance is either responsive (e.g, filling potholes, patching blowups) or preventative (e.g., sealing joints, improving drainage). Pavement maintenance differs from pavement rehabilitation in two ways.

1. Maintenance is intended to correct one specific aspect of a pavement in a relatively shorter time; therefore, it is not as comprehensive as pavement rehabilitation.
2. Maintenance usually does not include an in-depth evaluation of overall pavement condition.

For the above reasons, maintenance operations and rehabilitation operations are usually managed by different units within a highway agency. Since pavement maintenance can have a major effect on pavement performance and rehabilitation, lack of coordination between units responsible for pavement maintenance and rehabilitation may result in an inefficient utilization of resources.

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Therefore, a pavement management system should be able to address both maintenance and rehabilitation. However, since data is difficult to compile and is not available for maintenance activities, this research deals only with major pavement rehabilitation.

4.2 Pavement Rehabilitation Alternatives

There are three major categories of pavement rehabilitation: restoration, resurfacing, and reconstruction (Figure 4.1). Each alternative is appropriate for a certain pavement type and condition. A discussion of each pavement rehabilitation category follows.

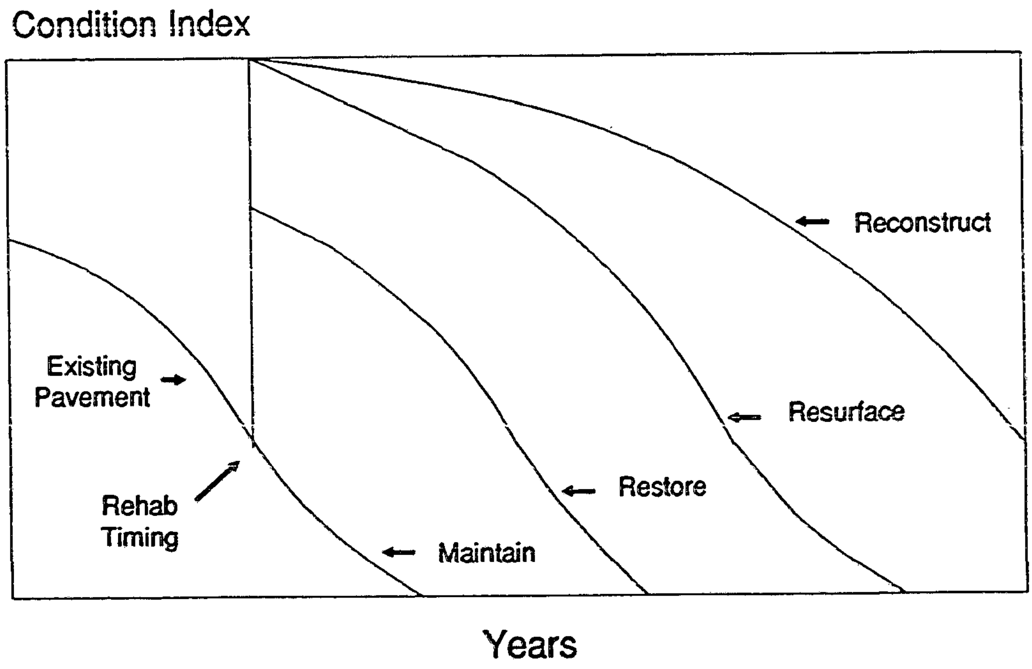

Figure 4.1 - Pavement Rehabilitation Types.

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4.2.1 Pavement Restoration

Restoration corrects specific aspects of an in-place pavement to improve its serviceability and, to some extent, reduce its future rate of deterioration. For example, for JRCP it can include full-depth and partial-depth patching, joint sealing, subsealing, grinding, and drainage improvement. A comprehensive plan for pavement restoration is usually determined after evaluation of its current condition and identification of deficiencies. Restoration is usually suitable for pavements with no major structural deficiency and in better pavement condition. Restoration do not improve the structural capacity of the pavement but can improve serviceability, drainage, and surface friction.

4.2.2 Pavement Resurfacing

Pavement resurfacing (overlay) is a major structural strengthening of pavement through adding another layer of new pavement material on the top of an existing pavement layer. Resurfacing may be different thicknesses of asphalt or concrete overlay. Concrete overlays are categorized on the basis of the type of bonding to the existing concrete pavement: fully bonded, partially bonded, or unbonded. Asphalt and concrete overlays are placed on existing asphalt or concrete pavements, or on previously overlaid pavements to improve:

1. Serviceability,
2. Structural capacity and performance,
3. Drainage,
4. Surface friction, and
5. Shoulder condition.

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Prior to placement of an asphalt overlay, the existing pavement is prepared. For concrete pavements, this usually involves pre-overlay repair work such as patching, subsealing, and drainage improvement. The pre-overlay repair of a previously overlaid concrete or an asphalt pavement involves patching of failed areas and in some cases, milling of the existing overlay to remove ruts and to ensure a good bond to the existing surface. The performance of an overlay is directly related to the condition of underlaying pavement and/or the amount of repair performed on the pavement prior to overlay. Alternatives to pre-overlay repair are crack and seat or rubblizing of the concrete layer prior to overlay. In the latter method, the concrete layer is converted to a base layer for an asphalt pavement; therefore, a thicker AC overlay may be required.

4.2.3 Pavement Reconstruction

Reconstruction of an existing pavement is the replacement of one or more layers with new layers. Reconstruction is the most comprehensive pavement rehabilitation that improves all aspects of an in service pavement and usually provides the longest service life, however, it is the most costly alternative. Recycling and inlays can reduce the cost of reconstruction. The material in existing layers may be recycled for the construction of the new layers. Surface concrete and AC layers are recycled into either surface (concrete or asphalt) or base layers. Inlays are possible when existing shoulders are in good condition and can be salvaged. With inlays, only the traffic lanes are reconstructed and shoulders are kept intact.

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4.3 Rehabilitation Alternatives Considered in ILLINET

Since almost all pavement sections on the Illinois Interstate network are reinforced concrete (either JRCP or CRCP), only the rehabilitation alternatives that relate to reinforced concrete pavements are considered in this research. The following rehabilitation alternatives that are currently used by IDOT are also considered in ILLINET.

1. Concrete Pavement Restoration (grinding, full-depth repair, subsealing, resealing joints, etc.),
2. 3.25-inch AC overlay (with or without milling),
3. 5.0-inch AC overlay (with or without milling), and
4. 10-inch CRCP pavement for reconstruction.

A 10-inch CRCP was used for reconstruction throughout ILLINET since this alternative provides an equivalent cost and performance to new reconstruction techniques.

4.4 Consequences of Pavement Rehabilitation

There are two kinds of consequences of major pavement rehabilitation; short term and long term (see Figure 4.2). The immediate or short-term effect is due to the correction of pavement deficiencies, which usually results in an improvement in pavement condition. This is shown as a sudden jump in pavement condition in Figure 4.2. The amount of improvement is based on the type of rehabilitation applied to the pavement and in some cases the condition of the pavement before rehabilitation.

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The long-term effect of the rehabilitation is the effect on the rate of deterioration. Usually, a major rehabilitation increases the structural capacity of a pavement and results in improved pavement performance. This results in the extension of the pavement's life beyond the service life that the original pavement would have offered. The amount of pavement improvement and the performance of pavement after rehabilitation is discussed in the next section.

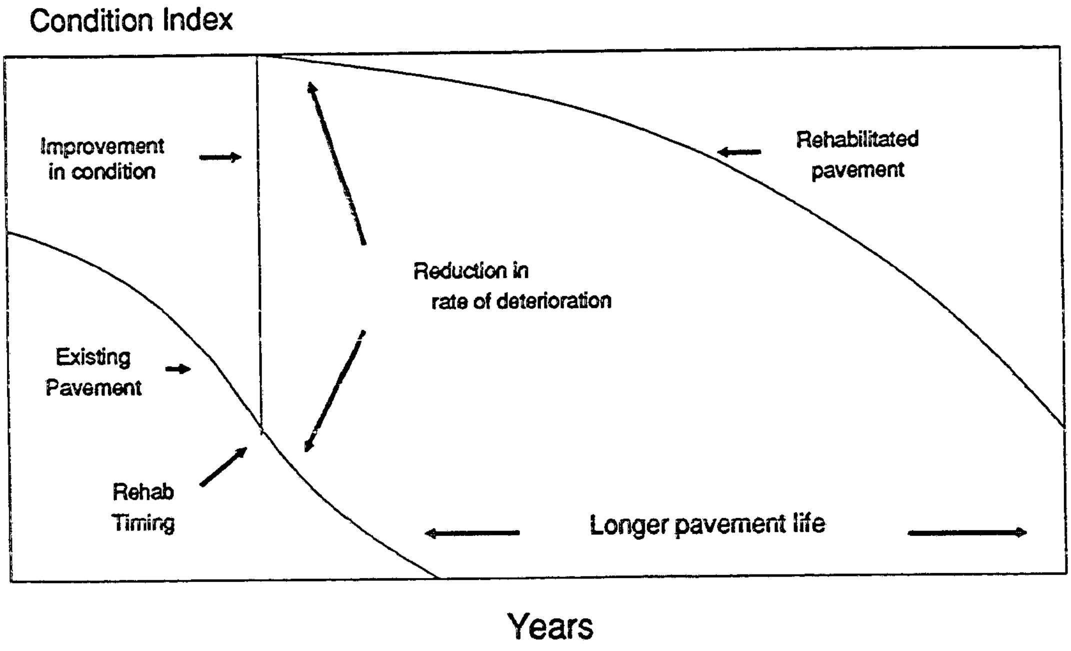

Figure 4.2 - Pavement Rehabilitation Consequences.

4.4.1 Pavement Condition Improvement due to Rehabilitation

The degree of improvement of pavement condition by rehabilitation is based on the type of rehabilitation and in some cases the extent of rehabilitation. This improvement is shown as the sudden increase in the pavement performance curve (Figure 4.2).

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In the case of Concrete Pavement Restoration (CPR), when several repair jobs are done on the pavement, the repair job that improves the condition of the pavement is considered to be concrete patching. The objective of concrete patching is to remove the concrete around a failure (failed joint or crack for JRCP and failed punchout for CRCP) and replace it with sound concrete. If patching is performed properly, it will correct the failure and provide a smoother surface than before. However, it can not totally remove the deficiency since the patched area is not as sound as the original pavement. For this reason, in the computed CRS model described in section 3.4, the deduct value for patching is considered to be half the deduct value for a failure. Thus the pavement condition improves when failures are replaced by low-severity patch distress. The amount of increase in CRS is also based on the extent of patching that is performed on a pavement. The extent of patching in a CPR job or pre-overlay repair is a user defined parameter but defaults to 80 percent of the existing failures. Faulting present after CPR is eliminated and the amount of this distress resets to zero.

Asphalt overlays, on the other hand, improve the pavement condition to the highest rating possible (CRS of 9). This is because an asphalt overlay initially provides a smooth surface with no observable distresses and thus for computing condition rating (computed CRS) there are no deductions. In the case of an overlay of a previously overlaid pavement, condition also jumps to the maximum value. In both cases rutting and reflective cracking are reset to zero.

Reconstruction also improves pavement condition to the condition of a new pavement (CRS of 9), since the old surface layer is completely replaced and there are no visible distresses. Since reconstructed pavements are treated like a new

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pavement, prediction models without calibration are used for their future performance.

4.4.2 *Pavement Performance after Rehabilitation*

Another consequence of pavement rehabilitation is improved pavement performance. Any major pavement rehabilitation that increases pavement structural capacity also extends the pavement's service life (Figure 4.2).

The complete CPR activity not only improves pavement condition by removing the existing failures, but also reduces the future rate of deterioration by correcting those deficiencies that contribute to pavement deterioration. For example, subsealing, resealing joints, and drainage improvement will reduce future joint faulting and deterioration to some degree. Also resurfacing and reconstruction improve pavement performance by strengthening pavement layers.

The models used to predict pavement deterioration after CPR are the same as those described in Chapter 3 for predicting pavement deterioration without rehabilitation, except that a different model is used for faulting of JRCP after CPR (see Appendix A).

The prediction of rutting and reflective cracking for AC overlays is performed using the same models presented in chapter 3. Also, since the only design choice considered for reconstruction is a 10-inch CRCP, the model that was described in chapter 3 for predicting CRCP failures is used. These models do not require any calibration since no pavement distresses initially exist for AC overlays and reconstruction.

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4.4.3 *Examples of Pavement Performance*

Some examples of pavement performance for overlays and reconstruction, which are derived from models discussed before, are given here. The performance (CRS versus age) for all three pavement types and each of four levels of traffic loadings are shown in Figure 4.3, Figure 4.4, and Figure 4.5.

Figure 4.3 shows the performance curve for a 10-inch JRCP. The life of this pavement (defined as the age to CRS of 6) for low traffic loadings (.5 million ESAL) is about 25 years. The life drastically decreases for one million ESAL per year to 16 years. For 2 million ESAL the life is only 7 years. Figure 4.4 shows that 8-inch CRCP performs about the same as 10-inch JRCP. The life of this pavement is about 26 years for low traffic loadings and 6 years for high traffic loadings.

Figure 4.5 displays the performance of a 3.25-inch overlay over an 8 inch CRCP. The life of this rehabilitation is 14, 9, and 5 years for 0.5, 1, and 2 million ESAL per year respectively. For JRCP overlays the life is usually shorter because of the reflected joint cracks. For 'D' cracked pavement the life is also shorter since twice as many failures are predicted for this type of pavement.

Figure 4.6 shows the performance of a reconstructed pavement. As mentioned earlier, a 10-inch CRCP is used for simulating the performance of reconstructed pavements. As Figure 4.6 shows, this alternative lasts 25 years over heavy traffic loadings of one million ESAL. For 1.5, 2, and 2.5 million ESAL, the life is 17, 13, and 10 years respectively. This indicates that for higher traffic loadings, this type of reconstruction may not be cost-effective.

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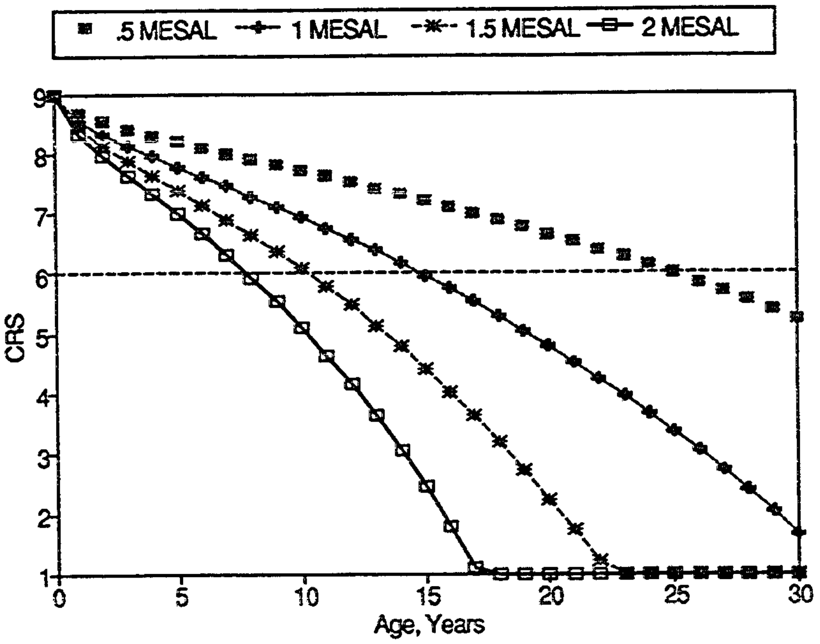

Figure 4.3 - Performance of a 10-inch JRCP for Different Levels of Annual ESALs.

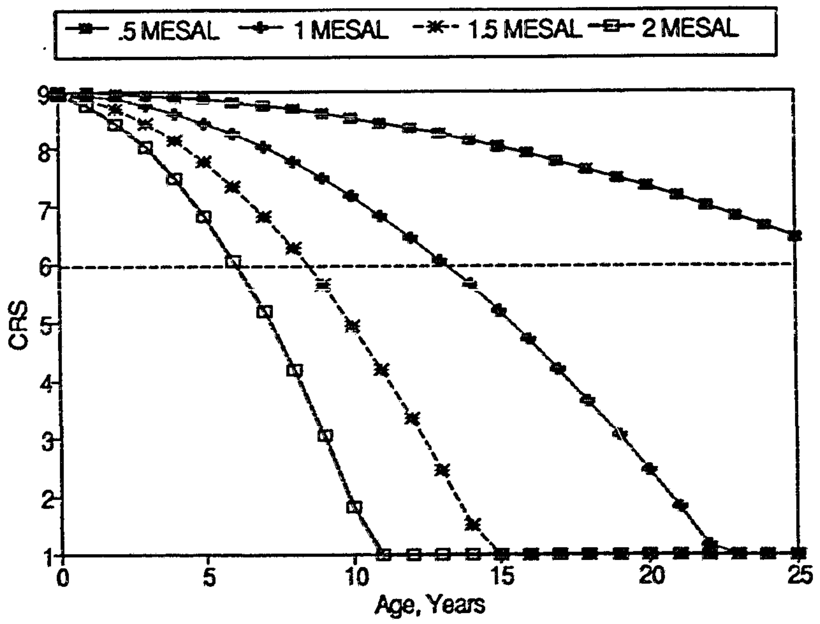

Figure 4.4 - Performance of a 8-inch CRCP for Different Levels of ESALs.

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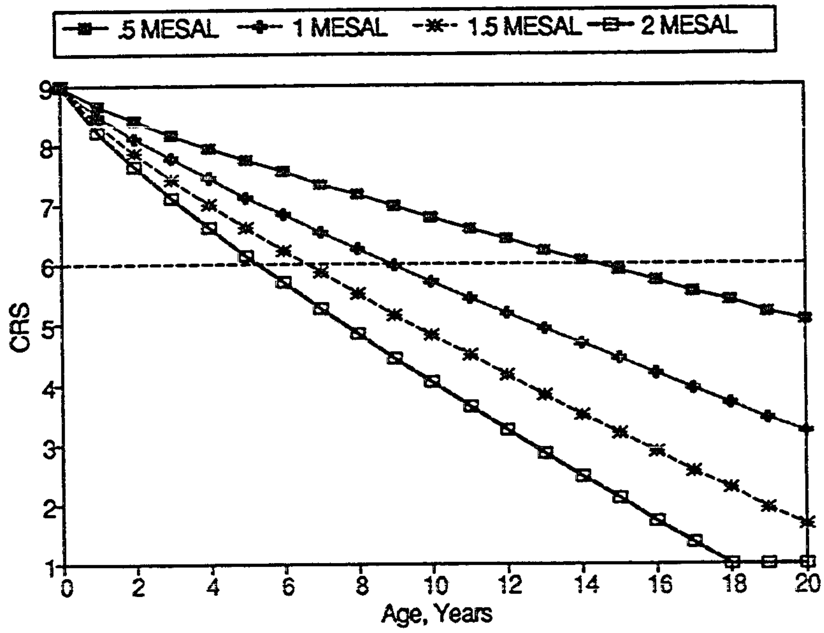

Figure 4.5 - Performance of 3.25-inch ACOL of CRCP for Different Annual ESALs.

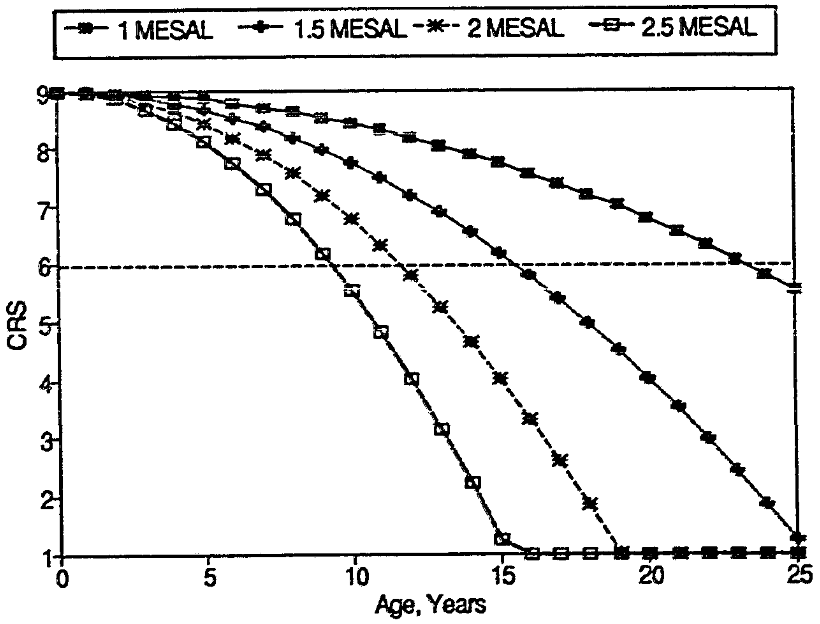

Figure 4.6 - Performance of a 10-inch CRCP for different ESAL per year.

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4.5 Cost of Pavement Rehabilitation

An accurate estimation of pavement rehabilitation costs is an important part of any pavement management system. At the project level, accurate estimates of rehabilitation costs are essential to any economic analysis of different alternatives. At the network level, cost estimates are used for pavement needs study, rehabilitation programming, and budget planning.

Unit rehabilitation costs are used to calculate the cost of different rehabilitation alternatives. An Illinois statewide average unit cost of rehabilitation (except for the metropolitan areas of Chicago and St. Louis) for 1987 is shown in Table 4.1. These costs include the cost of rehabilitation of traffic lanes, shoulders, drainage, and the cost of traffic control. The method of computing rehabilitation costs for each rehabilitation type follows.

4.5.1 Cost of Concrete Pavement Restoration (CPR)

The cost of CPR is calculated from the number of patches required to correct most or all of the failures and the unit cost of patching. Note that CPR is a complete restoration job and is not restricted to patching; however, since only an average cost of CPR per mile is available for concrete pavements (refer to Table 4.1), all other costs are assumed to be included in the unit cost of patching. The cost for patching one percent of a project's area (as reported by IDOT) is converted into the cost for one patch by assuming an average patch area of 72 square feet (12 feet wide by 6 feet long) for JRCP and 120 square feet (12 feet wide by 10 feet long) for CRCP. CRCP patches are usually longer than JRCP patches since the mode of failure in CRCP usually covers a wider area. Therefore, cost of patching is calculated as follows:

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$$Cost = C_p * P_l * N_f * P_p * N_l$$

Where:

- $Cost$ = cost of patching per mile of pavement, dollars
- C_p = cost of one foot of patch
  = unit cost for 1 percent (from Table 4.1) / (0.01 * (5280 feet/mi))
- P_l = length of each patch (10 ft for JRCP and 12 ft for CRCP)
- N_f = number of failures existing on concrete pavement
- P_p = percent patching allowed at one time / 100
- N_l = number of lanes

For example the cost of CPR per mile for a CRCP with 20 failures per mile for 80 percent patching of failures can be calculated from unit cost in Table 4.1 (2300 dollars for 1 percent patching of CRCP) as follows:

Cost of one foot of patch = 2300 / (0.01 * 5280) = 43.56

Cost of patching = 43.56 x 10 x 20 x 0.8 x 2

= 73600 dollars per mile

4.5.2 Cost of AC Overlay

The cost of AC overlay consists of the cost of pre-overlay patching plus the cost of the AC layer. Pre-overlay patching costs are calculated in the same way as the cost of CPR. For composite pavements, the unit cost of milling plus AC overlay (see Table 4.1) is used since the existing AC layer is partially milled prior to overlay.

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4.5.3 *Cost of Reconstruction*

The unit cost of a new 10-inch CRCP is used to estimate the cost of reconstruction. This cost is the average cost of reconstruction for different pavement designs and locations in the state.

Table 4.1 - Average Statewide Unit Costs of Rehabilitation for 1987.

Rehabilitation Type	Unit	Included	Unit Cost
JRCP Concrete Pavement Restoration (CPR)	12x6 ft Patch	Full-depth patch Grinding Subsealing Resealing Drainage Traffic control	$1,200
CRCP Concrete Pavement Restoration (CPR)	12x10 ft Patch	Full-depth patch Drainage Traffic control	$2,300
3 inch AC overlay	Two lane Mile plus shoulder	Drainage Traffic Control	$178,000
5 inch AC overlay	Two lane Mile plus shoulder	Drainage Traffic Control	$227,000
Reconstruct with 10 inch CRCP	Two lane Mile plus shoulder	Shoulders Drainage Traffic control	$600,000

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5 Project-Level Analysis for Pavement Rehabilitation

A comprehensive project-level analysis is essential prior to any major pavement rehabilitation. This includes the assessment of present pavement condition, the evaluation of pavement condition to identify deficiencies, and finally the recommendation of rehabilitation type or types appropriate for the pavement. Thus, project-level analysis is a major part of a pavement management system.

5.1 ILLINET Project-Level Approach

The network-level approach taken in ILLINET requires that one or more project-level strategies (rehabilitation type and timing) be generated for each section in the network (see Figure 2.4). Therefore, all pavement sections in the database are subject to project-level analysis prior to any network analysis. The objective of project-level analysis is to:

1. Evaluate pavement current condition,
2. Identify deficient pavement sections, and
3. Propose one or more rehabilitation alternative most appropriate for fixing deficient pavements (including routine maintenance).

This is accomplished by using the predicted variables (i.e. major distresses, CRS, performance, ESAL, and ADT) in the analysis. "Project-level" analysis required for a network-level analysis differs from "detailed project-level" analysis performed prior to pavement rehabilitation in the following ways:

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1. Only a few decision parameters are available for "project-level" analysis in the future since only a few parameters can be predicted.

2. Only an approximate project-level analysis is adequate for providing the estimates of network performance and cost.

5.2 Pavement Condition Evaluation

A simplified pavement condition evaluation method based on the concept of minimum condition level is employed in ILLINET to identify the projects in need of rehabilitation. When the pavement CRS falls below a certain user-specified limit (normally CRS of 6), the pavement is considered to be deficient and in need of rehabilitation. This trigger value is called minimum CRS for pavement rehabilitation, or simply minimum CRS (see Figure 5.1). The choice of rehabilitation(s) is then determined by the pavement rehabilitation selection routine.

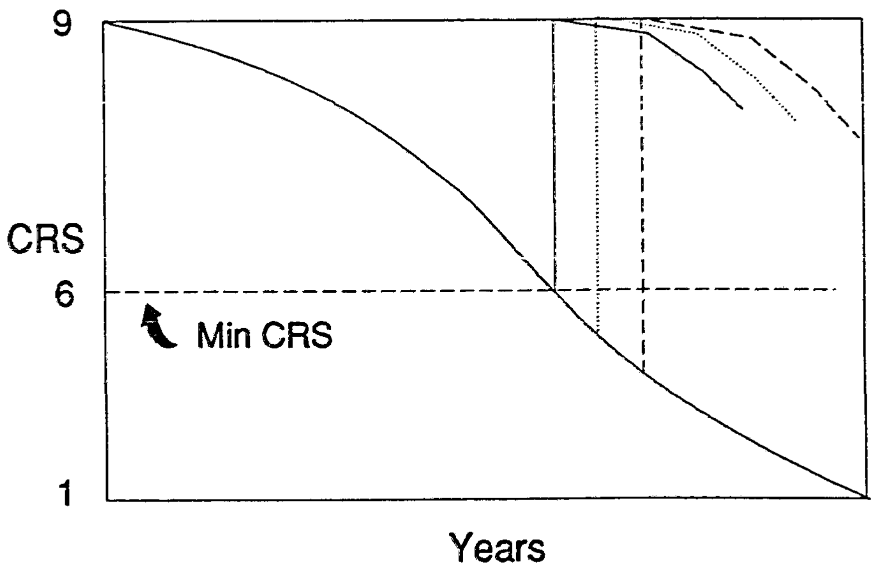

Figure 5.1 - Trigger Value for Rehabilitation (Minimum CRS).

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Since CRS is computed from major pavement distresses, it is associated with the amount of pavement deficiencies present. Thus, CRS is also an indication of pavement structural soundness, serviceability, and safety. Therefore, setting a minimum CRS level (trigger for rehabilitation) is a reasonable approach in identifying pavement deficiencies and rehabilitation need.

5.3 Pavement Rehabilitation Selection Routine

For all deficient pavements, one or several rehabilitation alternatives are selected as candidate rehabilitations for the network-level analysis. The choice of rehabilitation is determined by the pavement rehabilitation selection routine. Three different routines based on single rehabilitation, engineering judgement, and economic analysis are included in ILLINET. A discussion of each method follows.

5.3.1 Single Rehabilitation

The simplest case is when a single rehabilitation type is selected for each deficient pavement section in the network regardless of its condition or type. The choice of rehabilitation is defined by the user and can include any one of the rehabilitation types considered in ILLINET (also refer to chapter 4 for a list of rehabilitation types).

1- CPR for concrete pavements only
2- 3.25-inch AC overlay for all sections only
3- 5.0-inch AC overlay for all sections only
3- 10-inch CRCP Reconstruction for all sections only

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5.3.2 Rehabilitation Selection Based on Engineering Judgement

Engineering judgement can also be the basis for the selection of rehabilitation type most appropriate for the pavement. In ILLINET this is accomplished in two ways: subjectively and by the use of decision trees.

In the subjective rehabilitation selection method, the user specifies a choice of rehabilitation type and timing for each section or some sections in the network. This selection is purely based on the user's judgement, although the future

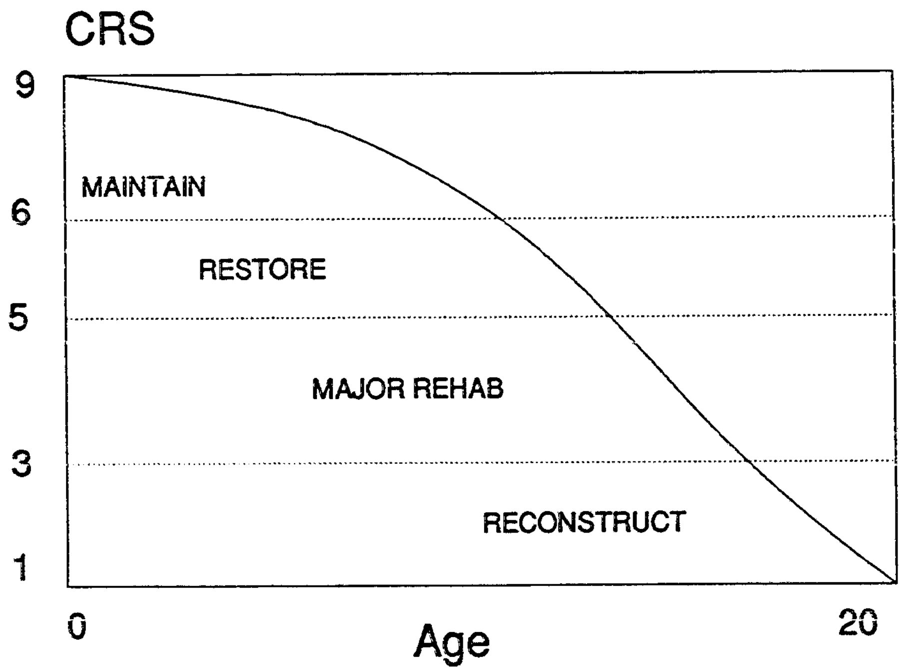

Figure 5.2 - Pavement Rehabilitation Selection Based on CRS Range.

prediction of major pavement parameters is available from ILLINET and can be the basis for the decision. In this method there is not necessarily a specific basis for the selection of rehabilitation type and timing.

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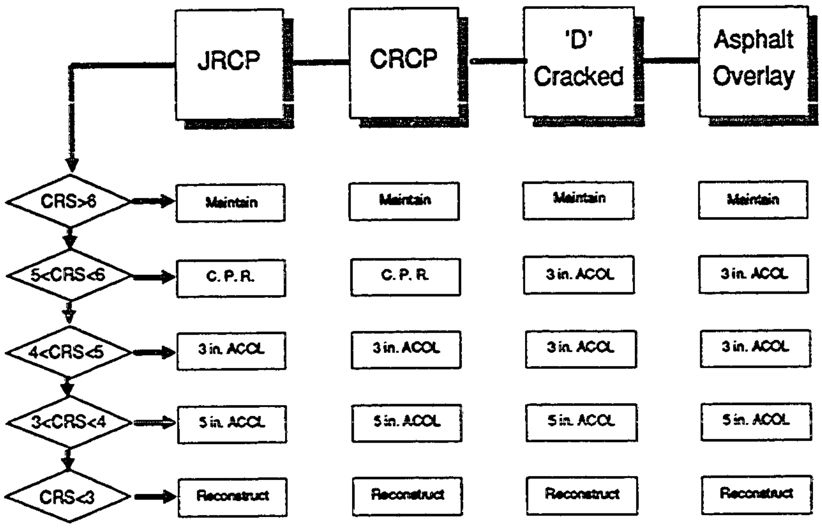

Figure 5.3 - Flow Chart Showing ILLINET's Decision Tree (values are set by user).

A more objective use of the engineering judgement is through selecting rehabilitation type by the use of decision trees. For each pavement type and condition range a type of rehabilitation is pre-selected as the most appropriate rehabilitation type for that pavement. ILLINET contains a decision tree that allows user to select the most appropriate rehabilitation type for every pavement type and CRS range (Figure 5.2). The range of CRS and the types of rehabilitation considered are user-specified and can be altered. This provides a more rational approach to identifying rehabilitation type and allows the effect of adopting different decision trees to be analyzed.

Generally, as pavement condition (CRS) deteriorates, more expensive rehabilitation types are considered for that pavement (see Figure 5.3). Routine maintenance (no major rehabilitation) is selected when CRS is above 6.0, and

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reconstruction is selected for CRS of 3.0 and lower for all pavement types. These limits reflect IDOT policy for pavement rehabilitation, but can be changed to any other value. For 'D' cracked pavements a more extensive rehabilitation type is considered since additional strengthening of the pavement layer is required.

5.3.3 Rehabilitation Selection Based on Economic Analysis

The criteria for selecting the pavement rehabilitation type could be based on the economic analysis of pavement rehabilitation alternatives in order to identify the best cost-effective rehabilitation for a certain pavement section. Life Cycle Cost (LCC) analysis is usually employed to calculate the Equivalent Uniform Annual Cost (EUAC) of a rehabilitation alternative as follows:

$$EUAC = C * \frac{i * (1+i)^L}{(1+i)^L - 1}$$

Where:

$EUAC$= Equivalent uniform annual cost

C = Cost of rehabilitation

i = Discount rate

L = Life of rehabilitation

Pavement rehabilitation life is calculated from the prediction of pavement condition over time (rehabilitation performance). A terminal value for CRS (usually CRS of 6) is used for the calculation of pavement rehabilitation life as shown in Figure 5.4. Pavement rehabilitation cost is also inflated for the year of rehabilitation. The rehabilitation with the lowest EUAC will be selected as the most feasible rehabilitation for the section (see Figure 5.5). This approach ensures the best utilization of funds for every section in the network.

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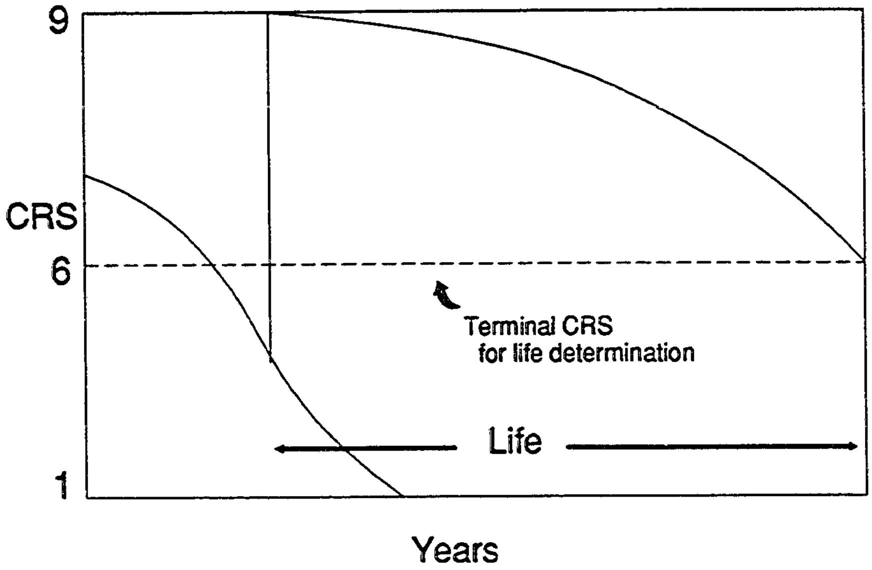

Figure 5.4 - Pavement rehabilitation life determination from CRS.

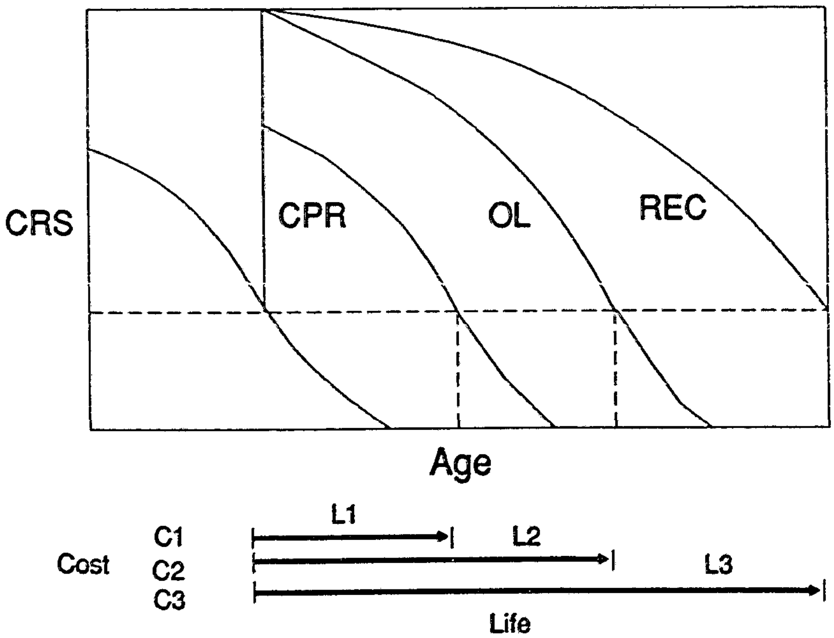

Figure 5.5 - Life Cycle Cost Analysis of Alternative Project-level Options.

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5.4 Pavement Rehabilitation Strategy Generation

The objective of project-level analysis is to generate one or more pavement rehabilitation strategies for consideration in the network-level analysis. There are two methods of generating project-level strategies: annual and multi-year. Each one of these methods corresponds to the specific type of network-level analysis. A discussion of each method follows.

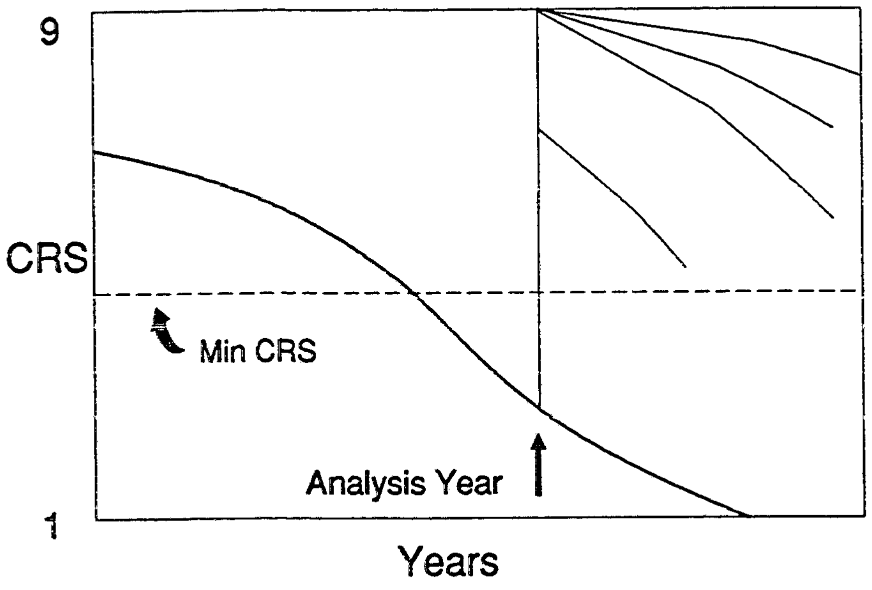

Figure 5.6 - Generating Yearly Strategies.

5.4.1 *Generating Annual Strategies*

Annual strategies are generated for use in annual network-level analysis by applying one or more of the rehabilitation alternatives at the year of the analysis. In this approach the timing of rehabilitation is fixed (e.g. the year of analysis) and each rehabilitation type constitutes a strategy for that section

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(Figure 5.6). One or more strategies can be generated with this method based on the type of network-level analysis that will be performed (choices of network-level algorithms are explained later in chapter 7.) For generating a single strategy, one of the pavement rehabilitation selection routines described previously can be applied to the section to choose the most appropriate rehabilitation alternative for that section. For multiple strategies, all rehabilitation alternatives are available for selection at the network level in the analysis year.

5.4.2 Generating Multi-year Strategies

Multi-year network-level analysis requires that several strategies (timing and type of rehabilitation) be generated over the period of analysis for each section in the network. These strategies are generated by applying one or more rehabilitation alternatives at each year in the analysis period (Figure 5.7). The length of the analysis period is user defined; however, a ten-year analysis period is considered throughout this research.

Applying all possible rehabilitations for every year results in a very large number of possible strategies. For example, for five possible rehabilitation alternatives over a ten-year period there would be 5^{10} (or about 10 million) possible strategies; however, many of these strategies are practically non-feasible and thus should be eliminated. If only one rehabilitation is allowed over a ten-year period there would only be a maximum of 5 x 10 = 50 different strategies for every section. This includes applying each rehabilitation alternative at every year in the analysis period.

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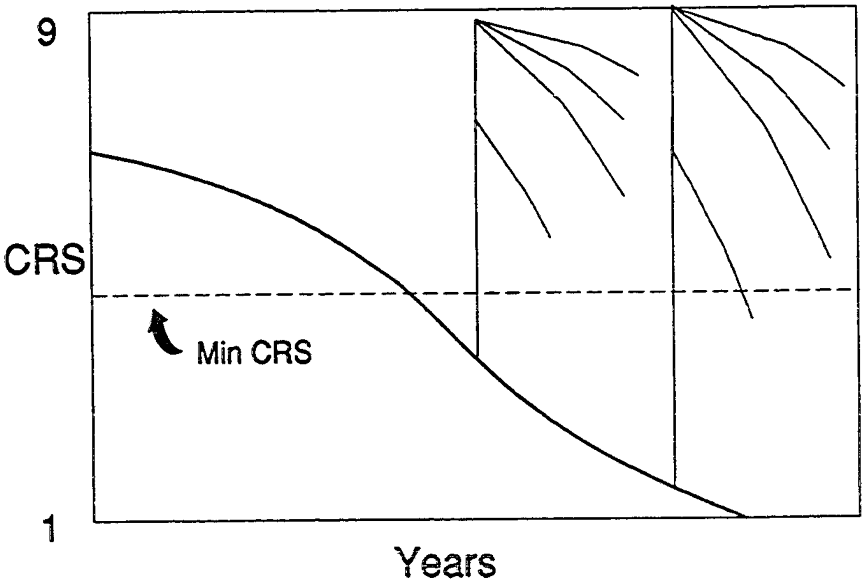

Figure 5.7 - Generating Multi-year Strategies.

When a rehabilitation selection routine is employed to select the one rehabilitation type most appropriate for every year in the analysis period, there would be a maximum of 1 x 10 =10 different strategies (one rehabilitation alternative applied at each year in the analysis period). In this case, however, the rehabilitation strategies available for network level selection is very limited.

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6 Benefits of Pavement Rehabilitation

Quantifying benefits for pavement rehabilitation is essential to any comprehensive network-level pavement rehabilitation management system. Pavement benefit is used as a measure of the effectiveness of rehabilitation alternatives for different pavement sections in a network. Quantifying benefits makes possible selection of sections and rehabilitation alternatives that ensure the best use of funds. For this reason, the benefit function has a great impact on network-level pavement rehabilitation selection. Benefits of pavement rehabilitation are related to the purpose of a pavement, to accommodate traffic safely and efficiently, and also to the objective of extending the service life of an existing pavement.

6.1 Travelling Public Versus Transportation Agencies

There are two perspectives to pavement rehabilitation; that of the highway agency and that of the highway user. Highway agencies are responsible for maintaining pavements to accommodate the travelling public safely and efficiently. Good pavement conditions also generally mean reduced maintenance costs. The major benefit of pavement rehabilitation that is realized by improved pavement condition really goes to the user in the form of reduced vehicle operation costs, lane closures, delays, and reduction in accident potential. User cost accounts for approximately 80 percent of the total transportation costs. Therefore, the main concern of the travelling public is adequate safety, reduced lane closures, and good ride quality, while for transportation agencies the long-term maintenance and rehabilitation costs of pavements is of prime importance. Some rehabilitation efforts, while minimizing costs to the agency, increase lane

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closure times and roughness, thus increasing user costs. Some rehabilitation efforts may decrease agency costs in the short run, but increase them and user costs over a long time period. Thus, the concept of a benefit is very important to network pavement management.

6.2 Elements of Pavement Rehabilitation Benefits

Prior to quantifying pavement rehabilitation benefit, the elements that contribute to pavement benefit should be identified. Pavement benefit relates to the objectives of the pavement rehabilitation (i.e., to accommodate traffic safely and efficiently). Following is a discussion of the main elements of pavement rehabilitation benefit.

6.2.1 Pavement Condition

Pavement condition is a measure of structural capacity, rideability, friction/hydroplaning and perhaps other measures. The benefit derived from use of a pavement is directly related to the pavement condition. Better pavement condition results in greater benefits and lower costs to the user. For the user, better pavement rideability is important. For pavement network managers, however, the measure of pavement condition that identifies the structural capacity of the pavement is of greater concern. Although pavement rideability and pavement structural condition are related, they are two different measures.

In this research, CRS is used as a measure of the pavement condition. CRS is based on pavement visual condition and is the measure of distresses on the pavement. CRS can be used as a measure of pavement structural capability since major structural distresses are used in its determination. CRS also correlates with

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rideability since the major distresses contribute to pavement roughness (i.e., cracks and faulting) and safety (rutting, potholes).

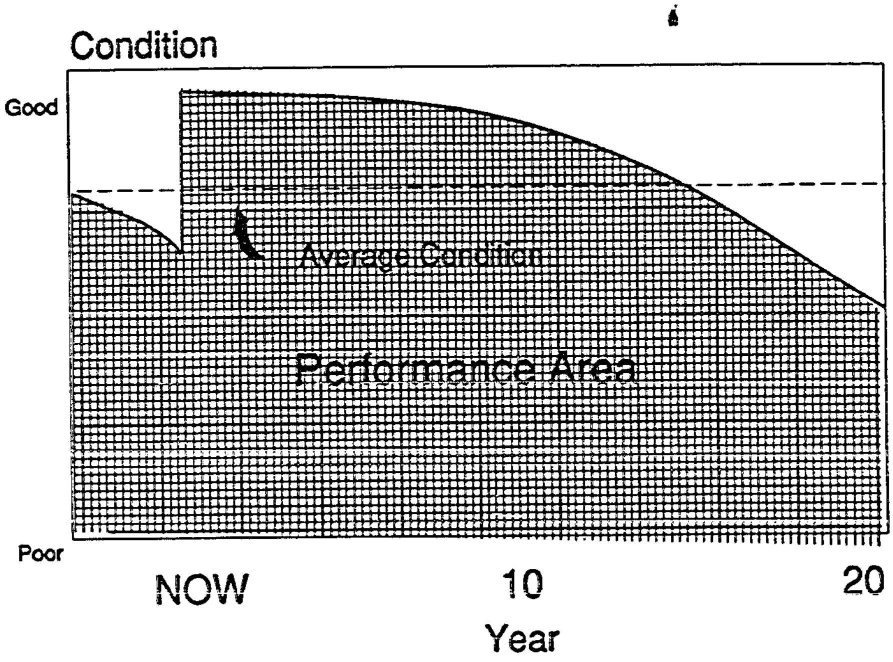

Figure 6.1 - Performance Area of a Rehabilitated Pavement.

6.2.2 Pavement Performance and Life

Most pavement rehabilitation alternatives provide an immediate improvement in pavement condition; however, their performance may vary considerably based on their design and anticipated traffic loadings. The benefits derived from a pavement section is directly related to the performance of the pavement section, since the longer it retains its structural integrity and serviceability, the more vehicles will be able to use the facility. There are two different ways of defining pavement performance. The area under the condition (e.g. CRS) versus time curve is often cited as a measure of pavement performance since it contains both elements of condition and length of time (see Figure 6.1).

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Another measure of performance is pavement life. Pavement life, which is defined as the length of time a pavement condition is adequate (its CRS is more than a minimum value) (see Figure 6.2), also contains a measure of pavement condition and duration of time. Both life and performance are directly related to pavement benefit.

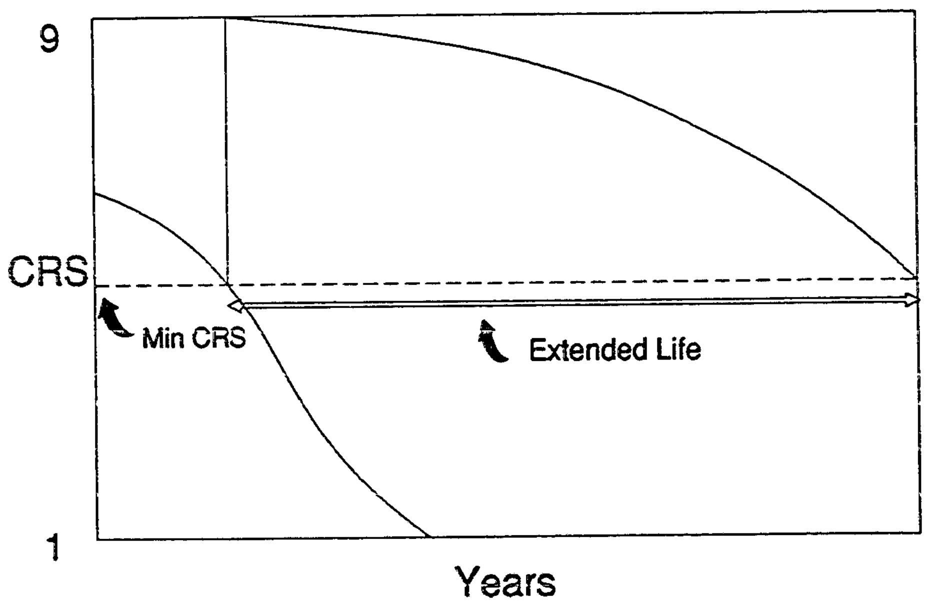

Figure 6.2 - Life of a Pavement Rehabilitation.

6.2.3 Pavement Use

Since roads are built to serve the public, more traffic on the road results in higher benefits. Therefore, traffic is a major element in any benefit calculation. In network-level management, this results in higher priority being assigned to rehabilitation of sections with more traffic. Average Annual Daily Traffic (AADT) is used as the estimate of traffic level. Vehicle Miles Travelled (VMT) is the measure of pavement use for one year and is calculated as follows:

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$$VMT = AADT * Pavement Length * 365$$

The proportion of total VMT travelled on pavements in good condition is an index of the adequacy of a highway network.

6.2.4 Pavement User's Cost

User's cost include different costs incurred to the user as a result of pavement condition. Vehicle operation cost, which is the cost of vehicle depreciation, fuel consumption, and vehicle parts to be replaced due to undesirable pavement condition, can be approximately calculated as can delay cost due to lane closures. Safety cost and discomfort cost due to poor condition, however, are difficult to measure in monetary terms. Previous work in this area has centered around assigning different unit user's costs to different pavement condition levels (22). These unit costs include a variety of costs incurred to the user as a result of pavement being in a certain condition. As pavement condition deteriorates, user cost increases as shown in Figure 6.3.

6.3 Pavement Use versus Pavement Performance

Some interaction exists between pavement use and pavement performance. This is because higher truck traffic (a subset of total traffic or AADT) contributes more to pavement deterioration, thus causing poorer pavement performance or shorter pavement life. Therefore, sections with the same design and different truck traffic level will provide difference performance (shorter life for higher load applications and vice versa) (see Figure 6.4). In the network-level analysis, when performance only is used as a measure of benefit, the sections with the higher AADT will have lower benefit (due to shorter life) and thus have less chance of

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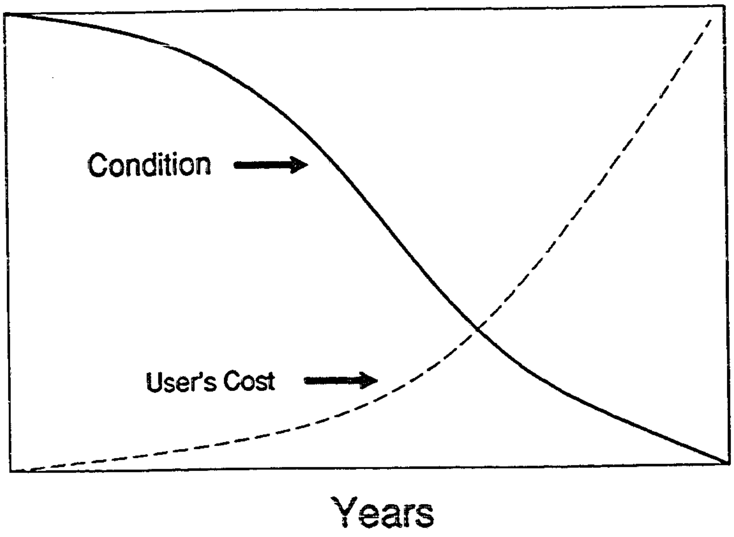

Figure 6.3 - Pavement Condition versus User's Cost.

being selected. To offset this effect, the benefit function for the sections should be weighted by traffic.

6.4 Alternate Pavement Benefit Functions

There are four different benefit functions available in ILLINET for use in network-level analysis. These benefit functions cover a range of feasible benefit functions for pavement management. Two of the benefit functions are not weighted by section traffic while the other two also consider traffic. It is assumed that the benefit derived from different vehicle types are the same, thus cars and trucks are weighted equally. This assumption might not be true since the user's costs (and thus user's benefits) differ for cars and trucks. All benefit functions, however, are weighted by pavement section length. A discussion of each benefit option available in ILLINET follows.

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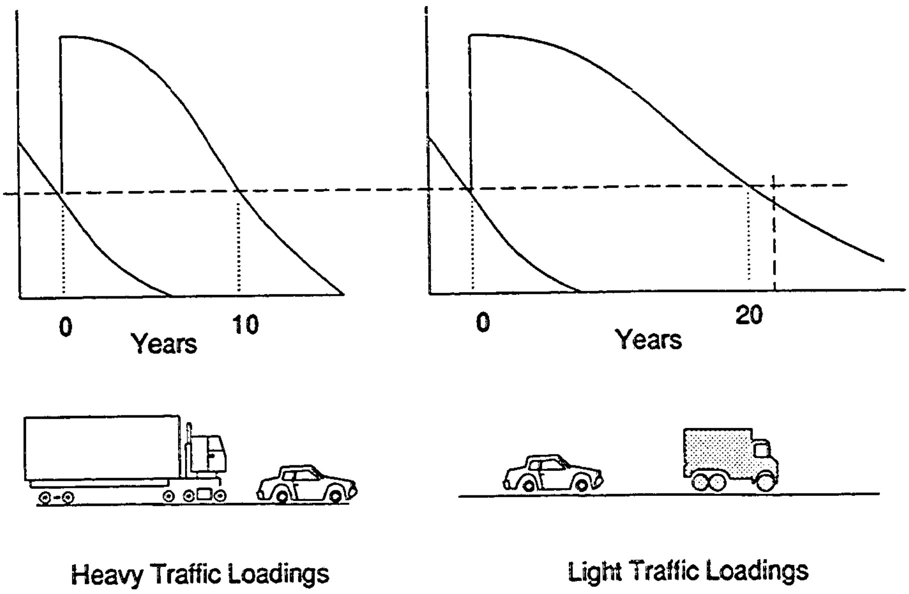

Figure 6.4 - Pavement Performance for Different Traffic Loadings.

6.4.1 Performance Area (AREA)

Added performance area due to pavement rehabilitation, which is the area under the CRS versus time curve, can be considered as the benefit from rehabilitation (see Figure 6.1). This benefit measure contains two elements of rehabilitation benefit: condition and life. Equal weight is given to all traffic levels in this option since AADT is not used in the benefit function. Using this benefit function should result in improved network performance during and beyond the analysis period.

6.4.2 Added Pavement Life (LIFE)

Extending pavement life can be the benefit considered in pavement rehabilitation management. This option is similar to the previous option except that it gives equal weight to different condition levels as long as a pavement is

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adequate (e.g. its CRS is more than 6). Therefore, it removes the subjectivity associated with the condition rating (as in the case of performance) and minimizes its effect on selection of pavement rehabilitation type and timing (see Figure 6.2).

6.4.3 User's Benefit from Pavement Rehabilitation (UBEN)

The most explicit benefit function to be used for any project-level and network-level project selection is pavement user's benefit. User's benefit is the benefit, in monetary form, passed to the user as a result of pavement rehabilitation. It is defined as the reduction in pavement user's cost due to pavement rehabilitation.

User's benefit is calculated from the difference between the user's cost of a rehabilitated and a non-rehabilitated pavement. Unit user's costs (see Figure 6.5) are used to calculate total user's cost over the period of analysis for each case. To calculate total cost, pavement unit user's costs are multiplied by the amount of traffic using the section over the analysis period. The difference between the rehabilitated and non-rehabilitated user's costs is then the user's benefit. Therefore, user's benefit includes all pavement benefit elements (i.e., user's cost and pavement life, condition, use, and length).

6.4.4 Vehicle Miles Travelled over Adequate Pavements (VMT-A)

Vehicle Miles Travelled over Adequate pavements (VMT-A) can also be used as the measure of benefit. VMT-A is the total number of vehicle miles that travel over an adequate pavement section as a result of pavement improvement. This function can be used as an indirect measure of the user's cost since it contains most of the elements in user's cost. VMT-A has AADT and pavement

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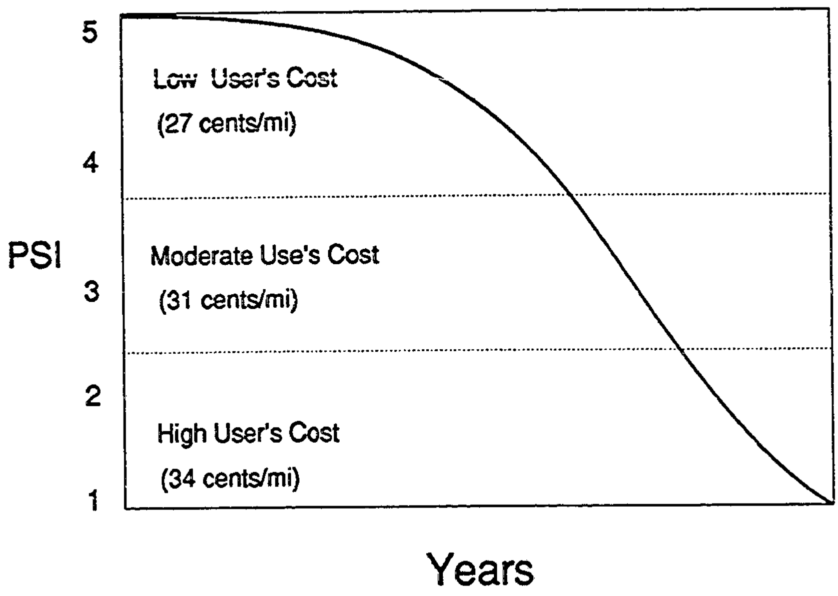

Figure 6.5 - User's Cost for Different Condition Levels.

length in common with the user's cost, however, instead of user's cost for different condition levels, rehabilitation life is used as the measure of pavement performance. The total Vehicles Miles Travelled (VMT) is calculated as follows:

$$\text{VMT-A} = \text{AADT} * \text{Length} * \text{Life} * 365$$

Where:

AADT	=	Average Annual Daily Traffic, Vehicles
Length	=	Pavement section length, Miles
Life	=	Rehabilitation life, Years

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7 Pavement Rehabilitation Network Management Algorithms

Several different algorithms exist for allocating pavement rehabilitation funds to different pavement sections in a network. These algorithms range from fairly uncomplicated (e.g. needs study and different ranking methods) to more complicated (e.g. long-range optimization) (Figure 7.1). Theses algorithms are employed for a variety of purposes including network budget planning and performance analysis, allocation of funds to projects, and estimation of future budget needs. An analysis of different algorithms is needed to assess the effectiveness and validity of each one and to specify the advantages and disadvantages of each algorithm. For example, it needs to be explored whether simple ranking is an effective tool for budget planning and allocation in the case of a constrained budget. Another issue is what other algorithm can provide a better answer. For this purpose several different algorithms have been considered in this research effort. This chapter explains each network-level management algorithm and its components and options. Application of different network management alternatives to a sample network and analysis of different options are presented in chapters 8 and 9 respectively.

7.1 Annual vs. Multi-year Network-Level Management

Alternate network-level pavement rehabilitation management algorithms are considered in two main groups: annual and multi-year. In annual analysis, decisions about rehabilitation or budget allocation are made each year in the analysis period, starting with the first year and advancing to the next year until the end of the analysis period is reached. Thus, decisions at each year are made independently of any decisions at other years in the analysis period. Yearly

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constraints are easily handled by the annual algorithms. Algorithms in this group are ranking, benefit-cost ratio, and yearly optimization (incremental benefit cost ratio).

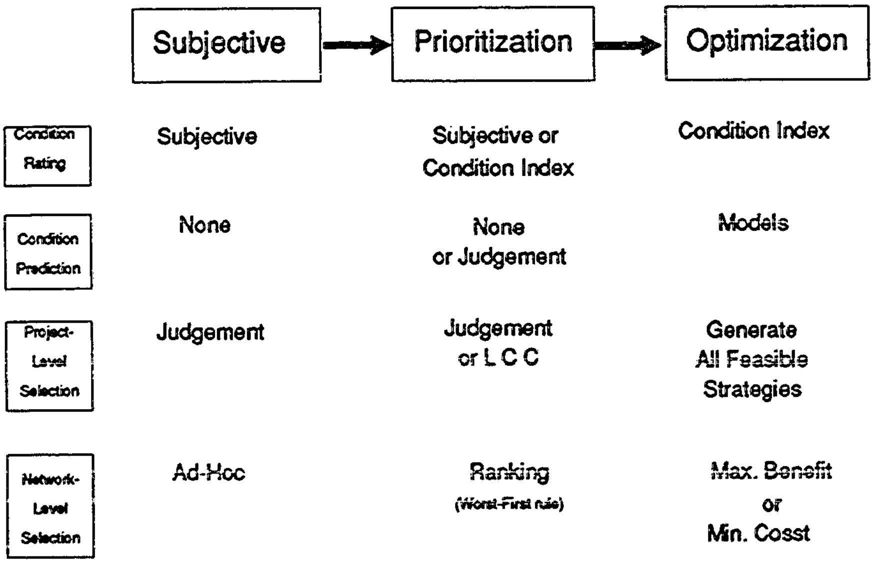

Figure 7.1 - Different Levels of Pavement Network management.

In multi-year network-level analysis, on the other hand, several long-range (multi-year) project-level rehabilitation strategies are generated for each section in the network. Thus, pavement rehabilitation timing trade-offs are considered and rehabilitation timings are selected such that benefit is maximized. In this method, multi-year constraints are used as the limiting criteria. Operation research techniques are employed to solve multi-year network-level analysis.

7.2 Constrained Budget vs. Constrained Performance

Network-level problems are usually formulated in two different ways based on the purpose of the analysis. For program planning, a constrained

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budget is allocated to the pavement sections in a network. This method is used to identify the sections to rehabilitate as well as the timing and type of rehabilitation (rehabilitation program) that result in the best use of the budget. For budget planning, however, budget is allocated to pavement sections until a certain performance constraint is met. This formulation is used to identify the least budget required to maintain a network over a certain condition. Both methods of network analysis are available for each algorithm in this research.

7.3 Unconstrained Network-Level Analysis (NEEDS)

The simplest case in the network-level analysis is when the budget for rehabilitation is unlimited. Thus, any section that becomes deficient (whose condition falls below the minimum acceptable limit) receives some kind of rehabilitation determined by the project-level rehabilitation selection routine (Figure 7.2). Since all deficient sections are funded at the network level, the network budget and performance is the sum of the cost and performance of all sections in need of rehabilitation in the network. The "needs" algorithm (NEEDS) is used to estimate the budget requirements for a pavement network to maintain all pavement sections in adequate condition. Since there is no network-level selection process, NEEDS is an uncomplicated and thus efficient algorithm that can be applied to a network of any size.

7.4 Annual Network-Level Management Algorithms

These algorithms apply when the yearly budget for rehabilitation is limited or a certain performance standard, usually lower than that used for NEEDS, is desired. Thus, not all the sections that need rehabilitation will receive funding. In this approach, decisions about pavement rehabilitation are made each year in

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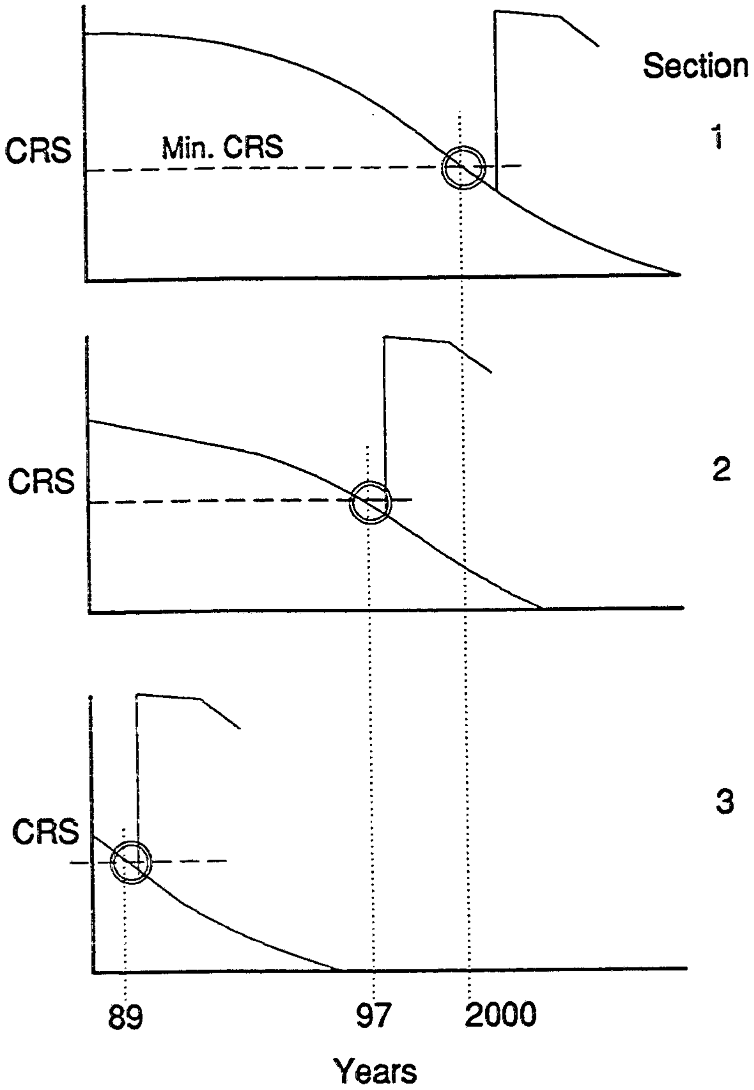

Figure 7.2 - Pavement Rehabilitation Needs Algorithm.

the analysis period, independently of any actions that might be taken in other years. Either a network budget limit or a performance standard can be the limiting criterion in the annual analysis. Three different algorithms considered for annual analysis are ranking, benefit-cost ratio, and incremental benefit-cost ratio. The explanation of each algorithm and discussion of the options follows.

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7.4.1 Simple Ranking (RANK)

In this algorithm funding is allocated annually based on a worst-first rule. Each year in the analysis period, deficient sections are identified and one candidate rehabilitation type based on the rehabilitation selection routine is considered for each deficient section. Sections are then ranked based on their condition from worst to best. Sections in the worst condition (e.g. lowest CRS) are considered for rehabilitation until the constraint (budget or performance) is met for that year. The same algorithm is applied each year in the analysis period. The deficient sections that do not receive any funding at a particular year are delayed at least one year (Figure 7.3). These sections then compete with other backlog pavements for funding the next year.

The choice of rehabilitation at the project level is selected by a rehabilitation selection option. Since only one candidate rehabilitation is considered for every section in the network-level analysis, this algorithm is not able to consider the rehabilitation type trade-offs. Either budget or performance constraints can be applied for each year in the analysis period.

7.4.2 Benefit-Cost Ratio (B/C)

Benefit-cost analysis is utilized in various engineering disciplines to find the most cost-effective solution to engineering problems. In a network rehabilitation management problem where the selection of pavement sections for rehabilitation is of concern, benefit-cost analysis can be utilized to allocate budget to pavement sections in the most cost-effective way for a specified budget limit.

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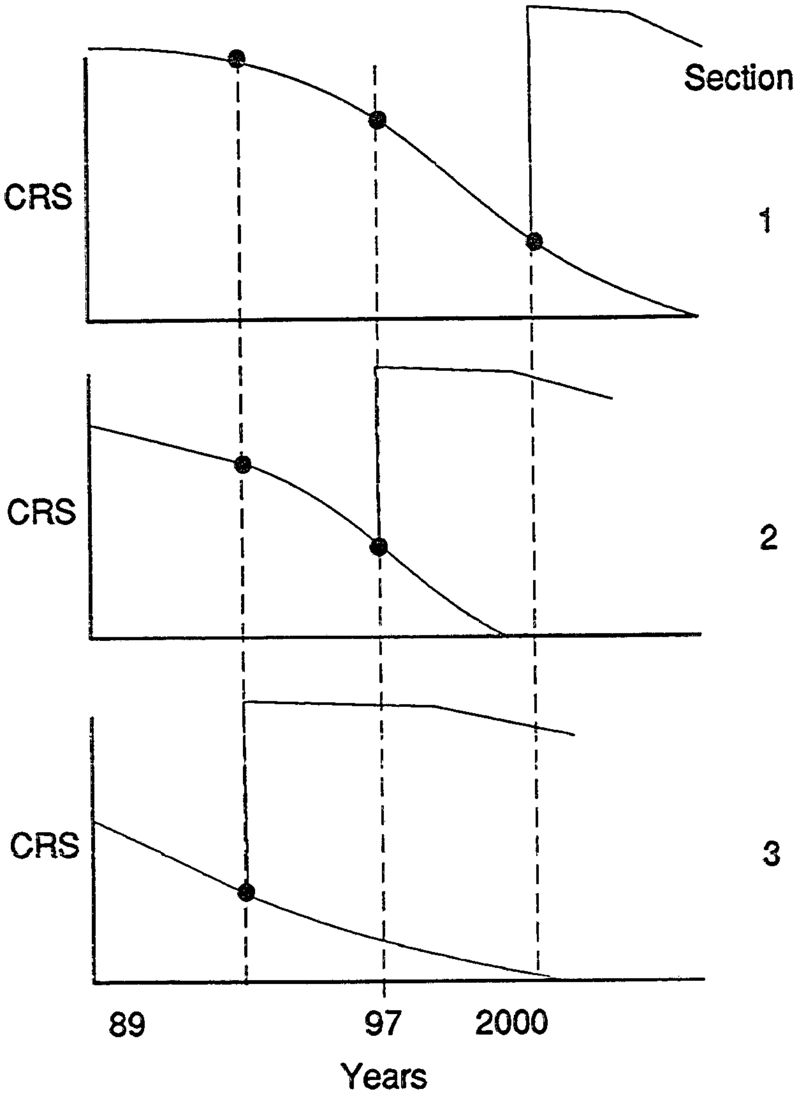

Figure 7.3 - Pavement Rehabilitation Ranking Algorithm.

In ILLINET, benefit-cost ratio is also utilized to allocate funds for a yearly budget. This is accomplished by selecting sections for rehabilitation based on their benefit-cost ratio. First the choice of benefit (one of the four benefit options) and the choice of project-level rehabilitation selection (one of the five options) are selected. Then those sections that are in need of rehabilitation (deficient

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pavements) are identified and the one candidate rehabilitation is selected for each one using the project-level rehabilitation selection routine. The benefit and cost of the rehabilitation and therefore the benefit-cost ratio is then calculated. Then candidate rehabilitations for deficient sections are ranked based on their benefit-cost ratio from highest to lowest and funds are allocated to pavements with the highest benefit-cost ratio until the yearly constraint is met. Those sections in need of rehabilitation that do not receive any funding in a particular year should compete for funding in the future years. The same process is repeated for every year in the analysis period.

A graphical illustration of the benefit-cost ratio algorithm for one year is shown in Figure 7.4. Figure 7.4 shows the benefits and costs for candidate rehabilitations of six deficient pavements. Projects are ranked based on their benefit-cost ratio (the slope of the solid lines for each project). From Figure 7.4 it is evident that the selection of projects for every budget by this algorithm results in the maximum possible network benefit for that year. Thus, in effect this algorithm maximizes the yearly network benefit for a yearly budget limit, although the choices for maximization are limited since only one candidate rehabilitation exists for every section.

7.4.3 Incremental Benefit-Cost Ratio (IBC)

This method is similar to the benefit-cost ratio except that more than one candidate rehabilitation for every deficient section is considered. Thus, the type of rehabilitation is not determined at the project level, as in the case of B/C, and all possible rehabilitation types for deficient sections are considered at the network level. For this reason, IBC provides a better maximization of benefit than

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B/C.

The IBC algorithm is accomplished by first calculating an incremental cost (ΔC), an incremental benefit (ΔB), and an IBC ($\Delta B/\Delta C$) for all rehabilitation types (called projects) that apply to a deficient pavement section at a particular year (see Figure 7.5). Only those projects that have a positive IBC are considered, since a negative IBC means that there are no benefits gained by selecting the project over a less costly project. The remaining projects for each section are ranked based on increasing cost and IBC's are graphed (see Figure 7.6) . The IBC graph should be concave down as shown in Figure 7.6. When the IBC curve is not concave down the IBC's should be modified to make a concave down curve (see Figure 7.7). The reason projects should have a lower IBC than their previous projects (concave down curve) is that projects are selected incrementally at the network level. Therefore, the benefit and cost of each project should be the sum of incremental benefit and cost of the project itself plus all previous projects for every section. When the IBC of a project (IBC_i) is larger than the IBC of the previous project (IBC_{i-1}) the previous project is set aside and a new IBC is calculated (IBC_n) as follows (Figure 7.7):

$$IBC_n = \frac{(\Delta B_{i-1} + \Delta B_i)}{(\Delta C_{i-1} + \Delta C_i)}$$

If the new IBC is still larger than that of project (IBC_{i-2}) it would be adjusted in a similar manner again.

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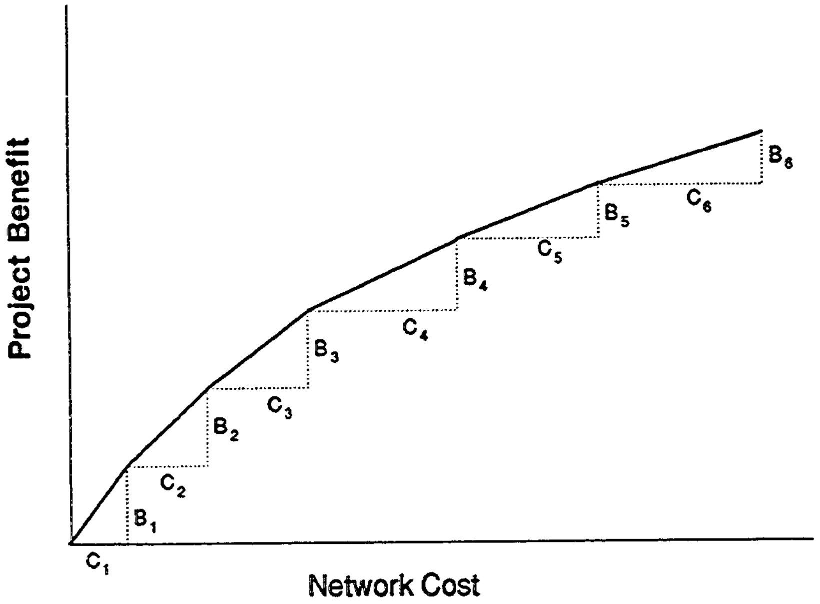

Figure 7.4 - Benefit-Cost Curve for Project Selection for a Given Year.

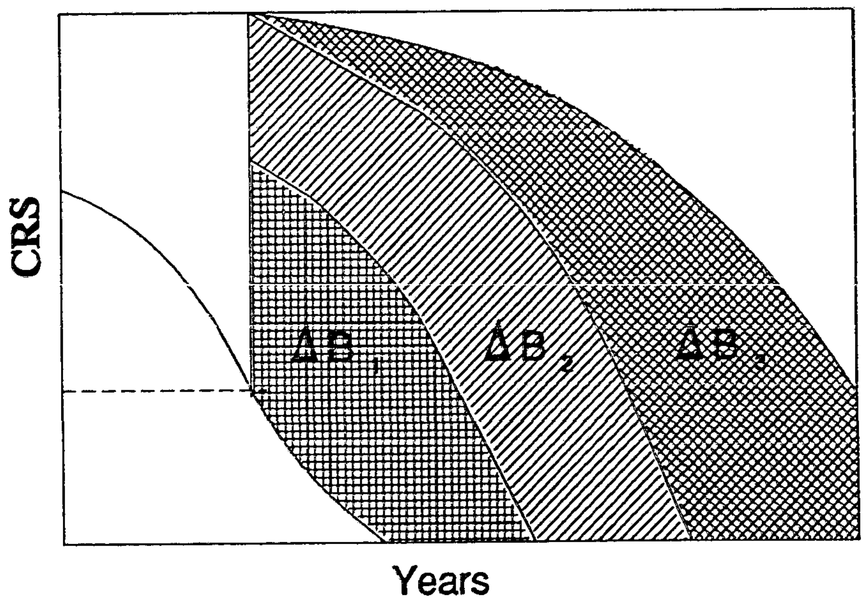

Figure 7.5 - Incremental Benefit and Costs for Different Projects.

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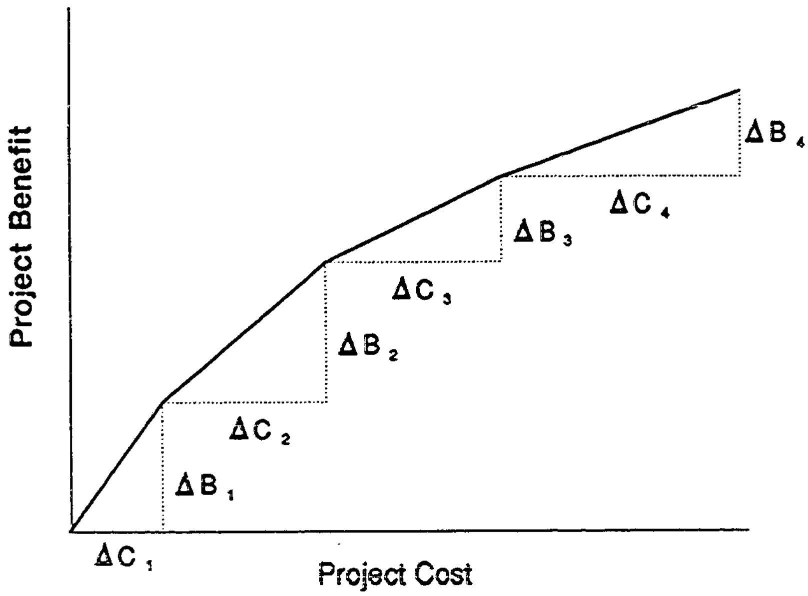

Figure 7.6 - Arranging IBC's for One Section (Concave Situation).

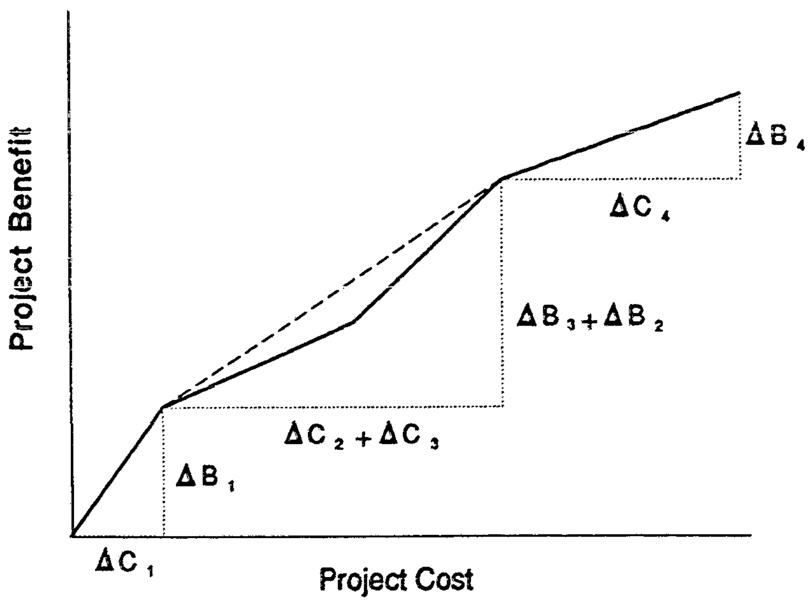

Figure 7.7 - Arranging IBC's for One Section (Non-Concave Situation).

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After projects for all deficient sections are arranged in the proper order at the project level, all projects for all sections are arranged in descending order of IBC such that the network IBC curve provides the steepest path when moving from low to high cost (see Figure 7.8). This network IBC curve also can be regarded as the steepest benefit path or highest gradient curve. Projects selected from the steepest path curve contribute the most to the network benefit since they provide the highest benefit per cost. The project selection continues on the steepest path until the budget limit is reached. It is evident from figure Figure 7.8 that the resulting network benefit is the maximum possible for the budget limit. When more than one project is selected for a section, the most recent project selected replaces all previous projects. Thus, only one project is selected for each section in the network. All sections that do not receive funding will be maintained (i.e. their rehabilitation is delayed for at least one year). When a project is not selected because its cost of rehabilitation exceeds the budget, other projects with the lower IBC are considered for selection. In this case those projects that were set aside at the project-level because they violated the concave down rule are also considered in selection.

As shown before, the IBC method selects projects such that the resulting network benefit is maximum for a yearly network budget limit. In effect, IBC solves the optimization formulation (to be discussed in the next section) to maximize yearly pavement network benefit for a limited budget.

7.5 Multi-Year Optimization

Operations Research (OR) techniques (optimization) have been utilized for network-level pavement rehabilitation planning and programming. For this

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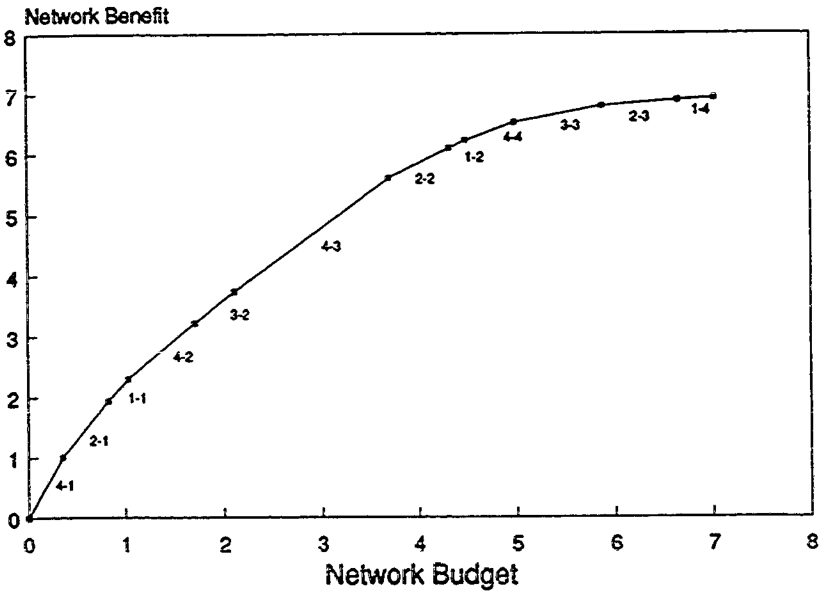

Figure 7.8 - IBC Steepest Benefit Path Curve for Project Selection.

purpose, several long-term strategies (rehabilitation timing and type over the period of analysis) are generated for each section in the network, and benefit and cost are calculated for each strategy. The general form of optimization is maximization or minimization of a function in the presence of one or several constraints.

Two different formulations are usually used for network rehabilitation management; one for rehabilitation programming and one for budget planning. For the purpose of the rehabilitation programming, where a constrained budget must be allocated to pavement sections in the network, pavement network benefit (sum of the benefits of the selected sections and strategies) is maximized for a certain budget limit. The budget limit is either a yearly budget limit or a budget limit over the whole analysis period. For budget planning where the cost of

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maintaining the pavement network at a certain standard (or condition level) is desired, the total pavement network rehabilitation cost is minimized for a network performance standard.

This research, however, only considers the rehabilitation programming formulation since this formulation is mainly considered for comparison with other ILLINET options. The formulation for rehabilitation programming with one multi-year (e.g. 10-year) budget limit is as follows:

MAXIMIZE:

$$\sum_{j=1}^{np} \sum_{i=1}^{ns_j} B_{ij} * P_{ij}$$

SUBJECT TO:

$$\sum_{j=1}^{np} \sum_{i=1}^{ns_j} C_{ij} * P_{ij} \leq \textit{Total Budget}$$

and

$$\sum_{j=1}^{ns_j} Pij = 1$$

Where:

P_{ij} is a decision variable identifying the jth strategy of ith section, binary (0 or 1)

B_{ij} the benefit of jth strategy in the ith section

C_{ij} the cost of jth strategy in the ith section

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ns_j number of feasible strategies for jth section

np number of sections in the network

Three alternate methods of solving this formulation are discussed below. The conventional method of solving this problem is by integer programming. One method that gives the same solution as integer programming and another which provides an approximation to integer programming is also discussed in this section.

7.5.1 Using Integer Programming

Since only one project-level strategy out of several strategies can be selected for every section, all decision variables (P_{ij}) for the multi-year formulation are binary (0 or 1). In this case, integer programming is the most conventional OR technique to solve the problem formulation. However, integer programming technique is very inefficient when a large number of variables and multiple constraints are considered. For a large network with many project-level strategies and several yearly constraints, integer programming may not be able to provide a solution even after millions of iterations.

7.5.2 Using Incremental Benefit-Cost Ratio (OPT)

The multi-year formulation can be solved using the incremental benefit-cost ratio algorithm discussed earlier in this chapter. The same approach used for yearly optimization can be used here to allocate funds to different projects in a network. In the yearly optimization problem, the project-level choices are five different rehabilitation alternatives, while in the multi-year optimization the

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project-level strategies are usually much more (maximum of 50) since all combinations of rehabilitation alternatives and years of rehabilitations are considered (see chapter 5 under multi-year project-level strategies for details).

The IBC approach provides similar solutions as integer programming (when there is only one constraint) but with much better computational efficiency. Unlike integer programming, the IBC method also provides the justification for selection of one project over another by creating a steepest benefit path curve that can be applied to any budget limit. Notice that this method is only utilized for solving the network problem when multi-year budget is the only constraint.

7.5.3 Approximate Linear Programming (LIN)

An alternative method of solving the multi-year formulation is by using the linear programming method. Using this method, not all resulting decision variables are integers and there is one non-integer decision variable for every constraint since linear programming does not require that all variables be integer. In the case of one multi-year constraint (10-year budget limit), decision variables (P_{ij}) for all sections will be binary except for one section (There is a split decision for this section). For yearly budget limit (for 10 years), however, there would be 10 sections with non-integer variables. For the sections with non-integer variables (split rehabilitation decision), the rehabilitation with the highest P_{ij} value is selected (set to 1) and other variables are set to zero. For this reason LIN provides an approximate solution since there is no guarantee of optimality and the selection of one split decision might result in violation of the constraint (budget limit).

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Since linear programming is an efficient algorithm, it ensures a solution to problems of a relatively large size even when multiple constraints are used. The accuracy of this method increases as the number of sections in the network increases, since the number of non-integer decisions only relates to the number of constraints. This method is not available in ILLINET but is considered in this research for comparison with other ILLINET methods. However, the long-range pavement rehabilitation strategies considered are generated by ILLINET. The generated strategies are then formulated and solved using the LINDO linear programming package (27).

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8 Application of ILLINET to a Sample Network

In order to demonstrate the capabilities of ILLINET, different pavement management methods available in ILLINET are applied to a sample network. This chapter includes the discussion of the sample network, the default variables and options considered, and also the presentation and discussion of some of the output reports for ILLINET application runs.

As mentioned in previous chapters, several network-level, project-level, and benefit options are available in ILLINET. These options cover a variety of methods commonly used by different transportation agencies around the world for managing pavement networks. Needs and different methods of ranking are probably the most commonly used algorithms, while benefit-cost analysis and optimization are becoming more and more used. However, for some agencies the transition from ranking to optimization is not easy. Apart from the problem of unavailability of models, other problems such as the complexity of some network management systems, or in other words the "black-box" approach, and the subjectivity of "optimization" criteria are the problems to overcome. Comparison of alternate network management alternatives can demonstrate the effectiveness of each method and the advantages and disadvantages of each method over the others. Such a comparison has not been performed prior to this study.

8.1 Description of Sample Network

A pavement network that includes all Interstate pavement sections in the District 5 of the Illinois Department of Transportation was used as a sample network in the analysis. IDOT District 5 is located in east central Illinois,

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(Figure 8.1) and is in the wet-freeze climatic region of the U.S.A. This network includes 121 one-directional pavement sections (two lanes in each direction) with a total length of 517 miles on four Interstate routes (I-57, I-70, I-72, and I-74). The pavement sections were built as early as 1958 and as late as 1976. All pavement sections in this network were originally built as jointed reinforced and continuously reinforced concrete pavements (JRCP and CRCP); however, at least half of these sections were later overlaid with asphalt concrete (AC).

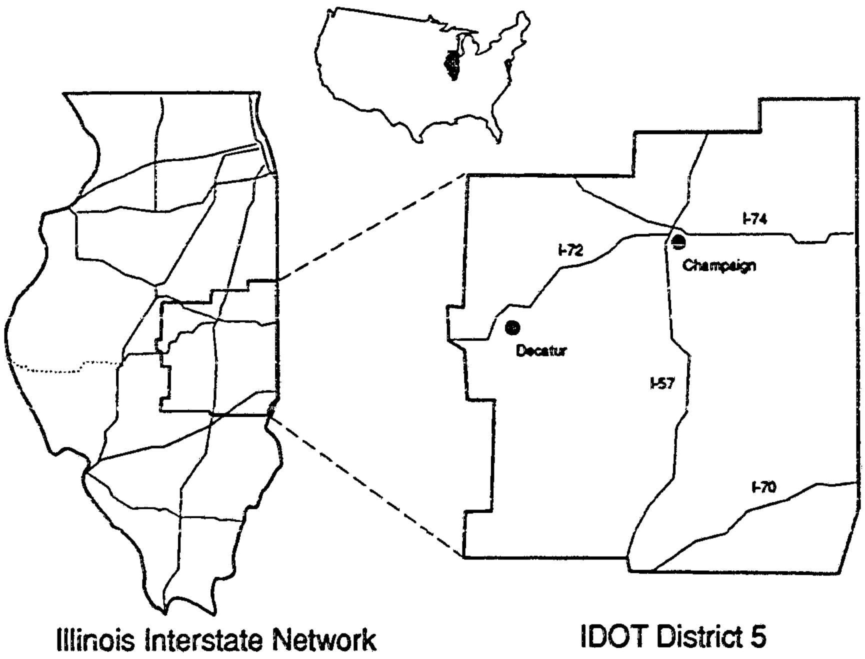

Figure 8.1 - Map of Illinois DOT District 5.

8.2 Input Database for Sample Network

The input database for the sample network includes several data items (variables) for each pavement section in the network. These data are regarding pavement identification, design, traffic, climate, distresses, and condition. A list of variables in the database is given in Table 8.1. The sample database is

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included in Appendix C. Following is a discussion of some of the variables in the sample database.

8.2.1 Pavement Types

The pavement network consists of four different pavement types: two concrete pavement types; jointed reinforced (JRCP) and continuously reinforced (CRCP) and two composite pavement types; AC overlays of JRCP and CRCP (JROL and CROL respectively). Figure 8.2 shows the distribution of each pavement type in the network. As Figure 8.2 shows, as of 1987, 55 percent of the network is bare concrete and the rest (45 percent) had been overlaid with asphalt concrete (composite pavements). About half of the network was originally built as JRCP and the other half as CRCP.

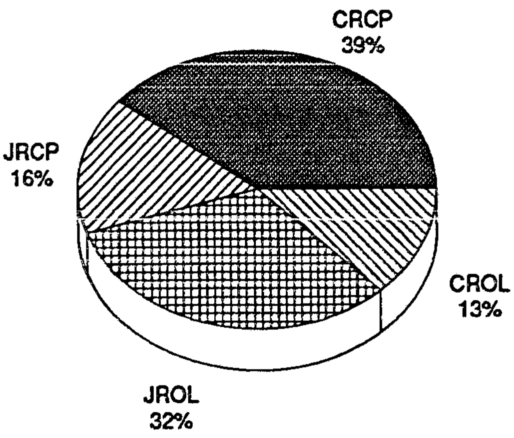

Figure 8.2 - Distribution of Pavement Types in District 5.

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Table 8.1 - Description of ILLINET's Input Variables.

	Variable	Description		Unit
IDENTIFICATION	ROUTE	Interstate Route Number	ALL	I-
	DIR	Direction	ALL	N,E,S,W
	BEGIN	Beginning Milepost	ALL	-
	END	End Milepost	ALL	-
	DIST	District Number	ALL	1-9
	TYPE	Pavement Type	ALL	CRCP,JRCP,
	THICK	Thickness of main pavement layer	ALL	inches
	AGE	Age since construction or rehab.	ALL	years
	LANES	Number of lanes in each direction	ALL	number
DESIGN	BASE	Base Type	JRCP	gran./stab.
	DRAIN	Drainage	JRCP	1,2,3
	SDIAM	Steel Diameter	BARE	inches
	SSPAC	Steel Spacing	BARE	inches
	OLTHK	Overlay Thickness	BARE	inches
TRAFFIC	ADT	Average Annual Daily Traffic	ALL	1000 veh.
	ADTGR	ADT Growth	ALL	percent
	CESAL	Accumulated ESAL since	ALL	millions
	YESAL	Annual ESAL	ALL	millions
	ESALG	ESAL Growth	ALL	percent
CLI	FI	Freezing Index	JRCP	deg days
	PREC	Precipitation	JRCP	cm
CONDITION	PATCH	Existing Patches	ALL	number
	FPAT	Failed Patches	ALL	number
	FAIL	Failures	ALL	number
	RTFLT	Faulting	JRCP	inches
	DETJT	Deteriorated Joints	JRCP	number
	DCRK	'D' Cracking	BARE	Yes/No
	PUMP	Pumping	JRCP	1,2,3
	CRS	CRS	ALL	1-9

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8.2.2 Section Length

The length of pavement sections range from less than a mile to 10 miles with an average of about five miles (see Figure 8.3). About 80 percent of the sections in the network, however, are between 2 and 6 miles long.

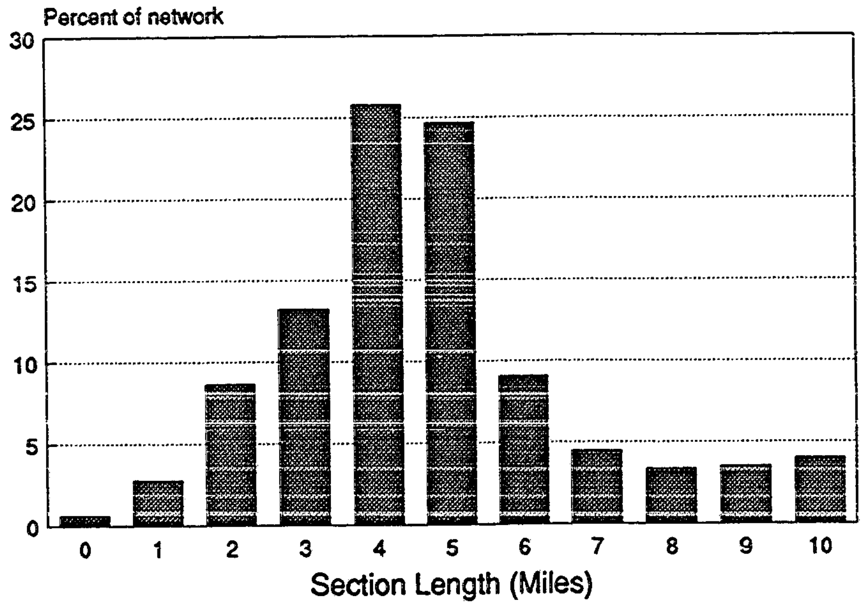

Figure 8.3 - Distribution of Pavement Section Lengths.

8.2.3 Pavement Age

The sample network includes a wide range of ages since original construction (see Figure 8.4). This network includes some of the first sections constructed on the U.S. Interstate in 1958 (Interstate 74, north of Champaign). However, most of the sections in the sample network were constructed during 1960's and some as late as 1976. The oldest sections are on Interstate 74, which was constructed between 1958 and 1961.

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Interstate 57, on the other hand, was constructed between 1964 and 1969. Interstate 70 was constructed between 1969 and 1970 and Interstate 72 between 1975 and 1976. As mentioned earlier, almost half of these sections were overlaid by 1987. Figure 8.5 is the distribution of ages since major rehabilitation (reconstruction or overlay). This figure shows that age varies from zero (for sections overlaid 1987) to about 20 years. Figure 8.6 shows the distribution of overlay ages. The overlay ages are between 0 and 11 years with an average of about 7 years.

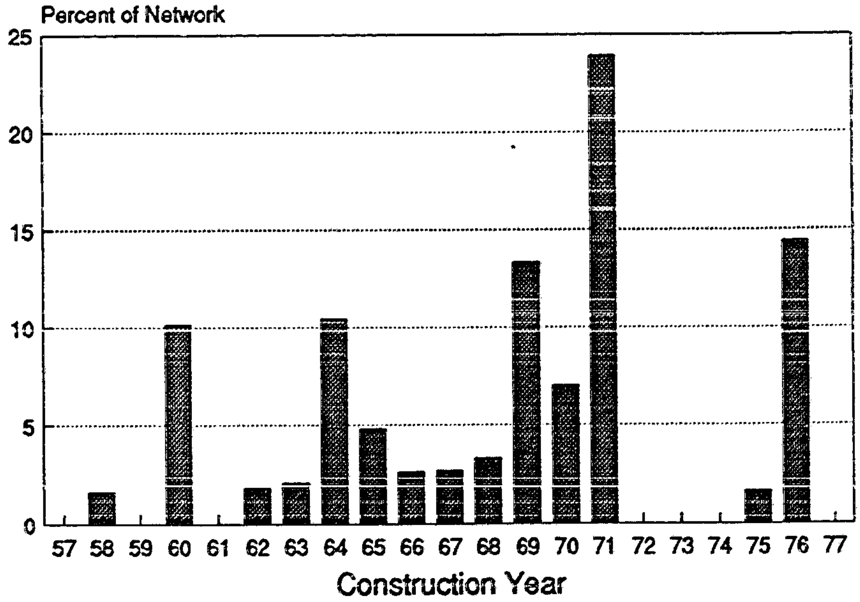

Figure 8.4 - Distribution of Construction Years.

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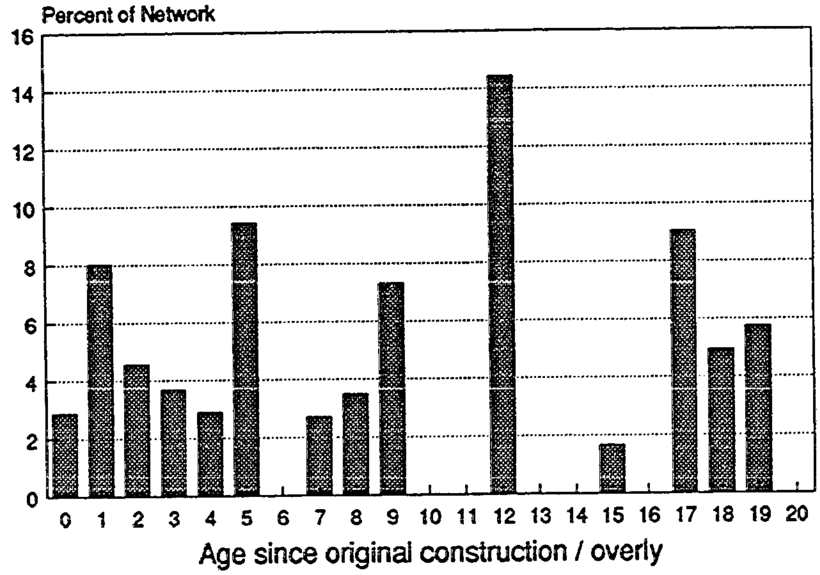

Figure 8.5 - Distribution of Ages since Last Rehabilitation.

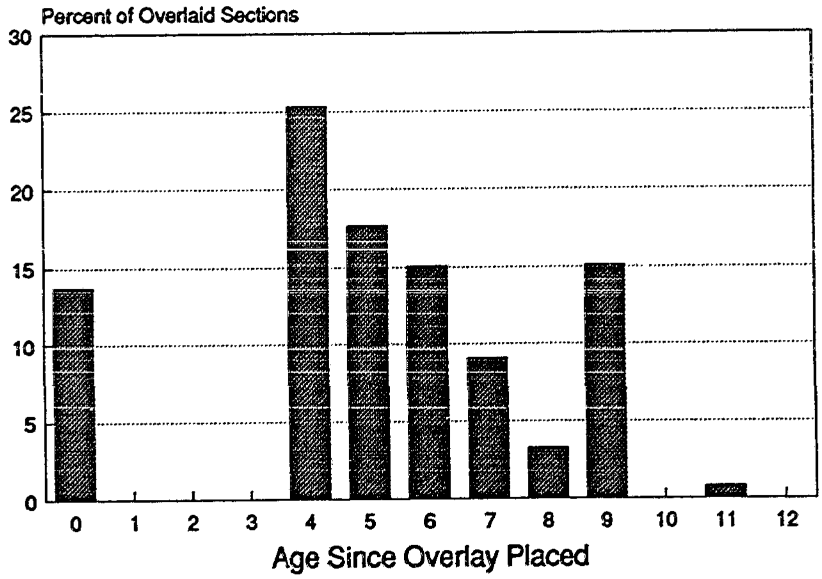

Figure 8.6 - Distribution of AC Overlay Ages since Construction.

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8.2.4 Traffic

The Average Annual Daily Traffic (AADT) for both directions ranges from 5 to 18 thousand vehicles per day with an average of 11 thousand vehicles per day (Figure 8.7). The annual 18-kip equivalent single-axle load (ESALs) for the network ranges from 0.2 to 1.2 million ESAL with an average of 0.77 (Figure 8.8). The accumulated ESALs since last rehabilitation, which is an input to most prediction models, is shown in Figure 8.9. Accumulated ESALs range between 0 and 15 million ESALs. Lower ESALs (from 0 to 6 million ESALs) are mainly for the overlaid sections while higher ESALs (more than 6 million ESALs) apply to original pavements.

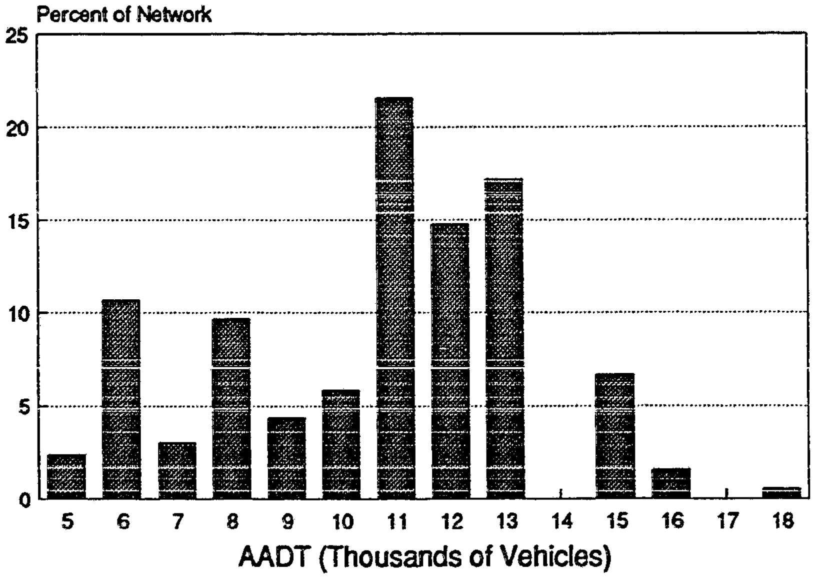

Figure 8.7 - Distribution of Average Annual Daily Traffic (AADT).

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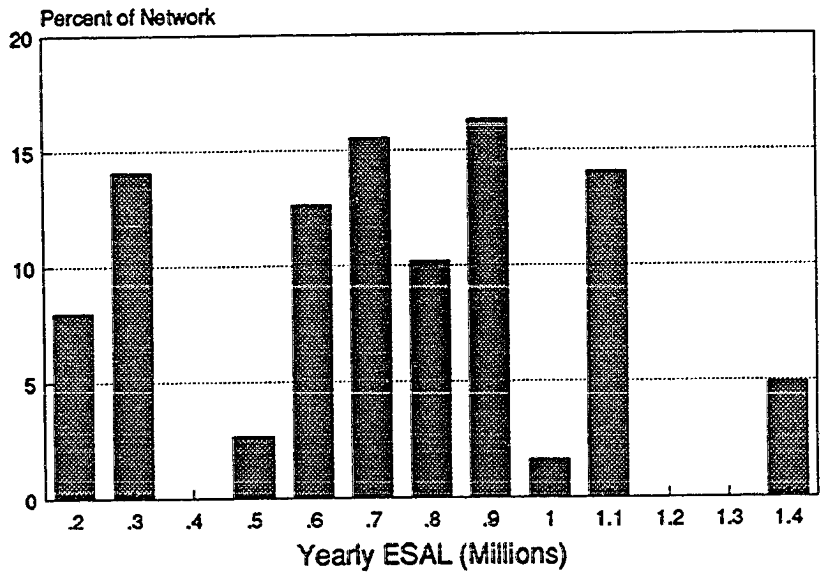

Figure 8.8 - Distribution of Annual ESAL.

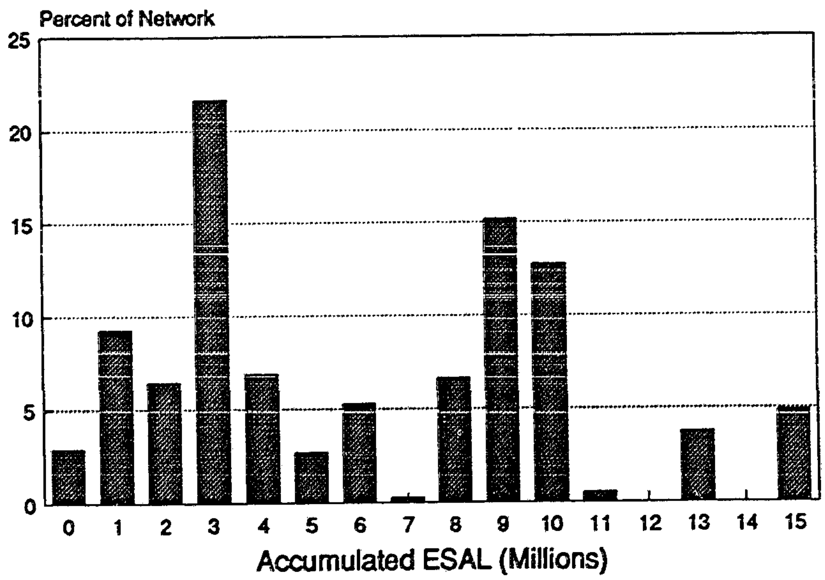

Figure 8.9 - Distribution of Accumulated ESAL since Last Rehabilitation.

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8.2.5 Condition and Distresses

The condition of the network as of 1987 (the beginning of the analysis) can be represented by the average network CRS. The average CRS was 7.55 and ranged from 3.5 to 9 (see Figure 8.10); about 75 percent of the network sections had a CRS of 7 or more and only 7 percent of the sections had a CRS of 5 or less (poor condition). These statistics indicate that the overall network condition is good.

Present (1987) quantities of distresses per mile are listed in the input database (see Appendix C). "D" cracking is a major distress for concrete pavements in Illinois which drastically affects pavement performance. About 12 percent of the total length of the District 5 pavement network has experienced different severities and extents of "D" cracking (see Database in Appendix C).

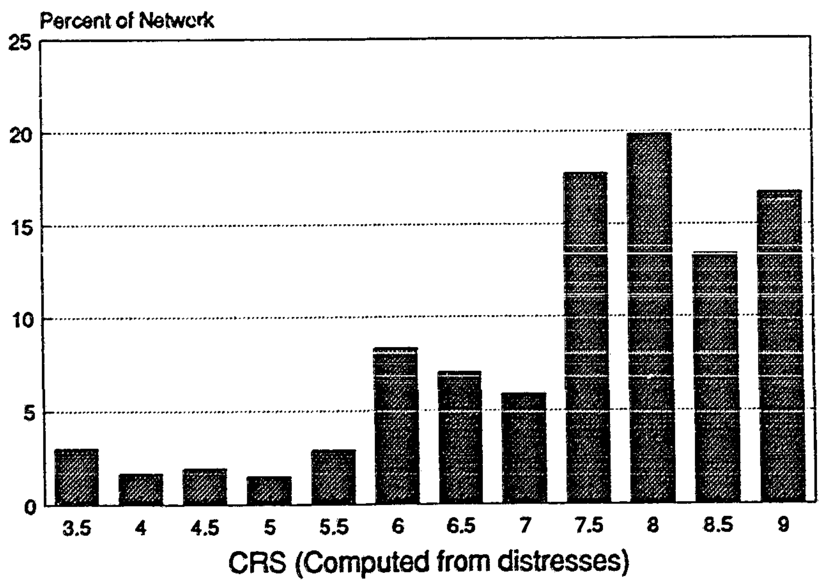

Figure 8.10 - Distribution of Current CRS.

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8.2.6 Climate

Figure 8.11 shows the United States divided into six major climatic regions that relate to pavement performance (38). Figure 8.11 shows that half of the State of Illinois is in region II and the other half in region III. Both regions II and III have wet climates. The District 5 network, however, is located in region II (freeze-thaw cycling region) on the border of region III (hard freeze and spring thaw region).

The annual precipitation and the Corps of Engineers Freezing Index (FI) (28) is also part of the District 5 input database (Appendix C). The annual precipitation in the District 5 is approximately 95 centimeters (ranges between 91 and 97 centimeters per year) and the FI is between 300 to 500 Degree Days.

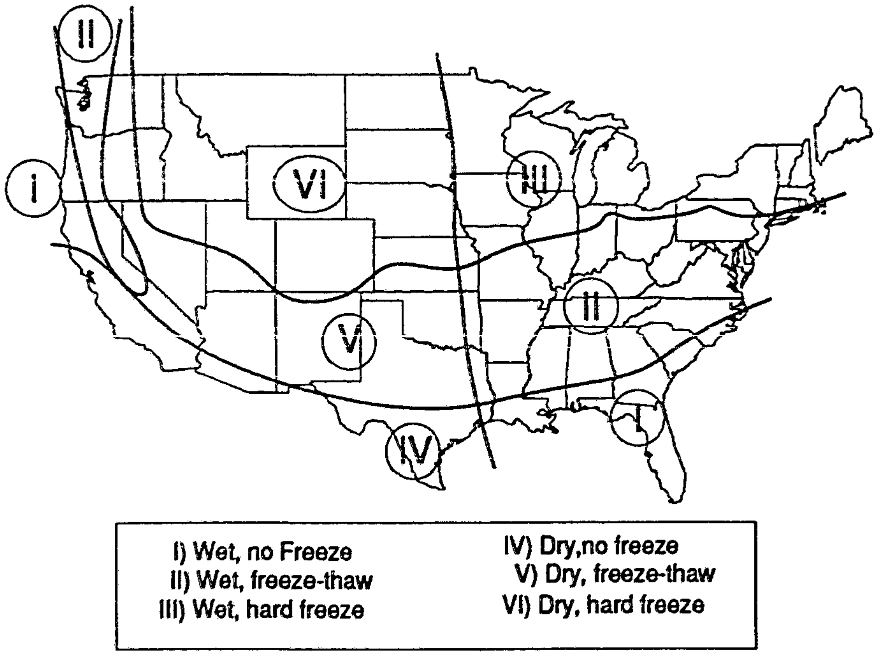

Figure 8.11 - U.S. Map with Major Climatic Zones for Pavement Performance.

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8.3 Default Parameters Used for the Application

ILLINET requires several user-defined parameters to be entered for the network analysis. These input parameters consist of:

1. Length of analysis period,
2. Rate of inflation during analysis period,
3. Number of rehabilitations allowed during analysis period,
4. Minimum CRS for rehabilitation and life determination,
5. Unit user costs, and
6. Decision tree trigger values.

Table 8.2 lists the default values used for the input parameters. A 10 year analysis period during which rehabilitation costs inflate at the rate of 5 percent per year and AADT grows at the rate of 2.5 percent per year is considered throughout the analysis. Only one rehabilitation was allowed in the 10 year period. It is also assumed that 80 percent of the failures existing on the concrete pavements are patched at the time of rehabilitation.

The decision tree trigger values are the same as trigger values used by IDOT for the Interstate network. These values are selected by the judgement of the engineer. Unit costs of rehabilitation are the average statewide unit costs (excluding Chicago and St. Louis metropolitan areas) for year 1987, as explained in chapter 4. The unit user costs were selected from a national study conducted in 1972 (22). These values are inflated at the rate of 4 percent per year to reflect 1987 costs. The same default values for input parameters are used for all ILLINET application runs and other runs performed in this research.

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Table 8.2 - Default User Input Values for ILLINET.

Default Parameter	Value	Unit
Analysis Year	1987	
Length of Analysis Period	10	Year
Analysis Interval	1	Year
Trigger for Accruing	6	CRS
Trigger for Backlog	4	CRS
Trigger for Rehabilitation	6	CRS
Inflation	5	Percent
No of Rehabilitations Allowed	1	
Percent Patching	80	Percent
User's Cost for CRS>=6	27	Cents/mi
User's Cost for 6 >CRS> 5	31	Cents/mi
User's Cost for CRS<=5	34	Cents/mi

Table 8.3 - Default Trigger Values for Decision Tree.

	Trigger Values for Rehabilitation			
Rehabilitation Type	BARE JRCP	BARE CRCP	BARE 'D' Cracked	Asphalt Overlays
CPR	6	6	n/a	n/a
3.25-inch Overlay	5	5	6	6
5.0-inch Overlay	4	4	4	4
Reconstruction	3	3	3	3

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8.4 ILLINET's Outputs

The results from the ILLINET program are included in three reports which cover the range from the "big picture" to the "most detailed." A sample output for each report is included in Appendix D. Following is a brief discussion of each output report.

8.4.1 Project Detailed Report

This report provides the most detailed project-level information available for every section in the network. It contains the following information for every year in the analysis period:

1. CRS prior to rehabilitation.
2. Type and cost of pavement rehabilitation.
3. Accumulated ESAL since last rehabilitation.
4. Quantity of existing patches and other distresses.

The project detailed report is useful for monitoring the predicted performance and distresses for every section in the network and examining the feasibility of pavement rehabilitation timing, type, and cost.

8.4.2 Project Summary Report

This report provides a summary of data for every section in the network. It contains section identification and other key pavement information, as well as the 10-year rehabilitation program (type and year of rehabilitation) and cost for every section. The main purpose of the project summary report is to provide two-, five-, and ten-year pavement rehabilitation plans for the network.

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8.4.3 Network Summary Report

This report contains information regarding average network performance for every year in the analysis period and for the duration of the analysis period. The following summary data for every year in the analysis period are available:

1. Average network CRS weighted by length.
2. Average remaining life of the network weighted by length.
3. Percent Vehicle Miles Travelled (VMT) over backlog pavements.
4. Percent length of the backlog pavement.
5. Pavement rehabilitation priorities (PRT) (see chapter 2 for description).
6. Quantity of rehabilitations.
7. Amount of added benefit of the network.
8. Total cost of rehabilitation.

The network summary report provides useful statistics on pavement performance during and beyond analysis period. These statistics (network parameters) are used in comparing different network management methods and in measuring the effectiveness of each.

8.5 Network Performance Parameters

Several network-level statistics which are listed as part of the network summary output can be used to compare alternate network management options. There are five major groups of statistics: network cost, network benefit, performance during the analysis period, performance beyond the analysis period, and network rehabilitation program. Following is a discussion of each network performance parameter.

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8.5.1 Network Cost

Network cost is the cost of applying the rehabilitation program, which is the sum of the cost of rehabilitation for all sections in the network (or total amount spent on the network). The cost of rehabilitation in every year includes inflation, thus, network cost is not the present worth of the cost.

8.5.2 Network Benefit

Network benefit is the sum of benefit gained by rehabilitation of all pavement sections in the network which is available from the network summary report. Four different benefit measures considered are:

1. Added area under performance curve (AREA),
2. Extra life due to rehabilitation (ALIFE),
3. Added Vehicle Miles Travelled on adequate pavements (VMT-A), and
4. Reduction in user cost due to rehabilitation (UBEN).

Network benefit includes added benefits during and beyond analysis period for the cost spent on the network.

8.5.3 Network Benefit-Cost Ratio

Network benefit-cost ratio is the total benefit derived from pavement rehabilitation divided by the rehabilitation cost spent on the network, or simply network benefit divided by network cost. This parameter provides the benefit per unit cost, which is valuable in assessing the effectiveness of each pavement management method.

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8.5.4 Performance during Analysis Period

The following parameters reflect the overall performance of the network during the analysis period:

1. Average 10-year network CRS, and
2. Percent VMT on backlog pavements during 10-year period.

8.5.5 Performance Beyond Analysis Period

The two parameters listed below reflect the condition of the network at the end of the analysis period and the performance of the network beyond the analysis period.

1. Percent VMT on backlog pavements in the last year of analysis period (year 10), and
2. Remaining life of the network at year 10.

8.5.6 Rehabilitation Program

The network rehabilitation program is the 10-year rehabilitation plan for all the sections in the network. The rehabilitation programs can be used for assessing the effect of different network options in selecting rehabilitation timing and type.

8.6 Application of ILLINET to a Sample Database

Four network management methods that represent a range of options available in ILLINET were applied to the District 5 sample network using the

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previously mentioned default user input variables. For all runs, VMT-A was selected as the benefit function where applicable. Following are the options considered for the ILLINET runs:

1. Needs network-level option with life cycle cost (LCC) analysis for the project level.

2. Ranking option with LCC for project-level and yearly budget limit of 7.5 million dollars.

3. Incremental benefit-cost ratio (IBC) with all project-level options (ALL) and yearly budget limit of 7.5 million dollars.

4. Long-term optimization (OPT) with all project-level options and a 10 year budget of 75 million dollars (no yearly budget restraint).

In addition to these methods, two other methods that are not available in ILLINET were also considered for purpose of comparison. Theses methods are:

1. Randomly generated rehabilitation program (RAND).

2. Rehabilitation program generated using approximate linear optimization (LIN) using ALL project-level option and yearly budget limit of 7.5 million dollars.

The randomly generated rehabilitation program was created using a random number generator. In this method, every section whose CRS at the beginning year of analysis (1987) was 7 or less qualified for rehabilitation. The timing of the rehabilitation during the analysis period and the type of rehabilitation was then randomly selected for the section. The rehabilitation program was then fed into the ILLINET program to produce the output reports that include performance parameters. The approximate linear programming method is described in chapter 7.

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8.7 Presentation of Results

The results of ILLINET's runs for all application network management methods described before are presented in several tables and graphs. Table 8.4 includes all network performance parameters for each run. The data in Table 8.4 are also presented in several figures (Figure 8.12 to Figure 8.16). The rehabilitation program created by each method is presented in Table 8.5.

The benefit gained by pavement rehabilitation in terms of VMT-A and the cost of rehabilitation for the different methods are listed in Table 8.4 and graphed in Figure 8.12. The highest cost belongs to Needs (about 90 million dollars) since this is the unlimited budget method. The cost of all other methods are about equal and range between 71 and 75 million dollars. The benefit of rehabilitation, which is shown in terms of added Vehicle Miles Travelled over Adequate pavements (VMT-A), is highest for Needs partly because of the higher cost of rehabilitation. The Random method offered the lowest benefit and Ranking the next lowest. The benefits for other methods (i.e., IBC, OPT, and LIN) are comparable since all these methods are based on maximizing the benefit. The network benefit to network cost ratio, which is the measure of the effectiveness of each method, is shown in Figure 8.13. From Figure 8.13 it can be seen that Random, followed by Ranking, have the poorest effectiveness of all methods. OPT has the highest effectiveness of all methods; however, the optimization methods are comparable in their effectiveness.

The average network CRS is highest for Needs and lowest for Random (see Table 8.4 and Figure 8.14). However, the CRS for all options only ranges between 6.5 and 7.15 and is comparable for all optimization methods. The remaining life

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shows a trend similar to that of CRS, except that it has a wider range (3.5 years for Random and 4.7 years for Needs).

Average Vehicle Miles Travelled over Backlog pavements (VMT-B) and VMT-B at the end of analysis period (year 10) are listed in Table 8.4 and also shown in Figure 8.15. The highest average VMT-B is 15.4 percent for Random method and the lowest is 2.6 for Needs. The lowest VMT-B among optimization methods belongs to OPT (4.2 percent); however, for the other two methods (IBC and LIN) VMT-B is about 6 percent. The VMT-B for RANK (3.5 percent) is also lower than for the optimization methods but higher than for Needs.

One way of presenting all of the results for the different methods is to show all network parameters for all methods on one single graph. For this reason, network parameters should be normalized since each parameter has a different scale. Figure 8.16 shows network parameters in percentages of NEEDS parameter values for the different methods considered here. From Figure 8.16 it can be seen that the network parameters that show a marked difference for the different methods are benefit (VMT-A), average VMT-B, and remaining life.

Rehabilitation timing and type for every section in the network (network rehabilitation program) and for each method are listed in Table 8.5. The rehabilitation program for RAND is completely different than any other method since it is randomly generated. There are some similarities between programs generated by NEEDS and by RANK. This is because some of the sections that initially have poor condition are selected for rehabilitation by both methods and since the same project-level selection routine is used for both, the same

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rehabilitation plan is generated for these sections. Also at some years in the analysis period, the budget for Ranking may be sufficient for rehabilitating sections whose conditions just dropped below the minimum CRS. In this case, the NEEDS and RANK rehabilitation plans will be similar.

From Table 8.5 it is also evident that for some sections, Needs and other optimization methods (IBC, OPT, and LIN) produce identical rehabilitation plans. For some other sections the rehabilitation plan is similar (i.e., rehabilitation type is the same but the timing is different by one or two years). This is due to the fact that for some sections the most cost-effective timing for rehabilitation is when the CRS is about 6, which is also the rehabilitation timing for Needs.

The fact that the optimization methods try to maximize the benefit, combined with the higher priority that these sections may have due to higher traffic levels, can result in selection of a similar rehabilitation plan as Needs. Optimization methods produced identical rehabilitation plans for some sections and similar plans for some others, while for some sections the rehabilitations plans (timing and type) were completely different. IBC and LIN produced more similar rehabilitation plans since both of these methods consider a yearly budget limitation, while OPT only considers a 10-year budget limit.

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Table 8.4 - Network Parameters for Six Application Runs for District 5.

Network-Level Opti	RAND	NEEDS	RANK	IBC	OPT	LIN
Project-Level Option	Random	LCC	LCC	All	All	All
Benfit Option	n/a	n/a	n/a	VMT	VMT	VMT
Budget Limit, Million Dollars	75	n/a	75	75	75	75
Cost, Million Dollars	74	90.1	73.8	73.3	75	71.2
Average network CRS 1-9 scale	6.49	7.15	6.74	6.82	6.99	6.81
Average % VMT on Backlog	15.4	2.6	3.5	6.1	4.2	6.2
Remaining Life, Years / mile	3.5	4.7	3.8	4.2	4.4	4.3
% VMT-Backlog @ Year 10	35	10	14	17	14	17
Total CRS Area, CRS-Year / mile	21.5	37.0	26.1	28.4	31.6	29.2
User Benefit, Million Dollars	218	443	287	386	408	383
Total Added Life, Years / mile	2.89	5.9	3.4	4.7	5.2	4.8
VMT on Adequate, Billions	2.98	6.44	3.82	5.64	6.02	5.63
Benefit (VMT-A)/Cost	40	71.5	52	77	80	79

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Table 8.5 - Pavement Rehabilitation Program for Sample Runs.

Sec No	(RAND)	(NEEDS)	(RANK)	(IBC)	(OPT)	(LIN)
1	----------	P---------	-P--------	P---------	P---------	P---------
2	--5-------	-P--------	----------	-P--------	-P--------	-P--------
3	----------	----------	----------	----------	----------	----------
4	----------	----------	----------	----------	----------	----------
5	----------	----------	----------	----------	----------	-R--------
6	------3---	-------3--	----------	-------3--	-------3--	-------3--
7	-----5----	P---------	--3-------	P---------	R---------	P---------
8	--R-------	-------3--	----------	----------	----------	----------
9	-----R----	----P-----	-------R--	----P-----	----P-----	----P-----
10	--3-------	----------	----------	----------	----------	----------
11	----------	-----P----	----------	-----P----	-----P----	-----P----
12	-3--------	-----P----	----------	-----P----	-----P----	-----P----
13	----P-----	------P---	----------	------3---	----------	------P---
14	P---------	----P-----	-----P----	----P-----	----P-----	----P-----
15	----------	----------	----------	----------	----------	----------
16	----------	--------3-	----------	---------3	----------	--------3-
17	----------	------3---	----------	------3---	------3---	------3---
18	----------	R---------	R---------	--3-------	R---------	---R------
19	-------5--	P---------	P---------	---3------	3---------	3---------
20	----------	----------	----------	----------	----------	----------
21	--P-------	R---------	R---------	---R------	R---------	----------
22	------5---	P---------	---R------	----------	R---------	P---------
23	----------	----------	----------	----------	----------	----------
24	----------	----------	----------	----------	----------	----------
25	--------P-	----------	----------	----------	----------	-----P----
26	--------5-	-------3--	----------	--------3-	-------3--	-------3--
27	-5--------	-P--------	--3-------	-3--------	-3--------	--3-------
28	----------	------3---	---------3	------3---	------3---	------3---
29	3---------	------3---	----------	------3---	------3---	------3---
30	-3--------	----------	----------	----------	----------	-----P----
31	----------	------3---	----------	----------	----------	----------
32	---3------	--P-------	----------	--R-------	--R-------	--R-------
33	-5--------	----P-----	----------	----R-----	----R-----	----R-----
34	---5------	3---------	3---------	3---------	R---------	-R--------
35	--------R-	----------	----------	----------	----------	----R-----
36	----------	----------	----------	----------	----------	----------
37	----------	---------3	----------	---------3	----------	---------3
38	----------	------3---	----------	------3---	------3---	------3---
39	----------	-----3----	--------R-	-----3----	----------	-----3----
40	--R-------	----------	----------	----------	----------	----P-----
41	----------	P---------	--P-------	P---------	3---------	P---------
42	----------	------3---	---------3	------3---	----------	----------
43	----------	------3---	---------3	-------3--	----------	----------
44	----------	------3---	----------	----------	----------	----------
45	----------	----------	----------	----------	----------	----------
46	----------	---3------	---3------	---R------	----------	----------
47	----------	--------3-	----------	--------3-	--------3-	--------3-
48	-5--------	R---------	R---------	----------	----------	----------
49	----------	---------3	----------	---------3	----------	---------3
50	----------	----------	----------	----------	----------	--------3-
51	----------	-----3----	----------	-----3----	-----3----	------3---
52	----------	--------3-	----------	--------3-	--------3-	---------3
53	----------	----3-----	------R---	----3-----	----3-----	----3-----
54	---5------	---------3	----------	---------3	---------3	---------3
55	----------	----------	----------	----------	----------	----------
56	----------	------3---	---------3	------3---	----------	----------
57	----------	------3---	----------	---------3	----------	----------
58	----------	------3---	----------	----------	----------	----------
59	----------	------3---	------3---	-------3--	----------	----------
60	-------R--	----------	----------	----------	----------	----------

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Table 8.5 - Pavement Rehabilitation Program for Sample Runs (continued).

Sec No	(RAND)	(NEEDS)	(RANK)	(IBC)	(OPT)	(LIN)
61	-------3--	-------3--	----------	--------3-	-------3--	--------3-
62	-----P----	----3-----	-----R----	----P-----	----------	----------
63	----------	-------3--	----------	-------3--	-------3--	-------3--
64	----------	--------3-	----------	--------3-	--------3-	---------3
65	----------	----------	----------	----------	----------	------3---
66	-5--------	----3-----	-----R----	----------	----3-----	----------
67	----------	-------3--	----------	-------3--	-------3--	-------3--
68	----------	----------	----------	----------	----------	----------
69	----------	----------	----------	----------	----------	----------
70	----------	----------	----------	----------	----------	----------
71	----------	----------	----------	----------	----------	----------
72	----------	----------	----------	----------	----------	----------
73	----------	----------	----------	----------	----------	----------
74	----------	------3---	----------	----------	----------	----------
75	----------	----------	----------	----------	----------	----------
76	----------	------3---	----------	----------	----------	----------
77	--R-------	---------P	----------	---------P	---------P	----------
78	----------	----------	----------	----------	----------	----------
79	----------	----------	----------	----------	----------	----------
80	----------	----------	----------	----------	----------	----------
81	----------	----------	----------	----------	----------	----------
82	----------	----------	----------	----------	----------	----------
83	----------	----------	----------	----------	----------	----------
84	----------	----------	----------	----------	----------	----------
85	----------	----------	----------	----------	----------	----P-----
86	----------	-----3----	----------	----------	----------	-----3----
87	----------	-----3----	----------	-----P----	----------	-----3----
88	---------R	3---------	--3-------	-3--------	R---------	--3-------
89	-----R----	----------	----------	----------	----------	----------
90	----------	----------	----------	----------	----------	----------
91	----------	----------	----------	----------	----------	----------
92	----------	----------	----------	----------	----------	----------
93	----------	--------P-	----------	----------	----------	----------
94	-----3----	---3------	------3---	---3------	---3------	---3------
95	----------	----------	----------	----------	----------	----------
96	----------	-------3--	----------	-------3--	-------3--	--------3-
97	----------	--P-------	--P-------	--R-------	--R-------	---R------
98	P---------	R---------	-R--------	R---------	R---------	R---------
99	----------	--3-------	----------	--3-------	--3-------	---3------
100	----------	----------	----------	----------	----------	----------
101	----------	----------	----------	----------	----------	----------
102	----------	----------	----------	----------	----------	----------
103	----------	----------	----------	----------	----------	----------
104	----------	---------3	----------	---------3	----------	----------
105	-----P----	----------	----------	----------	----------	--P-------
106	------3---	-P--------	---R------	----------	----------	----------
107	----------	--------3-	----------	----------	----------	----------
108	----------	--------P-	----------	----------	----------	----------
109	----------	-------3--	----------	---------3	----------	----------
110	----------	----------	----------	----------	----------	----------
111	----------	-----3----	----------	-----3----	-----3----	-----3----
112	----------	-----P----	--------R-	-----R----	-----R----	-----R----
113	-P--------	R---------	--R-------	R---------	R---------	R---------
114	----5-----	---3------	----------	---3------	---3------	---3------
115	----------	----------	----------	----------	----------	---------3
116	----------	----------	----------	----------	----------	----------
117	----------	----------	----------	----------	----------	----------
118	----------	----------	----------	----------	----------	----------
119	----------	----------	----------	----------	----------	----------
120	P---------	----------	----------	----------	----------	----------
121	---------3	-P--------	----R-----	----------	-P--------	-P--------

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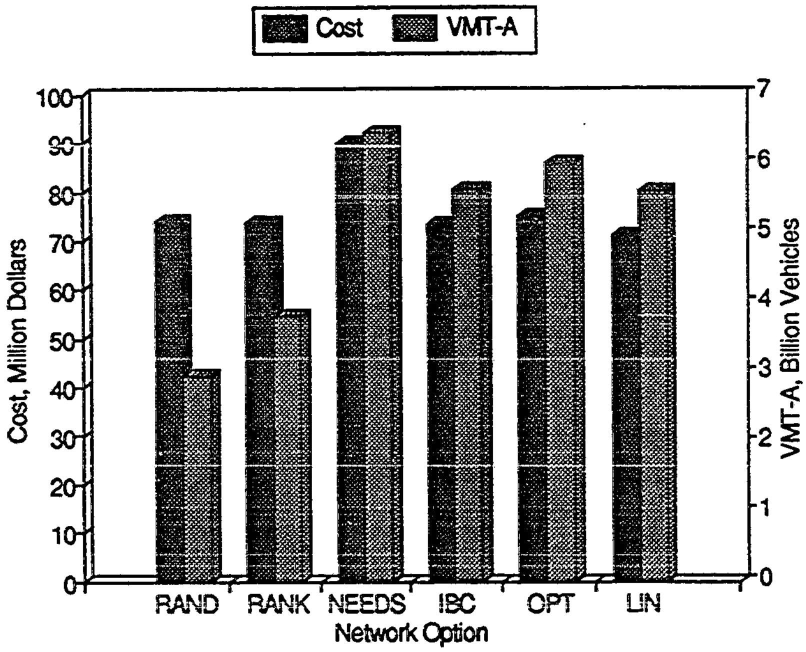

Figure 8.12 - Cost and benefit (in terms of VMT-A) for Application Runs.

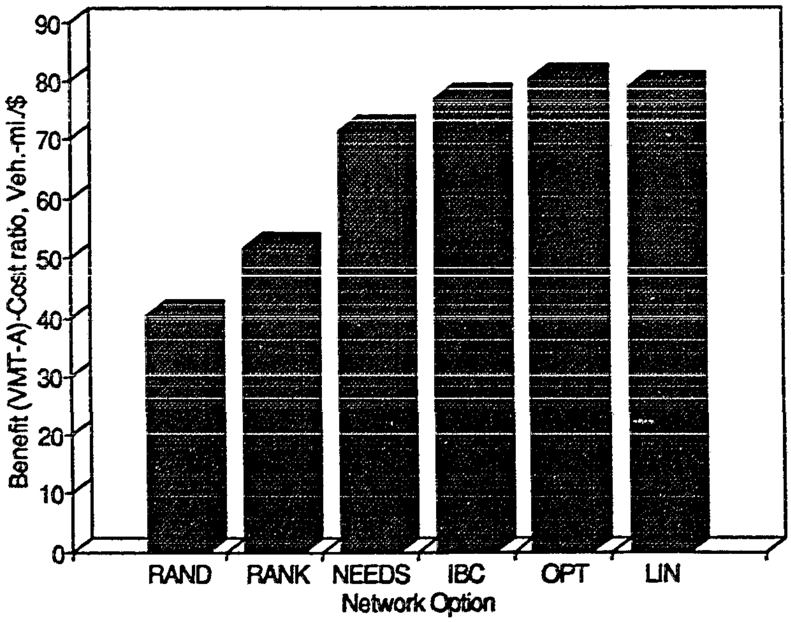

Figure 8.13 - Network Benefit (VMT-A) to Cost Ratio for Application Runs.

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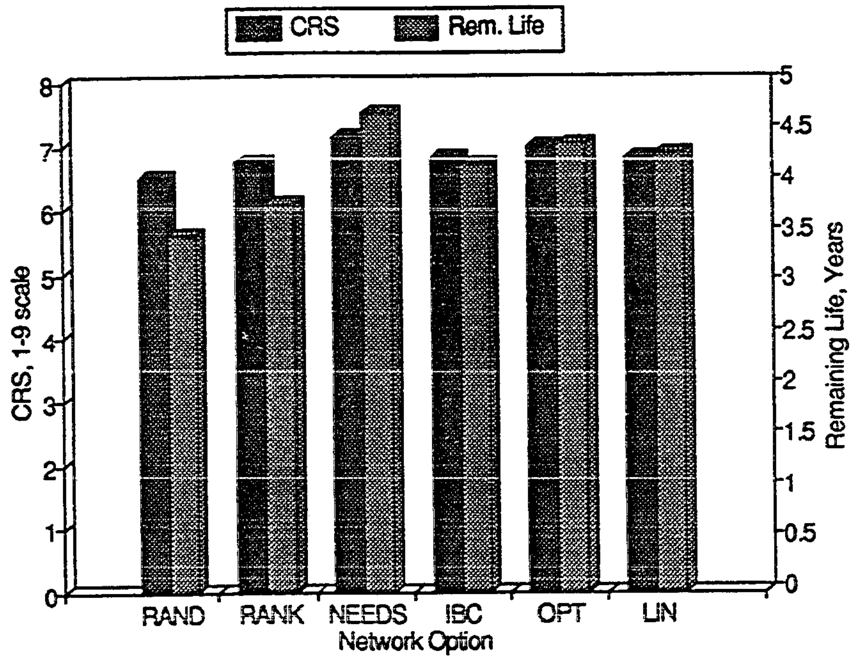

Figure 8.14 - Average Network CRS and Remaining Life for Application Runs.

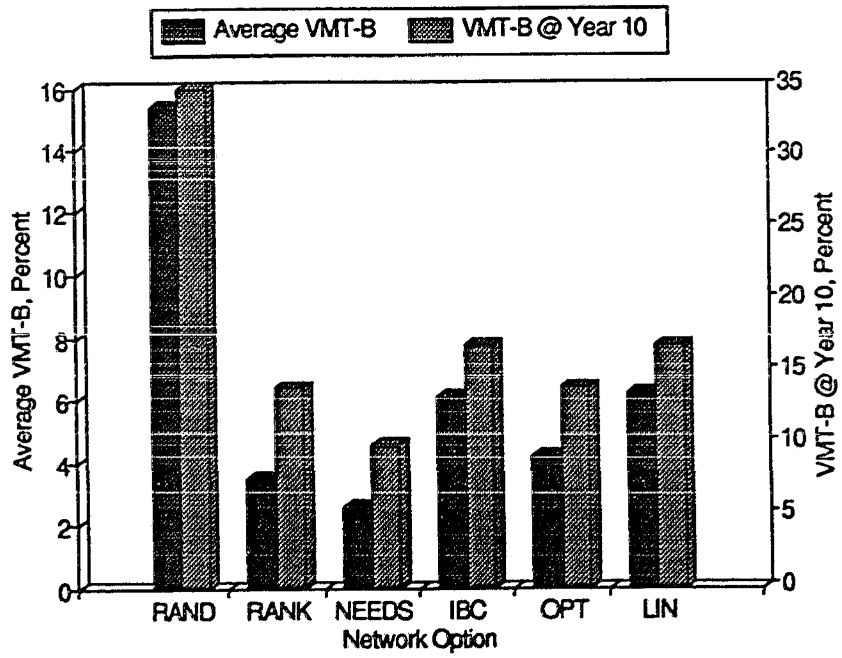

Figure 8.15 - Average 10-year VMT-B and VMT-B at year 10 for Application Runs.

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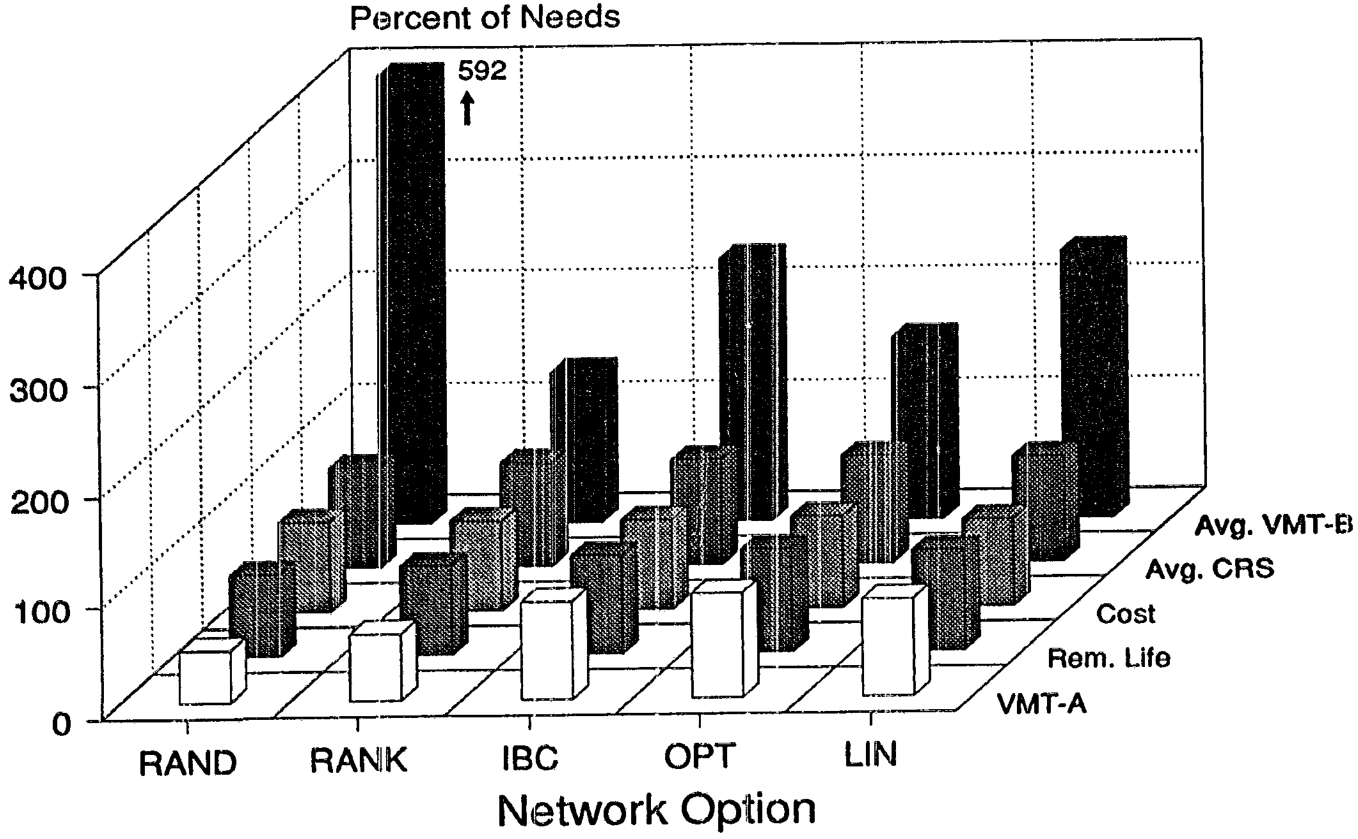

Figure 8.16 - Network Parameters as Compared to NEEDS parameters.

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8.8 Discussion of Alternate Pavement Network Management Methods

The discussion of different network management techniques presented in this chapter concentrated on the advantages and disadvantages of each method by examining the differences in their results and capabilities. From discussion in previous sections it is evident that different network management methods produced results that are different in some cases and similar in others. To demonstrate the advantages and disadvantages of each network management method, their capabilities and results should be compared with each other. Table 8.6 contains a general evaluation of performance of each network management method based on the results from pavement performance (see previous section). The information in Table 8.6 is used to demonstrate the advantages and disadvantages of network management techniques considered in this chapter.

8.8.1 The Random Method (RAND)

The random method (RAND) is only used as a comparison method to show the advantages of other methods and the consequences of adopting an ad hoc procedure for pavement network rehabilitation management. From Table 8.6 it is evident that this procedure does not have any criteria for rehabilitation selection. Adopting such a procedure results in serious network deterioration for equal funds spent as compared to other network management techniques.

8.8.2 Ranking Method (RANK)

This method is capable of considering yearly budget limit and is based on a worst-first rule (i.e., pavements in the worst condition are rehabilitated first). Using Ranking for the selection of sections for the first year of analysis does not

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Table 8.6 - Capabilities and Performance of Network Management Methods.

	Random	Ranking	Needs	IBC	OPT	LIN
Criteria	None	Worst-first rule	Min CRS	Max. Yearly Benefit	Max. 10-year Benefit	App. Max. 10-year Benefit
Budget Limit	None	Yearly	None	Yearly	10-year	Yearly
Rehab. Type Tradeoffs	No	No	No	Yes	Yes	Yes
Rehab. Timing Tradeoffs	No	No	No	No	Yes	Yes
Long Term Performance	V. Poor	Poor	Fair	Good	V. Good	Good
Analysis Period Performance	V. Poor	Good	V. Good	Good	Good	Good
Total Added Benefit	V. Poor	Poor	Fair	Good	V. Good	Good
Overall Effectiveness	V. Poor	Poor	Fair	Good	V. Good	Good

require any pavement condition prediction models; however, for multi-year analysis, prediction models are essential to predict pavement condition. This method is not capable of considering several rehabilitation alternatives at the network level; therefore, the trade-offs between rehabilitation types are not considered.

Rehabilitation timing is controlled by available budget and pavement condition, thus the rehabilitation of sections in need of rehabilitation whose condition are not low enough to compete for funding is delayed until funding becomes available and/or their condition is low enough to qualify.

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The long-term performance and gained benefit that Ranking provides is inferior to all other options except for Random; however, the network performance during the analysis period was fair. This is because the Ranking criteria is to remove pavement deficiencies without any regard to the long-term performance of sections and rehabilitations at the network level, although long-term performance is considered at the project level. Therefore, adopting RANK can result in significant long-term performance loss, although short-term performance might not be affected significantly. The benefit in terms of VMT-A gained and the effectiveness of this method are both poor in comparison with other methods.

8.8.3 The Needs Study (NEEDS)

NEEDS is the unrestrained budget network management method, thus, it can not consider any budget limitation. The criterion for rehabilitation in NEEDS is based on a minimum condition level. Any pavement section whose condition falls below a minimum CRS level (usually CRS of 6) is considered to be deficient and automatically receives some type of rehabilitation without consideration of rehabilitation type and timing trade-offs. Therefore, Needs has very limited capabilities in comparison with other methods.

The long-term performance that NEEDS provides is much improved over RAND and RANK; however, it is not as good as that of the optimization methods (i.e., IBC, OPT, and LIN). NEEDS performance during the analysis period is better than any other method partly because its cost of rehabilitation is higher than that of the other methods. The gained benefit and effectiveness of Needs is also greatly improved over Random and Ranking and is fairly good in comparing

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to other optimization methods.

Although Needs is very limited in capabilities, its performance is exceptionally good. This is because for most pavement sections, the most cost-effective timing for rehabilitation is around CRS of 6, and Needs takes advantage of this by allowing rehabilitation as soon as the pavement condition drops below this minimum. NEEDS seems to be an excellent tool for estimating future pavement rehabilitation needs.

8.8.4 Long-Range Optimization OPT

This method is capable of considering the total 10-year (multi-year) budget limit but not the yearly budget limitation. The criterion for this method is based on selecting rehabilitations for every pavement section in the network such that the total network benefit is maximized for a predetermined budget limit. In this approach, all rehabilitation types and timings are considered such that the timing and type that provides the maximum benefit is selected. Therefore, all rehabilitation type and timing trade-offs are considered in this approach.

The long-term performance that OPT provides is better than that of any other methods. This is because the long-term benefit of rehabilitation for every section is maximized. In addition to this, since yearly budget limitations are not enforced, OPT can provide better project rehabilitation selection and thus higher benefit than other optimization methods (i.e., IBC and LIN). The performance during the analysis period is also good, although not as good as those of Needs and Ranking.

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OPT is an excellent tool for multi-year pavement rehabilitation planning, nevertheless, there are some serious limitations with this approach. First, since yearly budget limitations are not enforced, the cost of rehabilitation may not be evenly distributed. This contradicts the actual budget situation, since only a certain amount of funding is usually available for pavement rehabilitation every year. Second, although multi-year rehabilitation programs are created for a network, pavement rehabilitations are actually funded on yearly basis. Thus, the rehabilitation of some sections that are originally scheduled in a multi-year program may be delayed due to lack of funds, or the fact that the section did not deteriorate as much as was originally predicted, or change of priorities. This change in multi-year rehabilitation program also changes the costs and benefits of rehabilitations accordingly.

8.8.5 Yearly Optimization (IBC)

IBC is based on yearly optimization (maximization) of pavement rehabilitation benefits, rather than multi-year optimization as in the case of OPT. Thus, this approach easily considers yearly constraints (yearly budget limits). IBC is also capable of considering all pavement rehabilitation type trade-offs for all deficient sections every year in the analysis period. Rehabilitation timing trade-offs are not directly considered since all deficient sections that qualify for funding are delayed and considered for funding in the next year.

The performance of IBC during the analysis period and beyond the analysis period as well as gained benefit is slightly lower but comparable to that of OPT. This is to be expected, since IBC considers a yearly budget limit while OPT does not. The effectiveness of IBC is also comparable to that of OPT.

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Since IBC considers yearly budget limits and allocates budget on yearly basis, it is closer to the real world situation than OPT. Therefore, it does not have some of the limitations that exist for OPT. On the other hand, benefits are maximized on a yearly basis, which does not guarantee optimized (or maximum) multi-year benefit, although it is very close to optimum.

8.8.6 Linear Programming (LIN)

This method provides more capabilities than any other method. The criterion is to maximize multi-year benefits in the presence of yearly budget limits. This is the only method that can consider the rehabilitation type and timing trade-offs and at the same time impose the yearly budget constraint. The performance of this method, however, is similar to or poorer than that of IBC. Notice that LIN is used as a replacement for integer programming since integer programming solutions were not possible. Thus, LIN does not guarantee that the solution is an optimal solution.

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9 Sensitivity Analysis of ILLINET's Alternate Options

Analysis of alternate ILLINET network management options includes the analysis of different network-level options, project-level options, benefit functions, and minimum CRS for rehabilitation. A database that contains the result of many ILLINET runs was created and used in the analysis (analysis database). This chapter includes the analysis of alternate ILLINET runs and the sensitivity of the network statistics to cost and several network management options. First the analysis database is described, and discussed, and later each option is analyzed separately. Finally, some of the results from each analysis are compared. Since comparing all alternatives is not possible, only a few representative runs were selected for the analysis of each option. In this chapter, different pavement management methods and options are analyzed to demonstrate the advantage of each method over the others and to compare the effectiveness of each method.

9.1 Analysis Database

A database containing the results of ILLINET runs using alternate options was developed. This database includes the total of 368 runs of ILLINET as described in Table 9.1. For each option, four different budget levels were considered. The maximum budget is 100 million dollars (slightly less than the budget required for NEEDS when a 3-inch overlay is selected) and the other budget levels are 75, 50, and 25 percent of the maximum budget. For yearly algorithms (like RANK) the yearly budget limit was assumed to be 10 percent of the total budget. The same database and user-defined input parameters that were used for the application runs explained in chapter 8 are also used here for the sensitivity analysis database. Pavement network parameters explained in chapter

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8 are also used here for the analysis. These runs cover a wide range of options available in ILLINET and represent different methods of network level management. Thus for every budget, there is a wide range of results for every network parameter. Some discussion of the ranges of network parameters in the database follows.

9.1.1 *Average Network CRS*

One of the parameters that shows the performance of the network during the analysis period (10 years in this case) is the average network CRS. Each network management option provides a different average network CRS for a budget level. Figure 9.1 shows the average network CRS for all 368 ILLINET runs considered in the analysis. On average, the network CRS improves as budget is increased, however, there is considerable variability for each budget level. As can be seen from Figure 9.1 for the lower cost level (25 million dollars budget limit), the average network CRS ranges from 6 to 6.4 . The range is wider, however, for higher budget limits (for a maximum budget limit of 100 million dollars the range is from 6.6 to 7.4). The highest average CRS is obtained from the NEEDS network option.

9.1.2 *Vehicle Miles Travelled on Backlog (VMT-B)*

Another indication of pavement performance during the analysis period is the percent of Vehicle Miles Travelled on Backlog pavements (VMT-B). VMT-B data for different budget levels and options are shown in Figure 9.2. As Figure 9.2 shows, there is a considerable range in the data, especially for the higher budget levels. VMT-B for the lowest budget level (25 million dollars) ranges from 9 to 16 percent. For the highest budget level however, VMT-B ranges

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from 0 to 10 percent. The VMT-B for NEEDS at the high budget level is in the middle of the range (about 4 percent), while in general, RANK provides the lowest VMT-B for this budget level.

9.1.3 Network Remaining Life

Network remaining life indicates the future performance of the network. The remaining life calculated from all ILLINET runs are shown in Figure 9.3. Figure 9.3 shows that remaining network life ranges from 1.5 years to 3.5 years for the lower budget limit (25 million dollars) and 3.5 years to 6.5 years (almost double) for the maximum budget level. The maximum remaining life of about 6.5 years is due to the network options that maximize the life of the network (i.e., OPT, IBC, and LIN).

9.1.4 Network Benefit

Network benefit determines the performance of the network both during and after the analysis period. Vehicle Miles Travelled on Adequate pavements (VMT-A) in billions of vehicle-miles is one of the network benefit measures considered in this study. Figure 9.4 shows VMT-A values for all of ILLINET analysis runs. VMT-A ranges from 1.5 billion to 3 billion vehicle-miles for the lower budget level and 3.5 to 7.5 billion for the highest budget level. The highest VMT-A resulted from the long-range optimization network-level algorithm (OPT). The lowest VMT-A is due to ranking (RANK).

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Table 9.1 - ILLINET Options and Analysis Runs.

Network-Level Options	Budget Limit (Yearly / Total)	Benefit Options	Project-Level Options	No. of Runs
NEEDS	n/a	n/a	Single (6)	6
RANK	Yearly (4)	n/a	Single (6)	24
B/C	Yearly (4)	Y (4)	Multiple (7)	112
OPT	Total (4)	Y (4)	Multiple (7)	112
LIN	Yearly (4)	Y (4)	Multiple (7)	112

Benefit Options	Multiple Rehab	Single Rehab
CRS-Area Life User's Benefit VMT-A	3-inch ACOL, and 5-inch ACOL, and Patching, and Reconstruct	3-inch ACOL, or 5-inch ACOL, or Patching, or Reconstruction, or Decision Tree, or Life Cycle Costing

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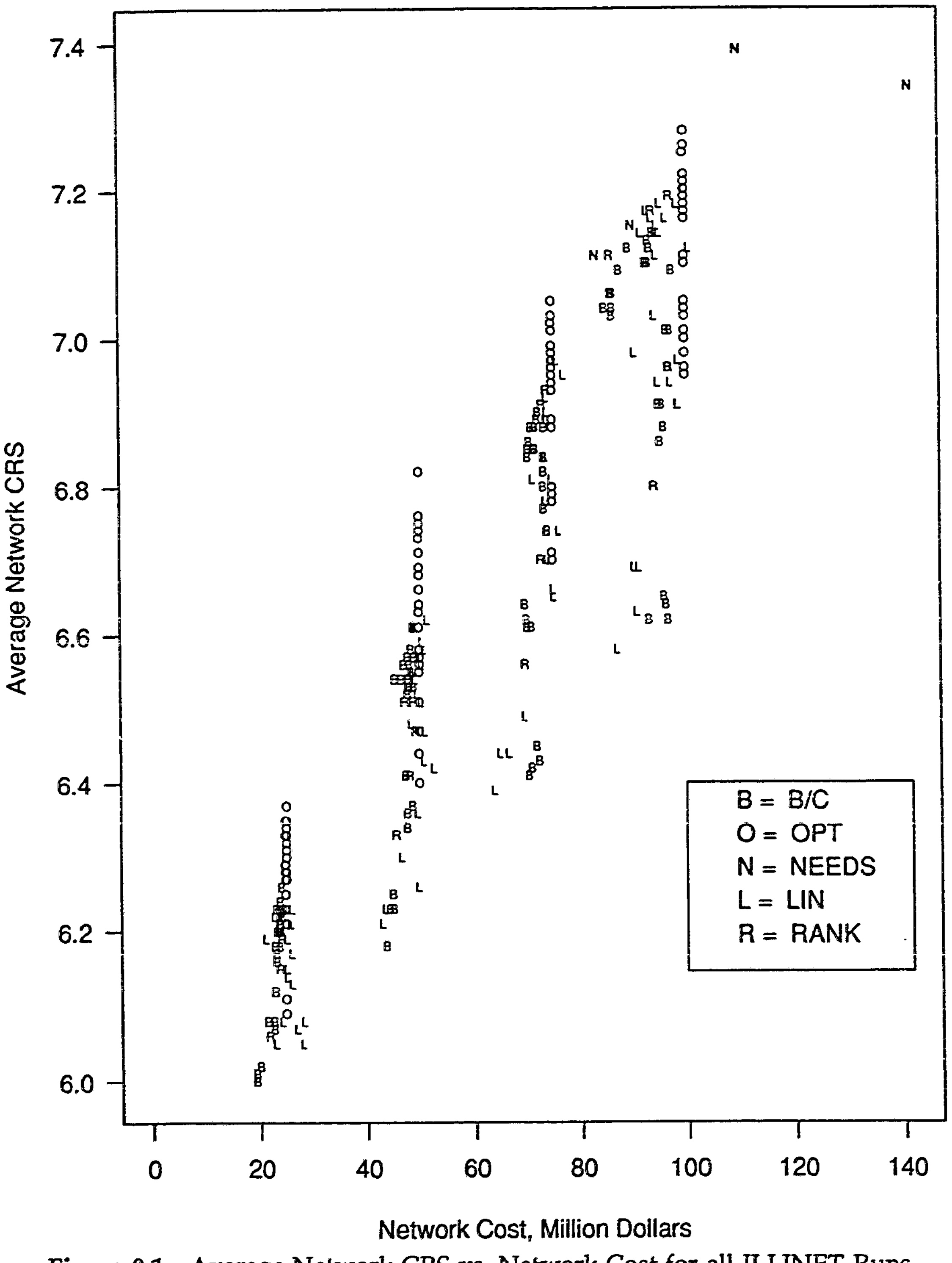

Figure 9.1 - Average Network CRS vs. Network Cost for all ILLINET Runs.

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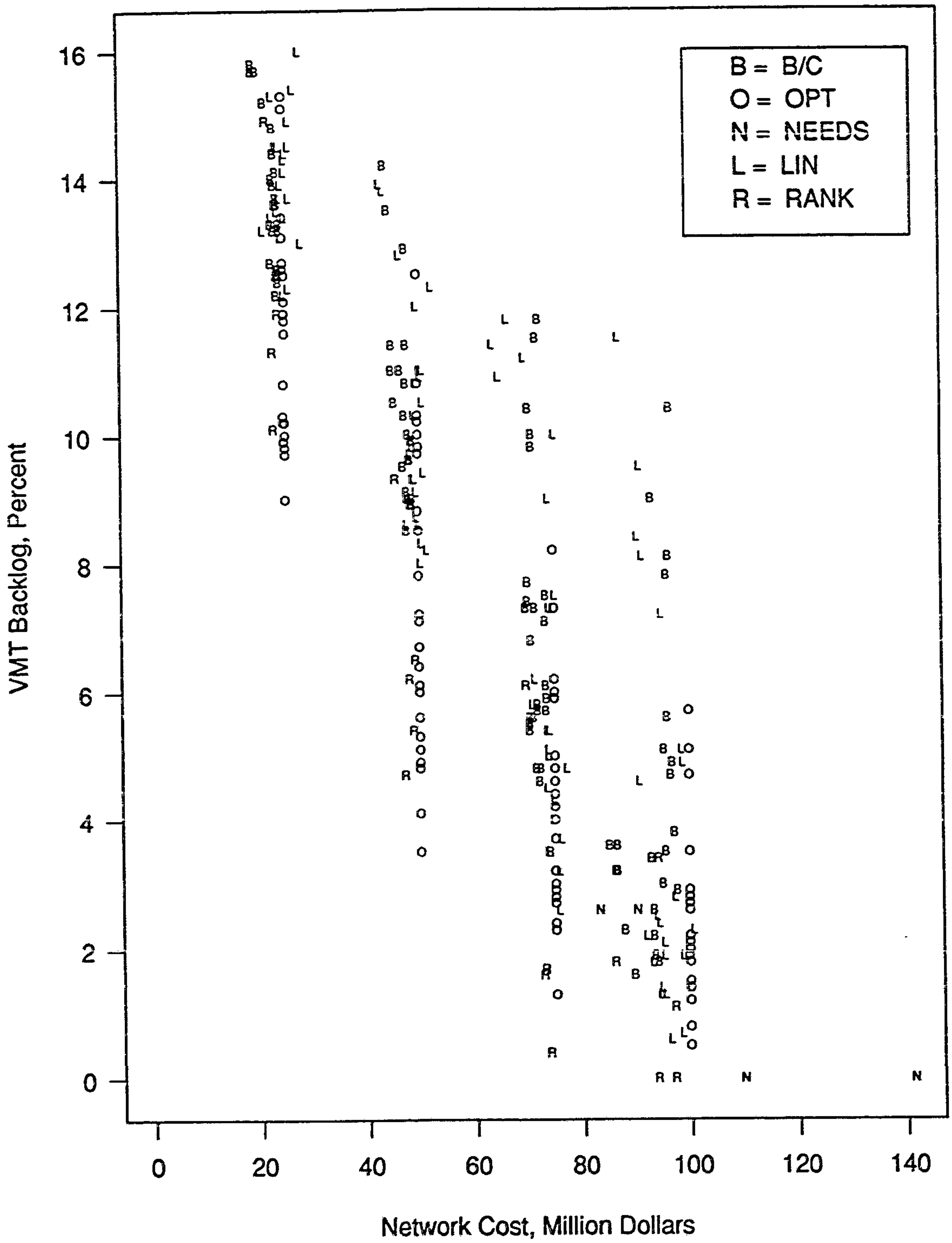

Figure 9.2 - Vehicles Miles Travelled on Backlog (VMT-B) for all Analysis Runs.

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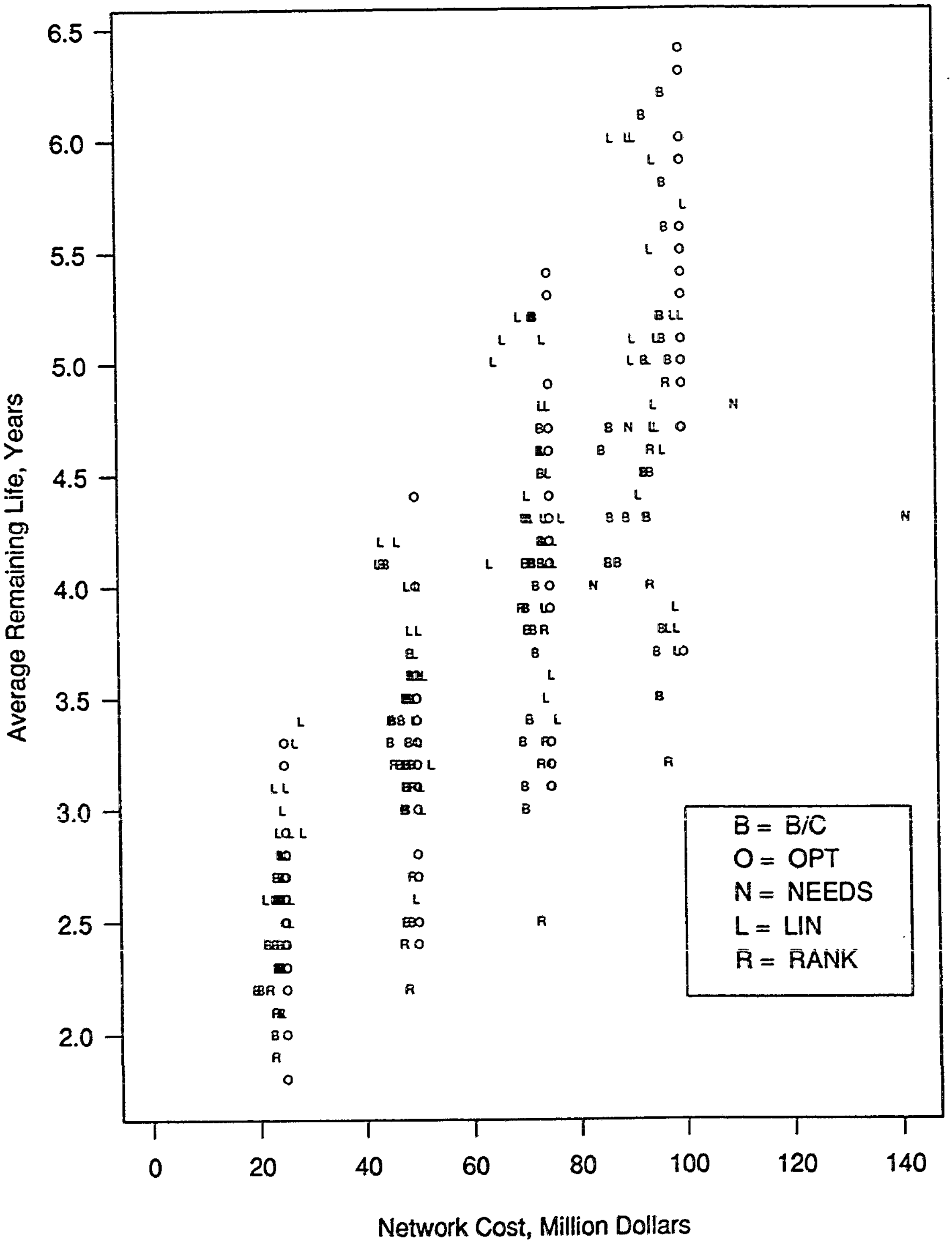

Figure 9.3 - Average Network Remaining Life for all ILLINET Runs.

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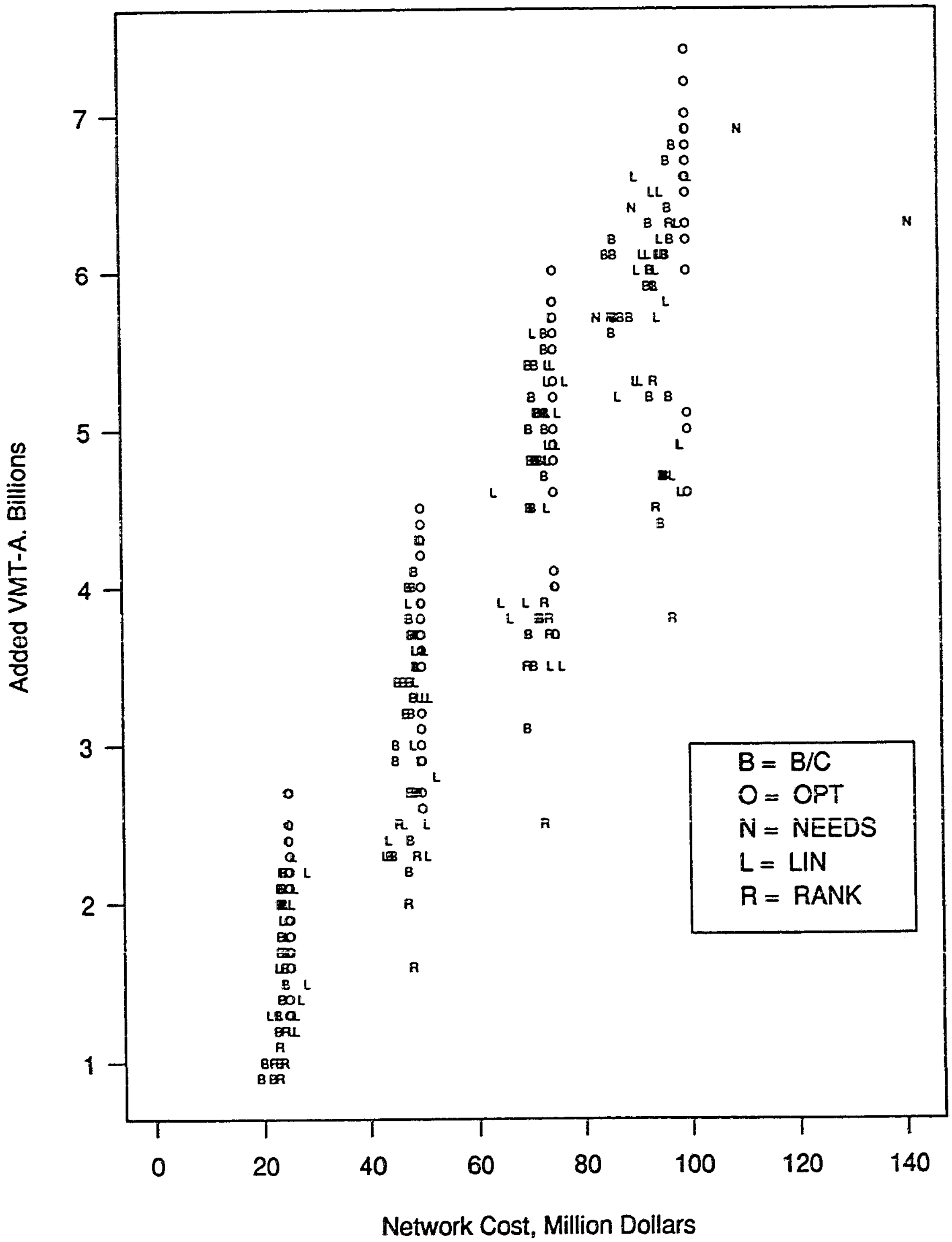

Figure 9.4 - Average Added VMT-A vs. Network Cost for All ILLINET Runs.

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9.2 Minimum CRS for Rehabilitation

Minimum CRS for rehabilitation (MCRS), which is the trigger CRS value for rehabilitations, is a user input variable in ILLINET. Only after a pavement's condition falls below this value will it be considered for rehabilitation. Different minimum CRS levels for different network-level methods were considered to analyze the effect of MCRS on the performance of the network. The network-level methods considered are:

1. NEEDS with Life Cycle Cost,
2. RANK with Life Cycle Cost,
3. Yearly Optimization (IBC) with All project-level option, and
4. Long-term Optimization (OPT) with All project-level option.

The VMT-A benefit function was used where applicable and four different budget levels are considered for all options except for NEEDS. Discussion of the analysis of each network option follows.

9.2.1 NEEDS

Two different cases were considered for the effect of minimum CRS on the network performance. In the first case only one rehabilitation was allowed in the 10-year analysis period, and in the second case more than one rehabilitation was allowed. For each case, the effect of using a different minimum CRS on pavement cost and benefit is analyzed. Since the network cost is different for different MCRS levels, benefit to cost (VMT-A per cost) instead of benefit was used as the measure of the effectiveness. For each case total network cost and VMT-A to cost ratio was graphed versus different minimum CRS levels.

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Figure 9.5 shows the data for the case of one rehabilitation for the duration of the analysis period. Figure 9.5 demonstrates a decreasing trend for cost as MCRS increases. This is because when pavement condition (CRS) is allowed to drop to lower values, a costly rehabilitation (i.e., a thick AC overlay or reconstruction) is required to fix the pavement deficiencies. In contrast, the rehabilitation at higher CRS levels is less costly (i.e., restoration or thin resurfacing). Although more sections qualify for rehabilitation at higher MCRS levels, the cost of rehabilitation is substantially lower and since only one rehabilitation is allowed for the period of analysis, the total cost of rehabilitation is lower at lower CRS levels than high CRS values. VMT-A per cost, however, peaks at CRS of about 6 and then drops substantially. This is because many of these lower cost fixes do not increase the benefit (VMT-A) since the pavement condition (CRS) may already be adequate (above CRS of 6).

Figure 9.6 illustrates the data for the second case (multiple rehabilitation) for Needs. Referring to Figure 9.6, the cost of rehabilitation initially drops, then levels out, and finally substantially increases when MCRS increases. The VMT-A per cost curve still peaks at a CRS of 6. The increase in cost at higher CRS levels is because a pavement CRS may drop to the MCRS level several times during the 10-year period. These rehabilitations increase the cost but may not increase the benefit substantially since the pavement condition may already be adequate (above CRS of 6).

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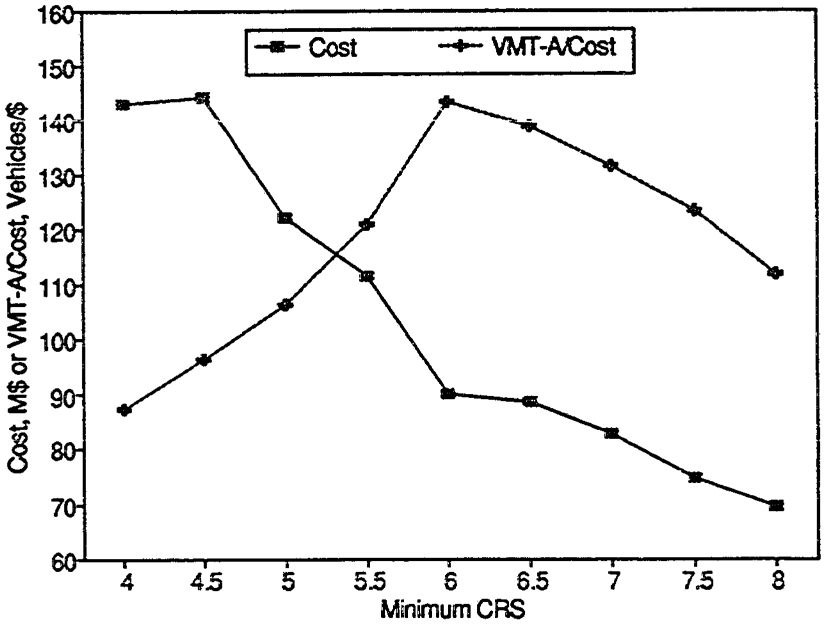

Figure 9.5 - Effect of MCRS on Needs with One Rehabilitation.

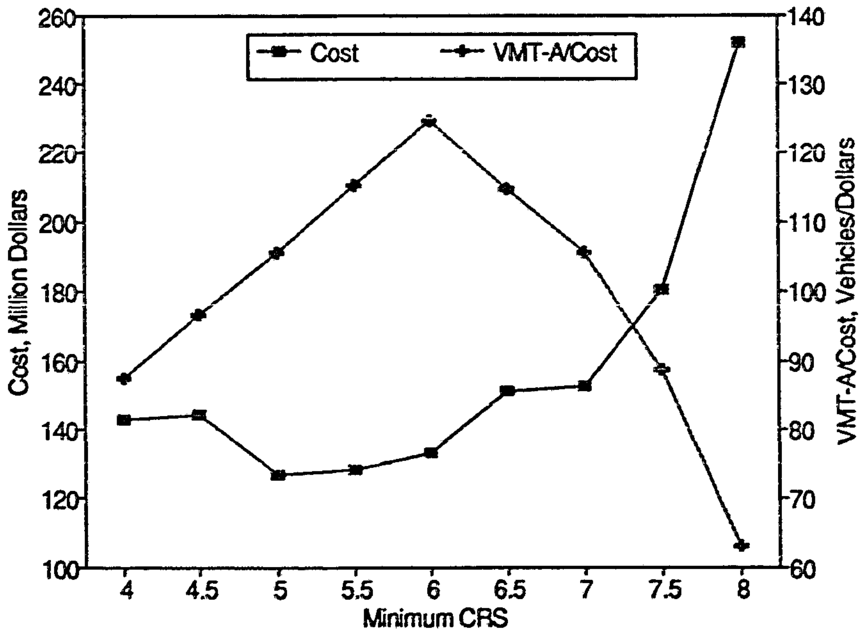

Figure 9.6 - Effect of MCRS on Needs with Multiple Rehabilitation.

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9.2.2 Ranking Method (RANK)

Four different budget levels are considered to analyze the effect of different MCRS levels on the performance of a network managed with the ranking method (RANK). For the three lower budget levels, benefit (VMT-A) does not change substantially as MCRS increases (Figure 9.7). For the maximum budget level, however, benefit (VMT-A) increases up to a CRS of about 6 and then levels out afterwards. This is because pavements are ranked each year based on their CRS; therefore, only after the sections with the lower CRS are rehabilitated will other sections with higher CRS be considered for rehabilitation. This, plus the fact that the yearly budget is limited, restricts the number of sections with higher CRS that can be rehabilitated. Thus, increasing MCRS may not affect the rehabilitation selection. For the highest budget level, however, more sections with higher CRS have a chance of being selected. This contributes to an increase in benefit as MCRS increases from 5 to 6. Benefit levels out for MCRS higher than 6 for the same reason that it does for lower budget limits (i.e. the ranking procedure overrides increasing MCRS effect).

9.2.3 Yearly Optimization (IBC)

The effect of MCRS on the yearly optimization with the incremental Benefit-Cost Ratio (IBC) procedure is illustrated in Figure 9.8. For all budget levels, benefit (VMT-A) increases up to an MCRS of 6 and subsequently levels out. In this procedure, projects are selected based on their contribution to network benefit, so limiting MCRS to lower values affects the performance of the network. MCRS values higher than 6 do not improve network performance, probably because less benefit is achieved by rehabilitating pavements at higher CRS values; strategies that the optimization procedure does not select.

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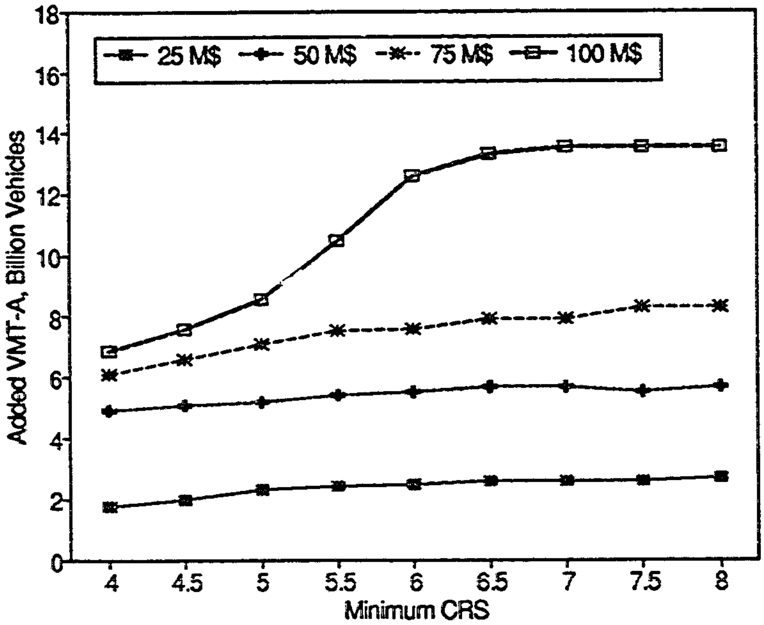

Figure 9.7 - Effect of MCRS on Ranking Network Option..

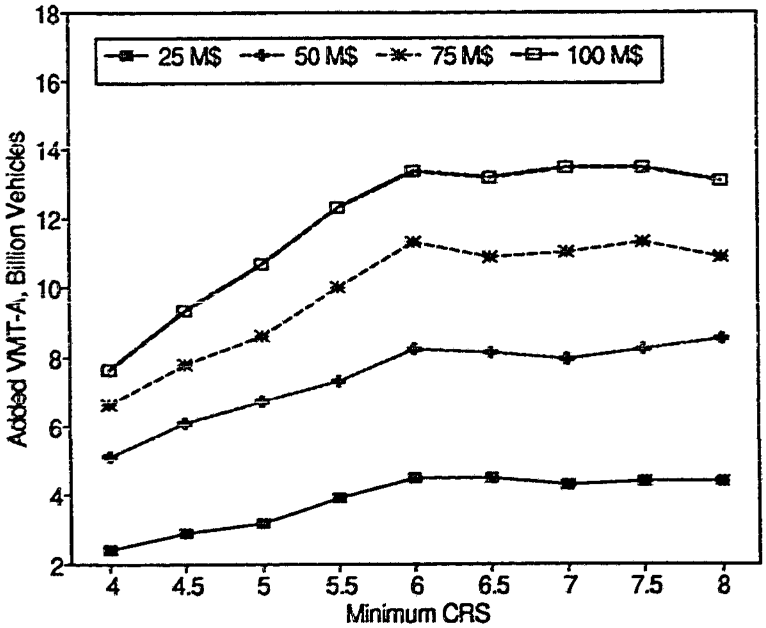

Figure 9.8 - Effect of MCRS on B/C Network Option.

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9.2.4 *Long-Range Optimization (OPT)*

The effect of MCRS on long-range optimization is shown in Figure 9.9. From Figure 9.9 it is evident that the effect of MCRS on total gained benefit is similar to that of IBC which was discussed in previous section. Benefit increase as MCRS increases up to an MCRS of 6 and for higher MCRS benefit stays the same. By limiting the MCRS to lower values than 6, the total gained benefit is reduced since pavement rehabilitations are delayed until their CRS becomes low enough. At that condition level, however, pavement rehabilitation does not last as much as for higher condition. MCRS of higher than 6 does not affect the benefit much, since the optimization procedure does not select rehabilitations at higher condition levels due to low benefit derived from these rehabilitations. Therefore, the minimum condition for rehabilitation that provides the optimum results is CRS of 6.

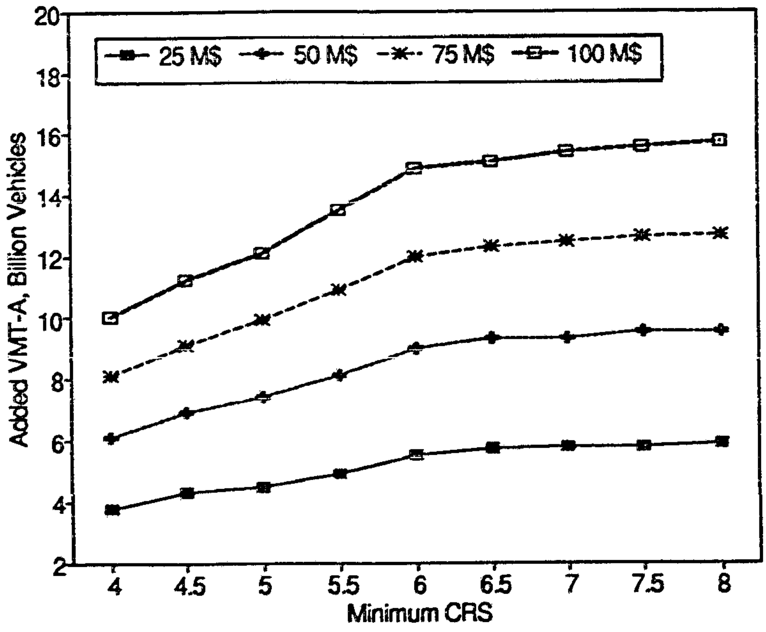

Figure 9.9 - Effect of MCRS on Long Range Optimization (Opt).

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9.3 Analysis of Benefit Functions

Four different benefit functions are considered in ILLINET to use with those network-level procedures that maximize a benefit function (i.e., B/C, IBC, and OPT). Different ILLINET benefit functions were described earlier in chapter 5 and were analyzed to observe the effect of each benefit function on the network performance. For this purpose, one network-level method that utilizes a benefit function was selected and the effects of four benefit functions on four network benefit measures were examined. The four benefit functions that are maximized are:

1. Pavement Rehabilitation Life (Life),
2. VMT on adequate pavements (VMT),
3. Added CRS area (Area), and
4. Reduction in user's cost or user's benefit (Uben).

A certain network performance results from the maximization (optimization) procedure. The objective of optimization is the maximization of the benefit function. The amount of benefit gained from the optimization that is added to the network is called the benefit measure. Thus, there are four benefit measures corresponding to the four benefit functions. The four benefit measures are:

1. Average added life per mile of network in years (LIFE),
2. Quantity of VMT on adequate pavements added to the network, in billions of vehicle-miles, (VMT-A)

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3. Average added performance area in CRS-year per mile of network (AREA),
4. Reduced user's cost due to network rehabilitation (Users' benefit) in Millions of dollars (UBEN).

Benefit functions and benefit measures are abbreviated by the terms in parentheses following their descriptions. To distinguish these two terms, capitalized lower case (i.e., Life) is used for benefit functions and upper case (i.e., LIFE) for benefit measures.

The Incremental Benefit to Cost ratio (IBC) network-level algorithm which considers all project-level options (ALL) is used for analysis here. Since the objective of the network-level analysis is to maximize benefit, it is expected that when a certain benefit function is used for maximization by any of the network-level algorithms, the network benefit measure will be the maximum for that benefit option. The analysis of results of ILLINET runs for four budget levels and four benefit functions follows.

Figure 9.10 illustrates the effect of various benefit functions on added CRS performance area (AREA) for various cost levels. When Area is optimized, the quantity of AREA should be more than if other measures of benefit (LIFE, VMT-A, and UBEN) were maximized. In Figure 9.10, the line representing the measure of AREA (solid line with filled rectangle) is at the top, indicating that this function is maximized. The quantity of AREA for the Life benefit measure is more than for the Ucost and VMT benefit measures since the last two are weighted by traffic while Area and Life are not.

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The data for average added life (LIFE) to the network for different budget levels and benefit options are illustrated in Figure 9.11. The highest quantity of LIFE is gained when the Life benefit function is chosen. The quantity of LIFE for benefits weighted by traffic (Ucost and VMT) is lower than that of Area.

Added VMT-A is also maximized when VMT is used as benefit option (see Figure 9.12. The quantity of VMT-A for the Uben option is very close to that of the VMT option in Figure 9.12. However the quantity of VMT-A for Area and Life option are lower. This is expected since these two options are not weighted by traffic. User's benefit is maximum when Uben is the option; however, when VMT is the benefit option, the UBEN quantity is still very close. UBEN for Area and Life options are lower but very close to each other.

Figure 9.13 illustrates user's benefit measure (UBEN) for different benefit measures. UBEN measure is maximum when Uben option is selected. Figure 9.13 shows that Uben provides a benefit function that relates to other benefit measures more closely. Also, UBEN for Uben and VMT are very close to each other, therefore, when user's cost is not known, VMT can be used to estimate user's cost fairly closely. An optimization process only maximizes one benefit function, thus, prior to optimization the benefit function (objective function) should be clearly defined. If it is desired to maximize several functions at the same time, the benefit function should include all those functions. The advantage of Uben benefit option is that it incorporates several measures of benefit. Uben is related to Area, since three levels of condition are considered in user's cost, and it is also related to VMT-A, since it considers traffic and section length.

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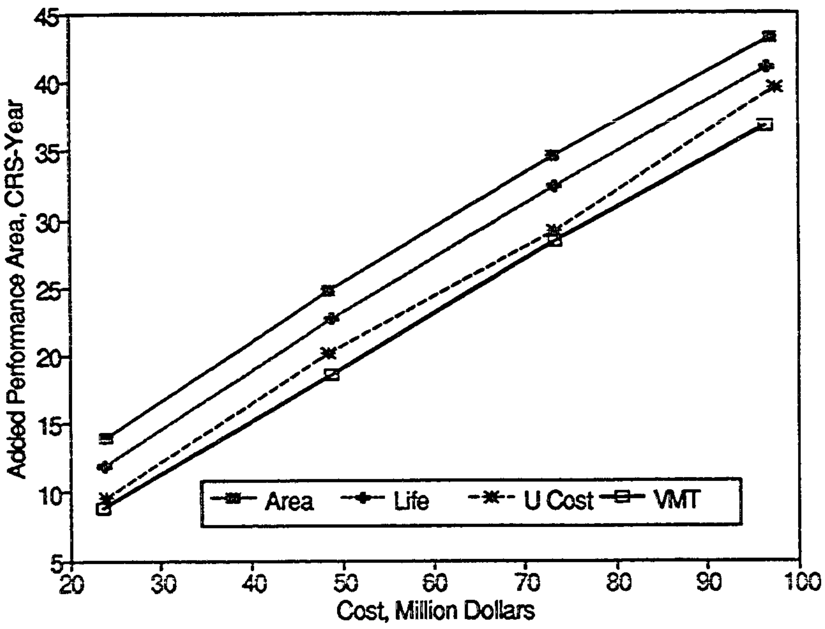

Figure 9.10 - Effect of Benefit Options on CRS performance Area.

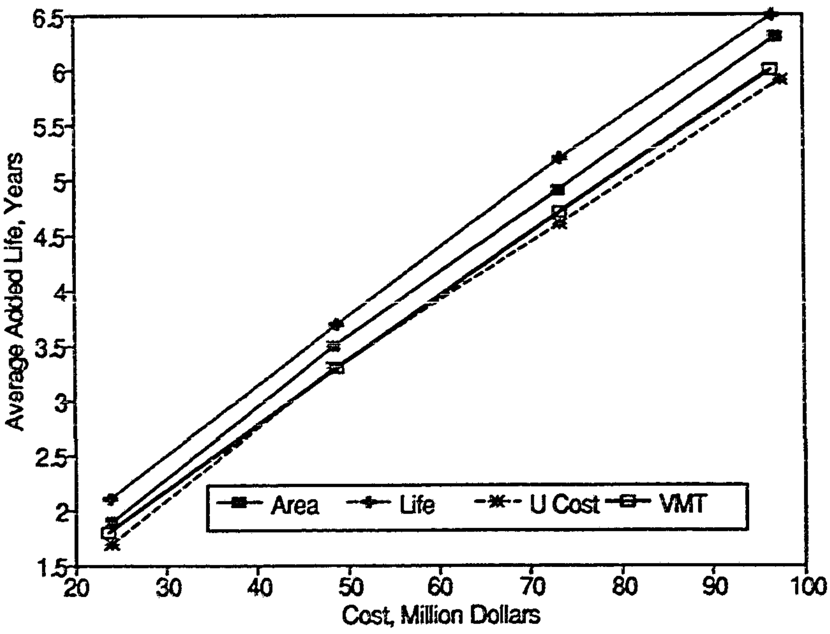

Figure 9.11 - Effect of Benefit Options on Added Network Life.

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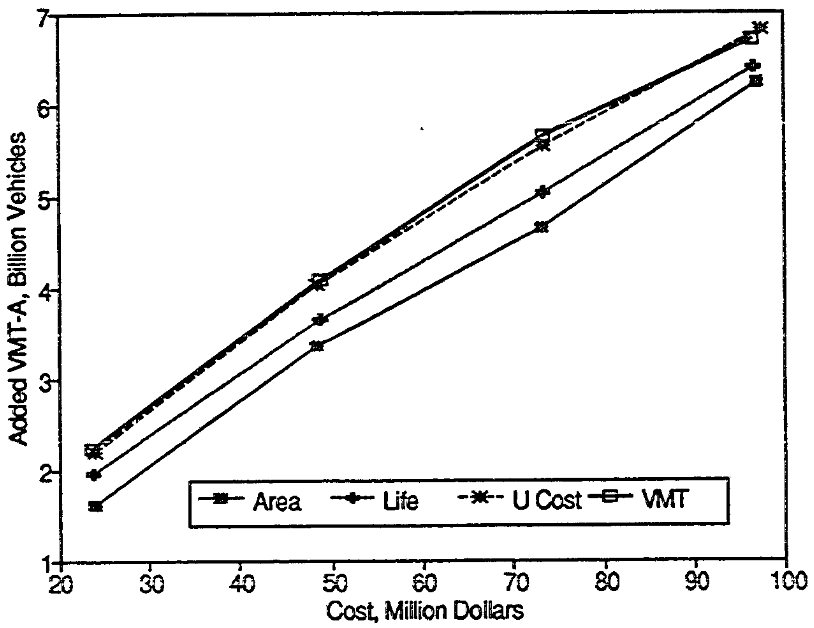

Figure 9.12 - Effect of Benefit Options on Added VMT-A.

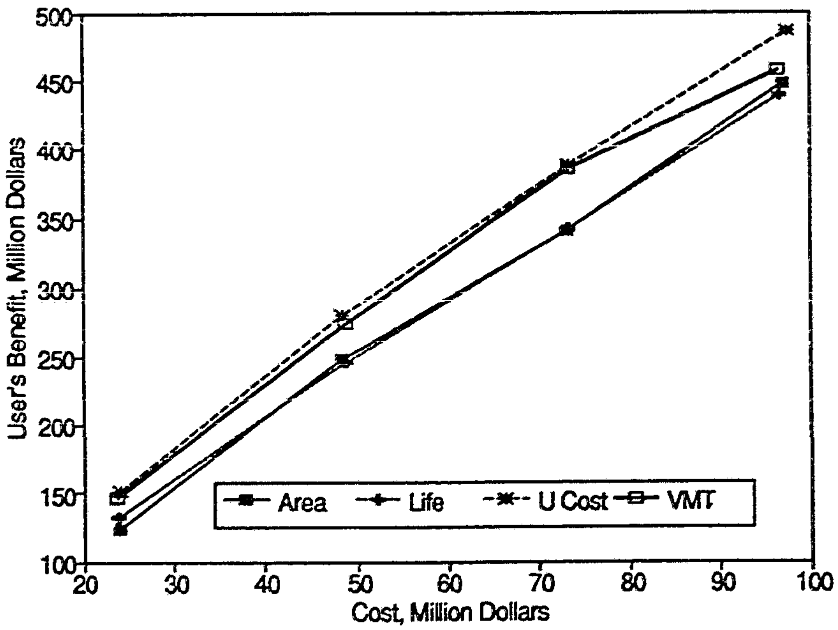

Figure 9.13 - Effect of Benefit Options on User's Benefit.

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9.4 Analysis of Project-Level Options

Analysis at the project level includes the study of the effects of different project-level options on several pavement network statistics. Six project-level options at four budget levels were considered and the pavement network performance statistics were analyzed individually and in comparison with each other. The B/C network option is used for the analysis and four project-level options are considered as follows:

1. Single Rehabilitation (e.g., 3.25- and 5-inch AC overlay and reconstruction),
2. Decision Tree,
3. Life-Cycle Cost, and
4. All rehabilitation.

Four different network statistics, which are the result of ILLINET runs, are considered. These statistics, which are the same as the statistics used for analysis of network options, are also listed below.

1. Average network CRS during analysis period.
2. Average remaining life at the end of analysis period.
3. Average VMT on Backlog pavements for the analysis period.
4. Added Vehicle Miles Travelled (VMT-A) (as the measure of benefit since VMT is used as a benefit function).

Four graphs that each show one of the performance parameters versus cost of rehabilitation for each project-level option were prepared and used for the

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analysis (Figure 9.14 to Figure 9.17). The analysis of each project-level option follows.

9.4.1 Reconstruction

When reconstruction is the only project-level alternative, fewer pavement sections receive rehabilitation since the cost of rehabilitation is rather high and budget is limited. Thus although some network parameters may increase, others reduce substantially. Referring to Figure 9.15, average remaining life is highest for the reconstruction only option. This is due to the fact that reconstruction provides the most increase in pavement life. However, the average network CRS is the lowest for this option (see Figure 9.14) since only a few sections are reconstructed because of the lack of sufficient funds, and others are allowed to deteriorate to low CRS values. For the same reason, average 10-year percent VMT on backlog pavement is also the highest for the reconstruction only option (Figure 9.16). Thus, adopting this option without increasing the budget results in more poor pavements, more vehicles travelled over them and as a result more complaints. The benefit gained by the reconstruction only option in terms of the amount of VMT-A is one of the lowest of all (Figure 9.17). This implies that the effectiveness of the reconstruction only option is lower than most other options.

9.4.2 5-inch AC Overlay

This options exhibits the poorest network performance standards of all other options. Using this option results in the lowest average network CRS (Figure 9.14), average remaining life (Figure 9.15), and benefit in terms of added VMT-A (Figure 9.17). The average VMT-B is only lower than reconstruction only option but higher than other options. The reason that only 5-inch AC overlay

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option results in a poor performance is because of the rather short predicted rehabilitation life on heavily loaded pavements due to rutting. Although for some conditions a 5-inch AC overlay may be cost effective, making it a network-wide policy results in poor performance.

9.4.3 3-inch AC Overlay

In contrast to a 5-inch AC overlay, this option provides a reasonable network performance if adopted throughout the network. The average network CRS due to this option is among the highest (Figure 9.14) while average VMT-B is among the lowest (Figure 9.16). The gained benefit due to this option is moderate; however, the average remaining life is one of the poorest parameters, (Figure 9.15) second only to a 5-inch AC overlay. The reason for the rather low remaining life is that a 3-inch overlay is not suitable for all conditions, although it might be a good option for many. If this options is used on very poor pavements, the cost of rehabilitation will be high (primarily due to high pre-overlay repair costs), while the performance will be worse.

9.4.4 Decision Tree

A decision tree selects one rehabilitation type most appropriate for the pavement type and condition level. Since these decisions are based on the judgement of an experienced engineer, it should lead to a network performance which is reasonably good. The average network CRS and average remaining life for this option was similar or better than a 3-inch AC overlay strategy (Figure 9.14 and Figure 9.15). The added benefit equaled that of a 3-inch AC overlay (Figure 9.17); however, the average VMT-B was a little higher (Figure 9.16). The overall performance of this option seems to be much better than a 5-inch AC

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overlay and marginally better than a 3-inch AC overlay.

9.4.5 *Life-Cycle Costing*

Life-cycle cost (LCC) analysis is performed among several feasible alternatives in this option to select the most cost effective alternative. The LCC option provides an improved network performance over single rehabilitation alternatives and decision tree. The added benefit (VMT-A) for this option is more than all options except ALL and in most budget levels equaled that of the ALL option (Figure 9.17). The average network CRS (Figure 9.14) and average VMT-B (Figure 9.16) is also better than or equal to all other options. The remaining life was less than reconstruction but equal to ALL and better than all others (Figure 9.15). This option seems to provide better pavement performance than all other single alternative options (i.e., single rehabilitation and decision tree).

9.4.6 *Multiple Rehabilitations (ALL) Option*

When this option is selected, all rehabilitation alternatives for all deficient sections are candidates for selection at the network level. The network-level problem is then solved using an incremental benefit-cost ratio (IBC) procedure. The benefit (VMT-A) achieved using this option is more than all other alternatives (Figure 9.17) since more than one rehabilitation is available for every section and the tradeoff between alternatives are accomplished. Achieving maximum benefit does not necessarily guarantee that all other network parameters are maximized. In fact, average network CRS (Figure 9.14), remaining life (Figure 9.15), and average VMT-B (Figure 9.16) are all not maximized, although these parameters are sufficiently high.

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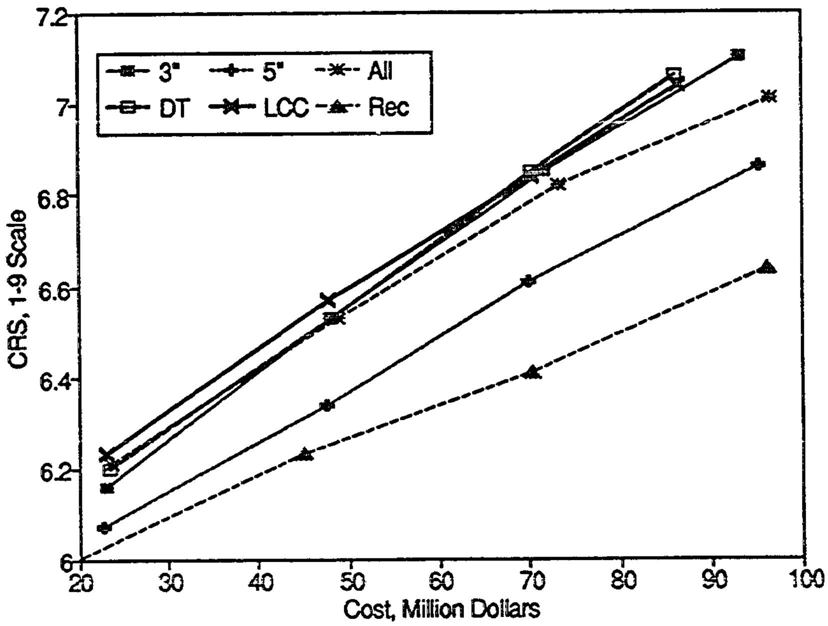

Figure 9.14 - Average Network CRS vs. Cost for Alternative Project Options.

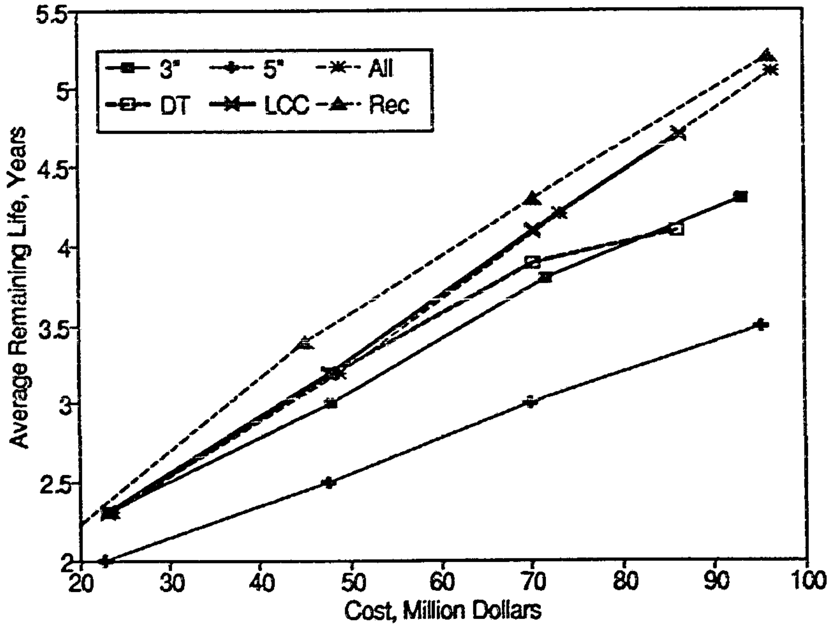

Figure 9.15 - Average Remaining Life vs. Cost for Alternative Project Options.

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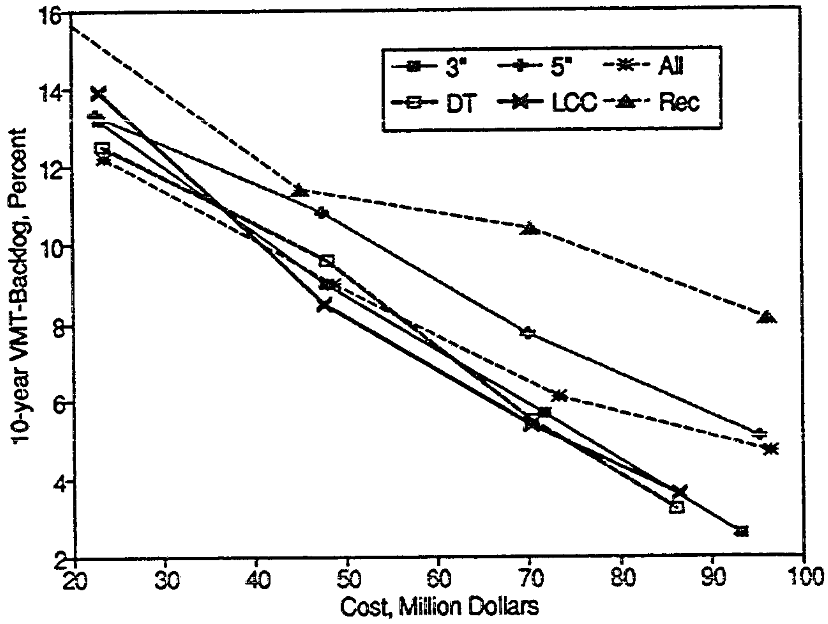

Figure 9.16 - 10-Year VMT on Backlog vs. Cost for Alternative Network Options.

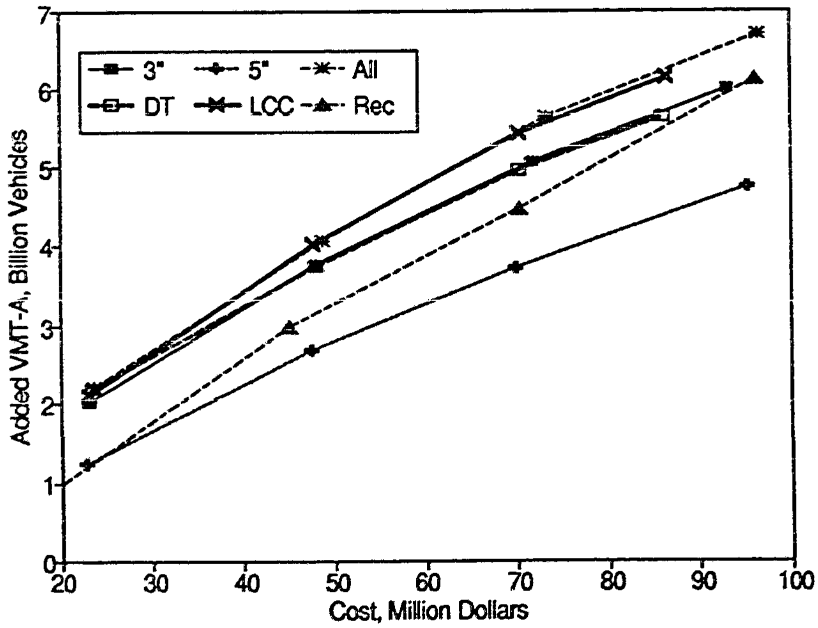

Figure 9.17 - Added VMT-A vs. Cost for Alternative Network Options.

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9.5 Analysis of Network-Level Options

There are several network-level options available in ILLINET ranging from Needs to Ranking to different levels of optimization. In this section, the effect of each network-level option on network performance is examined. A 3-inch AC overlay was considered the project level rehabilitation for all network options and the same user inputs as before were used. The following options are considered for analysis:

1. NEEDS network option.
2. RANK network option.
3. IBC network option and VMT benefit option.
4. OPT network option and VMT benefit option.
5. LIN network option and VMT benefit option.

Four network parameters were considered for analysis and comparing different options as follows:

1. Average network CRS during analysis period.
2. Average remaining life at the end of analysis period.
3. Average VMT on Backlog pavements for the analysis period.
4. Added Vehicle Miles Travelled (VMT-A).

9.5.1 RANK

Ranking performed the best in reducing average VMT-B (Figure 9.20). This is because RANK is based on a worst first rule; therefore, it performs the best in immediate removal of deficient pavements. This in turn translates into lower

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vehicle miles travelled over poor pavements (VMT-B). The average network CRS due to RANK is not different from that of OPT and LIN (Figure 9.18). However, the network parameter that indicates network health beyond the analysis period (i.e. remaining life) is substantially lower than other methods (see Figure 9.19). The total benefit added to the network by RANK is less than half of the benefit driven from the other methods. Therefore, although RANK performs adequately in the relatively short term (during the analysis period), its long-term performance as indicated by remaining life and total added benefit is very poor and may result in a substantial loss of investment.

9.5.2 Yearly Optimization by Incremental Benefit-Cost Ratio (IBC)

The incremental benefit-cost ratio (IBC) algorithm is an improvement over RANK in long range parameters. This is due to yearly maximization of benefit by this method. Both long-term network parameters (i.e., average remaining life and added VMT-A) are substantially improved over RANK (see Figure 9.19 and Figure 9.21). The average network CRS is similar to RANK (Figure 9.18), However, average VMT-B is substantially higher than RANK at lower budget levels but decreases at the maximum budget level (i.e., 100 M$) (Figure 9.20).

9.5.3 Linear programming (LIN)

This method provided a better remaining life than other options (Figure 9.19) for most budget levels. However, for other pavement network parameters it performed very similarly to the IBC algorithm.

9.5.4 Long-Range Optimization (OPT)

Long-range optimization provided the highest benefit (VMT-A) (see

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Figure 9.21). This is expected since the algorithm objective is to maximize the benefit over the period of analysis. This leads to a higher benefit than with B/C since all combinations of rehabilitation years are considered at the network level (in IBC, benefit maximization is accomplished every year in the analysis period). The network parameters for the period of analysis are both improved (see Figure 9.18 and Figure 9.20) while the remaining life is very close to that of B/C option. Overall, this option provides a better solution than IBC. However, it should be noted that OPT only considers the total budget 10-year budget limit, while the IBC algorithm considers yearly budget limits. For the same reason, OPT spends more of the budget than IBC and other yearly analysis algorithms.

9.5.5 NEEDS

NEEDS is the unrestrained budget network-level analysis. All pavement sections that become deficient will immediately receive some kind of rehabilitation (a 3-inch AC overlay in this case). The cost of NEEDS exceeds the maximum budget of 100 million dollars, thus it is not possible to compare NEEDS with the other algorithms directly. To compare these alternatives, separate ILLINET runs are made with the budget limit equal to NEEDS. RANK and IBC were not able to spend all of the budget because of yearly budget limitations. However, OPT used all of the budget, and its network performance results are identical to NEEDS. This indicates that it is not beneficial to delay the rehabilitation of sections in the network after condition drops below 6 when all the budget is available. On this basis, NEEDS provides a reliable estimate of pavement rehabilitation needs for unconstrained budget situations. In the case of a constrained budget, NEEDS can also provide reasonable estimates of pavement network performance.

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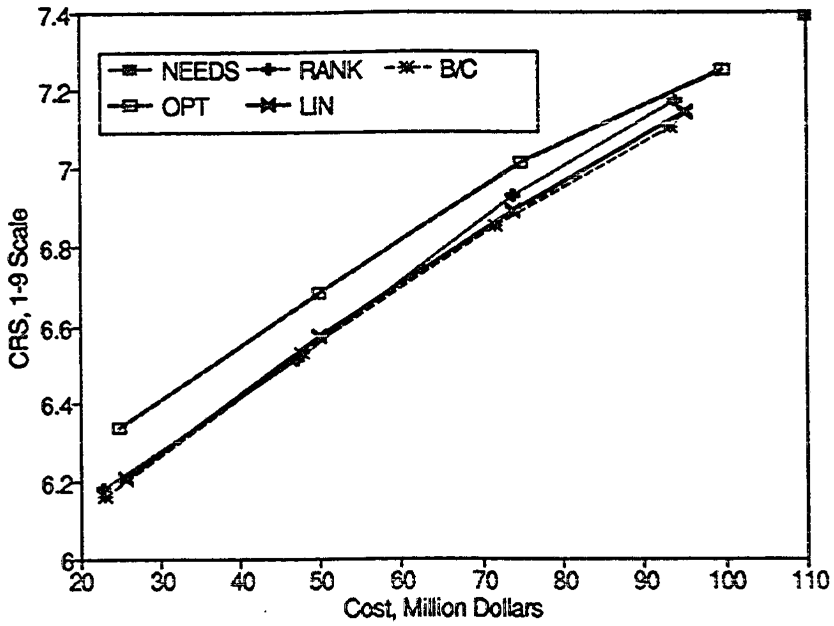

Figure 9.18 - Average Network CRS vs. Budget for Different Network Options.

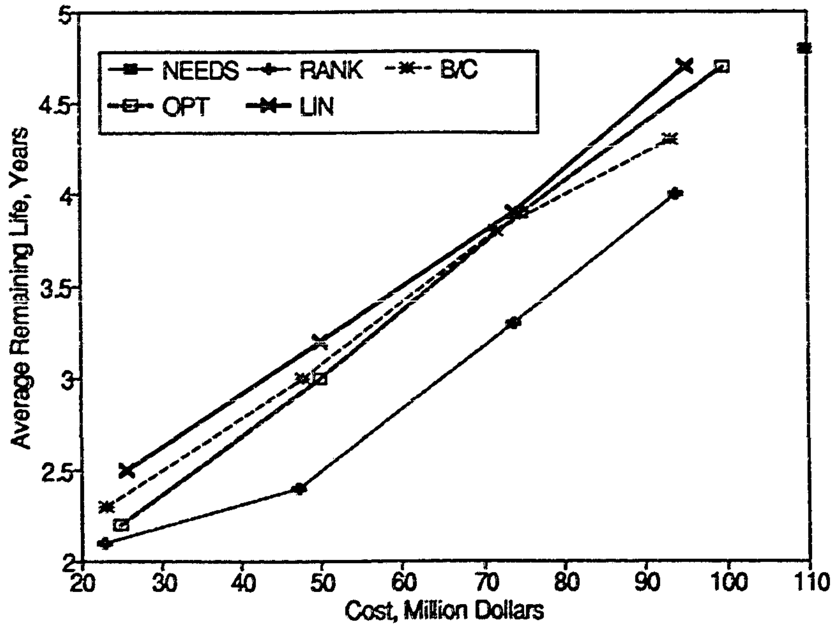

Figure 9.19 - Average Remaining Life vs. Budget for Different Network Options.

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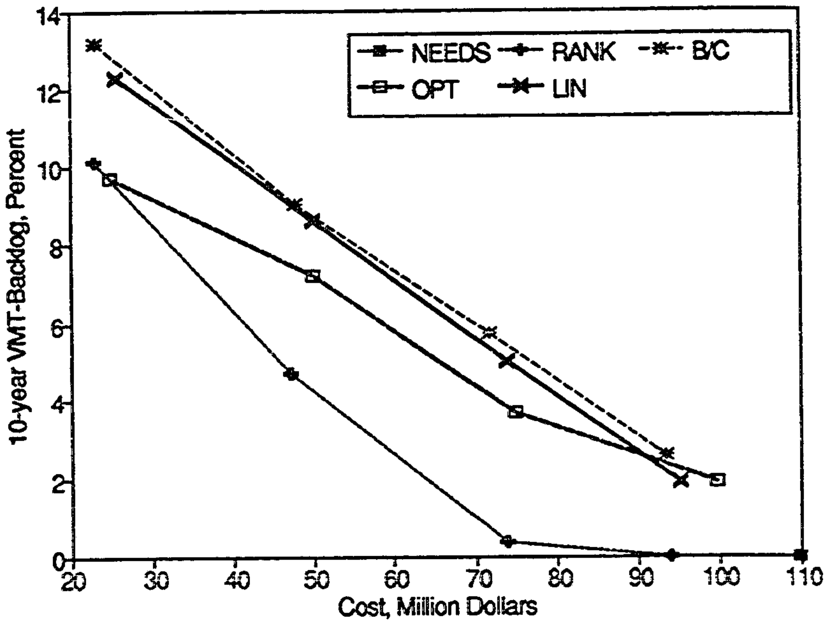

Figure 9.20 - Average VMT on Backlog vs. Budget for Different Network Options.

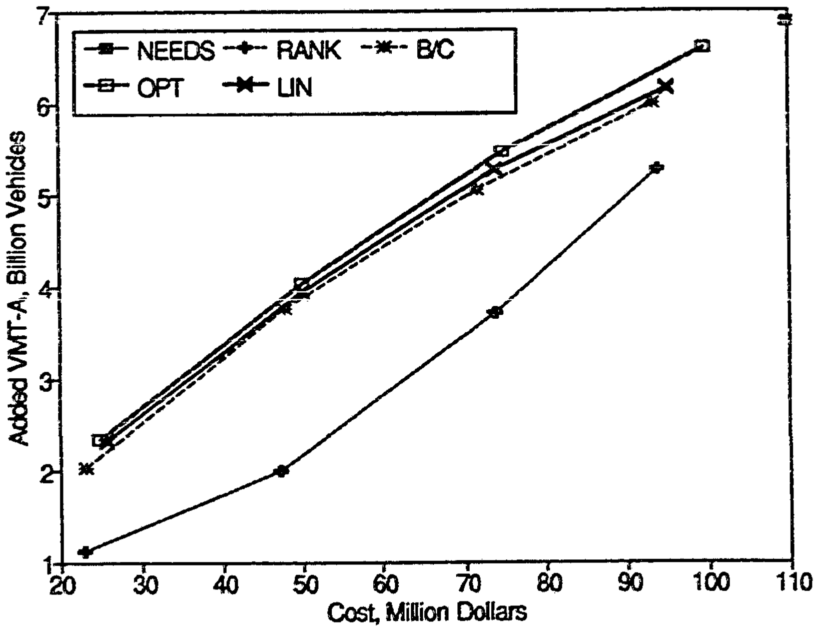

Figure 9.21 - Added VMT on Adequate vs. Budget for Different Network Options.

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9.6 ILLINET's Computational Efficiency

An important concern about network management programs are the efficiency of the programs in solving the network rehabilitation problems. With the advent of faster personal computers (PC's), it is now possible to run the network problems on these machines rather than in large mainframes as in the past. This makes network management programs accessible to a larger array of users than before and thus makes the network management programs an essential tool in the hand of the pavement planners and engineers. In addition to this, programs on PC's can accommodate much more user-friendly features in the form of menus, input screens, and graphics than the mainframe computers. Thus there are obvious advantages to running these programs on widely accessible PC's.

Processing time of the program is used to demonstrate the efficiency of ILLINET's algorithms and options on an IBM compatible PC with a 20 Megahertz Intel 386 microprocessor. Only a fraction of the processing time is spent on reading input and writing output and most of the processing time is spent on the computer's random access memory (RAM). The read time for the District 5 sample database that contains 121 sections is about 3 seconds and the write time for output is about 1 to 3 seconds depending on the type of output requested.

Figure 9.22 contains the average processing time for the sample database for different network-level and project-level options. From Figure 9.22 it is evident that NEEDS has the lowest processing time (about 10 to 15 seconds). The processing time for Ranking and B/C are about the same. However, the long-range optimization (OPT) requires two or three times more processing time when it is used with LCC and All project-level options. Processing time for some

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options depends also on the budget limit (see Figure 9.23). Figure 9.23 shows that for B/C and Ranking, processing time decreases as budget increases. For OPT however, ILLINET's processing time slightly increases as budget increases. Overall, the processing time of the sample database are well within the capabilities of a higher-end PC.

ILLINET's processing time for Needs, Ranking, and B/C increase linearly with increasing number of sections(see Figure 9.24). To analyze 800 sections, the processing time is about 180 to 210 seconds (3 to 3.5 minutes) depending on what network option is selected. This time is well within an acceptable waiting time.

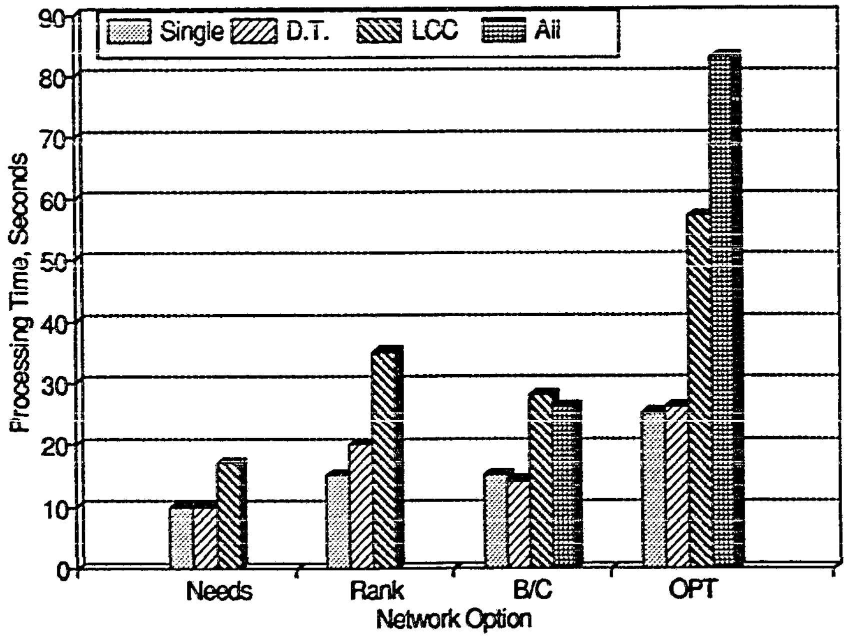

Figure 9.22 - Sample Database Processing Time for Different ILLINET Options.

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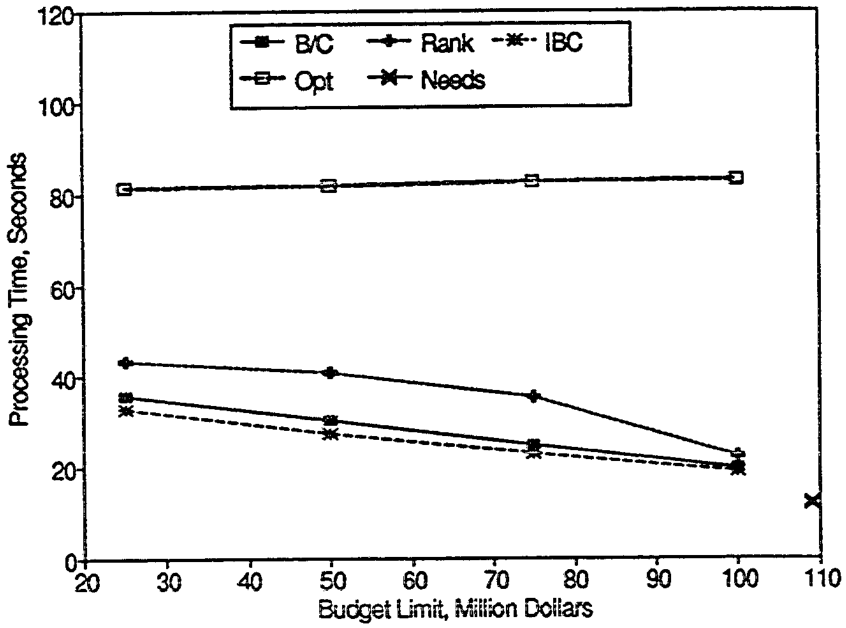

Figure 9.23 - Processing Time versus Budget Limit.

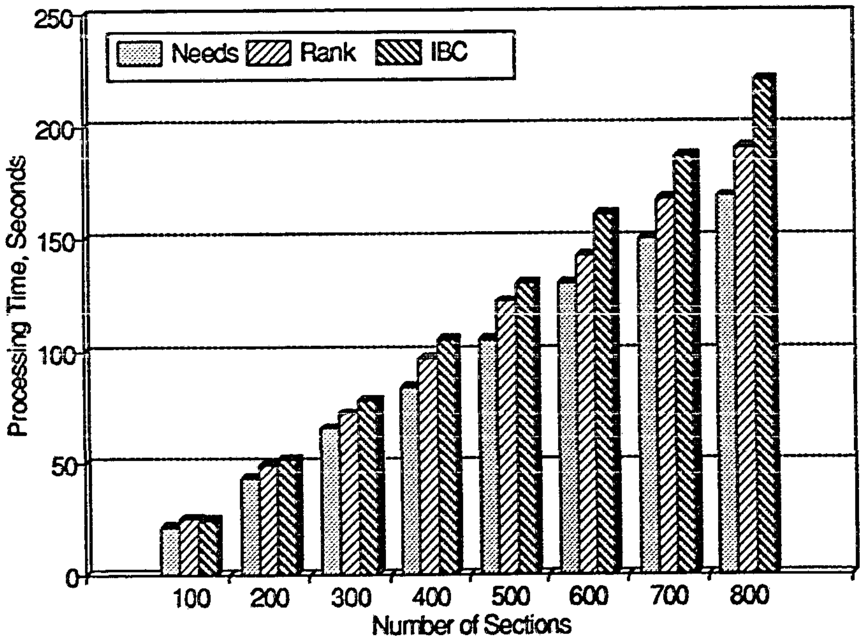

Figure 9.24 - Processing Time versus Number of Sections in the Database.

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10 Conclusions and Recommendations

A pavement network rehabilitation management program called ILLINET was developed to aid IDOT districts and central offices in planning and management of rehabilitation for the Illinois Interstate pavement network. ILLINET utilizes data for pavement sections and several pavement distress, condition, and cost models for different pavement types to:

1. Predict pavement performance for every section over a period of 10 years,

2. Propose one or more candidate rehabilitation strategies for every deficient pavement section in the network using different project rehabilitation selection routines,

3. Select rehabilitation type and timing for every section (multi-year rehabilitation program) using different network management methods,

4. Provide estimates of costs and benefits of pavement network rehabilitation and several pavement performance parameters.

The primary objective of this research was to use ILLINET to analyze different project-level, network-level, and benefit options available to demonstrate the advantages and disadvantages of each and to recommend ones for use by IDOT. Several conclusions were drawn about ILLINET components during the development and trial implementation of the system. Many recommendations were also made regarding enhancements of different ILLINET components and implementation of the program for use in management of the Illinois Interstate network. The conclusions drawn from this research and recommendations made for future work follow.

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10.1 Conclusions

This section includes conclusions drawn from analysis of several options available in ILLINET. More specifically, conclusions are made about different options available for project-level analysis, network-level analysis, triggers for rehabilitation, and benefit functions, as well as feasibility of models and efficiency of different network management methods considered in this research.

10.1.1 Modeling

1. Jointed reinforced and continuously reinforced concrete pavement models used in ILLINET predicted major pavement distresses with sufficient accuracy.

2. Validity of composite (AC-overlaid concrete pavements) models were difficult to verify. The rutting model lacks a measure of pavement temperature, which is a major factor in rutting. Reflective cracking models for both JRCP and CRCP overlays are reasonable but not verified.

3. Pavement condition (CRS) models were generated subjectively. Some of these models were compared to field data but validity of these models were not completely verified.

4. Condition models have a great impact on pavement rehabilitation selection. Predicted CRS is the basis of pavement life and performance estimates, which are a major part of any project-level and network-level analysis. CRS is also a major part of any benefit function used with the B/C method and other optimization methods.

5. Unit costs of rehabilitation used in this research were specific enough to obtain reasonable estimate of pavement network rehabilitation costs.

6. ILLINET's pavement modeling approach provides a detailed estimate of pavement network rehabilitation cost, since the quantity of repair (patching) is available from distress prediction models.

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10.1.2 Project-Level Alternatives

1. Life-cycle cost analysis of rehabilitation alternatives at the project level improves network performance over other single rehabilitation strategies when used together with any of the network methods.

2. Rehabilitation selection based on a decision tree developed by experienced engineers is reasonable and results in better network performance than for any single rehabilitation applied to all sections.

3. Optimum minimum condition (trigger value for pavement rehabilitation) for all network methods was found to be around CRS of 6. Significant loss of benefit was observed for lower minimum CRS values, while no improvement was realized for higher values.

10.1.3 Network-Level Alternatives

1. Optimization methods (OPT, IBC, and LIN) provided the best pavement network performance for a limited budget.

2. NEEDS provided a reasonable estimate of pavement rehabilitation needs over 10 years. Network performance for NEEDS was reasonable, although not as good as for optimization methods, and funding required varied year to year.

3. The long-term (10-year) performance of the network when rehabilitations were selected by the RANK method was significantly worse than when done by optimization methods, although the short-term performance was not different.

4. Randomly generated ad hoc pavement rehabilitation (the RAND option) demonstrated poor performance both in the short-term and the long-term in comparison with other methods, especially optimization methods for the same budget.

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5. The B/C method showed improved long-term performance over RANK, although not as good as the optimization methods.

6. Long-term optimization (OPT) provided the best short-term and long-term network performance for a multi-year budget limit; however, IBC and LIN were approximately equal to OPT.

7. LIN and IBC demonstrated similar performance, while each have different capabilities. Both methods can consider yearly budget constraints. IBC considers rehabilitation type trade-offs, while LIN considers rehabilitation type as well as timing trade-offs.

8. LIN provides a solution close to optimum but not optimum, thus, this option only provides an approximation to the integer programming solution.

9. OPT and IBC are two valid methods of network management with comparable results but different capabilities. OPT is capable of considering rehabilitation type and timing trade-offs, while IBC can only consider rehabilitation timing tradeoffs. Therefore, OPT provides more benefit than IBC for the same cost. On the other hand, IBC gives a more realistic estimate since it considers yearly budget limits and rehabilitation timing is controlled by delays.

10. OPT provides lower cost estimates than IBC mainly because it allows funds to be spent any year in the analysis (no yearly budget limit). Therefore, OPT may be suitable for multi-year planning and programming, while IBC is more effective for year-to-year programming.

11. NEEDS is the most computationally efficient network method. The efficiency of RANK and IBC are lower but comparable to that of NEEDS. OPT requires two to three times more computer time than IBC. The computer time required for each network method in ILLINET increases linearly with number of sections in the network.

12. All ILLINET network methods are efficient enough to run on a higher-end

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personal computer. Personal computers have the advantage of accessibility, user friendliness, and graphics capabilities.

10.1.4 Benefit Functions

1. User's benefit or reduction in user's cost due to pavement rehabilitation is the most comprehensive and meaningful benefit function to be used for pavement network management. User's benefit includes all elements of pavement benefit.

2. A reasonable and meaningful substitute for user's cost is vehicle miles travelled over adequate pavements (VMT-A). Using VMT-A provides results comparable to those obtained using user's cost. Engineers and top management can readily understand "percent VMT on good pavements" as an index of pavement network health.

3. Pavement benefit should include some measure of traffic volume since sections with higher traffic volume not only provide higher benefit but also have shorter life due to higher traffic loadings. Including traffic in the benefit function offsets the effect of worse pavement performance and provides a better chance of selection for higher volume roads.

10.2 Recommendations for Future Work

Many enhancements can be done to improve the results from the ILLINET program. These range from enhancements to the prediction and cost models, to improvements to benefit functions and network-level analysis. Following are recommendations for future work in this area.

1. Improved prediction models are necessary for AC-overlaid pavements: models for rutting of the AC layer and reflective cracking of overlays of JRCP and CRCP. Separate models for pavements with more than one overlay may also be necessary if they exhibit different performance.

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2. Models that consider the effect of 'D' cracking in concrete pavements on the AC overlays needs to be developed.

3. Prediction models for new types of rehabilitation and new pavement constructed on the interstate (such as crack and seat and full-depth asphalt) are necessary for future ILLINET implementation.

4. Condition models must be field verified and the feasibility of a more objective condition measure (such as international roughness index or IRI) should be investigated.

5. The input database must be accurate since ILLINET models are sensitive to many of the variables in the database. It is recommended that a routine be developed to detect any data that is outside the range of analysis and other flaws that might significantly affect the results.

6. A more comprehensive decision tree based on distress and traffic levels may be developed based on the judgement of experienced engineer. This can result in better pavement management.

7. More detailed unit costs for different locations and separate unit costs for drainage, shoulder repair, traffic control, and other pavement items would also result in better cost estimation.

8. Research on unit user's cost for vehicle operations, safety, and delay in relation to pavement condition in Illinois is necessary to estimate benefits gained from pavement rehabilitation in monetary form.

9. Field verification of ILLINET results are necessary to calibrate distress and condition models. ILLINET can be executed using data from the past 10 years and results compared with current network conditions to verify the feasibility and accuracy of the program.

10. Most importantly, ILLINET is ready for field trial implementation by the Illinois Department of Transportation.

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Appendix A: Performance Prediction Models

This appendix contains performance prediction and condition models used in ILLINET. Figures A1 through A8 contain distress prediction models for JRCP, CRCP, and AC overlays of JRCP and CRCP. Figures A9 through A12 contain CRS models for different pavement types. Following is a list of the models.

Distress Models

Jointed Reinforced Concrete Pavements (JRCP)
- Faulting
- Cracking
- Joint Deterioration
- Pumping

Continously Reinforced Concrete Pavements (CRCP)
- Failure (Punchouts plus Steel rupture plus Full depth repairs)

Asphalt Concrete (AC) overlays of JRCP
- Reflective Cracking
- Rutting

Asphalt Concrete (AC) overlays of CRCP
- Reflective Cracking
- Rutting

Condition Models

Jointed Reinforced Concrete Pavements (JRCP)

Continously Reinforced Concrete Pavements (CRCP)

Asphalt Concrete (AC) overlaid Pavements

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$$\text{FAULT} = \{ \text{ESAL}^{0.4731} * [-3.8536 - 1.5355\ \text{SOILCRS} + 197.124\ (\text{THICK} * \text{DOWEL}^{2.0})^{-1.7842} + 0.00024\ \text{FI} + 0.09858\ \text{JTSPACE} + 0.24115\ \text{PUMP}^{2.0}] / 100 \} + \text{FLTCALIB}$$

where:

FAULT =	mean transverse joint faulting, in
ESAL =	accumulated 18-kip [80 kN] equivalent single-axle loads since construction, millions
SOILCRS =	subgrade soil classification
=	0, if fine grained (A4 to A7)
=	1, if coarse grained (A1 to A3)
THICK =	thickness of PCC slab, in
DOWEL =	diameter of dowels, in (0.1 if no dowel bars used)
FI =	mean Freezing Index, Fahrenheit degree-days
JTSPACE =	transverse joint spacing of pavement, ft
PUMP =	pumping severity (from pumping model) (Note: PUMP can be any value between 0 and 3, e.g. 2.2)
=	0, if no pumping
=	1, if low severity
=	2, if medium severity
=	3, if high severity
FLTCALIB =	calibration of model to existing faulting
=	actual faulting (in) measured during survey - FAULT predicted for present year by above model

$R^2 = 0.69$
$n = 384$
SEE = 0.06 in [0.15 cm]

Source = NCHRP 1-19

Figure A.1- Prediction Model for Faulting of JRCP.

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$$CRACKS = \{ ESAL^{0.897} [7130.0\ JTSPACE / (ASTEEL * THICK^{5.0})] + ESAL^{0.10} (2.281\ PUMP^{5.0}) + ESAL^{2.16} [1.81 / (BASETYPE + 1)] + AGE^{1.3} [0.0036 (FI + 1)^{0.36}] \} + CRKCALIB$$

where:

CRACKS	=	total length of medium- and high-severity deteriorated cracks, ft/miie
ESAL	=	accumulated 18-kip equivalent single-axle loads since construction, millions
JTSPACE	=	transverse joint spacing of pavement, ft
ASTEEL	=	area of reinforcing steel in pavement, square in/foot width of slab
THICK	=	thickness of PCC slab, in
PUMP	=	pumping severity (from pumping model)
	=	0, if no pumping
	=	1, if low severity
	=	2, if medium severity
	=	3, if high severity
BASETYPE	=	type of base under PCC slab
	=	0, if granular base
	=	1, if stabilized base (cement, asphalt, etc.)
AGE	=	time since construction, years
	=	mean Freezing Index, Fahrenheit degree-days
CRKCALIB	=	calibration of model to existing cracking actual cracking (M-H cracks, ft/mile) measured during survey - CRACKS predicted for present year by above model

$R^2 = 0.41$
n = 314
SEE = 280 ft/mile 53 m/km]

Source: NCHRP 1-19 (5)

Figure A.2- Prediction Model for Cracking of JRCP.

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$$\mathrm{DETJT} = \mathrm{AGE}^{0.756} * 2.4367\ \mathrm{DCRACK} + 2.744\ \mathrm{REACTAGG} + \mathrm{AGE}^{2.1521}\ \mathrm{ESAL}^{0.1419}$$

$$* [\ 0.05202 + 0.0000254\ \mathrm{FI} + 0.01109\ \mathrm{TJSD}$$

$$- (0.003384 * \mathrm{K1} * \mathrm{JTSPACE}) - (0.0006446 * \mathrm{K2} * \mathrm{JTSPACE})\ ] + \mathrm{DETJTCALIB}$$

where:

DETJT = medium to high-severity deteriorated transverse joints, number/mile

AGE = time since construction, years

DCRACK = D cracking severity
= 0, if none
= 1, if low, medium, or high severity

REACTAGG = reactive aggregate distress severity
= 0, if none
= 1, if low, medium, or high severity

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads since construction, millions

FI = mean Freezing Index, Fahrenheit degree-days

TJSD = transverse joint sealant damage
= 0, if none or low severity
= 1, if medium or high severity

JTSPACE = transverse joint spacing of pavement, ft

K1 = 1, if JTSPACE = 27 ft [8.2 m]
0, if JTSPACE is not = 27 ft [8.2 m]

K2 = 1, if JTSPACE = 39 to 100 ft [11.9 to 30.5 m]
0, if JTSPACE is less than 39 ft [11.9 m]

DETJTCALIB = calibration of model to existing joint deterioration
= actual joint deterioration (M-H deteriorated joints/mile) measured during survey - DETJT predicted for present year by above model

$R^2 = 0.61$
$n = 319$
SEE = 15 joints/mile [9 joints/km]

Source = NCHRP 1-19 (5)

Figure A.3- Prediction Model for Joint Deterioration of JRCP.

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$$\text{PUMP} = \text{ESAL}^{0.670} [-22.82 + (26102.2 / \text{THICK}^{5.0}) - 0.129\ \text{DRAIN} - 0.118\ \text{SOILCRS} + 13.224\ \text{SUMPREC}^{0.0395} + 6.834\ (\text{FI} + 1)^{0.00805}]$$

where:

PUMP = pumping severity (PUMP can be any value between 0 and 3)
= 0, if no pumping
= 1, if low severity
= 2, if medium severity
= 3, if high severity

ESAL = accumulated 18-kip equivalent single-axle loads since construction, millions

THICK = thickness of PCC slab, in

DRAIN = longitudinal subdrains
= 0, if no subdrains present or present but not functional
= 1, if subdrains present and functional

SOILCRS = subgrade soil classification
= 0, if fine grained (A4 to A7)
= 1, if coarse grained (A1 to A3)

SUMPREC = average annual precipitation, cm (= 2.54 * inches)

FI = mean Freezing Index, Fahrenheit degree-days

$R^2 = 0.57$
$n = 481$
SEE = 0.52

Source = NCHRP 1-19 (5)

Figure A.4- Prediction Model for Pumping of JRCP.

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$$FAIL = 0.0001673\ ESAL^{1.9838} THICK^{-4.2772} ASTEEL^{-5.0}$$

$$+ 0.4127\ ESAL^{1.9553} (0.01584 BAM + 1.9080 CAM - 0.02005 BAR)$$

where:

FAIL =	total number of punchouts plus steel ruptures plus number of patches per lane mile
ESAL =	accumulated 18-kip [80 kN] equivalent single-axle loads outer lane, millions
THICK =	PCC slab thickness, in
ASTEEL =	area of reinforcement, in^2 /inch width of PCC slab
BAM & CAM =	both zero (0), if subbase material is granular 1 & 0, if subbase material is BAM 0 & 1, if subbase material is CAM
BAR =	0, if deformed welded steel fabric used 1, if deformed rebars used

Statistics:

R^2 = 0.62
SEE = 2.86 failures/mile [1.8 failures/km]
n = 137

Ranges in the database are as follows:

- o 18-kip [80 kN] ESAL: 700,000 to 30,800,000 in outer lane (mean = 5,600,000)
- o Age: 3 to 20 years (mean = 10.2 years)
- o Slab thickness: 7 to 10 in [17.8 to 25.4 cm]
- o Base: Bituminous treated, cement treated, untreated aggregate
- o Reinforcement content: 0.5 to 0.7 percent
- o shoulders: AC
- o Subgrade soils: Fine-grained mostly
- o Climate:Sections located in wet-freeze climate from north to south in Illinois

Figure A.5- Prediction Model for Failure of CRCP.

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$$MHCRACKS = [\, 2.8594 * (AGE * ESAL)^{0.19258} * OLTHICK^{-0.21163} * (PATCHES / 8.8)^{0.61169} \,] * 8.8$$

where:

MHCRACKS = total length of medium- and high-severity reflective transverse cracks after overlay, ft/mile

AGE = time since overlay, years

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads after overlay, millions

THICK = thickness of overlay, in

PATCHES = full-depth repairs existing or placed on original pavement prior to overlay, number/mile, computed as follows:
M-H deteriorated transverse cracks/mile
+ M-H deteriorated joints/mile
+ corner breaks/mile
+ existing full-depth repairs/mile

$R^2 = 0.83$
n = 50
SEE = 0.30

Source = Development of Illinois Pavement Feedback System, on-going study being conducted for the Illinois Department of Transportation. Data from Illinois Interstate highways.

Figure A.6- Prediction Model for Reflective Cracking of AC overlays of JRCP.

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$$RCRACK = 535787.[\ PCTHICK^{-5} * ACTHICK^{-2.58} * AGE^{0.982}\ ]$$

Where:

RCRACK =	Transverse reflection cracks (medium to high severity), number/mile
PCTHICK =	Thickness of concrete slab, in
ACTHICK =	Thickness of AC overlay, in
AGE =	Time since the AC overlay was placed, years

Statistics:

$R^2 = 0.53$
SEE = 3.45 cracks/mile [2.16 cracks/km]
n = 20

This model was obtained from an ongoing study by the University of Illinois and the Illinois Department of Transportation. Reflection cracking data were obtained from 20 projects in Illinois where CRCP had been overlaid with AC. The input data showed the following ranges:

- 18-kip [80 kN] ESAL: 500,000 to 8,000,000
- Thickness of CRCP slab: 7, 8 and 9 in [17.8, 20.3 and 25.4 cm]
- AC overlay thickness: 3 to 8 in [7.6 to 20.3 cm]
- Age of AC overlay: 1 to 10 years

Figure A.7- Prediction Model for Reflection Cracking of AC overlays of CRCP.

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$$RUT = ESAL^{.655} * AGE^{.138} * (0.55 + 0.009 * THICK)$$

Where :

RUT = Rutting in inches.
AGE = Age of overlay in years.
ESAL = Accumulated ESAL since overlay in millions.
THICK = Thickness of overlay in inches.

$R^2 = 0.74$

Source = Development of Illinois Pavement Feedback System, on-going study being conducted for the Illinois Department of Transportation. Data from Illinois Interstate highways.

Figure A.8- Prediction Model for Rutting of AC overlays.

$$CRS = 9 - (0.05 * FAIL + 8.0 * FAULT + 0.015 * PATCH)$$

Where:

CRACKS= Transverese cracks, no./mi
FAULT = average faulting of transverse joints, ins
PATCH = full-depth repair, no./mi

Figure A.9- Calculating CRS From Major JRCP Distresses.

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$$CRS = 9 - (0.2 * FAIL + 0.07 * PATCH)$$

Where:

FAIL = punchouts plus steel rupture, no./mi
PATCH = full-depth repair, no./mi

Figure A.10- Calculating CRS From Major CRCP Distresses.

$$CRS = 9 - (7 * RUT + 0.05 * FAIL)$$

Where:

RUT = average rutting, ins
FAIL = reflected cracking, no./mi

Figure A.11- Calculating CRS From Major Distresses of AC Overlaid Pavements.

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Appendix B: ILLINET User's Guide

Introduction

ILLINET is an interactive and user-friendly personal computer program developed to aid Illinois Department of Transportation (IDOT) engineers and planners in managing the rehabilitation of the Illinois Interstate pavement network system. ILLINET can be used to answer a variety of "what if" questions concerning funding needs, effects of various policies and pavement conditions. Some of ILLINET's capabilities are:

1. Predicting future network performance for any annual budget level.
2. Determining the annual budget level required to meet a desired network condition standard.
3. Analyzing the network performance with different inflation rates, traffic growth factors, preoverlay repair quantities, and project rehabilitation selection routines.
4. Considering a user-defined rehabilitation treatment for previously committed sections.
5. Analyzing the network with a variety of pavement rehabilitation management algorithms and benefit options.
6. Developing a user-defined decision tree for selection of rehabilitation types at the project level.
7. Providing a more accurate cost estimate for network rehabilitation by predicting the amount of patching required for CPR jobs and also preoverlay repair requirements for overlay jobs.
8. Editing capability for all the data in the input database.
9. Viewing all data and results in District graphic illustrations.

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10. Viewing and printing the output files, conducting file management operations, and plotting different maps of the network on a plotter.

11. Each District can be considered independently of the others, however, all results can be combined into a summary report.

System Requirements

To run ILLINET program you need to have the following:

- A DOS-compatible computer
- 640K bytes of base memory
- At least one Double Density (360 K) floppy drive
- A floppy disk or hard disk large enough to store output reports

(The size of disk storage is based on the number of sections in network.)

To use the graphics you need to have at least an EGA card and monitor. A math coprocessor is not required but recommended.

To run the program on a floppy disk system, simply insert a floppy disk containing all the system files into a drive, make the drive the default drive, and run the program by typing ILLINET. For example if the floppy drive you are using is drive B and you are in drive A, at the DOS prompt A:>, type 'B:' then hit the <Enter> key. The DOS prompt changes to B:>. At this point type 'ILLINET' to run the program.

To run the program on a hard disk system create a directory (say ILLINET) in the hard disk, then copy all the system files from the floppy disk to the directory in the hard disk. For example if your hard disk is drive C and you have your floppy in drive B do the following:

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```
B:> C: <Enter>
C:> MD\ILLINET <Enter>
C:> CD\ILLINET <Enter>
C:\ILLINET> COPY B: * . * <Enter>
C:\ILLINET> ILLINET <Enter>
```

An install utility is also supplied with the program that will let you install the program on a hard disk. To run the install program simply insert the floppy disk containing the program into a drive, make that drive the default drive, and type:

```
INSTALL [target drive]
```

For example, to install the program on drive C, type:

```
INSTALL C
```

Then, type ILLINET to run the program. INSTALL automatically creates a subdirectory called ILLINET and copies all the system files to that directory.

ILLINET System Files

ILLINET consists of two program files, and two input files as follows:

Program files

ILLINET.EXE	The interface and graphics program
NRMP.EXE	Network Rehabilitation Management Program

Input/Output files

NRMP$	Analysis inputs for NRMP.EXE
??????.DAT	Network input data-base file
??????.RPx	Program-generated report file

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The network input database file contains information such as section identification and all the inputs for the prediction models. The input database file can have any name (up to 8 characters) with "DAT" extension. The output is written to a file with the same name as the input, and extension "RPx" where x is a number between 0 and 9.

To use the file manager and print capability of the system the following two programs should be in the path of the system.

Utility files

FM.COM	is a file manager and display utility
PRINT.COM	is a DOS utility to print files

For example if PRINT.COM is in the "C:\DOS" directory and FM.COM is in the "C:\TOOLS" directory, these two directory should be included in the DOS PATH command as below:

PATH C:\DOS; C:\TOOLS

Another alternative is to copy these two files to the ILLINET directory.

Main Menu

The first screen is the main menu of the program. There are five items in the main menu as shown in Figure 1. To execute any of the items in the menu, use the up/down arrow keys to highlight your choice, then hit <Enter> to proceed. If you want to exit the program, highlight the last item "Exit to DOS" and press

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<Enter>. Selection of any of the items in the main menu leads to another menu or an input screen. Except for the main menu, all menus can be exited without making a choice by hitting the <Esc> key. This "escape" action will take you back to the previous menu. The five main items are:

1. Select District: To select a district.
2. Edit Inputs: To edit input data, system defaults and analysis parameters.
3. Run Programs: To run different network management algorithms using different project-level options, benefit options, and budgets.
4. Show Outputs: To display/print output files, show graphs, and to combine outputs from several runs into one condensed summary report.
5. Exit to DOS: To exit the program.

When the program is run, the first item is automatically selected, i.e., the user is asked to select a district. To do so, type a number between 1 and 9, and hit <Enter>. The program displays the current selection in the upper left corner of the screen, and returns to the main menu. The current selection can be changed again anytime during the session by selecting the first item from the main menu. A discussion of the other four items in the main menu follows.

2. Edit Inputs

This menu item allows the user to change system defaults and analysis parameters, to force specific rehabilitation decisions, and to make changes in the pavement data. Selection of this item leads to another menu with four items:

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1. Edit Default Parameters
2. Edit Forced Rehabs
3. Edit Pavement Data
4. Save Defaults and Forced Rehabs

2.1 Edit Default Parameters:

This item allows the user to change various analysis parameters that are used by the NRMP program. When this item is selected, the ILLINET program responds with yet another menu containing five items. Selection of any item from this sub-menu leads to an input screen where default values are displayed. These values can be changed by the user. The changes are accepted by the program when you hit <Enter> on the last line of the input screen. As in the case of menus, you can "escape" from an input screen without changing anything by hitting the <Esc> key. The five items are:

2.1.1 System Defaults:

This item enables the user to change the default values for the following three items:

Subdirectory:	The name of the subdirectory under ILLINET for storing outputs. Leave this blank to store output in the ILLINET directory.
Title for Run:	A title that will be printed in the output (up to 11 characters).
Starting Year:	The calendar year for which pavement data has been recorded. This would be the first year of the analysis period.

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2.1.2 Analysis Parameters:

This option enables the user to change the parameters required by the NRMP program. The parameters are:

Inflation Rate (percent):	Rate to be used for inflating all future costs.
Maximum Number of Rehabs:	Upper limit on the number of rehabilitation activities allowed in the analysis period.
% Patch before Overlay:	Percentage of failures patched before an overlay is placed.
Limit Budget or Performance:	<B> if the desired constraint is yearly budget, or <P> if it is percent backlog miles.
Default Yearly Constraint:	Budget in millions of dollars if <B> is selected, or Percent miles backlog if <P> is selected on the previous line.

2.1.3 Set Condition Trigger Values:

Trigger values for rehabilitation and pavement condition can be entered through this option. Minimum condition index is primarily used as a trigger value for rehabilitation. The other trigger values are mainly used for reporting.

Minimum CRS:	A number between 1 and 9 below which a rehabilitation is required. The default value is 6.0.
Trigger - Accruing:	CRS below which pavement is in "accruing" condition. The default is 6.0. Pavements with CRS greater than or equal to this value are said to be "adequate".
Trigger - Backlog:	CRS below which pavement is in "backlog" condition. The default is 5.0.
Trigger - Critical:	CRS below which pavement is in "critical" backlog condition. The default is 4.0.

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2.1.4 Set Unit Costs:

The user can enter the unit cost of rehabilitation through this option. Following is a description of each unit cost item used in the program. Note that all costs are in thousands of dollars per lane mile.

1% Patching-JRCP	Cost of patching of 1 percent lane mile area
1% Patching-CRCP	Cost of patching of 1 percent lane mile area
3" AC Overlay	Cost of 3 inch AC overlay including 4 percent patching
5" AC Overlay	Cost of AC overlay including 4 percent patching
Reconstruction	Cost of CRCP Reconstruction per lane mile

2.1.5 Set Decision Tree Trigger Values:

This option allows the user to create a custom made decision tree. For each pavement type, a rehabilitation is selected based on its CRS (between 1 and 9). The user enters the upper bound of the range of CRS which is applicable to each rehabilitation for each pavement type. A blank field means that the rehabilitation is not applicable for a particular pavement type. Pressing <Enter> at the last line maps the decision for each pavement on a line diagram, as shown in Figure 2. There are four rehabilitations and four pavement types. The <TAB> key changes fields (pavement type). A trigger value for each rehabilitation type must be entered as follows:

CPR	Trigger value for patching (Upper limit of patching range).
3" ACOL	Trigger for 3 inch AC overlay (Upper limit of 3-inch overlay range).
5" ACOL	Trigger for 5 inch AC overlay (Upper limit of 5-inch overlay range).
RECONST	Trigger for reconstruction (Upper limit of reconstruction range).

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The decision tree chosen in Figure 2 is shown below:

Criteria	JRCP	CRCP	D Cracked	ACOL
$CI \geq 6$	Maintain	Maintain	Maintain	Maintain
$6 > CI \geq 5$	Restore	Restore	3" ACOL	3" ACOL
$5 > CI \geq 4$	3" ACOL	3" ACOL	5" ACOL	5" ACOL
$4 > CI \geq 3$	5" ACOL	5" ACOL	5" ACOL	5" ACOL
$3 > CI$	Reconstruct	Reconstruct	Reconstruct	Reconstruct

2.2 Edit Forced Rehabs

This option allows the user to force specific rehab decisions for selected pavement sections in selected years. There are two ways to enter the rehabilitation year and type for a section:

1) Highlight a section and press <Enter>. An input screen will appear with all the years in the analysis period listed. The user may move to any year and enter one of the following keys for a rehabilitation type:

<–> for maintenance

<P> for patching

<3> for 3-inch AC overlay

<5> for 5-inch AC overlay

<R> for reconstruction

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2) Use the PgUp/PgDn keys to move to a year. Then highlight a section as before and press any of the keys explained before to enter the rehabilitation type. In addition to the five keys explained before, the following keys are available:

<E> to erase a rehabilitation type for a certain year and section

<I> to initialize or reset all rehabilitation types for all sections and years

In order for the Forced Rehab option to work properly, forced rehabilitations should start with the beginning year and must be continuous.

For all sections and all years, any unspecified rehabilitation type defaults to "maintenance".

2.3 <u>Edit Pavement Data</u>

Selection of this option leads to route map on the screen, as shown in Figure 3. The user can highlight any section on the map using the following keys:

- Left/Right arrow keys (←/→) to change sections along a route
- Down arrow key (↓) to change direction
- <C> to change route

Pressing <Enter> on a highlighted section results in an input screen with all the data for that section (Figure 4). You may move to any data field using arrow keys

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and enter new data. Except for section identification (i.e., route, direction, mileposts, and district number) and pavement type, all other data may be changed.

Use the <Esc> key to exit from this option. Before returning to the Main Menu, ILLINET asks whether you want to save the data. Type <Y> to save the data or any other key to return to Main Menu. The data will be saved in a file with the same name as the original; however, the old data will be saved in a file with the same name but with ".BAK" extension.

2.4 Save Defaults and Forced Rehabs

The changes made in default parameter values and forced rehab decisions will stay in memory until either they are changed again or the program is exited. This is sufficient for many uses; however, sometimes the user may want to save these values on disk for future use. That can be achieved by selecting this menu item. Then, in future, whenever the same district is selected, the program will use these saved values for default parameters and forced rehab decisions.

3. Run Programs

This item enables the user to run the Network Rehabilitation Management Program (NRMP) with different network level algorithms, project-level selection routines, benefit options, and budget or performance scenarios. Selection of this

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item from the main menu leads to a menu with five choices, each of which is a different network management algorithm contained in NRMP.

3.1 Forced Rehab only

This option only applies user-defined strategies (rehabilitation timing and type chosen by the user) to the network. If the rehabilitation type is unspecified for any section in any year, it defaults to "maintenance". When this option is selected, the only thing the program asks for is a report number for the output file. You can enter any number between 0 and 9. The output will be saved in a file with the same name as the input file and extension "RPx" where x is the report number. The cursor will blink in the lower central region of the screen while NRMP is running. This could take a minute or two.

3.2 Needs

"Needs" is an algorithm that has been developed to estimate the unconstrained budget rehabilitation needs in the next ten years for the Illinois Interstate network. Every section in the network whose condition falls below a user-defined minimum condition (CRS) level is a candidate for pavement rehabilitation. The type of rehabilitation is determined by the rehabilitation selection routine chosen by the user. When "Needs" is selected, the program offers a Rehab Selection menu with the following three choices:

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Decision Tree:	For every pavement type, a rehabilitation scheme is chosen based on its CRS, as explained in Section 1.5.
Life Cycle Cost:	For every rehab option, the cost and the expected pavement life is computed, and the one with the least cost per year is selected. Life is defined as the length of time the pavement stays "adequate", i.e., its CRS stays above a trigger value defined in Section 1.3.
Single Rehab:	This choice leads to another menu, from which one of the four rehab types should be selected. This choice of rehabilitation is then performed every time the pavement CRS falls below the minimum trigger.

After the selection of rehabilitation option, the user will be asked to enter the report number, as in the "Forced Rehab only" option.

3.3 Ranking

"Ranking" is similar to "Needs" except that the yearly budget is no longer unlimited. Therefore, not all the sections that need rehabilitation (CRS below a minimum level) will receive funding. Funding is allocated based on a worst-first rule. Those sections that have the lowest CRS for a certain year will be rehabilitated until the budget runs out for that year. In addition to the inputs required for "Needs", the user must also enter budgets in millions of dollars for each year. If the budget is the same every year, it can be entered just once as the Default Yearly Constraint from the Analysis Parameters input screen.

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3.4 Benefit Cost Ratio

This option is similar to "Ranking" except that pavement sections at each year are ranked based on their benefit-cost ratio rather than CRS. The user can choose from four benefit options:

CRS	Maximizes average network CRS
User Cost	Minimizes user cost weighted by ADT (Average Annual Daily Traffic)
Life	Maximizes pavement life (years pavement performs adequately) or minimizes number of backlog sections.
VMT	Maximizes vehicle miles travelled (VMT = Life * ADT) over adequate sections or minimizes VMT over backlog sections.

As in the "Ranking" algorithm, the user must also specify the choice of the rehabilitation selection routine and budgets for each year.

3.5 Incremental Benefit / Cost

This option is similar to the "Benefit-cost ratio" option except that all rehabilitation strategies applicable to a section at the project level are carried over to the network level and rehabilitation selection routine is not used to select the best rehabilitation type at the project level. Then, at the network level, the program selects the rehabilitation strategy that maximizes pavement benefit. The user only specifies the choice of benefit and yearly budgets.

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4.0 Show Outputs

Selection of this item leads to another menu with the following choices:

1. View Reports
2. Display Graphs
3. Print Reports
4. Show Statewide Summary

4.1 View Reports

A utility is supplied with the program that enables the user to view the contents of a file or perform other file operations. Selecting the View Report option will activate the utility. The contents of the subdirectory specified in the Set Parameters option will be shown on the screen. The user may use the up/down arrow keys (↑/↓) to highlight a file, and then hit <Enter> to browse the contents of the highlighted file or <F2> to delete the file. While in a file the user may press <F> to find a string and press <L> to repeat the search. This is helpful in locating a section by its beginning milepost. Pressing the <Esc> key while in the file will exit to the directory. Pressing <Esc> while in the directory will take you back to the View Reports menu.

4.1.1 Network Summary Report (Big Picture)

The heading of all reports are similar and include such information as the program title, report type and title, algorithm used, and rehabilitation selection

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routine used. Other network information in this report are:

- Number of sections in the network
- Total length of network in miles
- Average network CRS between 1 and 9
- Total cost of rehabilitation program for ten years in millions of dollars
- Percent VMT on backlog pavements

Other yearly data for ten years are as follows:

- Year of analysis
- Average CRS for the network weighted by section length
- Average remaining life (in years) for the network
- Percent VMT over backlog pavements
- Percent backlog miles in network (miles of pavement with CI<5)
- Percent accruing miles in network (miles of pavement with CI>5 and <6)
- Percent adequate miles in network (miles of pavement with CI >6)
- Miles of pavement reconstructed
- Miles of pavement overlayed with 3 inch AC overlay
- Miles of pavement overlayed with 5 inch AC overlay
- Miles of pavement patched (CPR)
- Annual cost of rehabilitation in millions of dollars
- Annual budget allocated in millions of dollars

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4.1.2 Project Summary Report (More Detailed)

The heading of the second report contains the program title and other program parameters, such as minimum condition level (CRS) and inflation rate. The body of the report contains the following data for every section in the network.

- Section identification number (route-direction-beginning milepost)
- Section length
- Number of lanes
- Pavement type
- Pavement age
- Pavement current CRS
- Rehabilitation decisions for year 1 through 2
- Cost of rehabilitation for years 1 through 2
- Rehabilitation decisions for year 3 through 5
- Cost of rehabilitation for years 3 through 5
- Rehabilitation decisions for years 6 through 10
- Cost of rehabilitation for years 6 through 10

4.1.3 Project Detailed Report (Very Detailed)

This report contains yearly detailed information for every section in the network. The heading is the same as the heading for the project summary report. For every section in the network, section ID number, pavement type and thickness, length, age, and AADT as well as the following yearly information are listed:

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CRS	Pavement CRS, between 1 and 9
REHAB	Rehabilitation type selected
COST	Cost of rehabilitation in thousands of dollars
ESAL	Predicted accumulated ESAL in millions
PATCH	Number of patches placed in that year
FAIL	Predicted failures
FAULT /RUT	Faulting of JRCP or rutting of AC overlays (0.01 in)

4.2 Display Graphics

This menu item enables the user to display some of the output data in graphics. A graphics adapter is required to run this part of the program. The user needs to enter the name of the output file which contains the desired information. The first two characters of the extension are always the letters "RP" and the third letter is the output number. The user only needs to enter the output number and not the full extension. The following graphs are included in this option.

4.2.1 Network Summary Graph

The same information that is listed in the network summary report is graphed here. The top graph is a bar chart showing the percentage of the network (miles) in each of the adequate (green), accruing (light blue), and backlog (red) categories. The line on the same graph shows the average network condition on a 1 to 9 scale. The middle graph shows the percentage of VMT over backlog pavements.

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The bottom bar graph shows the percentage of the network (miles) that is patched (green), overlaid (light blue), or reconstructed (red). Network description and pavement parameters are also listed on this screen.

4.2.2 Strip chart

This screen shows pavement conditions for every section in the network for the analysis period (ten years). Adequate sections are shown in green, accruing sections in yellow and backlog sections in red. The length of the bar for each section is equivalent to the length of the sections. Grids are drawn at the beginning of a new route.

4.2.3 Cost Histogram

The cost histogram is a bar chart showing the cost distribution of both thick and thin AC overlays. This graph shows the range and variability associated with the cost of overlays which is due to repairs needed prior to placement of the overlay. There are two bar charts: one for 3-inch overlays and the other for 5-inch overlays.

4.2.4 Project Level Graph

This screen shows the map of a district with sections drawn as a line. These lines are colored to show different pavement attributes as follows:

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- Pavement Type (JRCP, CRCP, JROL, or CROL)
- Current yearly ESAL (in millions)
- AADT (in thousands)
- Yearly pavement conditions
- Yearly rehabilitation decisions

The user can move between sections using the arrow keys. Down arrow key (↓) will switch direction, and the left/right keys (←/→) will change sections along a route. The route itself can be changed by pressing <C>. In addition, pressing <PgUp/PgDn> in the last two options will show the data for the following/preceding year.

Selecting a section by pressing <Enter> will display the Project Level Graph for that section. This graph displays the data listed in the Project Detailed Report. The top graph shows the pavement condition and rehabilitation for every year. The middle graph show the number of pavement failures and predicted faulting or rutting (in hundreds of an inch) for every year. The bottom graph shows the AADT (in thousands) and accumulated ESAL (in millions) for every year for that section. Some other pavement information is also shown on the right side of the screen.

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4.3 Print Reports

This option allows the user to print all or part of an output report file to a selected output device. The output device can be a printer, a file, or the screen. An input screen appears following the selection of this option. The user must enter the report filename and number to print, and the left margin for printed output. Then a menu appears with the following items:

1. Network Summary Report
2. Project Summary Report
3. Project Detailed Report
4. Print the Whole Report

The first three items are for printing a portion of the output. For item 1 and 2 the user need only specify an output device (i.e., screen, file, or printer). However, for item 3, the user must specify the starting section number and number of sections to print. Section number is a number associated with every section in the network which is shown in the edit data screen.

When "file" is chosen as the output device, all output is routed to a file named REPORTS.PRN. If this file already exists and contains information, new information will be appended. Item 4 is for using the DOS PRINT utility to print a file. Item 4 allows the user to print a whole report containing all three outputs, or to print the custom-made file REPORTS.PRN.

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4.4 Show Statewide Summary

This option allows the user to combine individual district reports generated by the NRMP program into one statewide summary report. In addition to generating the summary report, the program also graphically displays the network summary for the entire state. As usual, the <Esc> key should be pressed to exit from the display screen and return to the main menu.

5.0 Exit to DOS

Select this item to terminate the program and return to DOS or the environment from which the program was started.

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ILLUSTRATIONS

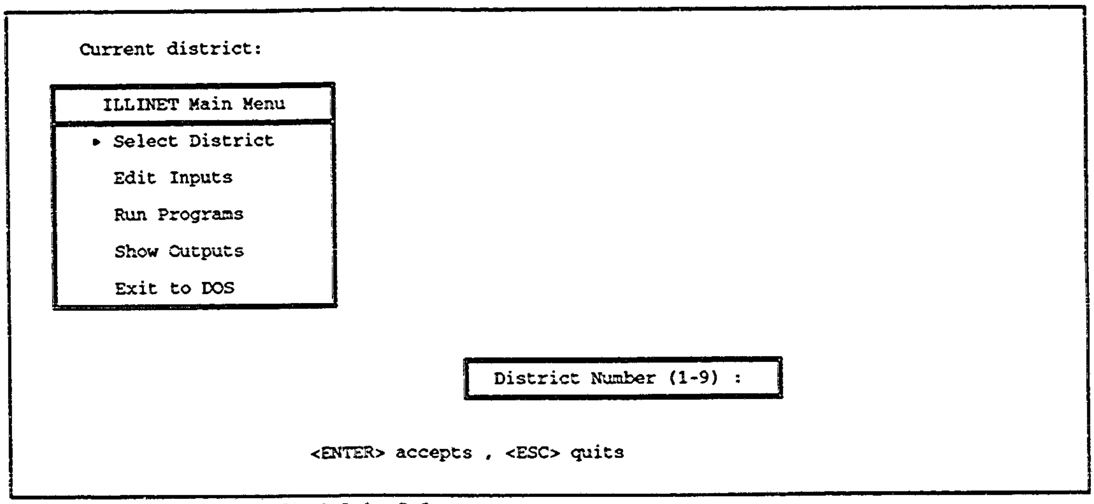

Figure B.1- ILLINET's Main Menu.

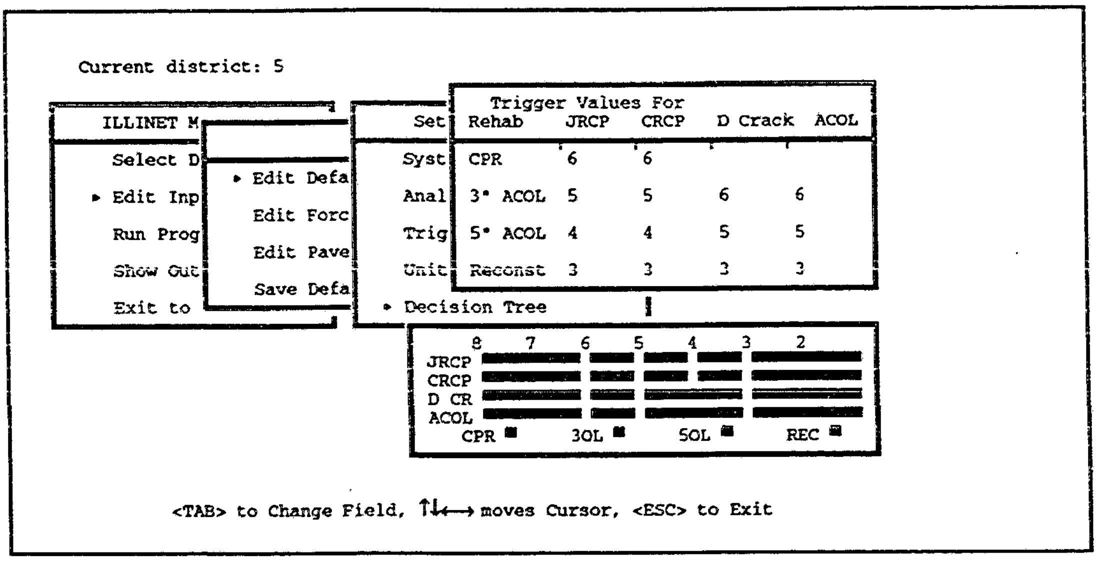

Figure B.2- Decision Tree Input Screen.

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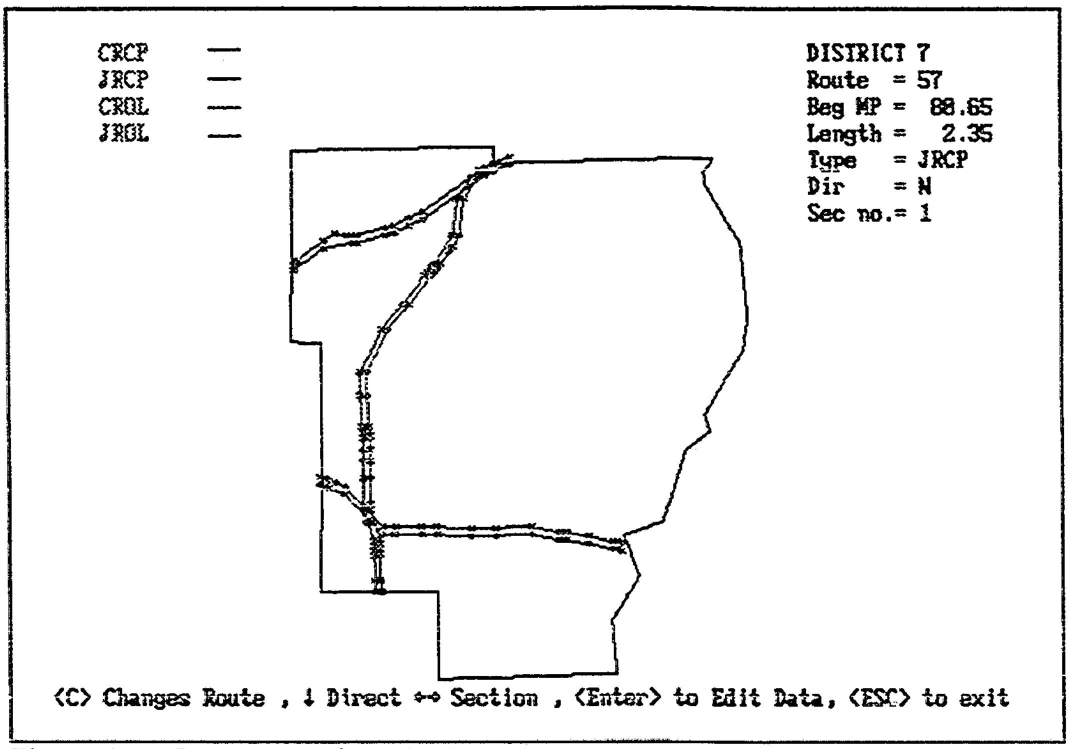

Figure B.3- Route Map for District 7.

Route: 64 Dir:E MP: 60.55 Type:CRCP

Design:	Thickness of Main layer (ins)...........	8.0
	Age of pavement (years).................	16
	Number of lanes.........................	2
	Base Type (Gran=0, Stablized=1).........	1
	Steel diameter (ins)....................	0.63
	Steel spacing (ins).....................	6.50
Traffic:	Average Daily Traffic (thousands).......	12.3
	Traffic growth (percent)................	5.3
	Cum ESAL since last rehab (millions)....	8.6
	Current ESAL per year (millions)........	0.99
	ESAL growth (percent)...................	9.5
Distress:	Existing good patches (no./mi)..........	0
	Existing failed patches (no./mi)........	0
	Failed cracks (M+H severity, no./mi)....	0
	'D' cracking (0-1)......................	1
Condition:	CRS (1-9)...............................	6.3

Figure B.4- Edit Data Screen for Selected Section.

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Appendix C: Sample Network Database

This appendix includes the sample database used for all application and analysis runs in this research. This sample database includes 1987 data for IDOT District 5.

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Table C.1- Sample network database.

SEC #	ROUTE	DIR	BEGIN	END	DIST	TYPE	THK	AGE	LANES	BASE	DRAIN	SDIAM	SSPAC	OLTHK	ADT	ADTGR	CESAL	YESAL	ESALG	FI	PREC	PATCH	FPAT	FAIL	RUTFL	DETJT	DCRK	PUMP	CRS
1	57	N	168.30	171.89	5	JRCP	10	24	2	0	1	.33	6.0	6.0	10.1	2.5	9.1	0.66	7.2	176	97	0	0	50	0.28	2	0	0	5.5
2	57	N	171.89	176.89	5	JRCP	10	24	2	0	1	.33	6.0	6.0	10.1	2.5	9.1	0.66	7.2	176	97	0	0	44	0.17	1	1	0	6.0
3	57	N	176.89	181.10	5	JROL	10	5	2	.	.	.	3.0	3.0	11.1	2.5	3.1	0.59	0.6	176	97	0	0	8	0.07	4	.	4	7.2
4	57	N	181.10	183.79	5	CROL	8	1	2	.	.	.	3.2	3.2	11.1	2.5	1.1	0.59	0.6	176	97	0	0	0	0.00	0	.	.	9.0
5	57	N	183.79	190.60	5	CRCP	8	22	2	0	0	.63	6.5	6.5	11.1	2.5	8.1	0.65	3.2	176	97	10	12	18	0.00	6	0	.	6.5
6	57	N	190.60	199.22	5	CROL	7	9	2	.	.	.	4.5	4.5	11.1	2.5	6.1	0.74	6.6	176	97	0	0	2	0.24	0	.	.	7.0
7	57	N	199.22	203.82	5	CRCP	7	19	2	1	0	.63	6.3	6.3	11.1	2.5	10.1	0.74	6.6	176	97	0	0	21	0.00	0	0	.	5.7
8	57	N	203.82	207.67	5	CRCP	7	19	2	1	0	.63	6.3	6.3	12.1	2.5	10.1	0.75	6.2	240	94	0	0	0	0.00	0	0	.	6.8
9	57	N	207.67	211.95	5	CRCP	7	19	2	1	0	.63	6.3	6.3	12.1	2.5	10.1	0.75	6.2	240	94	0	0	9	0.00	0	0	.	6.9
10	57	N	211.95	215.79	5	CRCP	7	18	2	1	0	.63	6.3	6.3	12.1	2.5	10.1	0.79	6.2	240	94	2	3	0	0.00	0	0	.	6.7
11	57	N	215.79	219.49	5	CRCP	7	18	2	1	0	.63	6.3	6.3	12.1	2.5	10.1	0.79	6.2	240	94	0	3	1	0.00	1	0	.	7.2
12	57	N	219.49	224.14	5	JRCP	10	24	2	0	0	.33	6.0	6.0	13.1	2.5	9.1	0.60	6.5	343	91	0	0	8	0.21	1	0	0	6.3
13	57	N	224.14	228.18	5	JRCP	10	25	2	0	1	.33	6.0	6.0	13.1	2.5	9.1	0.60	6.5	343	91	0	0	18	0.07	0	1	0	5.4
14	57	N	228.18	233.58	5	JRCP	10	25	2	0	1	.33	6.0	6.0	13.1	2.5	9.1	0.60	6.5	343	91	0	0	10	0.22	0	1	0	6.1
15	57	N	233.58	236.80	5	JROL	10	2	2	.	.	.	3.2	3.2	16.1	2.5	1.1	0.60	6.5	343	91	0	0	0	0.09	0	.	.	9.0
16	57	N	236.80	237.71	5	JROL	10	2	2	.	.	.	3.2	3.2	16.1	2.5	2.1	0.92	11.4	343	91	0	0	0	0.09	0	.	.	9.0
17	57	N	237.71	243.10	5	CROL	7	4	2	.	.	.	3.2	3.2	13.1	2.5	4.1	0.92	7.5	343	91	0	0	29	0.02	2	.	.	7.5
18	57	N	243.10	245.22	5	CRCP	7	19	2	1	0	.63	6.3	6.3	13.1	2.5	10.1	0.84	7.5	343	91	0	0	50	0.00	50	0	.	7.0
19	57	N	245.22	250.45	5	CRCP	7	18	2	1	0	.63	6.3	6.3	12.1	2.5	10.1	0.84	7	343	91	7	9	14	0.00	0	0	.	6.4
20	57	N	250.45	255.83	5	CRCP	7	17	2	1	0	.63	6.3	6.3	11.1	2.5	10.1	0.82	6.9	343	91	0	0	4	0.00	4	0	.	7.0
21	57	S	168.30	171.89	5	JRCP	10	24	2	0	1	.33	6.0	6.0	10.1	2.5	9.1	0.66	7.2	176	97	0	0	113	0.30	60	0	0	5.5
22	57	S	171.89	176.89	5	JRCP	10	24	2	0	1	.33	6.0	6.0	10.1	2.5	9.1	0.66	7.2	176	97	0	0	52	0.10	16	1	0	6.0
23	57	S	176.89	181.10	5	JROL	10	5	2	.	.	.	3.0	3.0	11.1	2.5	3.1	0.59	0.6	176	97	0	0	0	0.08	3	.	.	7.2
24	57	S	181.10	183.79	5	CROL	8	1	2	.	.	.	3.2	3.2	10.1	2.5	1.1	0.59	0.6	176	97	0	0	0	0.00	0	.	.	9.0
25	57	S	183.79	190.60	5	CRCP	8	22	2	0	0	.63	6.5	6.5	11.1	2.5	8.1	0.65	3.2	176	97	0	0	13	0.00	8	0	.	6.5
26	57	S	190.60	199.22	5	CROL	7	9	2	.	.	.	4.5	4.5	11.1	2.5	6.1	0.74	6.6	176	97	0	0	4	0.18	2	.	.	7.0
27	57	S	199.22	203.82	5	CRCP	7	19	2	1	0	.63	6.3	6.3	11.1	2.5	10.1	0.74	6.6	176	97	16	0	13	0.00	0	0	.	5.7
28	57	S	203.82	207.67	5	CRCP	7	19	2	1	0	.63	6.3	6.3	12.1	2.5	10.1	0.75	6.2	240	94	10	0	0	0.00	0	0	.	6.8
29	57	S	207.67	211.95	5	CRCP	7	19	2	1	0	.63	6.3	6.3	12.1	2.5	10.1	0.75	6.2	240	94	5	0	0	0.00	0	0	.	6.9
30	57	S	211.95	215.79	5	CRCP	7	18	2	1	0	.63	6.3	6.3	12.1	2.5	10.1	0.79	6.2	240	94	0	5	0	0.00	0	0	.	6.7
31	57	S	215.79	219.49	5	CRCP	7	18	2	1	0	.63	6.3	6.3	12.1	2.5	10.1	0.79	6.2	240	94	0	0	3	0.00	0	0	.	7.2
32	57	S	219.49	224.14	5	JRCP	10	24	2	0	0	.33	6.0	6.0	13.1	2.5	9.1	0.60	6.5	343	91	0	0	30	0.21	2	0	0	6.3
33	57	S	224.14	228.18	5	JRCP	10	25	2	0	1	.33	6.0	6.0	13.1	2.5	9.1	0.60	6.5	343	91	0	0	23	0.13	0	1	0	5.4
34	57	S	228.18	232.50	5	CRCP	8	25	2	0	0	.63	6.5	6.5	13.1	2.5	9.1	0.60	6.5	343	91	31	3	15	0.00	0	0	.	6.2
35	57	S	232.50	233.58	5	JRCP	10	25	2	0	1	.33	6.0	6.0	13.1	2.5	9.1	0.60	6.5	343	91	0	0	18	0.18	0	1	0	6.2
36	57	S	233.58	236.80	5	JROL	10	2	2	.	.	.	3.2	3.2	16.1	2.5	1.1	0.60	6.5	343	91	0	0	10	0.07	11	.	.	9.0
37	57	S	236.80	237.71	5	JROL	10	2	2	.	.	.	3.2	3.2	16.1	2.5	2.1	0.92	11.4	343	91	0	0	0	0.00	0	.	.	9.0
38	57	S	237.71	243.10	5	CROL	7	4	2	.	.	.	3.2	3.2	13.1	2.5	4.1	0.92	7.5	343	91	0	0	28	0.02	0	.	.	7.5
39	57	S	243.10	245.22	5	CRCP	7	19	2	1	0	.63	6.3	6.3	13.1	2.5	10.1	0.84	7.5	343	91	0	0	3	0.00	2	0	.	7.0
40	57	S	245.22	250.45	5	CRCP	7	18	2	1	0	.63	6.3	6.3	12.1	2.5	10.1	0.84	7	343	91	0	0	9	0.00	1	0	.	6.4

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Table C.1- Sample network database (continued).

SEC #	ROUTE	DIR	BEGIN	END	DIST	TYPE	THK	AGE	LANES	BASE	DRAIN	SDIAM	SSPAC	OLTHK	ADT	ADTGR	CESAL	YESAL	ESALG	FI	PREC	PATCH	FPAT	FAIL	RUTFL	DETJT	DCRK	PUMP	CRS
41	57	S	250.45	255.83	5	CRCP	7	17	2	1	0	.63	6.3	6.3	11.1	2.5	10.1	0.82	6.9	343	91	0	0	20	0.00	20	0	.	7.0
42	70	E	106.70	108.50	5	CROL	8	2	2	.	.	.	3.2	3.2	11.1	2.5	3.1	1.43	9.5	176	97	0	0	0	0.12	0	.	.	9.0
43	70	E	108.50	109.70	5	CROL	8	2	2	.	.	.	3.2	3.2	11.1	2.5	3.1	1.43	9.5	176	97	0	0	0	0.10	0	.	.	9.0
44	70	E	109.70	116.98	5	CROL	8	2	2	.	.	.	3.2	3.2	11.1	2.5	3.1	1.43	9.5	176	97	0	0	0	0.12	0	.	.	9.0
45	70	E	116.98	118.40	5	CROL	8	5	2	.	.	.	3.0	3.0	11.1	2.5	7.1	1.43	9.5	176	97	0	0	0	0.20	0	.	.	7.5
46	70	E	118.40	119.12	5	CRCP	8	17	2	1	0	.63	6.5	6.5	11.1	2.5	17.1	1.43	4.2	176	97	0	0	0	0.00	0	1	.	6.9
47	70	E	119.12	121.45	5	CROL	8	5	2	.	.	.	3.0	3.0	11.1	2.5	6.1	1.13	4.2	176	97	0	0	5	0.08	0	.	.	7.6
48	70	E	121.45	125.50	5	CRCP	8	17	2	1	0	.63	6.5	6.5	11.1	2.5	15.1	1.13	4.2	176	97	4	0	188	0.00	0	1	.	6.1
49	70	E	125.50	129.50	5	CROL	8	1	2	.	.	.	3.2	3.2	11.1	2.5	1.1	1.13	4.2	176	97	0	0	0	0.00	0	.	.	9.0
50	70	E	129.50	134.40	5	CROL	8	0	2	.	.	.	3.2	3.2	12.1	2.5	0.1	1.13	4.2	176	97	0	0	0	0.00	0	.	.	9.0
51	70	E	134.40	136.90	5	CROL	8	3	2	.	.	.	3.2	3.2	12.1	2.5	3.1	1.13	4.2	176	97	0	0	0	0.28	0	.	.	8.3
52	70	E	136.90	141.20	5	CROL	8	0	2	.	.	.	3.0	3.0	12.1	2.5	0.1	1.13	4.2	176	97	0	0	0	0.00	0	.	.	9.0
53	70	E	141.20	146.70	5	CRCP	8	17	2	1	0	.63	6.5	6.5	12.1	2.5	15.1	1.13	4.2	176	97	0	0	0	0.00	0	1	.	6.6
54	70	E	146.70	155.75	5	CROL	8	8	2	.	.	.	5.0	5.0	13.1	2.5	9.1	1.10	0.2	176	97	0	0	3	0.07	1	.	.	7.0
55	70	W	106.70	107.50	5	CROL	8	2	2	.	.	.	3.2	3.2	11.1	2.5	3.1	1.43	9.5	176	97	0	0	0	0.12	0	.	.	8.6
56	70	W	107.50	108.80	5	CROL	8	2	2	.	.	.	3.2	3.2	11.1	2.5	3.1	1.43	9.5	176	97	0	0	0	0.09	0	.	.	8.6
57	70	W	108.80	110.50	5	CROL	8	2	2	.	.	.	3.2	3.2	11.1	2.5	3.1	1.43	9.5	176	97	0	0	0	0.09	0	.	.	8.6
58	70	W	110.50	115.00	5	CROL	8	1	2	.	.	.	3.2	3.2	11.1	2.5	1.1	1.43	9.5	176	97	0	0	0	0.04	0	.	.	9.0
59	70	W	115.00	116.20	5	CROL	8	2	2	.	.	.	3.2	3.2	11.1	2.5	3.1	1.43	9.5	176	97	0	0	0	0.14	0	.	.	8.7
60	70	W	116.20	119.78	5	CRCP	8	17	2	1	0	.63	6.5	6.5	11.1	2.5	17.1	1.43	9.5	176	97	0	0	0	0.00	0	0	.	6.8
61	70	W	119.78	123.76	5	CROL	8	5	2	.	.	.	3.0	3.0	11.1	2.5	6.1	1.13	4.2	176	97	0	0	0	0.16	0	.	.	6.8
62	70	W	123.76	125.52	5	CRCP	8	17	2	1	0	.63	6.5	6.5	11.1	2.5	15.1	1.13	4.2	176	97	0	0	0	0.00	0	1	.	6.8
63	70	W	125.52	129.31	5	CROL	8	5	2	.	.	.	3.0	3.0	11.1	2.5	6.1	1.13	4.2	176	97	0	0	10	0.12	0	.	.	7.4
64	70	W	129.31	135.00	5	CROL	8	0	2	.	.	.	3.2	3.2	12.1	2.5	0.1	1.13	4.2	176	97	0	0	0	0.00	0	.	.	9.0
65	70	W	135.00	141.20	5	CROL	8	3	2	.	.	.	3.2	3.2	12.1	2.5	3.1	1.13	4.2	176	97	0	0	0	0.26	0	.	.	8.4
66	70	W	141.20	146.70	5	CRCP	8	17	2	1	0	.63	6.5	6.5	12.1	2.5	15.1	1.13	4.2	176	97	0	0	0	0.00	0	1	.	6.6
67	70	W	146.70	155.75	5	CROL	8	8	2	.	.	.	5.0	5.0	13.1	2.5	9.1	1.10	0.2	176	97	0	0	12	0.11	2	.	.	7.0
68	72	E	21.24	29.10	5	CRCP	8	12	2	1	0	.63	6.5	6.5	7.1	2.5	3.1	0.27	4	240	94	0	0	1	0.00	0	0	.	8.0
69	72	E	29.10	31.39	5	CRCP	8	12	2	1	0	.63	6.5	6.5	6.1	2.5	3.1	0.29	4.8	240	94	0	0	5	0.00	0	0	.	8.0
70	72	E	31.39	34.36	5	CRCP	8	12	2	1	0	.63	6.5	6.5	5.1	2.5	3.1	0.27	4.8	240	94	11	0	0	0.00	0	0	.	8.0
71	72	E	34.36	37.55	5	CRCP	8	12	2	1	0	.63	6.5	6.5	5.1	2.5	3.1	0.27	4.8	240	94	0	0	10	0.00	0	0	.	8.0
72	72	E	37.55	41.87	5	CRCP	8	15	2	1	0	.63	6.5	6.5	6.1	2.5	3.1	0.29	4.7	240	94	0	0	13	0.00	10	0	.	7.8
73	72	E	41.87	48.40	5	CRCP	8	12	2	1	0	.63	6.5	6.5	6.1	2.5	4.1	0.32	4.7	240	94	3	0	13	0.00	1	0	.	7.6
74	72	E	48.40	53.42	5	CRCP	8	12	2	2	0	.63	6.5	6.5	6.1	2.5	3.1	0.33	4.8	240	94	0	0	6	0.00	0	0	.	7.5
75	72	E	53.42	58.06	5	CRCP	8	12	2	2	0	.63	6.5	6.5	6.1	2.5	3.1	0.33	4.8	240	94	0	0	0	0.00	0	0	.	7.6
76	72	E	58.06	62.88	5	CRCP	8	12	2	2	0	.63	6.5	6.5	6.1	2.5	3.1	0.33	4.8	240	94	0	0	3	0.00	0	1	.	7.0
77	72	E	62.88	67.66	5	JRCP	10	26	2	0	1	.33	6.0	6.0	8.1	2.5	3.1	0.33	4.8	240	94	7	0	10	0.16	6	0	0	6.9
78	72	E	67.66	72.85	5	CROL	7	5	2	.	.	.	4.0	4.0	8.1	2.5	2.1	0.33	4.8	240	94	0	0	4	0.09	0	.	.	7.9
79	72	E	72.85	78.25	5	CROL	7	5	2	.	.	.	3.0	3.0	8.1	2.5	2.1	0.33	4.8	343	91	0	0	13	0.07	6	.	.	7.5
80	72	W	21.24	29.10	5	CRCP	8	12	2	1	0	.63	6.5	6.5	7.1	2.5	3.1	0.27	4	240	94	0	0	3	0.00	1	0	.	8.0

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Table C.1- Sample network database (continued)

SEC #	ROUTE	DIR	BEGIN	END	DIST	TYPE	THK	AGES	LANES	BASE	DRAIN	SDIAM	SSPAC	OLTHK	ADT	ADTGR	CESAL	YESAL	ESALO	FI	PREC	PATCH	FPAT	FAIL	RUTFL	DETJT	DCRK	PUMP	CRS
81	72	W	29.10	31.39	5	CRCP	8	12	2	1	0	.63	6.5	6.5	6.1	2.5	3.1	0.29	4.8	240	94	0	0	0	0.00	0	0	.	8.0
82	72	W	31.39	34.36	5	CRCP	8	12	2	1	0	.63	6.5	6.5	5.1	2.5	3.1	0.27	4.8	240	94	0	0	3	0.00	0	0	.	8.0
83	72	W	34.36	37.55	5	CRCP	8	12	2	1	0	.63	6.5	6.5	5.1	2.5	3.1	0.27	4.8	240	94	0	0	0	0.00	0	0	.	8.0
84	72	W	37.55	41.87	5	CRCP	8	15	2	1	0	.63	6.5	6.5	6.1	2.5	3.1	0.29	4.7	240	94	0	0	6	0.00	6	0	.	7.8
85	72	W	41.87	48.40	5	CRCP	8	12	2	1	0	.63	6.5	6.5	6.1	2.5	4.1	0.32	4.7	240	94	8	0	14	0.00	0	0	.	7.6
86	72	W	48.40	53.42	5	CRCP	8	12	2	2	0	.63	6.5	6.5	6.1	2.5	3.1	0.33	4.8	240	94	0	0	7	0.00	0	0	.	7.5
87	72	W	53.42	58.06	5	CRCP	8	12	2	2	0	.63	6.5	6.5	6.1	2.5	3.1	0.33	4.8	240	94	1	0	6	0.00	0	1	.	7.6
88	72	W	58.06	62.88	5	CRCP	8	12	2	2	0	.63	6.5	6.5	6.1	2.5	3.1	0.33	4.8	240	94	7	0	23	0.00	5	1	.	7.0
89	72	W	62.88	67.66	5	JRCP	10	26	2	0	1	.33	6.0	6.0	8.1	2.5	3.1	0.33	4.8	240	94	0	0	18	0.12	0	0	0	6.9
90	72	W	67.66	72.85	5	CROL	7	5	2	.	.	.	4.0	4.0	8.1	2.5	2.1	0.33	4.8	240	94	0	0	0	0.12	0	.	.	7.9
91	72	W	72.85	78.25	5	CROL	7	5	2	.	.	.	3.0	3.0	8.1	2.5	2.1	0.33	4.8	343	91	0	0	3	0.09	0	.	.	7.5
92	74	E	155.04	160.22	5	CROL	8	3	2	.	.	.	3.2	3.2	8.1	2.5	2.1	0.81	7.8	240	94	1	0	0	0.03	0	.	.	8.4
93	74	E	160.22	163.07	5	CRCP	8	17	2	1	0	.63	6.5	6.5	9.1	2.5	9.1	0.79	8	240	94	0	0	0	0.00	0	0	.	7.3
94	74	E	163.07	166.87	5	CROL	7	5	2	.	.	.	3.0	3.0	9.1	2.5	4.1	0.79	8	240	94	0	0	3	0.39	3	.	.	7.4
95	74	E	166.87	171.50	5	CRCP	7	17	2	1	0	.63	6.3	6.3	9.1	2.5	9.1	0.79	8.6	240	94	0	0	11	0.00	0	0	.	7.5
96	74	E	171.50	178.49	5	CROL	7	7	2	.	.	.	4.5	4.5	15.1	2.5	5.1	0.87	9.4	343	91	0	0	6	0.14	4	.	.	7.7
97	74	E	178.49	179.91	5	JRCP	10	24	2	0	1	.33	6.0	6.0	18.1	2.5	11.1	0.87	5.2	343	91	0	0	40	0.16	0	0	0	5.7
98	74	E	179.91	184.15	5	JRCP	10	30	2	0	0	.33	6.0	6.0	24.1	2.5	15.1	1.01	5.2	343	91	5	0	68	0.23	10	0	0	5.2
99	74	E	184.15	194.49	5	JROL	10	9	2	.	.	.	3.0	3.0	15.1	2.5	8.1	0.95	5.3	343	91	1	0	42	0.19	2	.	.	9.0
100	74	E	194.49	197.77	5	JROL	10	1	2	.	.	.	3.2	3.2	13.1	2.5	1.1	0.95	5.9	343	91	0	0	0	0.00	0	.	.	9.0
101	74	E	197.77	200.27	5	JROL	10	1	2	.	.	.	3.2	3.2	13.1	2.5	1.1	0.95	5.8	343	91	0	0	0	0.00	0	.	.	9.0
102	74	E	200.27	205.95	5	JROL	10	1	2	.	.	.	3.2	3.2	13.1	2.5	1.1	0.95	6.3	343	91	0	0	0	0.00	0	.	.	9.0
103	74	E	205.95	208.30	5	JROL	10	1	2	.	.	.	3.2	3.2	13.1	2.5	1.1	0.95	5.6	343	91	0	0	0	0.00	0	.	.	9.0
104	74	E	208.30	210.40	5	JROL	10	4	2	.	.	.	3.2	3.2	11.1	2.5	4.1	0.93	5.6	343	91	0	0	5	0.07	8	.	.	8.4
105	74	E	210.40	214.89	5	JRCP	10	24	2	0	1	.33	6.0	6.0	8.1	2.5	13.1	0.92	5.3	343	91	3	0	25	0.19	0	1	0	5.2
106	74	E	214.89	220.09	5	JRCP	10	24	2	0	1	.33	6.0	6.0	10.1	2.5	13.1	0.92	5.3	343	91	0	0	32	0.11	19	1	0	5.2
107	74	W	155.04	160.22	5	CROL	8	3	2	.	.	.	3.2	3.2	8.1	2.5	2.1	0.81	7.8	240	94	0	0	7	0.09	6	.	.	8.4
108	74	W	160.22	163.07	5	CRCP	8	17	2	1	0	.63	6.5	6.5	9.1	2.5	9.1	0.79	8	240	94	0	0	0	0.00	0	0	.	7.3
109	74	W	163.07	166.87	5	CROL	7	5	2	.	.	.	3.0	3.0	9.1	2.5	4.1	0.79	8	240	94	0	0	4	0.16	4	.	.	7.4
110	74	W	166.87	171.50	5	CRCP	7	17	2	1	0	.63	6.3	6.3	9.1	2.5	9.1	0.79	8.6	240	94	0	0	8	0.00	0	0	.	7.5
111	74	W	171.50	178.49	5	CROL	7	7	2	.	.	.	4.5	4.5	15.1	2.5	5.1	0.87	9.4	343	91	0	1	9	0.20	2	.	.	7.7
112	74	W	178.49	179.91	5	JRCP	10	24	2	0	1	.33	6.0	6.0	18.1	2.5	11.1	0.87	5.2	343	91	0	0	0	0.16	0	0	0	5.7
113	74	W	179.91	184.15	5	JRCP	10	30	2	0	0	.33	6.0	6.0	24.1	2.5	15.1	1.01	5.2	343	91	3	0	40	0.18	24	0	0	5.2
114	74	W	184.15	194.49	5	JROL	10	9	2	.	.	.	3.0	3.0	15.1	2.5	8.1	0.95	5.3	343	91	0	0	17	0.30	17	.	.	6.0
115	74	W	194.49	197.77	5	JROL	10	1	2	.	.	.	3.2	3.2	13.1	2.5	1.1	0.95	5.9	343	91	0	0	10	0.00	0	.	.	9.0
116	74	W	197.77	200.27	5	JROL	10	1	2	.	.	.	3.2	3.2	13.1	2.5	1.1	0.95	5.8	343	91	0	0	0	0.00	0	.	.	9.0
117	74	W	200.27	205.95	5	JROL	10	1	2	.	.	.	3.2	3.2	13.1	2.5	1.1	0.95	6.3	343	91	0	0	0	0.00	0	.	.	9.0
118	74	W	205.95	208.30	5	JROL	10	1	2	.	.	.	3.2	3.2	13.1	2.5	1.1	0.95	5.6	343	91	0	0	0	0.00	0	.	.	9.0
119	74	W	208.30	210.40	5	JROL	10	4	2	.	.	.	3.2	3.2	11.1	2.5	4.1	0.93	5.6	343	91	0	0	0	0.07	0	.	.	8.4
120	74	W	210.40	214.89	5	JRCP	10	24	2	0	1	.33	6.0	6.0	8.1	2.5	13.1	0.92	5.3	343	91	0	0	15	0.10	0	1	0	5.2
121	74	W	214.89	220.09	5	JRCP	10	24	2	0	1	.33	6.0	6.0	10.1	2.5	13.1	0.92	5.3	343	91	0	0	22	0.13	22	1	0	5.2

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Appendix D: Sample ILLINET Reports

This appendix includes a sample of each report available in ILLINET. A sample of the following reports is brought here.

1. Network Summary Report (Figure D.1).
2. Project Summary Report (Figure D.2).
3. Project Detailed Report (Figure D.3).

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*******************************************
*                                         *
*   ILLINOIS PAVEMENT FEEDBACK SYSTEM     *
*    NETWORK REHAB MANAGEMENT PROGRAM     *
*                                         *
*             ILLINET 2.0                 *
*        REVISED: 26 JUL 1990             *
*                                         *
*******************************************
*                                         *
* NETWORK SUMMARY FOR:                    *
* REHAB SELECTION:    LIFE CYCLE COST     *
* NETWORK ALGORITHM: NEEDS                *
* MEASURE OF BENEFIT: LIFE                *
*                                         *
*******************************************
```

NUMBER OF SECTIONS: 121
AVERAGE NETWORK CRS: 7.61
TOTAL COST (M$): 103.78

TOTAL LENGTH: 517.3 MI.
% VMT BACKLOG: .0
TOTAL BENEFIT: 17.05

YEAR	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
AVERAGE CRS	8.0	8.0	7.8	7.5	7.5	7.5	7.5	7.5	7.4	7.4
REMAINING LIFE (YRS)	11.2	10.8	9.8	8.9	8.8	8.5	8.7	8.8	8.4	8.1
% VMT BACKLOG	0	0	0	0	0	0	0	0	0	0
% BACKLOG MILES	0	0	0	0	0	0	0	0	0	0
% ACCRUING MILES	0	0	0	0	0	0	0	0	0	0
% ADEQUATE MILES	100	100	100	100	100	100	100	100	100	100
PRT 1-2 YEARS (% MILES)	8	2	10	12	16	14	11	13	10	11
PRT 3-5 YEARS (% MILES)	13	25	22	25	18	18	20	26	27	25
PRT 6-10 YEARS (% MILES)	24	15	15	25	26	30	35	23	26	26
PRT 10+ YEARS (% MILES)	56	57	53	38	39	38	34	38	37	37
RECONSTRUCTED MILES	12	0	0	0	4	0	10	4	0	0
3 IN AC OVERLAY MILES	4	11	0	1	4	11	5	10	30	27
5 IN AC OVERLAY MILES	7	0	0	0	18	5	17	22	0	0
PATCHED MILES	31	26	4	5	19	27	9	5	5	5
ADDED CRS AREA	9.2	2.9	.2	.4	6.9	5.7	8.8	8.6	4.9	4.8
REDUCED USER COST	121.3	45.3	2.4	4.9	86.0	59.7	92.4	101.3	66.8	68.7
ADDED LIFE	1.28	.57	.04	.06	.91	.82	1.13	1.12	.65	.67
ADDED VMT	16.1	7.2	.4	.7	11.4	8.3	12.1	12.8	8.9	9.1
ANNUAL COST (M$)	14.8	5.1	.6	.7	14.1	8.6	19.3	17.5	12.3	10.7

Figure D.1- Sample network summary report.

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*******************************************
*                                         *
*    ILLINOIS PAVEMENT FEEDBACK SYSTEM    *
*     NETWORK REHAB MANAGEMENT PROGRAM    *
*                                         *
*              ILLINET 2.0                *
*          REVISED: 26 JUL 1990           *
*                                         *
*******************************************
*                                         *
* PROJECT SUMMARY FOR:                    *
* REHAB SELECTION:    LIFE CYCLE COST     *
* NETWORK ALGORITHM: NEEDS                *
* MEASURE OF BENEFIT: LIFE                *
*                                         *
*******************************************
```

PROGRAM PARAMETERS

MINIMUM CRS = 6.0
INFLATION = 5.0%

REHAB DECISION LEGEND

- \- = MAINTENANCE ONLY
- P = PATCHING
- 3 = 3 IN AC OVERLAY
- 5 = 5 IN AC OVERLAY
- R = RECONSTRUCTION

ALL COSTS ARE IN THOUSANDS.

ROUTE BMP	LENGTH	LANES	TYPE	AGE	CRS	REHAB DECISIONS & COST FOR YRS 1-2		YEARS 3-5		YEARS 6-10	
57-N-168.30	3.59	2	10" JRCP	24	5.0	P-	467	---	0	---3-	1745
57-N-171.89	5.00	2	10" JRCP	24	6.0	-P	669	---	0	^H ---P-	1163
57-N-176.89	4.21	2	10" JROL	5	8.7	--	0	---	0	-----	0
57-N-181.10	2.69	2	8" CROL	1	9.0	--	0	---	0	-----	0
57-N-183.79	6.81	2	8" CRCP	22	4.2	P-	929	---	0	-----	0
57-N-190.60	8.62	2	7" CROL	9	8.1	--	0	---	0	-----	0
57-N-199.22	4.60	2	7" CRCP	19	5.6	P-	439	---	0	--5--	2136
57-N-203.82	3.85	2	7" CRCP	19	9.0	--	0	---	0	--5--	1788
57-N-207.67	4.28	2	7" CRCP	19	7.5	--	0	--P	449	----3	1796
57-N-211.95	3.84	2	7" CRCP	18	8.5	--	0	---	0	-5---	1698
57-N-215.79	3.70	2	7" CRCP	18	8.3	--	0	---	0	P---3	1883
57-N-219.49	4.65	2	10" JRCP	24	7.2	--	0	---	0	P----	593
57-N-224.14	4.04	2	10" JRCP	25	7.8	--	0	---	0	-P---	853
57-N-228.18	5.40	2	10" JRCP	25	7.0	--	0	--P	607	-----	0
57-N-233.58	3.22	2	10" JROL	2	8.8	--	0	---	0	-----	0
57-N-236.80	.91	2	10" JROL	2	8.8	--	0	---	0	-----	0
57-N-237.71	5.39	2	7" CROL	4	6.0	-3	939	---	0	-----	0
57-N-243.10	2.12	2	7" CRCP	19	1.0	5-	969	---	0	-----	0
57-N-245.22	5.23	2	7" CRCP	18	5.3	P-	547	---	0	-3---	1832
57-N-250.45	5.38	2	7" CRCP	17	8.3	--	0	---	0	P---3	2851
57-S-168.30	3.59	2	10" JRCP	24	1.0	R-	2154	---	0	-----	0
57-S-171.89	5.00	2	10" JRCP	24	5.6	P-	850	---	0	--P--	1003
57-S-176.89	4.21	2	10" JROL	5	8.8	--	0	---	0	-----	0
57-S-181.10	2.69	2	8" CROL	1	9.0	--	0	---	0	-----	0
57-S-183.79	6.81	2	8" CRCP	22	6.9	--	0	---	0	P----	751
57-S-190.60	8.62	2	7" CROL	9	8.1	--	0	---	0	-----	0
57-S-199.22	4.60	2	7" CRCP	19	6.9	--	0	-P-	484	---3-	1746
57-S-203.82	3.85	2	7" CRCP	19	9.0	--	0	---	0	--5--	1788
57-S-207.67	4.28	2	7" CRCP	19	9.0	--	0	---	0	--5--	1987
57-S-211.95	3.84	2	7" CRCP	18	8.2	--	0	---	0	P---3	1976

Figure D.2- Sample project summary report.

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57-S-215.79	3.70	2	7" CRCP	18	8.5	--	0	---	0	-5---	1636
57-S-219.49	4.65	2	10" JRCP	24	6.3	-P	452	---	0	---3-	2123
57-S-224.14	4.04	2	10" JRCP	25	7.2	--	0	--P	614	-----	0
57-S-228.18	4.32	2	8" CRCP	25	6.1	-P	392	---	0	-----	0
57-S-232.50	1.08	2	10" JRCP	25	7.0	--	0	--P	148	-----	0
57-S-233.58	3.22	2	10" JROL	2	8.6	--	0	---	0	-----	0
57-S-236.80	.91	2	10" JROL	2	9.0	--	0	---	0	-----	0
57-S-237.71	5.39	2	7" CROL	4	6.1	-3	939	---	0	-----	0
57-S-243.10	2.12	2	7" CRCP	19	8.5	--	0	---	0	P---3	1154
57-S-245.22	5.23	2	7" CRCP	18	7.5	--	0	--5	2069	-----	0
57-S-250.45	5.38	2	7" CRCP	17	5.8	P-	489	---	0	-P---	655
70-E-106.70	1.80	2	8" CROL	2	8.7	--	0	---	0	-----	0
70-E-108.50	1.20	2	8" CROL	2	8.7	--	0	---	0	-----	0
70-E-109.70	7.28	2	8" CROL	2	8.7	--	0	---	0	-----	0
70-E-116.98	1.42	2	8" CROL	5	8.5	--	0	---	0	-----	0
70-E-118.40	.72	2	8" CRCP	17	9.0	--	0	-3-	229	-----	0
70-E-119.12	2.33	2	8" CROL	5	8.3	--	0	---	0	-----	0
70-E-121.45	4.05	2	8" CRCP	17	1.0	R-	2430	---	0	-----	0
70-E-125.50	4.00	2	8" CROL	1	9.0	--	0	---	0	-----	0
70-E-129.50	4.90	2	8" CROL	0	9.0	--	0	---	0	-----	0
70-E-134.40	2.50	2	8" CROL	3	8.2	--	0	---	0	-----	0
70-E-136.90	4.30	2	8" CROL	0	9.0	--	0	---	0	-----	0
70-E-141.20	5.50	2	8" CRCP	17	9.0	--	0	--5	2267	-----	0
70-E-146.70	9.05	2	8" CROL	8	8.5	--	0	---	0	-----	0
70-W-106.70	.80	2	8" CROL	2	8.7	--	0	---	0	-----	0
70-W-107.50	1.30	2	8" CROL	2	8.8	--	0	---	0	-----	0
70-W-108.80	1.70	2	8" CROL	2	8.8	--	0	---	0	-----	0
70-W-110.50	4.50	2	8" CROL	1	8.9	--	0	---	0	-----	0
70-W-115.00	1.20	2	8" CROL	2	8.6	--	0	---	0	-----	0
70-W-116.20	3.58	2	8" CRCP	17	9.0	--	0	--3	1158	-----	0
70-W-119.78	3.98	2	8" CROL	5	8.6	--	0	---	0	-----	0
70-W-123.76	1.76	2	8" CRCP	17	9.0	--	0	--5	725	-----	0
70-W-125.52	3.79	2	8" CROL	5	7.7	--	0	---	0	----3	976
70-W-129.31	5.69	2	8" CROL	0	9.0	--	0	---	0	-----	0
70-W-135.00	6.20	2	8" CROL	3	8.3	--	0	---	0	-----	0
70-W-141.20	5.50	2	8" CRCP	17	9.0	--	0	--5	2267	-----	0
70-W-146.70	9.05	2	8" CROL	8	7.5	--	0	---	0	-----	0
72-E- 21.24	7.86	2	8" CRCP	12	8.8	--	0	---	0	-----	0
72-E- 29.10	2.29	2	8" CRCP	12	8.2	--	0	---	0	-----	0
72-E- 31.39	2.97	2	8" CRCP	12	9.0	--	0	---	0	-----	0
72-E- 34.36	3.19	2	8" CRCP	12	7.4	--	0	---	0	-----	0
72-E- 37.55	4.32	2	8" CRCP	15	6.9	--	0	---	0	-----	0
72-E- 41.87	6.53	2	8" CRCP	12	6.9	--	0	---	0	-----	0
72-E- 48.40	5.02	2	8" CRCP	12	8.0	--	0	---	0	-5---	2189
72-E- 53.42	4.64	2	8" CRCP	12	9.0	--	0	---	0	--3--	1648
72-E- 58.06	4.82	2	8" CRCP	12	8.5	--	0	---	0	-5---	2043
72-E- 62.88	4.78	2	10" JRCP	26	7.2	--	0	---	0	----P	742
72-E- 67.66	5.19	2	7" CROL	5	8.3	--	0	---	0	-----	0
72-E- 72.85	5.40	2	7" CROL	5	7.5	--	0	---	0	--5--	1748
72-W- 21.24	7.86	2	8" CRCP	12	8.5	--	0	---	0	-----	0

Figure D.2- Sample project summary report (continued).

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72-W- 29.10	2.29	2	8" CRCP	12	9.0	--	0	---	0	-----	0
72-W- 31.39	2.97	2	8" CRCP	12	8.5	--	0	---	0	-----	0
72-W- 34.36	3.19	2	8" CRCP	12	9.0	--	0	---	0	-----	0
72-W- 37.55	4.32	2	8" CRCP	15	8.0	--	0	---	0	-----	0
72-W- 41.67	6.53	2	8" CRCP	12	6.8	--	0	---	0	-----	0
72-W- 48.40	5.02	2	8" CRCP	12	7.9	--	0	---	0	3----	1617
72-W- 53.42	4.64	2	8" CRCP	12	8.0	--	0	---	0	5----	1873
72-W- 58.06	4.82	2	8" CRCP	12	5.3	5-	1613	---	0	-----	0
72-W- 62.88	4.78	2	10" JRCP	26	7.4	--	0	---	0	-----	0
72-W- 67.66	5.19	2	7" CROL	5	8.7	--	0	---	0	-----	0
72-W- 72.85	5.40	2	7" CROL	5	8.4	--	0	---	0	-----	0
74-E-155.04	5.18	2	8" CROL	3	8.9	--	0	---	0	-----	0
74-E-160.22	2.85	2	8" CRCP	17	9.0	--	0	---	0	---3-	1063
74-E-163.07	3.80	2	7" CROL	5	7.6	--	0	---	0	--3--	888
74-E-166.87	4.63	2	7" CRCP	17	7.2	--	0	--P	537	---3-	1726
74-E-171.50	6.99	2	7" CROL	7	8.0	--	0	---	0	-----	0
74-E-178.49	1.42	2	10" JRCP	24	6.3	-P	179	---	0	--3--	697
74-E-179.91	4.24	2	10" JRCP	30	4.3	R-	2544	---	0	-----	0
74-E-184.15	10.34	2	10" JROL	9	7.8	--	0	---	0	-----	0
74-E-194.49	3.28	3	10" JROL	1	9.0	--	0	---	0	-----	0
74-E-197.77	2.50	2	10" JROL	1	9.0	--	0	---	0	-----	0
74-E-200.27	5.68	2	10" JROL	1	9.0	--	0	---	0	-----	0
74-E-205.95	2.35	2	10" JROL	1	9.0	--	0	---	0	-----	0
74-E-208.30	2.10	2	10" JROL	4	8.7	--	0	---	0	-----	0
74-E-210.40	4.49	2	10" JRCP	24	6.7	--	0	P--	569	--R--	3791
74-E-214.89	5.20	2	10" JRCP	24	6.2	-P	833	---	0	-R---	4181
74-W-155.04	5.18	2	8" CROL	3	8.1	--	0	---	0	-----	0
74-W-160.22	2.85	2	8" CRCP	17	9.0	--	0	---	0	---3-	1063
74-W-163.07	3.80	2	7" CROL	5	8.2	--	0	---	0	----3	979
74-W-166.87	4.63	2	7" CRCP	17	7.7	--	0	---	0	3----	1572
74-W-171.50	6.99	2	7" CROL	7	7.5	--	0	---	0	---3-	1714
74-W-178.49	1.42	2	10" JRCP	24	7.9	--	0	---	0	3----	542
74-W-179.91	4.24	2	10" JRCP	30	5.2	3-	1416	---	0	-----	0
74-W-184.15	10.34	2	10" JROL	9	7.9	--	0	---	0	-----	0
74-W-194.49	3.28	2	10" JROL	1	8.8	--	0	---	0	-----	0
74-W-197.77	2.50	2	10" JROL	1	9.0	--	0	---	0	-----	0
74-W-200.27	5.68	2	10" JROL	1	9.0	--	0	---	0	-----	0
74-W-205.95	2.35	2	10" JROL	1	9.0	--	0	---	0	-----	0
74-W-208.30	2.10	2	10" JROL	4	8.8	--	0	---	0	-----	0
74-W-210.40	4.49	2	10" JRCP	24	7.7	--	0	--R	3275	-----	0
74-W-214.89	5.20	2	10" JRCP	24	6.3	-P	737	---	0	-R---	4181
						TOTAL =	19987		15398		68390

Figure D.2- Sample project summary report (continued).

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           ******************************************
           *                                        *
           *    ILLINOIS PAVEMENT FEEDBACK SYSTEM   *
           *     NETWORK REHAB MANAGEMENT PROGRAM   *
           *                                        *
           *              ILLINET 2.0               *
           *          REVISED: 26 JUL 1990          *
           *                                        *
           ******************************************
           *                                        *
           * DETAILED REPORT FOR:                   *
           * REHAB SELECTION:    LIFE CYCLE COST    *
           * NETWORK ALGORITHM: NEEDS               *
           * MEASURE OF BENEFIT: LIFE               *
           *                                        *
           ******************************************

 PROGRAM PARAMETERS                                    REHAB DECISION LEGEND

 MINIMUM CRS        =  6.0                             - = MAINTENANCE ONLY
 INFLATION          =  5.0%                            P = PATCHING
                                                       3 = 3 IN AC OVERLAY
                                                       5 = 5 IN AC OVERLAY
 ALL COSTS ARE IN THOUSANDS.                           R = RECONSTRUCTION
 FAULT AND RUT ARE IN 100THS OF ONE INCH.
 PATCHES AND FAILURES ARE IN NO. PER MILE.

                          1987  1988  1989  1990  1991  1992  1993  1994  1995  1996
*************************************************************************************
ID#  57-N-168.30      10" JRCP      LENGTH =  3.59       AGE = 24        ADT = 10.1
-------------------------------------------------------------------------------------
AVERAGE 7.60    CRS       5.0   8.6   8.2   7.9   7.5   7.1   6.6   6.2   5.7   8.2
              REHAB        P     -     -     -     -     -     -     -     3     -
TOTAL   2212   COST       467     0     0     0     0     0     0     0  1745     0
     REMAINING LIFE         8     7     6     5     4     3     2     1    10     9
               ESAL       9.1   9.8  10.5  11.2  12.0  12.9  13.8  14.8  15.9   1.2
            PATCHES        52    52    52    52    52    52    52    52   114   114
           FAILURES        52     5    11    17    24    32    41    51    62    38
       FAULT OR RUT        28     3     5     6     8     9    10    11    12     7
*************************************************************************************
ID#  57-N-171.89      10" JRCP      LENGTH =  5.00       AGE = 24        ADT = 10.1
-------------------------------------------------------------------------------------
AVERAGE 7.30    CRS       6.0   5.7   8.6   8.1   7.7   7.2   6.8   6.3   5.7   7.6
              REHAB        -     P     -     -     -     -     -     -     P     -
TOTAL   1832   COST         0   669     0     0     0     0     0     0  1163     0
     REMAINING LIFE         1     7     6     5     4     3     2     1     4     3
               ESAL       9.1   9.8  10.5  11.2  12.0  12.9  13.8  14.8  15.9  17.1
            PATCHES         0    51    51    51    51    51    51    51   114   114
           FAILURES        45    51     6    13    21    30    40    51    63    14
       FAULT OR RUT        17    18     3     5     7     8     9    10    11    12
*************************************************************************************
ID#  57-N-176.89      10" JROL      LENGTH =  4.21       AGE =  5        ADT = 11.1
-------------------------------------------------------------------------------------
AVERAGE 8.03    CRS       8.7   8.5   8.4   8.2   8.1   8.0   7.9   7.8   7.7   7.6
              REHAB        -     -     -     -     -     -     -     -     -     -
TOTAL      0   COST         0     0     0     0     0     0     0     0     0     0
     REMAINING LIFE        27    26    25    24    23    22    21    20    19    18
               ESAL       3.1   3.7   4.3   4.9   5.5   6.1   6.7   7.3   7.9   8.5
            PATCHES         0     0     0     0     0     0     0     0     0     0
           FAILURES         8    13    17    21    24    27    30    33    36    39
       FAULT OR RUT         7    10    12    15    17    19    22    24    26    28
*************************************************************************************
```

Figure D.3- Sample project detailed report.

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ID# 57-N-181.10 | 8" CROL | LENGTH = 2.69 | AGE = 1 | ADT = 11.1

AVERAGE 8.25 CRS	9.0	8.8	8.7	8.6	8.4	8.2	8.1	8.0	7.8	7.6
REHAB	-	-	-	-	-	-	-	-	-	-
TOTAL 0 COST	0	0	0	0	0	0	0	0	0	0
REMAINING LIFE	22	21	20	19	18	17	16	15	14	13
ESAL	1.1	1.7	2.3	2.9	3.5	4.1	4.7	5.3	5.9	6.5
PATCHES	0	0	0	0	0	0	0	0	0	0
FAILURES	0	1	1	2	3	4	4	5	6	7
FAULT OR RUT	0	3	6	9	12	15	17	20	22	25

ID# 57-N-183.79 | 8" CRCP | LENGTH = 6.81 | AGE = 22 | ADT = 11.1

AVERAGE 8.02 CRS	4.2	8.8	8.7	8.5	8.3	8.0	7.9	7.5	7.4	7.1
REHAB	P	-	-	-	-	-	-	-	-	-
TOTAL 929 COST	929	0	0	0	0	0	0	0	0	0
REMAINING LIFE	13	12	11	10	9	8	7	6	5	4
ESAL	8.1	8.8	9.4	10.1	10.8	11.6	12.3	13.1	13.9	14.8
PATCHES	40	40	40	40	40	40	40	40	40	40
FAILURES	30	1	2	3	4	6	7	9	10	12
FAULT OR RUT	0	0	0	0	0	0	0	0	0	0

ID# 57-N-190.60 | 7" CROL | LENGTH = 8.62 | AGE = 9 | ADT = 11.1

AVERAGE 7.42 CRS	8.1	8.1	7.9	7.8	7.6	7.4	7.3	7.1	7.0	6.8
REHAB	-	-	-	-	-	-	-	-	-	-
TOTAL 0 COST	0	0	0	0	0	0	0	0	0	0
REMAINING LIFE	14	13	12	11	10	9	8	7	6	5
ESAL	6.1	6.8	7.6	8.5	9.4	10.3	11.3	12.4	13.6	14.8
PATCHES	0	0	0	0	0	0	0	0	0	0
FAILURES	2	2	3	3	4	5	5	6	6	7
FAULT OR RUT	24	27	30	34	37	41	44	48	52	57

ID# 57-N-199.22 | 7" CRCP | LENGTH = 4.60 | AGE = 19 | ADT = 11.1

AVERAGE 7.82 CRS	5.6	8.7	8.2	7.9	7.4	6.8	6.3	5.5	8.7	8.5
REHAB	P	-	-	-	-	-	-	5	-	-
TOTAL 2575 COST	439	0	0	0	0	0	0	2136	0	0
REMAINING LIFE	7	6	5	4	3	2	1	14	13	12
ESAL	10.1	10.8	11.6	12.5	13.4	14.3	15.3	16.4	1.2	2.4
PATCHES	21	21	21	21	21	21	21	43	43	43
FAILURES	21	2	5	7	10	14	17	22	1	1
FAULT OR RUT	0	0	0	0	0	0	0	0	8	15

ID# 57-N-203.82 | 7" CRCP | LENGTH = 3.85 | AGE = 19 | ADT = 12.1

AVERAGE 7.80 CRS	9.0	8.7	8.2	7.9	7.4	6.8	6.1	5.5	8.7	8.5
REHAB	-	-	-	-	-	-	-	5	-	-
TOTAL 1788 COST	0	0	0	0	0	0	0	1788	0	0
REMAINING LIFE	7	6	5	4	3	2	1	14	13	12
ESAL	10.1	10.9	11.6	12.5	13.4	14.3	15.4	16.4	1.1	2.4
PATCHES	0	0	0	0	0	0	0	22	22	22
FAILURES	0	2	5	7	10	14	18	22	1	1
FAULT OR RUT	0	0	0	0	0	0	0	0	8	15

Figure D.3- Sample project detailed report (continued).

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*****************************************************************************
ID#  57-N-207.67      7" CRCP       LENGTH =  4.28       AGE = 19       ADT = 12.1
-----------------------------------------------------------------------------
AVERAGE 7.26    CRS    7.5   7.2   6.8   6.4   6.0   8.3   7.7   7.1   6.3   5.3
              REHAB     -     -     -     -     P     -     -     -     -     3
TOTAL   2245   COST     0     0     0     0   449     0     0     0     0  1796
     REMAINING LIFE     4     3     2     1     5     4     3     2     1    11
               ESAL  10.1  10.9  11.6  12.5  13.4  14.3  15.4  16.4  17.6  18.8
            PATCHES     0     0     0     0    19    19    19    19    19    42
           FAILURES     9    11    14    16    19     4     8    12    17    23
       FAULT OR RUT     0     0     0     0     0     0     0     0     0     0
*****************************************************************************
ID#  57-N-211.95      7" CRCP       LENGTH =  3.84       AGE = 18       ADT = 12.1
-----------------------------------------------------------------------------
AVERAGE 7.69    CRS    8.5   8.2   7.7   7.2   6.8   6.1   5.5   8.7   8.5   8.2
              REHAB     -     -     -     -     -     -     5     -     -     -
TOTAL   1698   COST     0     0     0     0     0     0  1698     0     0     0
     REMAINING LIFE     6     5     4     3     2     1    14    13    12    11
               ESAL  10.1  10.9  11.7  12.6  13.6  14.6  15.6   1.1   2.3   3.6
            PATCHES     2     2     2     2     2     2    24    24    24    24
           FAILURES     3     5     8    11    14    18    22     1     1     2
       FAULT OR RUT     0     0     0     0     0     0     0     8    15    21
*****************************************************************************
ID#  57-N-215.79      7" CRCP       LENGTH =  3.70       AGE = 18       ADT = 12.1
-----------------------------------------------------------------------------
AVERAGE 7.54    CRS    8.3   8.0   7.5   7.1   6.6   6.0   8.3   7.7   6.8   5.8
              REHAB     -     -     -     -     -     P     -     -     -     3
TOTAL   1883   COST     0     0     0     0     0   408     0     0     0  1475
     REMAINING LIFE     6     5     4     3     2     4     3     2     1    11
               ESAL  10.1  10.9  11.7  12.6  13.6  14.6  15.6  16.8  18.0  19.3
            PATCHES     0     0     0     0     0    19    19    19    19    39
           FAILURES     4     6     9    12    15    19     4     8    14    20
       FAULT OR RUT     0     0     0     0     0     0     0     0     0     0
*****************************************************************************
ID#  57-N-219.49     10" JRCP       LENGTH =  4.65       AGE = 24       ADT = 13.1
-----------------------------------------------------------------------------
AVERAGE 6.95    CRS    7.2   6.9   6.6   6.3   6.0   5.7   8.3   7.7   7.2   6.5
              REHAB     -     -     -     -     -     P     -     -     -     -
TOTAL    593   COST     0     0     0     0     0   593     0     0     0     0
     REMAINING LIFE     5     4     3     2     1     6     5     4     3     2
               ESAL   9.1   9.7  10.3  11.0  11.7  12.5  13.3  14.2  15.1  16.1
            PATCHES     0     0     0     0     0    40    40    40    40    40
           FAILURES     9    14    19    25    32    40     8    18    28    40
       FAULT OR RUT    21    22    23    24    24    25     5     8    10    12
*****************************************************************************
ID#  57-N-224.14     10" JRCP       LENGTH =  4.04       AGE = 25       ADT = 13.1
-----------------------------------------------------------------------------
AVERAGE 7.16    CRS    7.8   7.5   7.1   6.8   6.5   6.1   5.6   8.3   7.8   7.1
              REHAB     -     -     -     -     -     -     P     -     -     -
TOTAL    853   COST     0     0     0     0     0     0   853     0     0     0
     REMAINING LIFE     6     5     4     3     2     1     5     4     3     2
               ESAL   9.1   9.7  10.3  11.0  11.7  12.5  13.3  14.2  15.1  16.1
            PATCHES     0     0     0     0     0     0    63    63    63    63
           FAILURES    18    24    31    38    45    54    63    10    22    34
       FAULT OR RUT     7     8     9    10    10    11    12     4     5     7
*****************************************************************************
```

Figure D.3- Sample project detailed report (continued).

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References

1. Darter, M.I., et al, "An Illinois Pavement Feedback System: Feasibility and System Requirements," Research Report 517-1, Department of Civil Engineering, University of Illinois at Urbana-Champaign, August 1985.

2. Hall, J.P., Dwiggins, M.E., Darter, M.I., Flowers, C.L., and Dubose, J.B., "Development and Implementation Methodology for the Illinois Pavement Feedback System," Proceedings, Second North American Conference on Managing Pavements, Vol. 1, pp. 1.41-1.54, 1987.

3. Artman, D.H., Liebman, J.S., and Darter, M.I., "Optimization of Long-Range Major Rehabilitation of Airfield Pavements," Transportation Research Record No. 938, Transportation Research Board, Washington, D.C., 1983.

4. Hall, K.T., Connor, J.M., Darter, M.I., and Carpenter, S.H., "Development of an Expert System for Concrete Pavement Evaluation and Rehabilitation," Proceedings, Second North American Conference on Managing Pavements, Vol. 2, pp. 2.289-2.300, 1987.

5. Darter, M.I., Becker, J.M., and Snyder, M.B., "Concrete Pavement Evaluation System (COPES)," NCHRP Report No. 277, Transportation Research Board, 1985.

6. LaCoursiere, S.A., Darter, M.I., and Smiley, S.A., "Performance of Continuously Reinforced Concrete Pavement in Illinois," Research Report 901-1, Illinois Cooperative Research Program, University of Illinois, December, 1978.

7. Shahin, M.Y., Kohn, S.D., Lytton, R.L., and McFarland, W.F., "Pavement Budget Optimization Using the Incremental Benefit-Cost Technique," Proceedings, North American Pavement Management Conference, Vol. 3, pp. 6.96-6.107, 1985.

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8. Kher, Ramesh K. and Cook, Wade D., "PARS The MTC Model for Program and Financial Planning in Pavement Rehabilitation," Proceedings, North American Pavement Management Conference, Vol. 2, pp. 6.23-6.40, 1985.

9. Haas, Ralph, Karan, M.A., Cheetman, A., and Khalil, Sue, "Pavement rehabilitation Programming: A Range of Options," Proceedings, North American Pavement Management Conference, Vol. 2, pp. 6.41-6.66, 1985.

10. Ullidtz, Per, "A Danish Pavement Management System," Proceedings, North American Pavement Management Conference, Vol. 2, pp. 6.85-6.95, 1985.

11. Cook, Wade D. and Lytton, Robert L., "Recent Developments and Potential Future Directions in Ranking and Optimization Procedures for Pavement Management," Proceedings, Second North American Conference on Managing Pavements, Vol. 2, pp. 2.135-2.155, 1987.

12. Paterson, William D.O. and Fossberg, Per E., "Achieving Efficiency in Planning and Programming Through Network-Level Policy Optimization and Pavement Management," Proceedings, Second North American Conference on Managing Pavements, Vol. 2, pp. 2.183-2.194, 1987.

13. Thompson, Paul D., Neumann, Lance A., Miettinen, Martti, and Talvitie, Antti, "A Micro-Computer Markov Dynamic Programming System for Pavement Management in Finland," Proceedings, Second North American Conference on Managing Pavements, Vol. 2, pp. 2.241-2.252, 1987.

14. Lytton, Robert L., "Concepts of Pavement Performance Prediction and Modeling," Proceedings, Second North American Conference on Managing Pavements, Vol. 2, pp. 2.3-2.19, 1987.

15. Haas, Ralph and Hudson, Ronald W., Pavement Management Systems, McGraw-Hill, 1978.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission. www.manaraa.com

16. Karan, M.A., Haas, R.C.G., Cheetham, A., Christison, T.J., and Khalil, S.M., "Development and Implementation of a New Rehabilitation Information and Priority Programming System (RIPPS), "Transportation Research Record No. 997, Transportation Research Board, Washington, D.C., 1984.

17. Smith, Roger E., Shahin, Mohammad Y., Darter, Michael I., and Carpenter, Samuel H., "A Comprehensive Ranking System for Local Agency Pavement Management, "Transportation Research Record No. 997, Transportation Research Board, Washington, D.C., 1987.

18. Jackson, Newt , "Operation of Washington State Pavement Management System, "Transportation Research Record No. 1048, Transportation Research Board, Washington, D.C., 1985.

19. Uzarski, D.R. and Darter, M.I., "Comparing Different Strategies for Selecting Pavement Sections for Major Repair," Transportation Research Record No. 1060, Transportation Research Board, Washington, D.C., 1986.

20. Watanatada, Thawat, Harral, Clell, G., Paterson, William D.O., Dhareshwar, Ashok M., Bhandari, Anil, and Tsunokawa, Kojil, The highway Design and Maintenance Standards Model, Volume 1- Description of the HDM-III Model, A World Bank Publication, The John Hopkins University Press, 1987.

21. Watanatada, Thawat, Dhareshwar, Ashok M., Lima, Paulo Roberto S. Rezende, Vehicle Speeds and Operation Costs, The highway Design and Maintenance Standards Series, A World Bank Publication, The John Hopkins University Press, 1987.

22. McFarland, William F., "Benefit Analysis for Pavement Design Systems," A System Analysis of Pavement Design and Research Implementation, Texas Transportation Institute, April 1972.

23. Khatami, Ali, George, K. P., "Network Level Optimization / Prioritization of Pavement Rehabilitation," Transportation Research Record No. 1196, Transportation Research Board, Washington, D.C., 1988.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission. www.manaraa.com

24. Finn, F., Peterson, D. and Kulkurani, R., "AASHTO Guidelines for Pavement Management Systems," Final Report Project 20-7, Task 38, Prepared for Transportation Research Board, ARE Inc, November 1989.

25. Nelson, Thomas L. and LeClerc, R. V., "Developments and Implementation of Washington State's Pavement Management System," Washington State Department of Transportation, Technical Report No. WA-RD 50.1, February 1983.

26. Uddin, Waheed, Carmichael III, R. F., and Hudson, W.R., "Life Cycle Analysis for Pavement Management," Texas Research and Development Foundation, March 1986.

27. Schrage, Linus, Linear, Integer and Quadratic Programming with LINDO, Third Edition, The Scientific Press, 1986.

28. Yoder, E. J. and Witczak, M. W., Principles of Pavement Design, Second Edition, John Wiley & Sons, Inc., 1975.

29. Oglesby, Clarkson H. and Hicks, R. Gary, Highway Engineering, Fouth Edition, John Wiley & Sons, Inc., 1982.

30. Meredith, Dale D., Wong, Kam W., Woodhead Ronald W., and Wortman, Robert H., Design and Planning of Engineering Systems, Prentice Hall, Inc., 1973.

31. Thuesen, G. J. and Fabrycky, W. J., Engineering Economy, Sixth Edition, Prentice Hall, Inc., 1984.

32. Microsoft Fortran User's Guide, Version 5, Microsoft Corporation, 1987-1989.

33. Microsoft Quick Basic User's Guide, Version 4.5, Microsoft Corporation, 1987-1989.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission. www.manaraa.com

34. Peterson, Dale E., "Pavement Management Practices," NCHRP Sunthesis of Highway Practice, No. 135, Transportation Research Board, 1987.

35. Mohseni, A., Darter, M. I., and Hall, J. P., "Pavement Management for Concrete Pavements," Proceedings, 6th International Symposium on Concrete Roads, 8-10 october, 1990.

36. "Guidelines on Pavement Management", Federal Highway Administration, 1990.

37. Kulkurani, R., Golabi, K., Finn, F., and E. Alviti, "Development of a Network Optimization System," Woodward-Clyde Consultants, San Francisco, CA, For Arizona Department of Transportation, August 1980.

38. "AASHTO Guide for Design of Pavement Structures", American Association of State Highway and Transportation Officials, 1986.

39. "Highway Pavement Distress Manual for Highway Condition and Quality of Highway Construction Survey", U.S. Department of Transportation, Federal Highway Administration, March 1979.

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