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NEW JERSEY
PAVEMENT MANAGEMENT STUDY

by

Nicholas P. Vitillo - Principal Engineer
Brian A. Margerum - Principal Research Assistant

Prepared by

New Jersey Department of Transportation
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16. Abstract

This report describes the results of an eight year study undertaken to develop an improved pavement management program for New Jersey. It details the steps undertaken to verify the accuracy of the mileposting system, the testing and calibration of procedures and equipment to measure pavement roughness and distress, the development of computerized data bases, and the first attempt at formally introducing engineering-economic theory into the decision-making process.

The current pavement management system bases priority ranking on a weighting procedure that accounts for riding quality, surface distress, and traffic volume. Tentative mathematical models of pavement performance, cost of repair, and effect of repair have been used only to study the general effects of various possible strategies and to provide general guidance. It is recommended that several of these areas be explored further in a follow-up study.

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We are grateful to the four regional Maintenance offices and the Pavement Management Group for their cooperation and assistance.

A special note of thanks is extended to the members of the Winter Assignment Program, without whose help much of our work would not have been accomplished.

IMPLEMENTATION STATEMENT

The rating and ranking procedures developed in this study have already been implemented to a large extent by the Bureaus of Maintenance, Design, and Traffic Safety Programs in their Pavement Management Priority List and Safety Improvement Programs respectively.

Equipment is currently calibrated using techniques developed in the study to insure the reliability of the data.

Our evaluations of pavement ride quality incorporates user opinion of the surface roughness through relationships developed as a satellite study to this research project {NCHRP 1-23 (2)}.

The study was responsible for initiating revisions to the State's Milepost system to insure accurate location of pavement related information.

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PART I - INTRODUCTION

1.0 OBJECTIVES

The primary objective of this research study was to revise the existing pavement selection and rehabilitation procedures by development of a Pavement Management System (PMS). The purpose of the PMS is to make the evaluation, selection, and rehabilitation process more efficient by coordinating pavement related activities (e.g., planning, design, construction, and maintenance). Pavement Management accomplishes it's purpose by formalizing an objective pavement evaluation and selection process, by developing initial pavement performance and economic models allowing prediction of future pavement condition and estimate expenditures and by compiling pavement information data bases.

New Jersey has taken its first steps on the long journey to the "ultimate" PMS. The form of our models and procedures are thus tentative. Time and experience will provide the information necessary to develop a more comprehensive system.

The objectives of this report are to summarize the structure, procedures, analyses, and computer information system of the current pavement management system, to illustrate the capabilities of the developed system, and to describe planned future enhancements.

2.0 BACKGROUND

New Jersey Department of Transportation's efforts to develop a formalized PMS was a outgrowth of an FHWA review of the Department's rehabilitation programming strategies. The Department decided to develop a PMS to formalize programming strategies and to objectively evaluation pavement condition and selection (prioritization) criteria.

In 1980, the Department organized a Pavement Management Task Force (PMTF) consisting of high level managers from Design, Maintenance, and Research units. The task force produced a report (1) which is the basis for this research study. The Department's general approach to Pavement Management was stated in the cited report as follows:

> "The economic health and stability of the State of New Jersey is to a great extent dependent on the vitality of its transportation system. Highways and, in particular, the pavement structure of those highways constitute a substantial component of the State's investment in the transportation field. For this reason, a good deal of the operational efforts of the New Jersey Department of Transportation (NJ DOT) are directed at keeping pavements at an adequate level of serviceability for the motoring public. These efforts which involve the programming, planning, design, construction, maintenance, and rehabilitation functions of the Department when taken in total are NJDOT's approach to Pavement Management" (1).

Pavement Management is the motivator or driver of all pavement related activities throughout the department. Pavement management provides the structure for coordination and feedback of pavement information. It emphasizes the state-of-the-art in laboratory, field, and computer equipment, in pavement evaluation equipment, in material sciences, in pavement design, in construction technology, and maintenance methodology. It provides the decision-makers with a basis for short- and long-term planning by projecting future needs, expenditures and benefits and optimizing use of fiscal resources. Most importantly, it acts as a conduit for the flow of information within and among the operational units of the Department. These activities help to focus on maintaining the most cost effective highway network for the tax payers.

New Jersey's development of its PMS was guided by references 1-4 and the review and suggestions of the PMTF. NCHRP 215 - "Pavement Management System Development" (2), and NCHRP Project 20-7, Task 15 Report No. NA-3/1, "Simplified Pavement Management at the Network Level" (3), provided the general framework for the structure while New Jersey's reports "Guidelines for Implementing a Pavement Management System" (1), and the HPR Research "Pavement Management Study" (4) proposal tailored the general structure to meet our specific information needs.

The basic structure which evolved incorporates the evaluation of the pavement condition of the State network, creation of a computerized Pavement Information System (PAVIS), development of initial safety, performance, economic models, and prioritization of the State's rehabilitation expenditures. Figure 1 presents the major activities within the PMS. The State pavement network, as used in this report, refers to all State numbered routes as well as U.S. routes and the Interstate System. Pavement Serviceability data (roughness, and distress) and Safety data (accident statistics and friction measurements) are collected and summarized for 0.2 mile increments in both directions along each route.

3.0 STUDY OVERVIEW

The report sections which follow describe the activities incorporated within each area of the PMS. Section 4 describes the procedures and models which evaluate the present condition of the network and prioritize pavement rehabilitations. Section 5 summarizes the performance and economic models used to predict the future condition of the network and expenditures necessary to maintain the system. Section 6 describes the structure, and usefulness of the various data bases which comprise the Pavement Information System. Section 8 summarizes the proposed refinements or enhancement to the current PMS procedures and models. The appendices describe additional activities performed by Research as part of the overall PMS development. These activities were performed to ensure the accuracy and reliability of the PM data. They include milepost system verification, Mays-ARAN calibration and correlation, skid trailer calibration, highway user panel studies - (1985 & 1986), performance model development, and validation analysis of the economic model.

MAJOR ACTIVITIES
OF THE
PAVEMENT MANAGEMENT SYSTEM

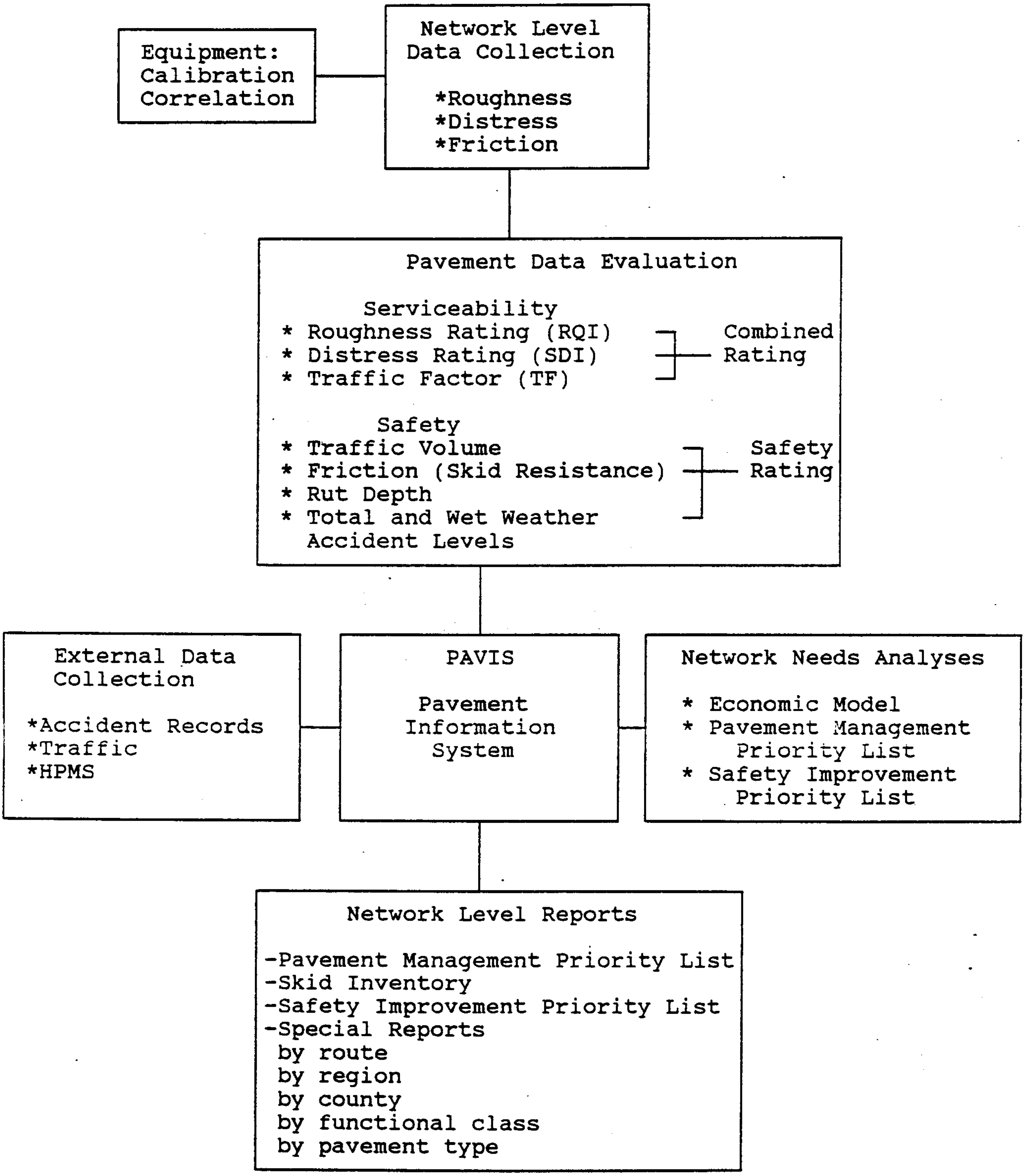

Figure 1

PART II - NETWORK PAVEMENT EVALUATION

4.0 NETWORK PAVEMENT SURVEYS, EVALUATION, AND MONITORING

4.1 GENERAL

The key element of any Pavement Management System is the measurement of the pavement's current condition in terms of the various serviceability parameters (roughness, distress, and skid resistance). These measurements provide the primary source of information for use in all areas of pavement management. Evaluation of the pavement condition measurements requires some engineering judgment to interpret the meaning of the collected data. Monitoring consists of periodic measurements of serviceability parameters to determine the current level of service of each pavement section as well as changes in service over time. Long term monitoring can be used to evaluate the performance capabilities or cost effectiveness of various departmental policies related to design, construction, and maintenance strategies.

The serviceability parameters are currently measured, summarized, and recorded in 0.2 mile increments in both directions along a given route. Testing or data collection is performed in the outer or "slow" lane of the roadway.

4.2 PAVEMENT RATING MODEL

4.2.1 Pavement Roughness Rating

Roughness is defined as the deviation of the road surface from a true planar surface with characteristic dimensions that affect vehicle dynamics, ride quality, and dynamic loads. These deviations are objectively measured by electromechanical devices. Some devices (e.g., Surface Dynamic's Profilometer) approximate the road profile in both wheelpaths. Other measuring devices (e.g., Mays Ride Meter and ARAN) measure the vehicle response to the profile of the road surface.

New Jersey has traditionally used the Mays Ride Meter to measure pavement roughness. The Mays Meter measures the number and magnitude of vertical deviations between the body of the test vehicle and the center of the rear axle. New Jersey has recently purchased an Automated Road Analyzer (ARAN II) to measure road roughness and other serviceability parameters. The ARAN uses an accelerometer to measure the vertical acceleration of the rear axle due to the longitudinal road profile. The ARAN is now used to collect all roughness survey data.

Pavement ride quality is subjectively defined as the user's opinion of pavement roughness. The main factors which influence the user's perception of road roughness are road profile and vehicle response (to the longitudinal wheelpath profiles).

Findings from New Jersey's panel studies (Appendix D) were used to tie the pavement roughness and ride quality concepts together. Data from the Mays and ARAN calibration and correlation studies (Appendix B) were used to estimate the variability of these units under various roughness, temperature, and speed conditions. The correlation studies were also used to estimate the relationships between the output from the different devices. The latter allows the output of any unit to act as a surrogate for another after the data has been "normalized" for speed and temperature (40 m.p.h. and 70 ^{o}F), and the correlation relationship has been used to convert the data to that of the "standard" vehicle.

The ARAN roughness measurements, taken at 40 m.p.h. in the outer lane, are recorded on the system's on-board computer for each 0.2 mile section. The information collected includes the route number, direction, starting milepost, date, lane, sample interval, test speed, roughness value, operators, control section number, rutting data, gyro data, and distress (severity and extent) evaluations. The ARAN data is edited and analyzed on a PC and then transferred to the mainframe computer data base. Additionally, the ARAN roughness data is converted using relationships developed in the panel study to an estimate of user opinion (Ride Quality Index, RQI) and both the ARAN roughness value and the RQI are input into the pavement management serviceability database.

4.2.2 Pavement Surface Distress Rating

This portion of the pavement management system has undergone more evolutionary changes than any other. The stages of this evolution are worth discussing so that other agencies may benefit from our experience.

Unlike the pavement roughness rating, the pavement distress rating is difficult to uniquely quantify. There are numerous surface distresses which occur on each type of pavement. The PMTF initially chose to monitor 19 distress types. Figure 2 is a listing of the distresses initially selected for each pavement type. After choosing the distress types, the next most difficult process was defining the severity and extent of each distress and determining an appropriate weighting scheme. This would allow scores from individual distresses to be combined into an overall Surface Distress Index (SDI) for each road section.

Figure 2

INITIAL DISTRESS TYPES
CONSIDERED IN THE NEW JERSEY
PAVEMENT MANAGEMENT SYSTEM

BITUMINOUS	COMPOSITE	CONCRETE
Longitudinal Cracking	Longitudinal Cracking	Joint Spalling
Transverse Cracking	-Single	Joint Faulting
Multiple Cracking	-Dual	Slab Cracking
Alligator Cracking	Transverse Cracking	Slab Faulting
Patching	-Single	Patching
Rutting	-Dual	Scaling
	Patching	Pavement Wear
	Rutting	

This process was accomplished through the use of an "expert panel" of the PMTF. Figure 3 shows a distress form, formally used in the manual data collection process.

The PMTF, realizing that evaluating this many distress types on each pavement section would be a time-consuming process, sought an abbreviated survey plan. They decided that the use of a "trigger value" (based on roughness level) would help by limiting the number of road sections which would receive the time-consuming distress survey. The distress survey site was bounded by the adjacent sections which fell below the trigger value. A single distress evaluation was performed on the site. This limited survey plan was used for a number of reasons and based on the following assumptions:

1. When a pavement deteriorates due to loads, weather, or time (aging), physical distress becomes visible.
2. As the extent and severity of these distresses in the wheelpaths increased, the pavement's ride quality would decrease.
3. Since it is less time-consuming to measure roughness than it is to survey the severity and extent of numerous pavement distresses, deteriorated ride quality values could identify which pavement sections should be subjected to the detailed distress surveys. This implies that these sections would have correspondingly higher levels of visible distress.

For bituminous or composite pavements, the distress surveys were performed on the "worst" 1500 foot portion. The 1500 foot section was divided into fifteen 100-ft panels. On concrete pavements, the distress survey was performed on the 15 "worst" consecutive slabs. Each section required 45-60 minutes to survey. The pavement section's overall distress rating is converted to a Surface Distress Index (SDI) based on a 0-5 rating scale. Pavements with more surface distress received a lower distress index. This method allows the SDI to be combined with the RQI to form an overall Pavement Index (PI).

Correlation analyses were performed on the roughness and distress data collected over a two year period. These analyses showed a lack of strong correlation between the Mays roughness values, which are used to trigger the distress surveys, and the distress ratings. It is believed that the lack of strong correlation is due to the distress types within the SDI which do not directly influence roughness.

Based on these analyses and the cababilities of the ARAN's distress rater keyboard, distress data is now collected continuously along the roadway. We believe that this will also facilitate future performance model development. Figure 4 depicts the layout of the distress rater keyboard, the severity key identification, and the special event keys. Figure 5 includes a listing of the surface distresses presently recorded on the ARAN along with the distress type weighting and severity and extent weighting scheme, and an example of the SDI calculation. For the purpose of simplification, extent is defined as the number of records out of 20 in the 0.2 mile section expressed as a percent which exhibits a particular level of seveirity of that distress. For example, if the rater selects slight severity of longitudinal cracking for 5 out of the 20 records in the 0.2 mile section, the extent is calculated as 25%. This value is used along with the the distress type weight and severity weight to calculate a distress rating for the section.

In a follow-up to this Pavement Management Study, the distress survey will be reexamined to update the weighting scheme, based on Department pavement experts and to take further advantage of the ARAN's automated distress rater keyboard. The video logging system on board the ARAN will be used to verify the distress survey.

Figure 3

Bituminous Distress Survey Form

(Bituminous Pavements)

NEW JERSEY
DEPARTMENT OF TRANSPORTATION
DISTRESS SURVEY FORM

Overall Pavement Distress Rating: ________________

Route:______ Start MP:_____ End MP:_____ Control Section:_____ Divided:___ Undivided:___ Region:_____
Raters:_____/_____ Computed By:_____

MP	MP	Panel	Cracking											Patching			Rutting			Shoulder
			Longitudinal		Transverse			Multiple			Alligator									
			<50'	>50'	1-3	4-6	>6	5-25%	25-50%	>50%	25%	25-50%	>50%	10%	10-25%	>25%	1/4"-1/2"	1/2"-1"	>1"	
		1																		
		2																		
		3																		
		4																		
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		13																		
		14																		
		15																		
Weighting			10	20	10	20	30	50	80	100	80	120	200	40	80	120	20	100	150	
Totals																				

Figure 4

RATER KEYBOARD LAYOUT

Identification of rater board keys is as follows:

1) Distress Categories– Key (Both Rater 1 & 2)

Key	X	A	B	C	D	E	F	G	H	I	J
	CLEAR BOARD	MULT CRACKS	TRAN CRACKS	CLONG CRACKS	PATCHING	SHOUL COND	SHOUL DROP	CRACKS	FAULTING	LONG JOINT	TRAN JOINT
		BC&COMP.			BC, COMP, & RC			RC			

2) Distress Severity– There are ten severity keys to utilize. They are located in the block of keys marked severity and are positioned on the left side of the keyboard.

Distress Severity identification is as follows:

Key	00	01	02	03	
		11	12	13	ROW 1–Bituminous Pavement
		21	22	23	ROW 2–Composite Pavement
	NO DISTRESS	SLIGHT	MODERATE	SEVERE	ROW 3–Reinforced Concrete Pavement

3) Special Event Keys– Four Keys on each board are marked "EVENT".

Key	Rater 1 Event	Rater 2 Event
K	TRAFFIC SIGNAL	MILEPOST
L	INTERSECTION	BRIDGE DECK
M	REFERENCE	PAVEMENT CHANGE
N	RR CROSSING	CONSTRUCTION

Figure 5

SURFACE DISTRESS INDEX (SDI)
DISTRESS TYPE WEIGHTS BY PAVEMENT TYPE

DISTRESS TYPE	BITUMINOUS	COMPOSITE	CONCRETE
Multiple Cracking	149	149	--
Transverse	138	138	--
Longitudinal	139	139	--
Patching	25	25	25
Shoulder Condition	15	15	15
Shoulder Drop	34	34	34
Cracks	--	--	70
Faulting	--	--	70
Longitudinal Joint	--	--	143
Transverse Joint	--	--	143

SEVERITY/EXTENT MATRIX

EXTENT (Percentage of Occurances)	SEVERITY LEVEL 1 (Slight)	SEVERITY LEVEL 2 (Moderate)	SEVERITY LEVEL 3 (Severe)
0 - 25%	0.2	0.4	0.6
25 - 50%	0.4	0.6	0.8
50 - 75%	0.6	0.8	0.9
75 - 100%	0.8	0.9	1.0

For Example:

Longitudinal Cracking weight on bituminous pavement section = 139.

Severity/Extent weight for 4 records (20%) of moderate severity = 0.4

Individual Distress Weight (i) = Severity/Extent Wt * Distress Wt
0.4 * 139 = 55.6

Surface Distress Index (SDI) = Sum of Individual Distress Weights subtracted from 500 and divided by 100.

(500 - sum (i))/100 = SDI
(500 - 55.6)/100 = 4.44

4.3 RANKING OR PRIORITIZATION MODEL

New Jersey's ranking or prioritization model employs a Pavement Index (PI) to establish the rehabilitation program. The PI provides an indication of the overall serviceability level of each pavement section in terms of ride quality, and surface distress. This composite value provides a convenient means of ranking each pavement section relative to the remainder of the network.

The current form of the ranking model is

$$PI = 0.6 * RQI + 0.3 * SDI + 0.1\ TF \qquad (1)$$

where PI = Pavement Index
RQI = Ride Quality Index
SDI = Surface Distress Index
TF = Traffic Factor
= 5.0 - 0.0000833 * (Average Daily Traffic)
= 0 for ADT > 60,000.

The Traffic Factor is based on the relative level of traffic on the road section. It is used in this equation as a tie breaker. Pavement sections which have equivalent RQI and SDI values are ranked relative to the section's traffic level. The section with the higher traffic volume receives a lower TF and a slightly lower PI. The lower PI value causes the section to be placed higher on the rehabilitation priority list.

The ranking or prioritization scheme handles the short-term needs of the system by identifying those pavement sections in need of repair. It allows the pavement sections with the lowest overall serviceability level (Pavement Index) to be rehabilitated first.

Later in Section 5.2 (Economic Models) the term Estimated Pavement Index (EPI) will refer to a combined pavement index based on engineer opinion for use in the model analyses.

4.4 SAFETY -

The overall safety of the Network pavements is of paramount concern to the PMTF. The Department's safety program is addressed separately from the pavement rating and ranking models to emphasize this importance. The safety section of the Bureau of Traffic Engineering and Safety Programs (TESP) is responsible for identifying those pavement sections in need of safety improvements. These pavement sections are tabulated in a Safety Improvement Priority List.

The current safety model utilizes measurements of pavement friction, the posted speed limit, pavement rut depths, and wet weather accident frequency to identify those pavement sections in need of improvements. As mentioned earlier, pavement friction or skid resistance is monitored as part of the network pavement condition evaluation by the Pavement Management Group. Skid trailers, conforming to the ASTM E-274 specification are used to collect the data. Friction data is collected in the outside lane at 40 m.p.h. (SN40) on 0.2 mile increments in both directions. The data is recorded on cassette tapes in the skid trucks and is later transferred to the mainframe computer. After the information is processed through a Fortran program which adjusts it based on speed and unit corrections (Appendix C), it is input into the Serviceability database. Two year accident information as well as posted speed limits are summarized through a RAMIS program for input in the Serviceability database.

The methodology for selecting candidate sites was developed to identify pavement sections with a combination of safety deficiencies; low friction number (based on speed limit), excessive rut depths, and high wet weather accident frequency. Each 0.2 mile section in the Serviceability database contains friction numbers, rut depths, and wet weather accident frequencies.

Figure 6 presents the classification scheme for bituminous, composite, and concrete pavements. A section receives its classification based on its level of skid resistance, rut depth and wet weather accident frequency. For instance, if a bituminous or composite pavement section has deficient rating for skid resistance, rut depth, and wet weather accident frequency it receives a Safety Index of 1. If the section has any two of the three deficiencies, it receives a Safety Index of 2. Rutting is not considered for Concrete pavement sections, therefore, sections which are deficient in skid resistance and wet weather accident frequency receive a Safety Index of 1. Sections which are deficient in skid resistance or wet weather accident frequency receive a Safety Index of 2. Pavement sections with only one deficiency are given a Safety Index of 3. Sections which exhibit no deficiencies are grouped under Safety Index 4.

A section is considered deficient in skid resistance if the value falls below the recommended level in NCHRP report No. 37 based on the posted speed limit.

The wet weather accident frequency is defined as the number of wet weather accidents occurring within the 0.2 mile section divided by the total number of accidents. This value is considered deficient if it is higher than the statewide average.

The rut depths are taken every 52.8 feet and averaged for the 0.2 mile section. Sections are considered deficient if this average rut depth is greater than 0.5 inches.

<u>Generation of Candidate Sites</u> -

A printout is generated of all pavement sections with a Safety Index of 1, 2 or 3. The printout is tabulated by route, direction, and milepost, displaying the level of each safety attribute and the resulting Safety Index. Candidate projects are selected by identifying contiguous sections of highway which appear on the list.

Figure 6

Safety Index Ranking Scheme

Safety Index Parameters

A = Wet Weather Accident Frequency > System Average
S = Skid Number below NCHRP Report 37 recommendation
R = Average Section Rut Depth > 0.5"

Safety Index Classification	Safety Parameter Deficienies Bituminous/Composite	Concrete
1	A & S R	A & S
2	A & S or A & R or S & R	A or S*
3	A or S or R*	A or S
4	None	None

* Only one parameter is deficient, however, it is extremely deficient (e.g., rut depth > 2.0")

5.0 NETWORK NEEDS ANALYSES

The network needs analyses addresses the long-term needs of the highway system. These analyses utilize pavement performance and economic models to forecast future pavement condition and to estimate the future cost of maintaining or improving the highway system.

5.1 PAVEMENT PERFORMANCE MODELS

Performance, in its simplest form, relates serviceability rendered to elapsed time or loads. Two such models were developed in this study. The first specifically focused on pavement ride quality while the second more generally described the pavement's overall condition. We refer to this overall parameter as the Estimated Pavement Index (EPI). Both models provide valuable insights into the nature of pavement performance.

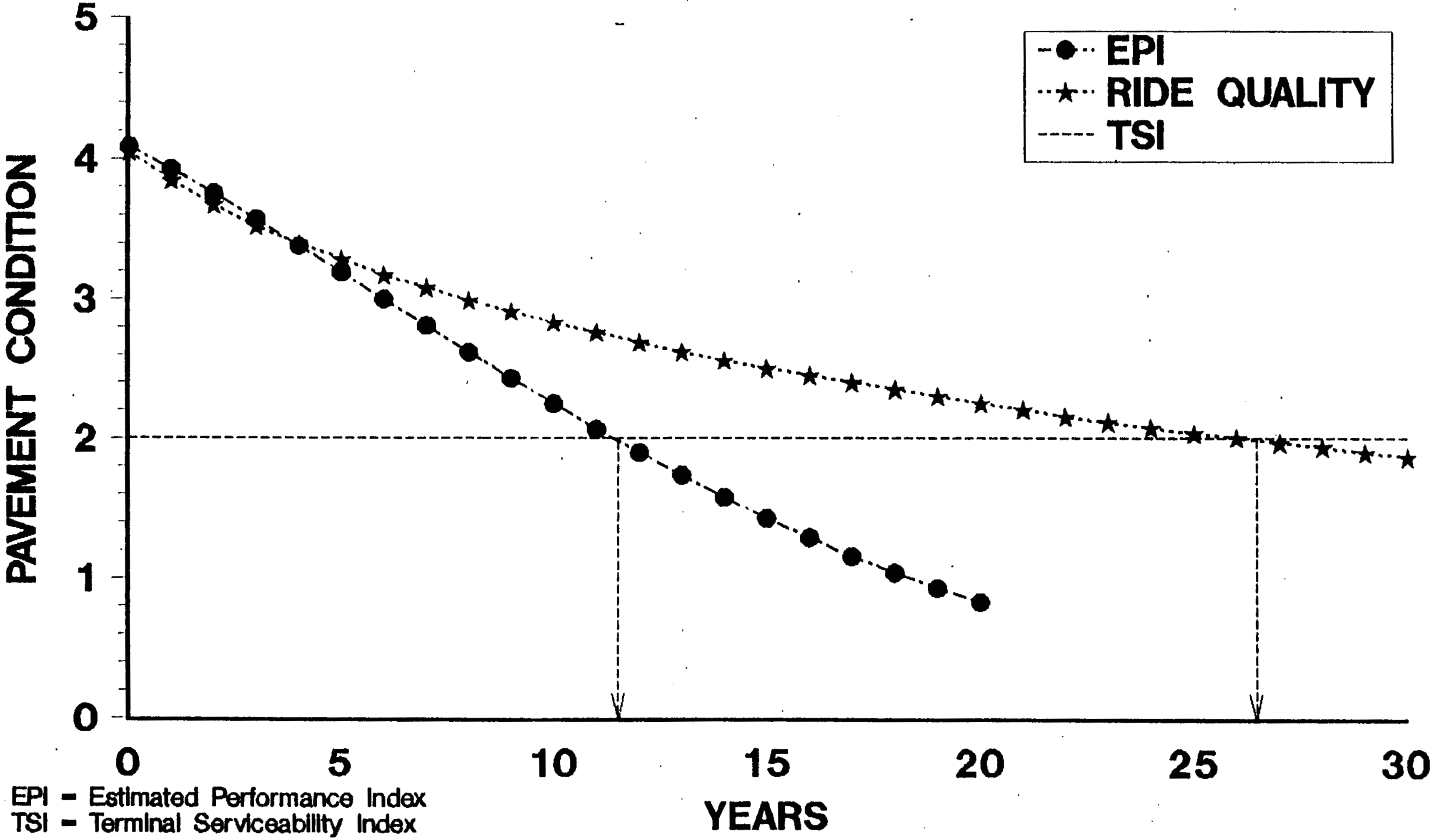
These models are expected to have a significant influence on the future direction taken by New Jersey's pavement management system. Thus it is important that both the strengths and the weaknesses of each be understood for, while their results are not in conflict, the information they produce is indeed different. The essential elements relating to the performance model analyses are presented below. Readers interested in more detailed description of the ride quality performance model development are referred to Appendix E.

The two performance models for bituminous pavement are presented in Figure 7. While both models are of an asymptotic form, they differ in estimated pavement longevity. Under typical conditions the ride quality performance model predicts a useful pavement life of approximately 25 years while the Estimated Performance Index (EPI) model predicts a useful life of approximately 11 years. A sensitivity analysis suggests the potential magnitude of error associated with the ride quality model does not extend to this lower value (11 years). Under extreme conditions the ride quality model predicts a pavement life of, at worst, approximately twelve years. While sensitivity analyses for the Estimated Performance Index model was not performed, the curve for this model seems to be generally lower than that of the ride quality performance model. That is, the Estimated Performance Index curve suggests that pavements need repair sooner.

Three fundamental differences may have bearing on this model comparison. First is the scope of serviceability addressed. The ride quality model exclusively addresses the annual increase in pavement roughness. (Equivalently, because of a direct relationship between roughness and user opinion, it addresses the corresponding discomfort to motorists.) This model ignores other parameters, such as cracking and excessive rutting, which may also develop during the analysis period. The EPI model, on the other hand, characterizes estimated changes in pavement serviceability as a whole. In this later model, a pavement might be considered unsatisfactory even though its ride quality had not yet reached the failure threshold.

Figure 7

COMPARISON OF PERFORMANCE MODELS



EPI - Estimated Performance Index
TSI - Terminal Serviceability Index

The second difference lies in the information used in the model's development. The ride quality performance model used two sets of historical pavement roughness data, collected three years apart, to estimate the systemwide average annual increase in roughness. Historical data was not available for the development of the EPI model. As an alternative approach, a select group of knowledgeable Department engineers expressed their opinions of historical pavement performance or the estimate of the pavement's overall condition at various ages.

The third difference lies in the emphasis of the two analytical approaches. The ride quality model focused on the rate with which pavements get rougher. This rate was experimentally observed and used to empirically derive the mathematical form of the performance model. Reasonableness checks were performed on the final product to the extent possible. The EPI model, on the other hand, hypothesized a series of model forms and adjusted them to correspond with the previously established consensus of engineering opinion. Theoretical boundary conditions were used whenever possible to assure that both models were capable of performing satisfactorily throughout their range.

Comparison of these two models presents an inference of some consequence to the pavement management study. They suggest that ride quality is only one of several factors affecting pavement serviceability and should not be overemphasized. Further, with regard to pavement longevity in New Jersey, these other factors may play the more prominent role. If so, then future efforts should focus on these more critical influences.

The EPI model was felt by some to more fully characterize overall pavement performance in New Jersey and was adopted for use in the economic analysis which follows.

5.2 ECONOMIC MODELS

5.2.1 GENERAL

There are many methods of ranking deteriorated pavement sections to establish a priority list for the order of repair. These range from a simple subjective ranking based on engineering judgment to highly sophisticated methods using linear programing, Markov processes, or other mathematical techniques. While the simpler methods are easier to administer, it is believed that they produce rankings that may be far from optimal in terms of cost effectiveness (11).

For example, earlier ranking schemes typically select the most deteriorated pavements sections to be repaired first. Recent assessments of this type of strategy suggests that this may not be the most cost effective. This conclusion was reached by using some newer, more sophisticated methods and the following logic: proper maintenance applied early in the life of a pavement might substantially prolong its life at a relatively low cost; repairs applied to a badly deteriorated pavement may be both more costly and less effective in extending its life.

While this reasoning seems logical enough, it was desired to develop a procedure that confirms its validity. To provide a meaningful check, the procedure must be capable of accounting for most factors that are included in the sophisticated systems. At the heart of the procedure are the following basic models (mathematical equations):

- A performance model relating condition (Estimated Performance Index) to time (Years)
- A cost model for relating reconstruction/resurfacing cost to condition
- A cost model for relating maintenance cost to condition
- An effect model for reconstruction/resurfacing relating resultant condition to initial condition
- An effect model for routine maintenance relating resultant condition to initial condition

These models must be rational, satisfying a variety of logical boundary conditions. It is planned that these models will be refined empirically as the necessary data becomes available. Ultimately, different models will be developed for different pavement types (rigid, flexible, and composite). Initially, for exploratory purposes, models were developed only for flexible pavements.

The procedure must also have the capability of accounting for the following variables:

- Funding constraints (how much and when)
- Interest and inflation rates (annual percentage)
- Threshold condition requiring repair
- Repair strategy (best first or worst first)
- Analysis period (years)
- Operational objective (desired condition)

A procedure capable of accounting for these various factors need not necessarily be conceptually complex but it inevitably will require a tremendous bookkeeping effort. For practical purposes, these models were computerized.

Although the necessary data is not yet available to develop the various performance, cost, and effect models precisely, they can be estimated reasonably well based on engineering experience. In this way, the program will serve as an investigative tool to study the general effects of various strategies and operating conditions.

5.2.2 DEVELOPMENT OF MATHEMATICAL MODELS

Before any attempts were made to empirically fit the performance, cost, and effect models, engineering rationale was used to determine the appropriate shapes and boundary conditions for these curves. Once the basic form for each model was selected, any data that could be obtained was combined with engineering judgment to calibrate the equation for each curve.

The pavement deterioration model relates pavement condition expressed as the Estimated Performance Index (EPI) on the Y-axis to age (years) on the X-axis. While it is recognized that, for any given age, there would be a distribution of pavement conditions, the relationship that is being sought refers to the average of that distribution. Although this relationship was treated as deterministic in the program, it can later be converted to a stochastic relationship if this added measure of realism is felt to be necessary.

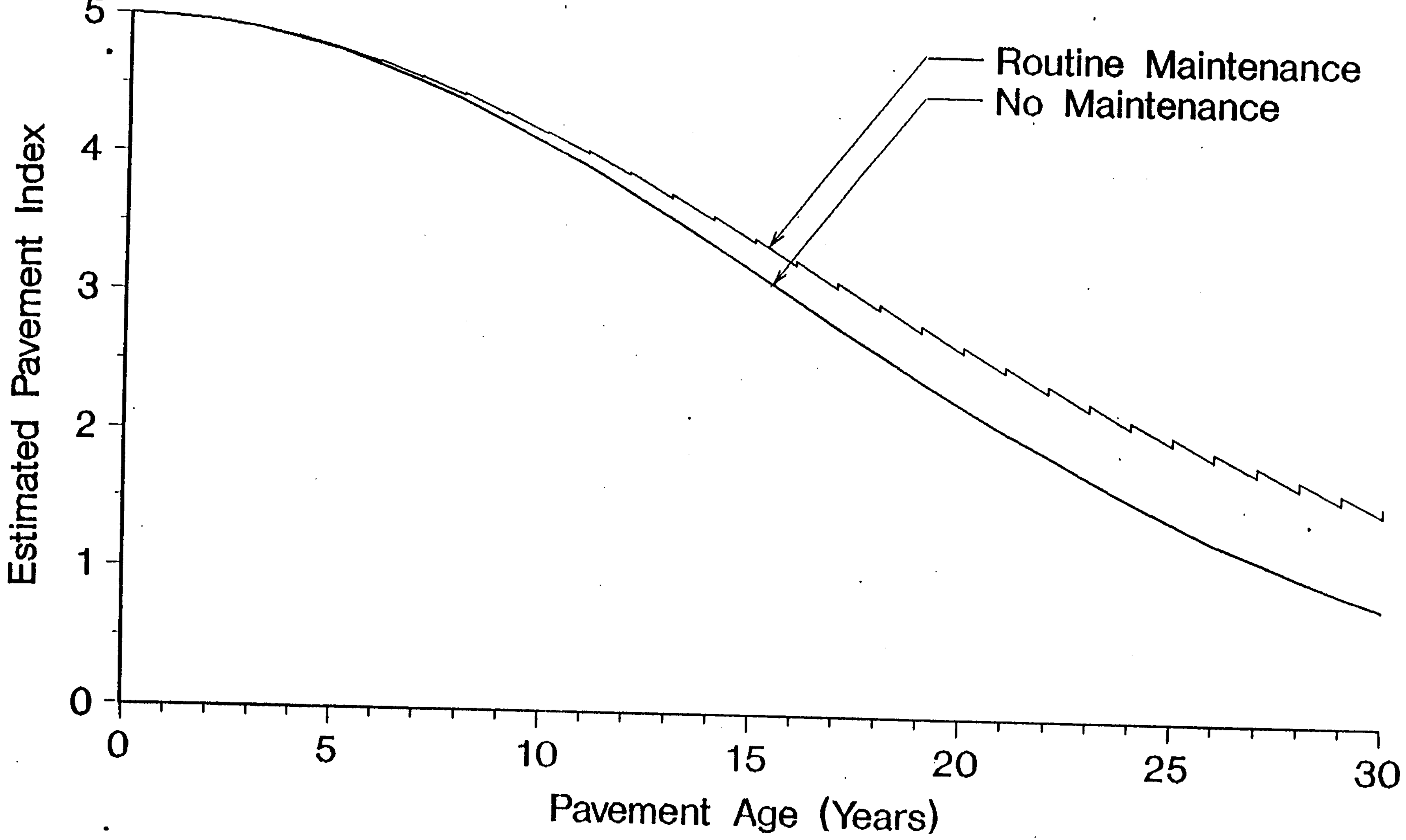
It is known that pavement condition starts at some relatively high level and declines as time passes and vehicle loads accumulate. To be realistic, the model must allow for the possibility of an increasing rate of decay throughout the middle stage of a pavement's life followed by a decreasing rate of decay later on as the curve levels off and becomes asymptotic to the X-axis. An exponential decay function is particularly well suited for this application. In the absence of reliable data from which to precisely establish this curve (or family of curves), engineering judgment was relied upon. More than a dozen Design, Construction, Maintenance, and Research engineers were surveyed within the New Jersey Department of Transportation to estimate the number of years it would take for a bituminous pavement in "very good" condition (approximately EPI=4.0) to deteriorate to a "needs repair" condition (approximately EPI=2.0) if no routine maintenance were performed. Their combined estimate of 10 years was used to establish the idealized decay curve labeled "No Maintenance" in Figure 8. The second curve in this figure illustrates the series of small upward shifts that reflect routine annual maintenance which, in effect, results in a slower rate of decay.

Since there wasn't sufficient data to distinguish a family of curves, and it was desired to keep the initial model as simple as possible, it was decided to use only the single decay curve representing "No Maintenance" in Figure 8. To do this, it was necessary to start this idealized curve at the maximum value of EPI = 5.0 although, within the program, individual pavement sections can start at any value. Conceptually, this is accomplished by "sliding" the curve to the left so that its Y-intercept [Years = 0] equals the desired initial value. There are two notable consequences of this approach:

1. Pavement sections that start at a lower EPI value decay at a slightly faster rate. It is not known whether or not this effect has been observed in the field but it is at least plausible. The rougher pavements receive a greater dynamic load from traffic which could

Figure 8

Idealized Decay Curves For Bituminous Pavements



increase their rate of decay.

2. When no maintenance activities are performed, the condition of a pavement section in the following year is a function only of its condition in the present year. More sophisticated models tend to account for past as well as present condition when predicting the future.

Sensitivity tests have indicated that small changes in the shape of this curve do not have a large effect on the results obtained over the analysis period. Therefore, it is felt that the use of a single decay curve is adequate for a preliminary exploratory analysis to study the effects of various input conditions. However, for a long-range goal, it is still considered desirable to obtain the data necessary to develop a family of curves that will account for more than just present conditions when predicting future condition.

The cost model for major resoration or reconstruction is based on recent NJDOT data. These costs are typically about $200,000 per lane mile. This type of repair is usually applied to sections in very poor condition so, for modeling purposes, it is assumed to occur at approximately EPI = 1.0.

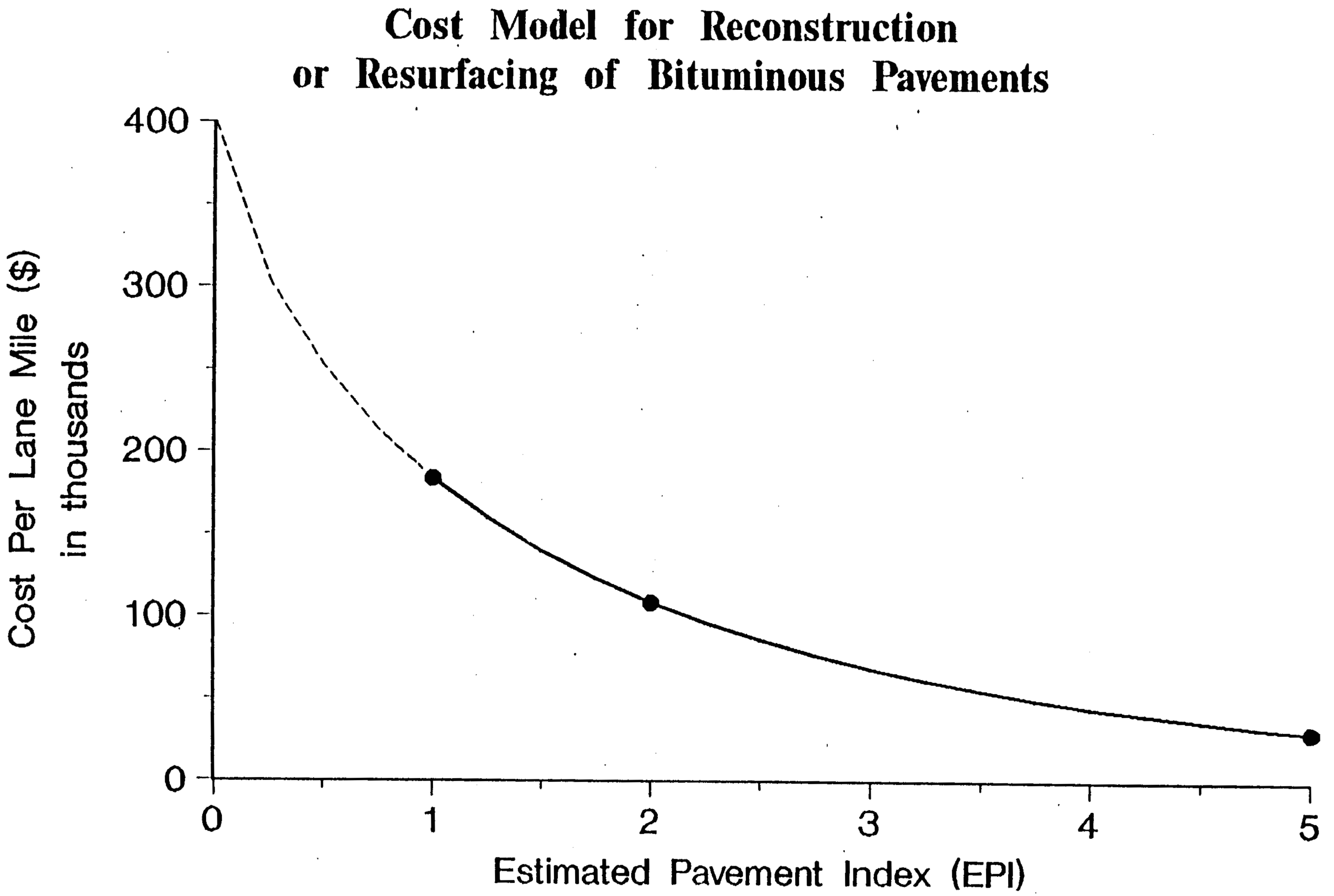
A typical resurfacing project costs about $100,000 per lane mile. This type of repair is used when pavements are not too severely deteriorated and is assumed to occur at an average EPI value of 2.0.

It is also necessary to estimate the minimum cost that would occur if a pavement in very good condition were resurfaced. This is necessary to complete the mathematical model even though, in all likelihood, this option would not be selected. Based on information from NJDOT Design units, it appears that this would cost about $30,000 per lane mile. From the foregoing information, the model shown in Figure 9 can be constructed.

The cost model for routine annual maintenance was more difficult to develop. Detailed information on routine annual maintenance costs as a function of pavement condition was not available. However, it was known that the average maintenance cost (for pavement related items) for all types and ages of pavements was about $900 per lane mile. By knowing the shape and the range of the distribution of condition for the pavement system as a whole, it was possible to deduce approximately what the lower portion of this curve must look like. The upper portion of the curve was based on an estimate of what it would cost to maintain a severely deteriorated pavement. The resultant model is shown in Figure 10.

The effect model for reconstruction and resurfacing was based on experience and engineering judgment. It is assumed that any repair action will improve the condition of the pavement to some

Figure 9



Cost Model for Reconstruction or Resurfacing of Bituminous Pavements
400
300
200
100
0
Cost Per Lane Mile ($) in thousands
0
1
2
3
4
5
Estimated Pavement Index (EPI)

degree. Very poor pavements [EPI<1.0] will usually be reconstructed and experience has shown that EPI values of 4.0 can realistically be achieved. When the initial condition is less deteriorated [EPI=1.0 to 2.0], a large percentage of the pavements will receive only a resurfacing. In these cases, there is less control of the underlying layers than with reconstruction and EPI values of around 3.8 may be the maximum achievable. Pavements in fair condition [EPI>3.0] will only be marginally improved by rehabilitation efforts. This information is used to construct the model in Figure 11.

The effect model for routine annual maintenance required the greatest degree of engineering judgment to develop since virtually no data was available that could be used to estimate it. Like the effect curve for reconstruction/resurfacing, it is assumed that any repair action will improve the condition of the pavement to some degree. Since the appropriate shape of this curve is not known, a straight line was used for the first approximation. It was then determined by trial and error that the effect relationship shown in Figure 12 is consistent with the two performance curves in Figure 8. In other words, if the basic decay curve labeled "No Maintenance" is given annual incremental upward shifts in accordance with the maintenance-effect relationship in Figure 12, the curve labeled "Routine Maintenance" is produced.

5.2.3 OPERATION OF THE MODEL

The five curves just described are the primary components necessary for the testing of a variety of pavement management strategies. Whenever a decision for any specific action is made (reconstruct, resurface, routine maintenance, do nothing), these curves provide the cost of the action and the resultant condition of the pavement. The model tracks each pavement section in the data base, decreases its EPI value with time, applies whatever decision rules for repair that the user has specified, computes an improved level of EPI, and tallies the cost. If funds are not available, no repairs are made and, if there is a surplus, it is accumulated and added to the following year's appropriation. Both interest and inflation are accounted for. An entire population of simulated pavement sections can be treated in this manner over an equivalent period of several years and costs and conditions can be recorded. In this way, various strategies can be tested to determine which are more effective. Figure 13 illustrates in a graphic way how the curves are used.

5.2.4 VALIDATION

In order to check that the computer model is working properly, an input option has been provided that will cause each step to be printed out so that it can be checked by hand. To keep this down to a manageable number of steps, a special data set was used that consisted of five pavement sections covering a range of conditions that assured that the various modes of operation would be tested. The checks consisted of two types, computational and

Figure 10

Cost Model for Routine Annual Maintenance of Bituminous Pavements

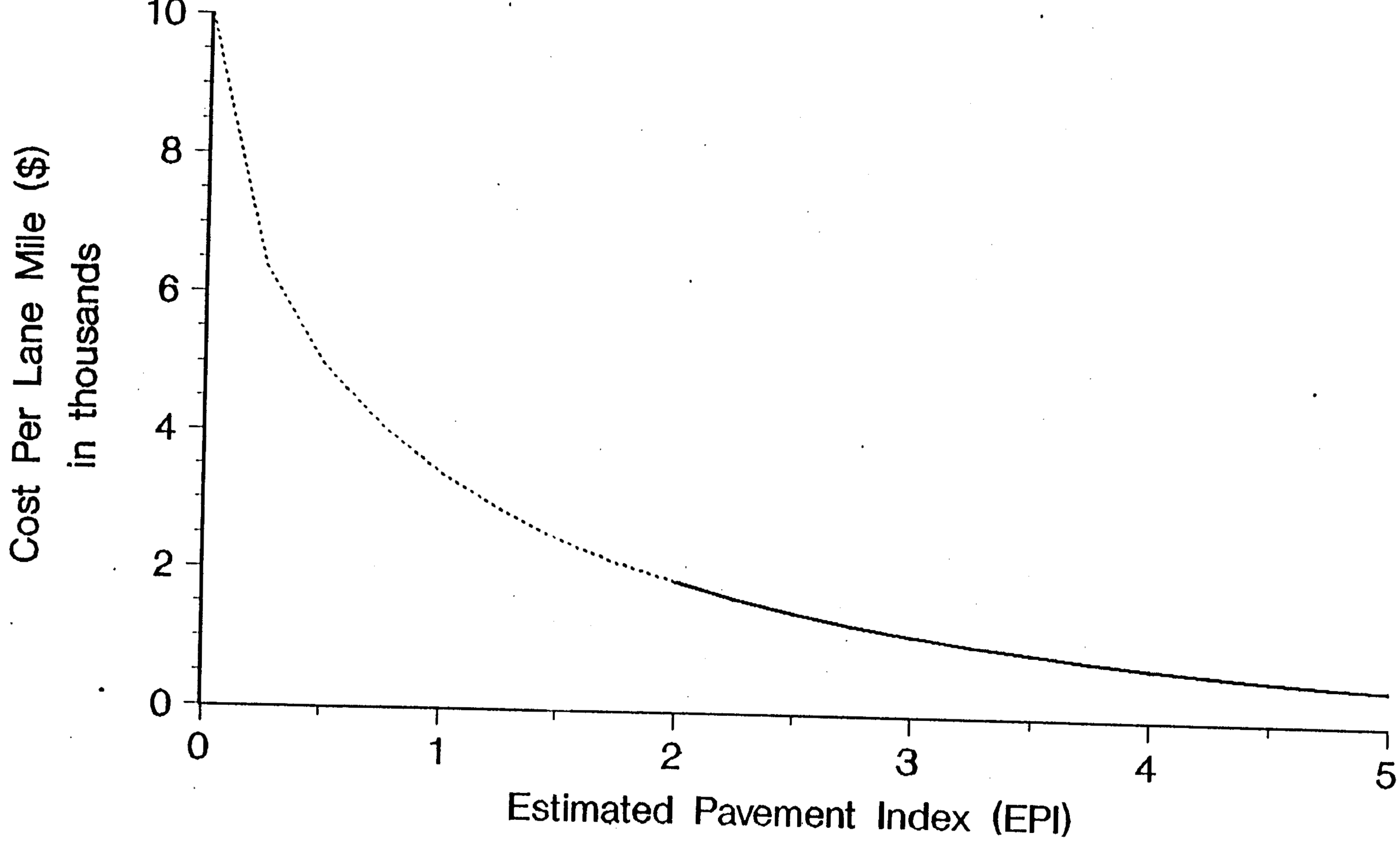


Figure 11

Effect Model for Reconstruction or Resurfacing of Bituminous Pavements

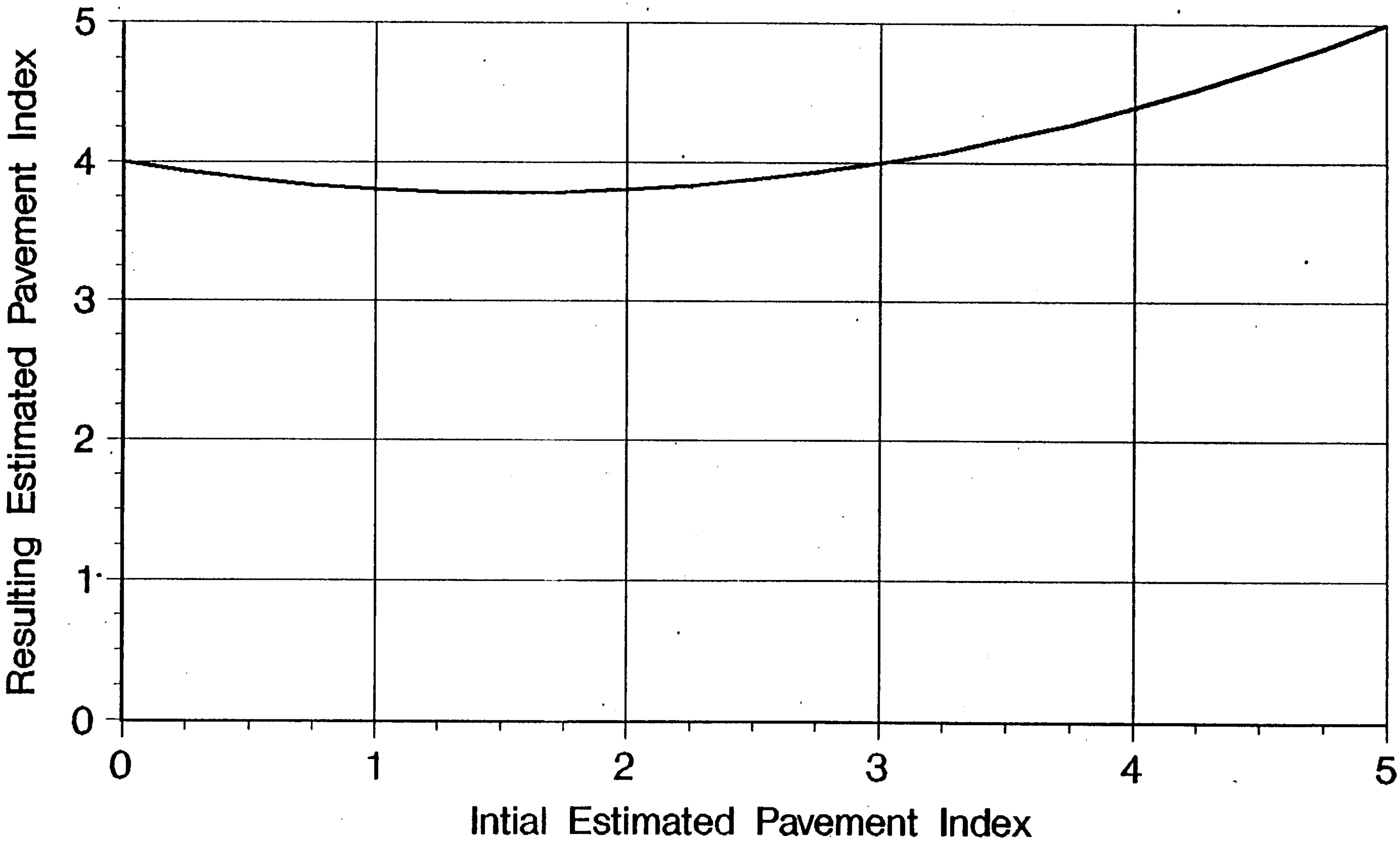
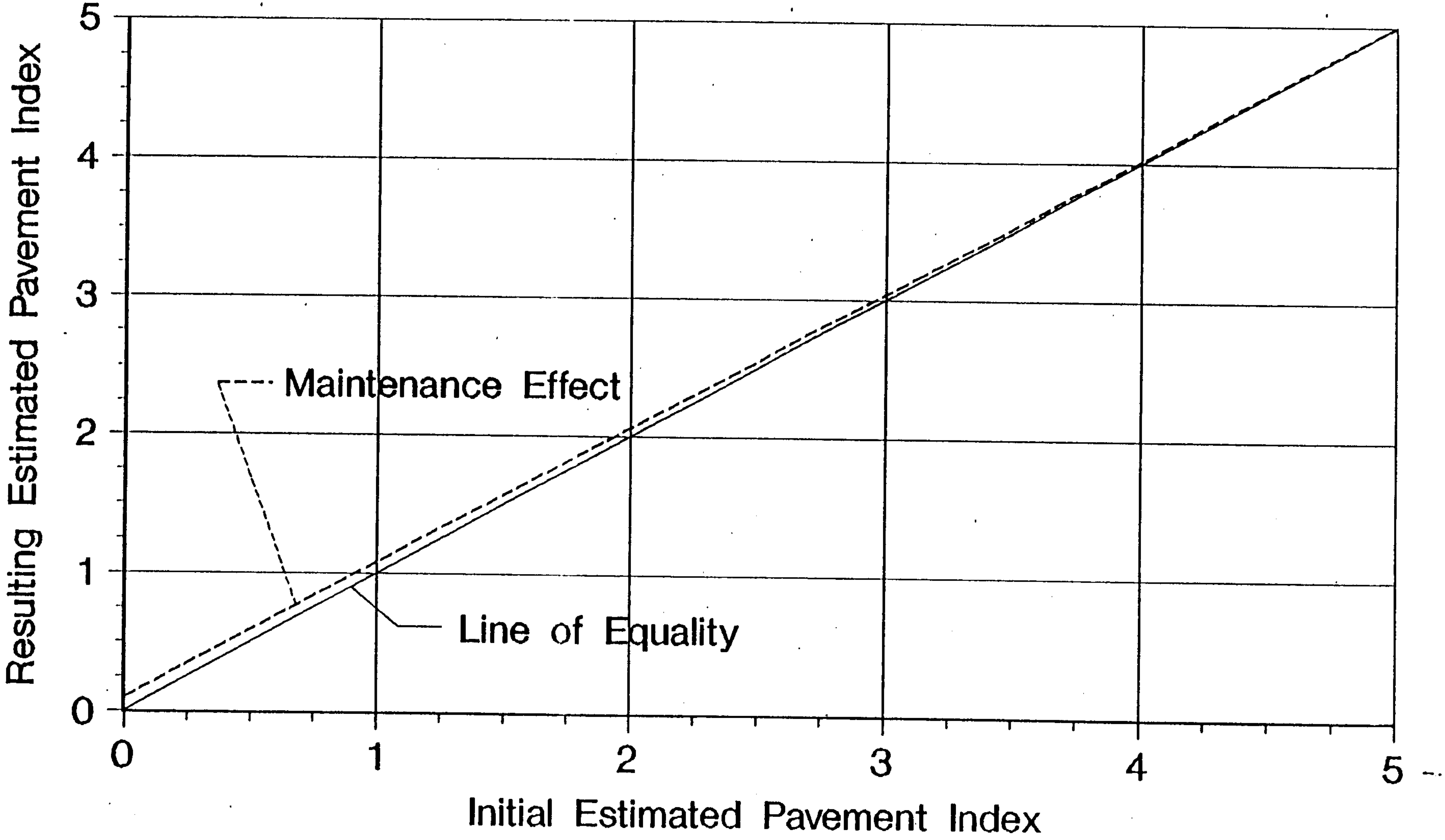


Figure 12

Effect Model for Routine Annual Maintenance of Bituminous Pavements



operational. The computational checks confirmed that the various arithmetic steps were being performed correctly. The operational checks confirmed that the proper actions occurred (resurfacing, routine maintenance, do nothing, etc.). A typical validation computer run is illustrated in Appendix F.

5.2.5 INITIAL RUN OF THE MODEL

Although much of the sensitivity testing remains to be done to determine the importance and criticality of the basic assumptions (rate of decay, cost of repair, effect of repair, etc.), it is believed that the model is sufficiently well developed that its output can provide general guidance in estimating funding needs or predicting the effect of a lack of sufficient funding. The sample run shown in Figures 14-16 was made precisely for this purpose.

The current model, which is based on flexible pavement performance, was run with a data set patterned after actual NJ DOT pavement ride quality data. Since a large portion of the New Jersey system consists of flexible pavement, the results of this run can be used to provide general guidance on costs and long-term performance for the entire system.

Figure 14 illustrates the various input options that are available to the user at an interactive terminal. Although the decay curve will eventually be "hard wired" into the program, its parameters were left as an input option at this stage so that the effect of differently shaped curves could be studied. The remainder of the input screen requires the user to specify the interest and inflation rates, the number of years in the analysis period, the total number of lane miles, the rehabilitation and maintenance funding level, and a repair strategy and threshold. The final input prompt asks what type of output is desired. Unless the run is being done for validation purposes, only the annual summaries would be desired.

Figure 15 shows the table printed at the beginning of each run to describe the five basic decay, cost, and effect models. If desired, the curves can be plotted from the information in this table. The small table that follows gives an approximate accounting in present worth of the average amount spent per year and indicates that there was not any significant surplus left at the end of the analysis period.

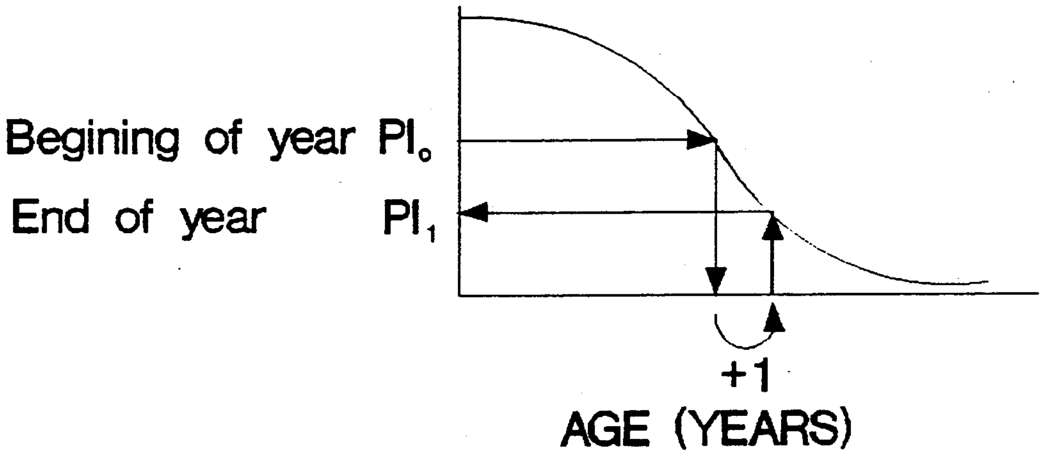
Figure 16 illustrates the primary output that gives the status for each year of the analysis period. This includes the amounts spent on resurfacing and maintenance in both future and present worth dollars, the minimum and average condition of the pavement system, and the percentages falling below selected levels of EPI.

As seen in Figure 16, the system had an initial average EPI value of 3.85 which reflects the generally good condition of flexible pavements in New Jersey. With annual funding levels of $80

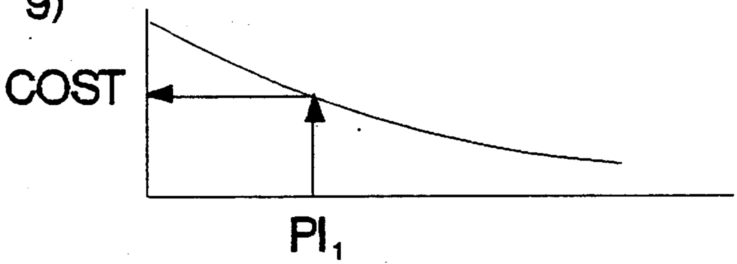
Figure 13

TYPICAL OPERATIONAL STEPS IN ECONOMIC MODEL

1. ONE YEAR'S DETERIORATION:
   (Ref. Figure 8)



2. COST OF RESURFACING:
   (Ref. Figure 9)



3. EFFECT OF RESURFACING:
   (Ref. Figure 11)

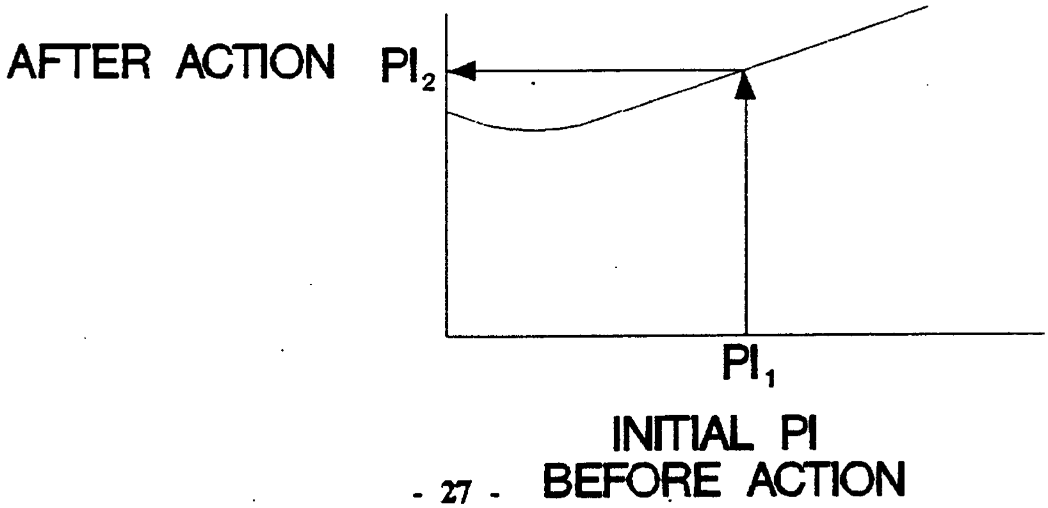


Figure 14
ECONMOD8 INPUT SCREEN

```
ENTER PERFORMANCE MODEL COEFFICIENTS A1 AND A2 OF
EPI= 5*E**(-A1*YEARS**A2)

?    0.002 2

ENTER INTEREST AND INFLATION RATES (ANNUAL PERCENT) AND ANALYSIS
PERIOD (YEARS)

?    8 4 20

ENTER NUMBER OF LANE MILES IN SYSTEM

?    10000

ENTER INITIAL RESURFACING FUNDING ($MILLION/YEAR) AND PERCENT
ANNUAL INCREASE

?    80 4

ENTER INITIAL LIMITATION ON MAINTENANCE FUNDING ($MILLION/YEAR)
AND PERCENT ANNUAL INCREASE

?    10 4

ENTER REPAIR STRATEGY

     1. WORST FIRST
     2. BEST FIRST

?    1

ENTER EPI THRESHOLD BELOW WHICH REPAIR IS REQUIRED

?    3

SELECT TYPE OF OUTPUT DESIRED

     1. DETAILED PRINTOUT OF REPAIR ACTIVITIES
     2. ANNUAL SUMMARIES FOR ANALYSIS PERIOD

?    2
```

Figure 15

************************************** BASIC OPERATIONAL INFORMATION **************************************

PAVEMENT PERFORMANCE MODEL (ASSUMES NO MAINTENANCE OR REPAIRS)				COST MODELS ($1000/LANE MILE)				EFFECT MODELS (EPI)			
				RECONSTRUCTION OR RESURFACING		ROUTINE ANNUAL MAINTENANCE		RECONSTRUCTION OR RESURFACING		ROUTINE ANNUAL MAINTENANCE	
EPI = F(AGE)		ANNUAL DECAY (EPI)									
YEAR	EPI	YEAR(I)	YEAR(I+1)	EPI	COST	EPI	COST	BEFORE	AFTER	BEFORE	AFTER
0	5.00	0.0	0.0	0.0	400.0	0.0	10.000	0.0	4.00	0.0	0.10
5	4.76	0.5	0.44	0.5	252.3	0.5	4.972	0.5	3.87	0.5	0.59
10	4.09	1.0	0.89	1.0	184.3	1.0	3.386	1.0	3.80	1.0	1.08
15	3.19	1.5	1.36	1.5	139.9	1.5	2.468	1.5	3.77	1.5	1.57
20	2.25	2.0	1.83	2.0	108.6	2.0	1.867	2.0	3.80	2.0	2.06
25	1.43	2.5	2.32	2.5	85.7	2.5	1.448	2.5	3.88	2.5	2.55
30	0.83	3.0	2.81	3.0	68.4	3.0	1.143	3.0	4.00	3.0	3.04
35	0.43	3.5	3.31	3.5	55.1	3.5	0.916	3.5	4.18	3.5	3.53
40	0.20	4.0	3.83	4.0	44.7	4.0	0.742	4.0	4.40	4.0	4.02
45	0.09	4.5	4.36	4.5	36.5	4.5	0.607	4.5	4.68	4.5	4.51
50	0.03	5.0	4.99	5.0	30.0	5.0	0.500	5.0	5.00	5.0	5.00

	PRESENT WORTH ($MILLION)		
	RECONSTRUCTION OR RESURFACING	ROUTINE ANNUAL MAINTENANCE	TOTAL
AVERAGE ANNUAL COSTS	52.852	6.130	58.983
SURPLUS FUNDS AT END	2.726	9.851	12.578

million for reconstruction/resurfacing and $10 million for routine annual maintenance (plus a 4% annual increase to compensate for inflation), the model indicates that there will be a small but steady decline of average condition of the system. Although the value of EPI=3.13 after 20 years would be considered generally satisfactory, it appears that an annual resurfacing budget on the order of $100 million or more (plus annual increases to offset for inflation) would be required to maintain the current status of the system.

5.2.6 **INDEPENDENT CHECKS OF THE MODEL**

Since expenditures of this magnitude substantially exceed New Jersey's anticipated capital program for the foreseeable future, these results are obviously cause for concern. Consequently, it was decided to perform "reasonableness checks" of these findings.

The first involved a simplified assumption in which the annual turnover rate of resurfacings was assumed to be constant. If the average life of a (flexible) pavement is 13 years, then approximately 1/13 or 8 percent of the 10,000 lane miles in the system will be resurfaced each year. Interest and inflation are ignored for this rough check. At a typical resurfacing cost of $100,000 per lane mile, it will cost approximately $80 million per year. This is in good agreement with the output of the analysis.

The second check actually preceded the development of the computerized models and was done at the request of Department management to estimate resurfacing costs for the next five years. Whereas the current computer analysis is based on overall pavement condition, this earlier study considered rutting, distress, and skid resistance separately. Several individuals in Research, Design, Construction, and Maintenance participated in this study and a variety of simplifying assumptions had to be made. The final conclusion was that, in order to maintain the system at generally desired levels, the annual expenditures might range from $80 million to $150 million. This, also, is in reasonably close agreement with the current computer solution.

A third check was performed by the Bureau of Transportation Priorities, a separate unit that independently analyzed the needs and estimated the projected costs for the entire system. Their evaluations suggested that the annual costs might be closer to the $150 million figure, also in reasonable agreement with both the computer model and the other checks.

Although much remains to be done in refining the computer model, including a planned future series of sensitivity tests discussed in Section 8.5, a very significant preliminary finding seems to have emerged. Unless some flaw can be found in the basic assumptions, or unless some relaxation in the current desired standards of pavement condition can be made, it appears that it will be more costly than previously anticipated to maintain the highway system at its present level.

Figure 16

** ANNUAL SUMMARIES FOR ANALYSIS PERIOD **

	FUTURE WORTH COSTS ($MILLION)			PRESENT WORTH COSTS ($MILLION)			EPI RATING AT END OF YEAR					
									PERCENT BELOW INDICATED VALUE			
YEAR	RESURF	MAINT	TOTAL	RESURF	MAINT	TOTAL	MINIMUM	AVERAGE	1.5	2.0	2.5	3.0
0	********	********	********	********	********	********	2.25	3.85	0.0	0.0	1.0	4.0
1	50.983	8.161	59.144	47.206	7.557	54.763	3.10	3.77	0.0	0.0	0.0	0.0
2	23.130	9.220	32.350	19.830	7.905	27.735	3.04	3.65	0.0	0.0	0.0	0.0
3	48.212	9.724	57.936	38.272	7.719	45.992	3.09	3.56	0.0	0.0	0.0	0.0
4	81.945	10.025	91.971	60.232	7.369	67.601	3.13	3.50	0.0	0.0	0.0	0.0
5	51.217	11.292	62.509	34.857	7.685	42.542	3.08	3.41	0.0	0.0	0.0	0.0
6	221.527	9.487	231.014	139.600	5.979	145.579	3.10	3.51	0.0	0.0	0.0	0.0
7	212.512	9.658	222.171	123.999	5.636	129.635	2.99	3.59	0.0	0.0	0.0	1.0
8	99.063	11.626	110.688	53.521	6.281	59.802	2.94	3.54	0.0	0.0	0.0	10.0
9	108.988	12.268	121.256	54.521	6.137	60.658	2.90	3.50	0.0	0.0	0.0	9.0
10	114.791	12.952	127.743	53.171	5.999	59.170	2.89	3.46	0.0	0.0	0.0	6.0
11	116.610	13.744	130.354	50.012	5.895	55.907	2.90	3.42	0.0	0.0	0.0	6.0
12	131.861	14.418	146.279	52.364	5.726	58.090	2.91	3.39	0.0	0.0	0.0	1.0
13	122.039	15.522	137.561	44.874	5.707	50.581	2.90	3.35	0.0	0.0	0.0	16.0
14	133.426	16.466	149.892	45.427	5.606	51.033	2.78	3.31	0.0	0.0	0.0	29.0
15	144.430	17.400	161.830	45.531	5.485	51.016	2.77	3.28	0.0	0.0	0.0	29.0
16	139.197	18.597	157.794	40.631	5.428	46.059	2.63	3.25	0.0	0.0	0.0	30.0
17	154.320	19.572	173.892	41.708	5.290	46.998	2.49	3.22	0.0	0.0	1.0	34.0
18	161.090	20.620	181.709	40.313	5.160	45.473	2.48	3.20	0.0	0.0	3.0	32.0
19	154.326	21.956	176.282	35.760	5.088	40.847	2.45	3.16	0.0	0.0	5.0	35.0
20	164.249	23.158	187.407	35.240	4.969	40.208	2.44	3.13	0.0	0.0	6.0	37.0

PART III - PAVEMENT INFORMATION SYSTEM

6.0 PAVEMENT INFORMATION SYSTEM

6.1 GENERAL

A well organized Pavement Information System (PAVIS) is a vital part of a complete Pavement Management System. The primary purpose of any data base is to provide information to all units of the Department (6). The sections which follow discuss the elements of New Jersey's Pavement Information System and the data bases which support the system.

The following were considered key factors in the formulation of the data bases:

1. Users of the data bases
2. Basic functions of the data bases
3. Data input and files
4. Data processing requirements
5. Data retrieval

In considering the users of the data bases, we realized that the Pavement Information System must be compatible with other data bases and accessible to units throughout the Department. These considerations, as well as the volume of data (approximately 23,000 records) resulted in selection of the central mainframe computer as the primary hardware.

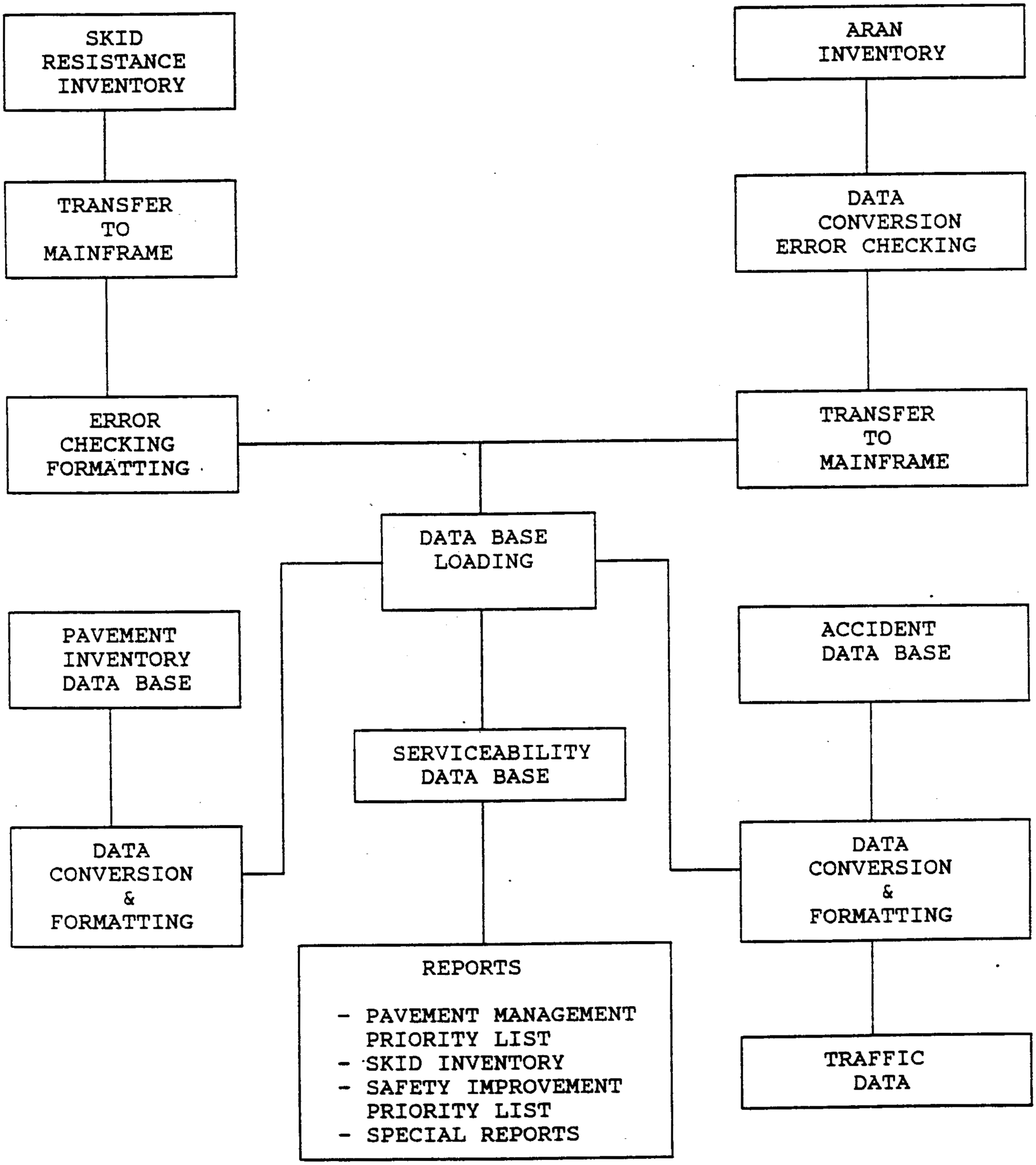
The major function of the data base is to provide users with information, not just data storage. It is this information, prepared from standard and nonstandard analyses of the data,which fills the needs as they arise. The data within the data base must therefore contain the information anticipated to be of use to each user. To be useful, the data base also requires a sophisticated and flexible data management system which can internally perform needed analyses or can supply specific data to external computer programs for further analyses. For these reasons, the RAMIS Software System and the Intergraph CAD/CAM System were selected as the core software. These are described in sections which follow.

The selection of the data base items or fields is one of the most important parts of the Pavement Information System development. A great deal of time and effort was expended in the initial selection and modification process (7).

The data processing requirements (data input, editing, formatting, storage, updating and retrieval) are under the control of the Pavement Management Group in the Bureau of Maintenance. An illustration of the data processing activities is contained in Figure 17. The PAVIS is capable of data or information retrieval in "standard" or special report formats with text and/or graphics presentations.

Figure 17

PAVEMENT INFORMATION SYSTEM FLOWCHART



6.2 DATA BASES

6.2.1 SERVICEABILITY DATA BASE

The Serviceability data base is the yearly consolidation of all network pavement-related serviceability data (e.g., ride quality, distress, skid resistance, etc.). It uses the RAMIS II data base system because of its flexibility and sophistication. This Data Base Management System is capable of providing the output required by users of the PMS quickly and without extensive programing effort. RAMIS uses a hierarchical structure (similar to a pyramid) which allows large volumes of data to be stored in less space than conventional flat files. Data elements (fields) are stored in "levels", each being associated with the (key) field above it. A graphical representation of a hierarchical file structure is shown in Figure 18. The file structure of the Serviceability data base is shown in Figure 19. The 4th level of the data base includes serviceability and related information for each 0.2 miles increment (in both direction of the route). The ride quality information is presented in terms of ARAN and RQI. Each distress type as well as the SDI are also presented. Accident data, geometric information, and skid resistance data are stored here along with the section's pavement type, functional class, maintenance control section, ADT, number of lanes, and speed limit. This depth provides the PMS with the flexibility to handle almost any user requirement.

6.2.2 AS-BUILT DATA BASE

The serviceability parameters monitored in the performance and economic models of the PMS are strongly influenced by the complex pavement history of each pavement system (i.e., initial pavement materials, engineering properties of each layer at the time of rehabilitation, reduction of stress/strains in the pavement layers due to the rehabilitation, etc.). An ultimate pavement history would include all information on the pavement's design (original or rehabilitation), construction, maintenance,loads (traffic and climate), and costs. The material data would include material and construction data such as material types, layer arrangement, and summary statistics on thicknesses, and material properties of each layer. The traffic information (for each section) would consist of vehicle type, axle loads, wheel loads or the dynamic forces, and the number of axle repetitions. Cost information would incorporate initial construction costs, maintenance material costs, and any rehabilitation costs as well as inflation and depreciation.

Unfortunately, New Jersey has not kept this information current. To rectify this problem, at least in part, a limited As-Built data base was developed in a two-phase process. First, staff from Maintenance's Winter Assignment Program recorded design and construction information (Figure 20) from available construction and maintenance resurfacing As-Built plans and

Figure 18

Hierachial Structure Serviceability Database

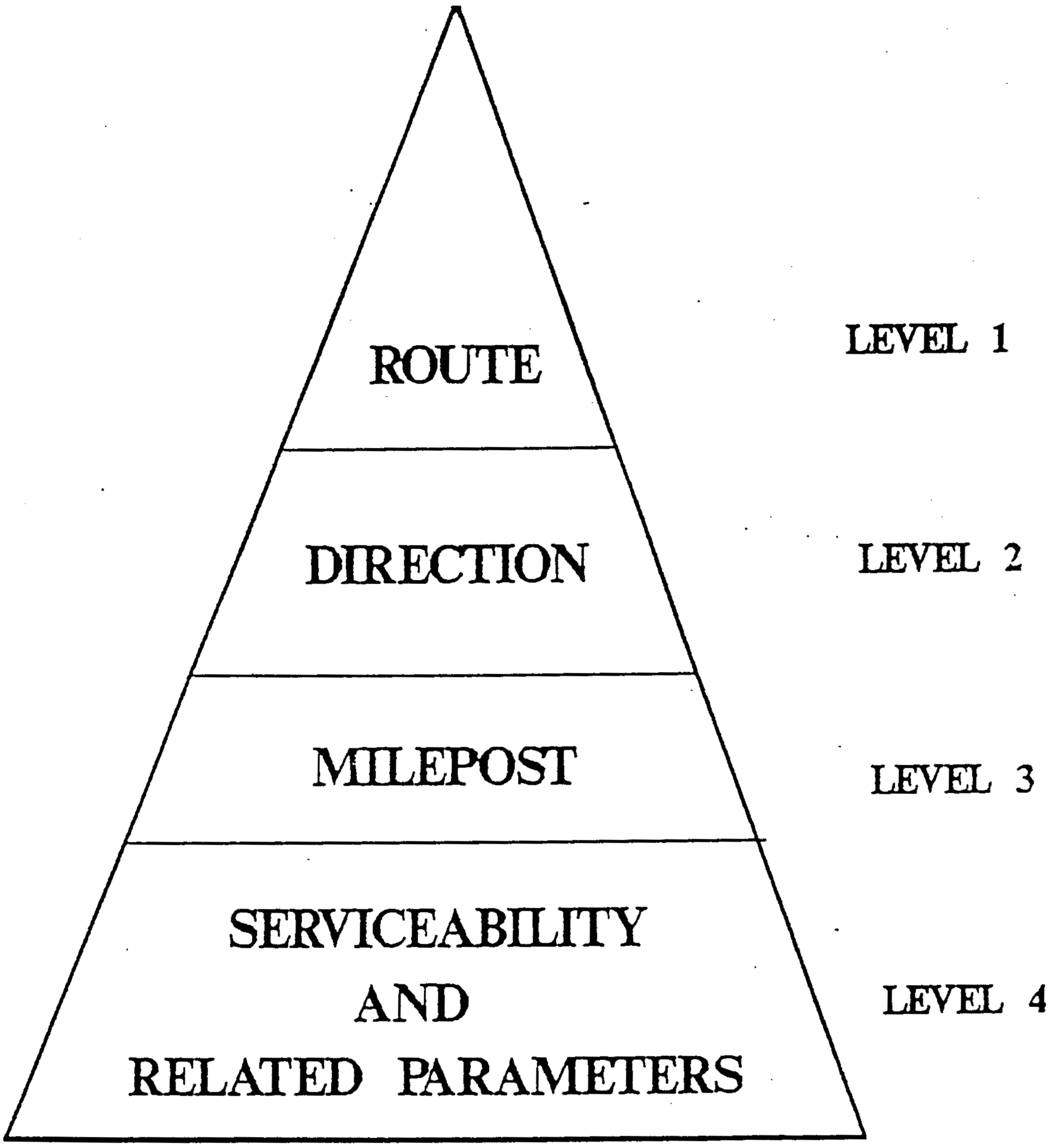


Figure 19

DESCRIPTION OF RAMIS II FILE: PMS
ON THE ACTIVE DATABASE: RAMDATA DATA

LIST	FIELDNAME	SYNONYM	LEVEL NAME	TYPE	SEGMENT FACTOR	FORMAT	
1	ROUTE	RT	1	D	10	A	4
2	DIRECTION	DIR	2	S	2	A	1
3	MILEPOST	MP	3	S	2	F	6.2
4	PAVETYPE	PV	4	U	1	A	2
5	FUNCTCLS	FC	4	U	1	A	2
6	CONSECT	CS	4	U	1	A	4
7	AADT-2WAY	ADT	4	U	1	I	6
8	TRAF-FACT	TF	4	U	1	F	4.2
9	PAVE-INDEX	PI	4	U	1	F	4.2
10	LANES	LNS	4	U	1	I	2
11	SPDLIM	SPD	4	U	1	I	2
12	MEDIAN	MED	4	U	1	A	1
13	SKID	SN	4	U	1	F	4.1
14	SKID-DATE	SDA	4	U	1	A	6
15	MAYS-RQI	MRQI	4	U	1	I	4
16	MAYS-DATE	MDA	4	U	1	A	6
17	ARAN-RQI	ARQI	4	U	1	F	4.2
18	ARAN-ROUGH	ARR	4	U	1	I	4
19	ARAN-DATE	ADA	4	U	1	A	6
20	L-RUT	LRUT	4	U	1	F	4.1
21	R-RUT	RRUT	4	U	1	F	4.1
22	DIS-INDEX	DI	4	U	1	F	4.2
23	SHOULDER	SH	4	U	1	I	2
24	PATCHING	PA	4	U	1	I	2
25	TRANS-CR	TC	4	U	1	I	2
26	LONG-CR	LC	4	U	1	I	2
27	MAP-CR	MC	4	U	1	I	2
28	ALLIG-CR	AC	4	U	1	I	2
29	CON-CR	CC	4	U	1	I	2
30	TRANS-JT	TJ	4	U	1	I	2
31	LONG-JT	LJ	4	U	1	I	2
32	SHLD-DROP	SD	4	U	1	I	2
33	ACC-YEAR	AYR	4	U	1	A	2
34	TOT-ACC	ACC	4	U	1	I	3
35	WET-ACC	WET	4	U	1	I	3
36	BET-ACC	BACC	4	U	1	I	3
37	BET-WET	BWET	4	U	1	I	3
38	FATAL	FACC	4	U	1	I	3
39	INJ-ACC	IACC	4	U	1	I	3
40	PD-ACC	PACC	4	U	1	I	3
41	GRADE	GRD	4	U	1	F	4.1
42	ROLL	ROL	4	U	1	F	4.1
43	XFALL	XF	4	U	1	F	4.1
44	RADIUS	RAD	4	U	1	I	5
45	SPARE1	S1	4	U	1	A	4
46	SPARE2	S2	4	U	1	A	4

microfilm, dating back to the early 1900's. A chronological project section summary was then created by plotting the milepost limits of each project on a straight line diagram for each route after the information was sorted by construction date. This summary formed a visual diagram of each route pavement history.

The second phase involved development of the structure of the As-Built data base and the procedures necessary for updating the information as the pavement is modified through resurfacing or reconstruction.

New Jersey's limited As-Built data base contains a summary of "As-Built" construction and design information from the As-Built data forms on each capital improvement or maintenance resurfacing project. In the future, the As-Built data form (Figure 20) will be completed by the construction or maintenance staff at the completion of the each project. The forms are sent to the Pavement Management Group for updating the As-Built data base.

The unique requirements of the As-Built information severely challenged conventional data management software. That is, a variety of features of typical new and rehabilitated designs had to be accommodated. Such features include different number of pavement layers and variable thicknesses, milling, variable thickness overlays, and variable width widenings. Data base structures which are capable of handling this variability are cumbersome and require large amounts of wasted storage space. The Intergraph CAD/CAM System handles this unique information efficiently by merging its graphics and data management capabilities. Figure 21 lists the Intergraph As-Built data base fields and material code list. Note that the structure utilizes code lists to reduce data storage requirements and possible errors (e.g., misspellings, incorrect abbreviations,etc.) The data management features of the Intergraph System allows sorting of the data by single or multiple fields, and permits the creation of data subsets. These features will facilitate the investigation of pavement components between milepost locations along a single route, or locate pavements with a particular layer material or similar structure throughout the State system.

The Intergraph features a CAD/CAM system capable of drawing pavement cross sections at any desired location indicating the construction section number, material type(s), thickness(s), and date of construction from the information within the data base. These drawings can be edited to show unique situations (e.g. two foot widenings, experimental pavement details, etc.) within the pavement structure. Text notes can be "attached" to the drawings to further explain otherwise cumbersome information.

Phase 1 was accomplished over three winter periods (January 1 through March 15, 1985 to 1987). The procedure for updating the data base was developed and implemented in 1986. An initial As-Built data base structure for the Intergraph was created along with the various code lists. Test data is currently being loaded

Figure 20

PAGE _____ OF _____

ROUTE: ______________ SECTION: ____________________ ASBUILT DATE: __________

Type of Work: ____

Town/County: ___________ / ___________ Region: _____ Control Section: _______

Begin Station: __________ End Station: _________ Total Miles: _____________

Begin Milepost: __________ End Milepost: _________ Median Type: _____________

AADT/Year: _______________ / _______________ DHV: _________ %D: _____________

_______________ / _______________ % Truck: _____ V: _________mph

	CROSS SECTION INFORMATION			
	MAINLINE		SHOULDER	
STA/MILEPOST	MATERIAL	THICKNESS	MATERIAL	THICKNESS

SHOULDER AND LANE WIDTHS					
STATION	MILEPOST	DIR	SH/LANES/SH	DIR	SH/LANES/SH

REMARKS: ____

____

____

Person Completing Form: ________________________.

Figure 21

INTEGRAPH AS-BUILT DATA BASE

FIELD DESCRIPTION

Field Names	Field Names
1 Route	35 Layer 4
2 Section	36 Thickness 4
3 Route and Section	37 Layer 5
4 Control Section	38 Thickness 5
5 Type of Work	39 Layer 6
6 Date Completed	40 Thickness 6
7 Primary Direction	41 Layer 7
8 Divided	42 Thickness 7
9 Municipality	43 Layer 8
10 County	44 Thickness 8
11 Region	45 Shoulder Layer 1
12 Legislative District	46 Shoulder Layer Thickness 1
13 Begining Milepost	47 Shoulder Layer 2
14 End Milepost	48 Shoulder Layer Thickness 2
15 Total Miles	49 Shoulder Layer 3
16 Initial AADT	50 Shoulder Layer Thickness 3
17 Initial Year	51 Shoulder Layer 4
18 Projected AADT	52 Shoulder Layer Thickness 4
19 Projected Year	53 Shoulder Layer 5
20 Design Hourly Volume	54 Shoulder Layer Thickness 5
21 Percent Trucks	55 Shoulder Layer 6
22 Percent Distribution	56 Shoulder Layer Thickness 6
23 Velocity mph	57 Shoulder Layer 7
24 Median Type	58 Shoulder Layer Thickness 7
25 Subgrade Soil	59 Shoulder Layer 8
26 Subgrade Number	60 Shoulder Layer Thickness 8
27 BSubgrade Soil	61 Width of Inside Shoulder-Primary
28 CSubgrade Soil	62 Width of Outside Shoulder-Primary
29 Layer 1	63 Width of Inside Shoulder-Secondary
30 Thickness 1	64 Width of Outside Shoulder-Secondary
31 Layer 2	65 Number of Lanes
32 Thickness 2	66 Width in Feet
33 Layer 3	67 Remarks1
34 Thickness 3	68 Remarks2

Figure 21 continued

ASBUILT DATA BASE
MATERIAL CODE LIST

CODE NO.	DESCRIPTION				
1	ASPHALT				
2	BITUMINOUS	CONCRETE			
3	BITUMINOUS	STABILIZED	BASE	COURSE	
4	CABC	(COARSE	AGGREGATE	BASE	COURSE)
5	CINDERS				
6	CONCRETE	BASE	COURSE		
7	CONTINUOUSLY	REINFORCED	CONCRETE		
8	CRUSHED	GRAVEL	FRICTION	COURSE	
9	FABC	(FINE	AGGREGATE	BITUMINOUS	CONCRETE)
10	GRANITE	BLOCK			
11	GRAVEL				
12	LIME/FLY	ASH	BASE	COURSE	
13	AGGREGATE	LIME	POZZALON	BASE	COURSE
14	CEMENT	TREATEED	BASE	COURSE	
15	MABC	(MEDIUM	AGGREGATE	BITUMINOUS	CONCRETE)
16	MACADAM	BASE			
17	OGFC	(OPEN-GRADED	FRICTION	COURSE)	
18	DRY	BOUND	MACADAM		
19	PENETRATION	MACADAM			
20	PLAIN	CONCRETE			
21	QUARRY	PROCESSED	STONE		
22	REINFORCED	CONCRETE			
23	RRNS	HOT	MIX		
24	SAND	ASPHALT	(OTHER)		
25	SLAG				
26	BLAST	FURNACE	SLAG		
27	BOILER	SLAG			
28	SLURRY	SEAL			
29	SP1	(SAND	ASPHALT)		
30	SP2(SAND	ASPHALT)			
31	CHIP	SEAL			
32	BITUMINOUS	CONCRETE	FRICTION	COURSE	
33	BITUMINOUS	SURFACE	COURSE	I-3	
34	BITUMINOUS	SURFACE	COURSE	I-4	
35	BITUMINOUS	SURFACE	COURSE	I-5	
36	BITUMINOUS	SURFACE	COURSE	I-6	
37	BITUMINOUS	BASE	COURSE	I-1	
38	BITUMINOUS	BASE	COURSE	I-2	
39	STONE				
40	SUBBASE				
41	SURFACE	TREATMENT			
42	SUBBASE	DESIGNATION	I-1		
43	SUBBASE	DESIGNATION	I-2		
44	SUBBASE	DESIGNATION	I-3		
45	SUBBASE	DESIGNATION	I-4		
46	SUBBASE	DESIGNATION	I-5		
47	SUBBASE	DESIGNATION	I-6		
48	SUBBASE	DESIGNATION	I-7		
49	SUBBASE	DESIGNATION	I-8		
50	SUBBASE	DESIGNATION	I-11		
51	SUBBASE	DESIGNATION	I-12		
52	SUBBASE	DESIGNATION	I-13		
53	SUBBASE	TYPE 1	CLASS A		
54	SUBBASE	TYPE 1	CLASS B		
55	SUBBASE	TYPE 1	CLASS C		
56	SUBBASE	TYPE 2	CLASS B		
57	SUBBASE	TYPE 4	CLASS H		
58	SUBBASE	1A			
59	SUBBASE	1B			
60	SUBBASE	1C			
61	SUBBASE	2B			
62	SUBBASE	4H			
63	DENSE	GRADED	AGGREGATE	BASE	COURSE
64	WASHED	GRAVEL			
65	WARRENITE	BITULITHIC			
66	WATERBOUND	MACADAM			

into the data base to debug any problems and to develop the drawing routines. The complete data base is planned to be loaded within the next two years.

6.3 EXTERNAL DATA BASES

6.3.1 GENERAL

Part of the initial work in developing the Pavement Information System was to perform a search of all data bases routinely maintained by the Department. The intent was to prevent duplication of data storage. This search identified sources of traffic, roadway, and accident information which are presently utilized in the Serviceability data base.

6.3.2 TRAFFIC AND ROADWAY DATA

The traffic and roadway data (speed limits, functional classes, median type,etc.) are accessed from the Bureau of Data Base Generation's System Mileage File. The file contains traffic data for each FHWA Highway Performance Monitoring System (HPMS) section. These HPMS sections vary in length from 0.01 to 18 miles. The data from the System Mileage File is reformatted for the PAVIS by processing the HPMS section data through a series of Fortran programs to calculate the appropriate values for each 0.2 mile PMS section. The data is periodically updated based on ADT changes in the System Mileage File. Traffic data from the System Mileage File mainly consists of two-way Average Daily Traffic (ADT) volumes for each HPMS section.

6.3.3 ACCIDENT RECORDS

Accident data, stored on a RAMIS data base by the Bureau of Traffic Engineering and Safety Programs (TESP), is identified by route and milepost location. The roadway direction of the accident is not identified on the police accident report. Therefore, the direction(s) of the vehicles involved is used to determine the roadway direction. The police accident reporting system charges all accidents which occur at the intersection with State highways to that State route.

Determining the breakdown of accident data for each 0.20 mile increment, by direction,required significant programing effort. Accident data which is included in the PAVIS consists of the accident date, the total accident volume,or number of occurrences, the number which occurred in wet weather, the number of non-intersection accidents and the number of these (non-intersection accidents) which occurred in wet weather, and the total number of accidents resulting in injuries, fatalities,or property damage.

6.4 SYSTEM REPORTS

6.4.1 GENERAL

As important as accurate data collection procedures and sophisticated software may be in a PMS, the main function of the PAVIS is to supply Department administrators (and/or State Legislators) with the key information needed to make decisions and allocate funds.

At the present time, several standard reports have been developed to satisfy the current needs of the Department. Other reports are generated on an as-needed basis to respond to specific inquires. Both types are discussed in the following sections.

6.4.2 PAVEMENT MANAGEMENT PRIORITY LIST

As mentioned earlier, one main objective of the PMS is to identify those sections of State maintained roads which need repair. Once each year, a pavement management priority list is published to provide the design and maintenance units with an inventory of candidate pavement sections for consideration in their respective rehabilitation programs.

The detailed data contained in the pavement management priority list is illustrated by a sample page from the Department's 1986 annual report (see Figure 22). As shown, pertinent information relative to each candidate project such as location, physical features, and various pavement rating indices (e.g., RQI, SDI, etc.) are included. Note that the ranking of projects is based on the final combined pavement rating (PI) from low to high.

6.4.3 SKID RESISTANCE INVENTORY

New Jersey's network is divided into four maintenance districts of which two are skid tested each year. A skid resistance inventory of the entire highway network is published yearly. However, it contains the combined data from one year's testing program with that from the previous year for the remaining two districts. A sample of the inventory report can be found in Figure 23. This report is also sent to the Bureau of Traffic Engineering and Safety Programs for use in the Safety Improvement Priority List (section 6.4.4).

6.4.4 SAFETY IMPROVEMENT PRIORITY LIST

Safety Index data (sections which exhibit low skid numbers, high rut depths, and high occurrence of wet weather accidents) are provided to the Bureau of Traffic Engineering and Safety Programs for the formulation of the Safety Improvement Priority List explained previously in section 5.4.

Figure 22

1986 BUREAU OF MAINTENANCE PAVEMENT MANAGEMENT PRIORITY LIST

PRIORITY NUMBER	ROUTE	START MILE	END MILE	LENGTH MILES	CONTROL SECTION	COUNTY	PVMT TYPE	LANES	SHOULDER	AVG SKID NUMBER	TRAFFIC AADT	TRAFFIC FACTOR	ROUGHINESS (MAYS PSI)	SURFACE DISTRESS RATING	FINAL PAVEMENT RATING	COMMENTS
1	078 EB	4.25	5.00	0.75	2113	WARR	RC	3	POOR	39.0	35494	2.04	1.32	1.67	1.49	INCLUDED IN DESIGN PROJECT RT 78, SEC 6G 7G 2V, MP 3.5 TO 4.9, 6.1 TO 9.1 AND 11.6 TO 12.5. SCHEDULED TO BE ADVERTISED 12-17-86.
2	078 EB	6.75	9.00	2.25	1014	HUNT	RC	3	FAIR	43.0	39654	1.70	1.25	2.01	1.52	INCLUDED IN DESIGN PROJECT RT 78, SEC 6G 7G 2V, MP 3.5 TO 4.9, 6.1 TO 9.1 AND 11.6 TO 12.5 SCHEDULED TO BE ADVERTISED 12-17-86.
3	295 NB	26.50	27.50	1.00	0427	CAMD	RC	3	FAIR	33.0	123609	0.0	1.94	1.51	1.62	
4	080 EB	49.25	51.00	1.75	0726	ESSX	CO	3	GOOD	39.0	79902	0.0	2.25	1.15	1.69	INCLUDED IN DESIGN PROJECT RT 80, SEC 3AD 4AY, MP 46.5 TO 52.8 SCHEDULED TO BE ADVERTISED 10-01-86.
5	080 EB	51.75	53.00	1.25	0726	ESSX	BC	3	GOOD	38.4	86574	0.0	2.18	1.70	1.82	INCLUDED IN DESIGN PROJECT RT 80, SEC 3AD 4AY, MP 46.5 TO 52.8 SCHEDULED TO BE ADVERTISED 10-01-86
6	080 WB	39.00	40.25	1.25	1414	MORR	BC	3	GOOD	39.4	77421	0.0	2.04	2.05	1.84	INCLUDED IN DESIGN PROJECT RT 80, SEC 8E 2S 3AC, MP 34 TO 44 SCHEDULED TO BE ADVERTISED 10-02-87.

RATING LEGEND: 0.00-1.00 VERY POOR, 1.01-2.00 POOR, 2.01-3.00 FAIR, 3.01-4.00 GOOD.

Figure 23

NEW JERSEY DEPARTMENT OF TRANSPORTATION

1985-1986 SKID TEST INVENTORY

ROUTE 077

DIR.	START MILE	END MILE	SN1	SN2	SN3	SN4	SN5	PAVE TYPE	TEST LANE	TEST DATE
NORTH	0	1	40.6	31.0	37.3	31.8	33.9	BC	1	07-03-86
NORTH	1	2	36.1	34.3	32.1	37.7	40.3	BC	1	07-03-86
NORTH	2	3	35.3	35.6	39.3	36.3	34.2	BC	1	07-03-86
NORTH	3	4	40.7	44.3	48.2	45.9	43.6	BC	1	07-03-86
NORTH	4	5	48.4	48.8	45.1	49.1	0.0	BC	1	07-03-86
NORTH	5	6	45.1	43.6	37.3	43.3	46.1	BC	1	07-03-86
NORTH	6	7	49.3	52.0	52.2	50.7	50.9	BC	1	07-03-86
NORTH	7	8	52.7	50.2	42.7	45.7	44.4	BC	1	07-03-86
NORTH	8	9	52.2	51.4	51.0	50.9	50.8	BC	1	07-03-86
NORTH	9	10	49.9	49.6	52.3	49.2	53.3	BC	1	07-03-86
NORTH	10	11	50.0	50.8	49.9	42.8	38.2	BC	1	07-03-86
NORTH	11	12	45.0	45.8	41.3	43.0	42.2	BC	1	07-03-86
NORTH	12	13	43.3	45.8	45.8	44.9	48.5	BC	1	07-03-86
NORTH	13	14	45.8	45.8	49.2	45.8	44.0	BC	1	07-03-86
NORTH	14	15	44.6	46.7	50.0	52.7	50.2	BC	1	07-03-86
NORTH	15	16	52.2	52.1	54.5	52.7	0.0	BC	1	07-03-86
NORTH	16	17	52.5	45.8	53.8	50.7	51.3	BC	1	07-03-86
NORTH	17	18	52.9	53.0	51.0	45.4	51.5	BC	1	07-03-86
NORTH	18	19	54.7	50.2	48.2	53.3	50.5	BC	1	07-03-86
NORTH	19	20	55.2	49.5	51.2	44.6	46.6	BC	1	07-03-86
NORTH	20	21	43.6	43.6	44.1	45.3	48.5	BC	1	07-03-86
NORTH	21	22	49.7	48.8	44.1	48.1	43.4	BC	1	07-03-86
NORTH	22	23	40.6	0.0	0.0	0.0	0.0	BC	1	07-03-86
SOUTH	1	0	37.2	36.2	0.0	0.0	0.0	BC	1	07-03-86
SOUTH	2	1	39.7	37.3	39.8	42.7	40.4	BC	1	07-03-86
SOUTH	3	2	31.5	34.6	31.4	35.6	36.6	BC	1	07-03-86
SOUTH	4	3	48.6	50.6	29.4	34.8	0.0	BC	1	07-03-86
SOUTH	5	4	45.6	45.4	50.1	50.2	46.0	BC	1	07-03-86
SOUTH	6	5	41.1	41.2	48.4	46.9	0.0	BC	1	07-03-86
SOUTH	7	6	51.6	50.6	45.9	46.0	39.8	BC	1	07-03-86
SOUTH	8	7	45.7	45.7	48.7	48.3	49.2	BC	1	07-03-86
SOUTH	9	8	49.1	48.7	48.3	45.0	39.4	BC	1	07-03-86
SOUTH	10	9	46.9	49.8	50.8	43.9	0.0	BC	1	07-03-86
SOUTH	11	10	51.4	49.4	48.6	48.8	49.8	BC	1	07-03-86
SOUTH	12	11	44.2	40.0	44.4	42.3	45.6	BC	1	07-03-86
SOUTH	13	12	45.7	47.0	49.2	45.8	40.5	BC	1	07-03-86
SOUTH	14	13	47.7	49.3	47.0	49.3	0.0	BC	1	07-03-86
SOUTH	15	14	49.3	46.4	43.3	44.2	0.0	BC	1	07-03-86
SOUTH	16	15	52.0	53.2	51.6	54.6	51.0	BC	1	07-03-86
SOUTH	17	16	49.8	49.6	51.3	48.9	51.5	BC	1	07-03-86
SOUTH	18	17	49.4	48.5	49.3	51.6	49.9	BC	1	07-03-86
SOUTH	19	18	45.3	49.2	49.1	47.7	45.7	BC	1	07-03-86
SOUTH	20	19	50.0	50.2	49.7	46.4	0.0	BC	1	07-03-86
SOUTH	21	20	44.9	48.3	46.5	45.6	0.0	BC	1	07-03-86
SOUTH	22	21	38.2	40.3	44.0	41.3	40.8	BC	1	07-03-86

6.4.5 SPECIAL REPORTS

Due to the flexibility of the RAMIS System, summary type reports can be generated upon request for any variable or combination of variables in the data base. Various statistics (mean, std. deviation,etc.) are available for any numeric variable. Reports can be generated "by" any variable or combination of variables (i.e., by route, by direction, by milepost, etc.). New variables can be "defined" as a mathematical function of variables or variables, functions, and constants.

Summary reports involving all 23,000 records are generally available in less than one minute. Data meeting the requirements of the parameters set in the report request can be saved to a sequential file for use in other mainframe programs such as Basic, Fortran, or SAS (Statistical Analysis System) or downloaded to a personal computer for spreadsheets, local data bases, word processing documents, and graphics summaries.

7.0 SUMMARY AND CONCLUSIONS

While New Jersey's present Pavement Management System is not the "ultimate" system, the data and reports produced by this system are used by operating units (design, maintenance,and the safety group) in the formulation of their respective rehabilitation/improvement programs. In addition, the current system establishes a basis for further development.

The network pavement evaluation area is quite strong. Adherence to well developed equipment calibration and correlation procedures should ensure that accurate and repeatable data is obtained on the State pavement network. Planned improvements of the equipment (e.g., vertical-looking video cameras, computerized data collectors,etc.) and the procedures are expected to enhance data quality and reduce the time/manpower requirements.

Despite the very simple performance and economic models currently developed, the future needs of the network can be estimated. The mechanisms for collection of this data for future model development and enhancement are being formulated.

The Pavement Information System is the solid core of the PMS. Future modifications and refinements based on user needs and computer hardware and software developments will make the system more responsive and useful to the operating units throughout the Department.

8.0 PLANNED IMPROVEMENTS TO THE CURRENT PMS

8.1 GENERAL

A basic pavement management system has been developed and implemented. Progress towards an "ultimate" pavement management system will proceed along various paths (improved procedures, designs, equipment, and new user needs). As mentioned earlier, PMS is dynamic in nature. Its evolutionary progress is influenced by a number of factors (e.g., experience, changes in pavement evaluation equipment, design procedures, material science, computer technology, etc.).

During the process of implementing the initial PMS, certain improvements to the current system were identified as well as topics for future research. This section highlights these areas.

8.2 EQUIPMENT CALIBRATION

The present Mays and ARAN calibration procedures use the current relative roughness level of each test site to estimate the correction factors to normalize the roughness data to data at 70 °F and 40 m.p.h.. A problem with this procedure is that when these sites are rerun at different times, it is not possible to determine how much of the change in roughness reading to attribute to changes in the vehicle suspension and how much to attribute to the deterioration of the pavement's ride quality.

The next evolutionary step in the roughness unit calibration will involve the use of the pavement profiles for both wheelpaths to estimate a ride statistic for the road section. All roughness correlations will be based on this new method. Since the wheelpath profiles are measured each time the calibration is needed, only changes in the unit's suspension characteristics are evident.

Besides roughness, the ARAN is also capable of measuring rutting and roadway geometrics. A calibration procedure must be developed to insure accurate, reliable, and repeatable rutting and geometrics information.

8.3 SAFETY MODEL

Rutting and roadway geometrics data plays a significant role in traffic safety. Future modifications of the Safety model will incorporate these parameters into the Safety Improvement project selection process.

8.4 PERFORMANCE MODEL

As discussed in section 6.1, the development of performance models is data intensive. Future efforts will be geared to developing roughness, distress (cracking, rutting, etc.), and skid resistance performance curves for each pavement type and major rehabilitation techniques. We plan to tie this data collection effort to the Department's LTPP (Long Term Pavement Performance) Study, part of the SHRP (Strategic Highway Research Program).

8.5 ECONOMIC MODELS

The present computer model is believed to be a very useful exploratory tool that is capable of answering general questions about overall funding levels and system condition. However, it must be recognized that a small amount of quantitative data was combined with a considerable amount of engineering judgment to develop the basic decay, cost, and effect curves that drive the model. It is anticipated that the necessary data to confirm or revise these assumptions will eventually be available and, accordingly, the Fortran program has been designed in a modular fashion to facilitate an easy updating.

Because it may be some time before the necessary data is available to precisely establish the basic curves, an extensive series of sensitivity tests is planned to determine which assumptions are most critical. Whereas it may not be possible at this time to pinpoint the location of any particular curve, it may be possible to specify a range within which it very likely will fall. In this way, a "best/worst" type of analysis can be performed which should make it possible to place confidence limits on the resulting estimates of costs and condition.

The present model deals only with flexible pavement. A similar model will have to be developed to deal with the approximately 25 percent of the system that is rigid pavement. In addition, when a rigid pavement receives its first overlay, it becomes a composite pavement. The overlay therefore changes the pavement type, and associated deterioration, cost, and effect models.

A specific question that has not yet been answered by this model concerns the presumed efficacy of repairing marginally deteriorated pavement sections before those that are more severely deteriorated. The initial runs suggest that this may be beneficial but the effect is so slight that it is uncertain whether it is either real or important. It will be one of the major goals of the continuation of this study to provide a more definitive answer to that question.

8.6 <u>COMBINED RANKING MODELS</u>

The current ranking model, which establishes the priority order for pavement rehabilitation programs, uses the combined Pavement Index (PI) based on RQI (60%), SDI (30%) and TF (10%). While this relationship provides a good initial mechanism for estimating an overall pavement rating, it tends to mask the individual contributions of ride quality level and the severity and extent of the various distress data.

In the future, separate lists of serviceability parameters will be produced (by pavement type) to highlight sections which exhibit RQI below the terminal serviceability level, or SDI (with the individual distress type, severity and extent) beyond an established trigger value. These trigger values for the distress attributes will need to be established by an expert panel in the follow-up study.

8.7 PAVEMENT MANAGEMENT INFORMATION SYSTEM

8.7.1 SERVICEABILITY DATA BASE

While the initial structure of the data base is well established, it is likely that future information needs may require modifications.

The next set of tasks envisioned for PAVIS is the creation of user-friendly menu screens and publishing documentation on data input, processing, and report generation. These tasks are fluid and will constantly be updated as the needs of the users evolve.

8.7.2 AS-BUILT DATA BASE

While the information for this data base was gathered from actual construction and maintenance plans and/or microfilm, there are sections of routes with missing or questionable data (e.g., plans show no overlay on a section for 50 years). The next critical task will be to verify the data base information and collect field information on sections with missing or questionable data. This verification process will utilize information from new construction and maintenance projects.

9.0 STATUS OF THE NETWORK

The following section illustrates the capabilities of the pavement management system's data base to summarize the condition of the New Jersey highway system. Figures 24-28 are graphical representation of key pavement management parameters for the interstate, non-interstate, and total system based on 1988 data.

9.1 PAVEMENT RIDE QUALITY INDEX

The collective illustrations on Figure 24 reveal that pavement ride quality is very high throughout the state. Approximately 10 percent of the total system falls below the terminal serviceability index of 2.5 (developed in the 1986 panel study), and less than 2 percent of the interstate pavements are rated below this level.

This is a marked improvement in the system ride quality which has been attributed to the Department emphasis on high ride quality levels at the time of construction. Because of this marked shift in pavement ride quality, the pavement management task force is now considering revising the combined pavement index to shift the emphasis from ride quality towards surface distress.

9.2 SURFACE DISTRESS INDEX

Figure 25 shows that the extent of surface distress on the interstate system is less than that on the non-interstate sytem as might be expeceted. The distribution on the non-interstate is more dispersed with a sizeable peak at the 2.75 level.

At present there is no "terminal serviceability" level for the combined surface distress attributes (e.g., longitudinal cracking, rutting, faulting, etc.). This will be a topic for the next pavement management research project. However, using the 2.5 from the ride quality as a guide, approximately 30 percent of the non-interstate and 35 percent of the total system falls below this level. This percentage of the system below the traditional terminal serviceability level suggests that a significant portion of the network is in need of rehabilitation and is the reason why the emphasis has shifted from pavement ride quality to pavement surface distress.

9.3 PAVEMENT INDEX

The distribution of the pavement index for the network are illustrated in Figure 26. Because this combined pavement index is heavily weighted towards pavement ride quality, deficient surface distress levels are masked by the the high ride quality levels. For this reason, the pavement management follow-up study will examine alternate forms of the combinied pavement index.

9.4 RUTTING

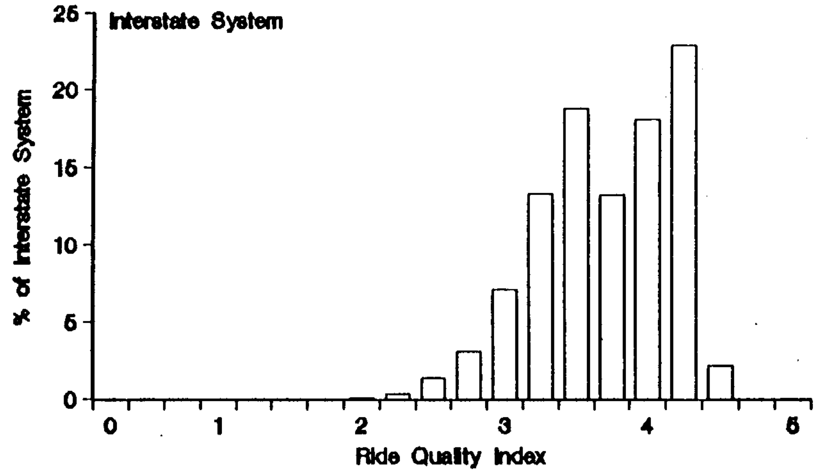
Rut Depth distributions are presented on Figure 27. The distributions indicate that about 4 percent of the non-interstate system has rut depths in excess of 0.5 inches, while rut depths on the interstate system exceeds 11 percent at this level. This higher percentage can be attributed to the larger percentage of heavy trucks using New Jersey's interstate system. The magnitude of this problem has prompted further research studies into the development of rut resistant asphalt mixes.

9.5 SKID RESISTANCE INDEX

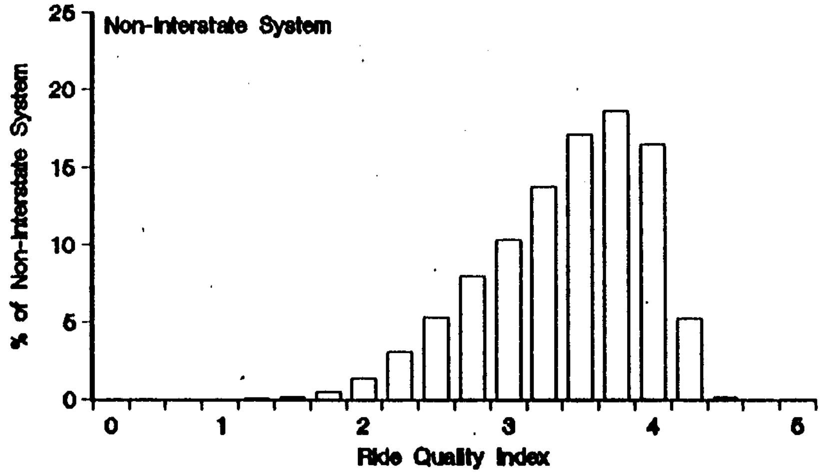
The skid resistance index, illustrated on Figure 28, is presently used in the Safety Index, but not in the Pavement Index. Note that nearly one third of the total network manifests a skid resistance lower than the NCHRP threshold of $SN_{40} = 39$. While a lack of skid resistance alone is not necessarily an indication of a safety related problem, these sites are examined inconcert with the other safety related parameters (e.g., rutting, speed limit, etc.).

Figure 24

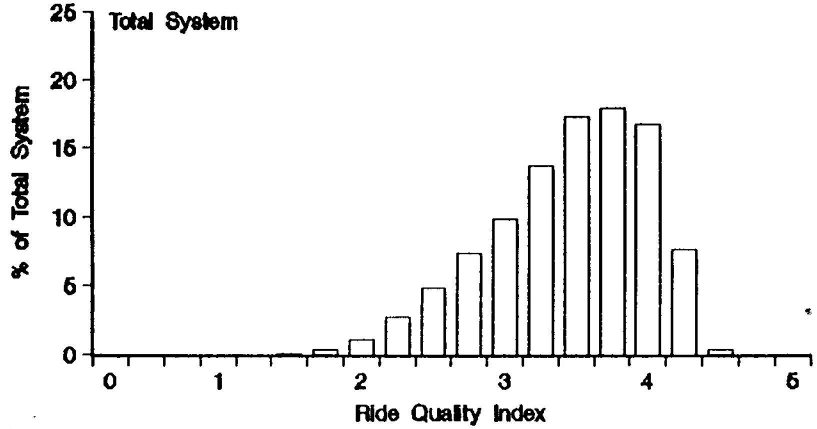
1988 RIDE QUALITY INDEX



Percentage based on 2,966
Inventory Sections (0.2 miles)
on the Interstate System



Percentage based on 19,774
Inventory Sections (0.2 miles)
on the Non-Interstate System



Percentage based on 22,740
Inventory Sections (0.2 miles)
on the Total System

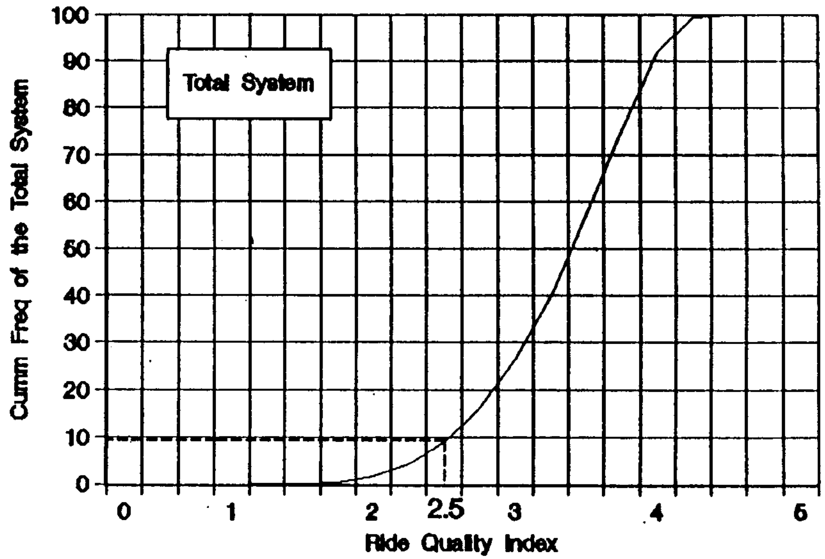
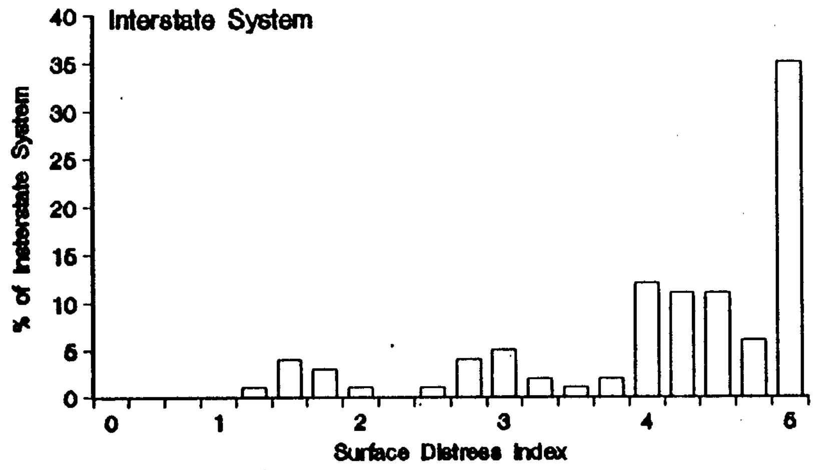
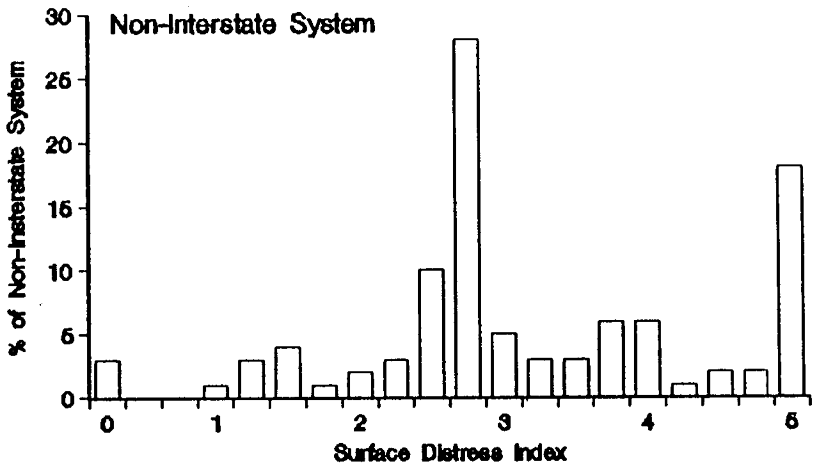


Figure 25

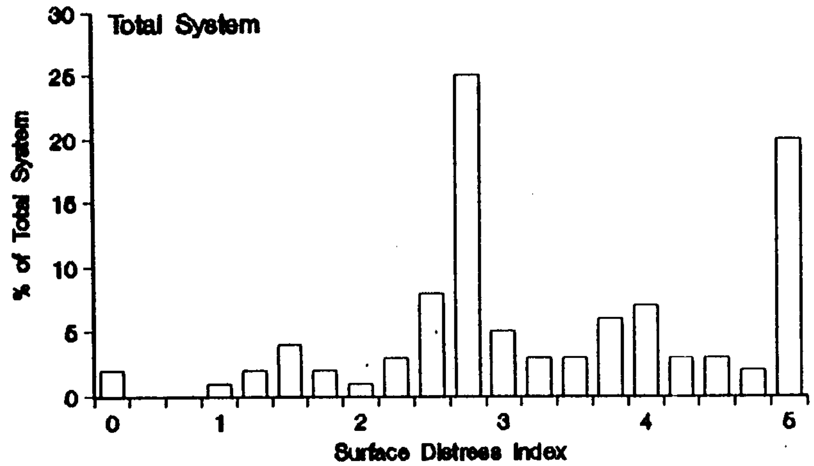
1988 SURFACE DISTRESS INDEX



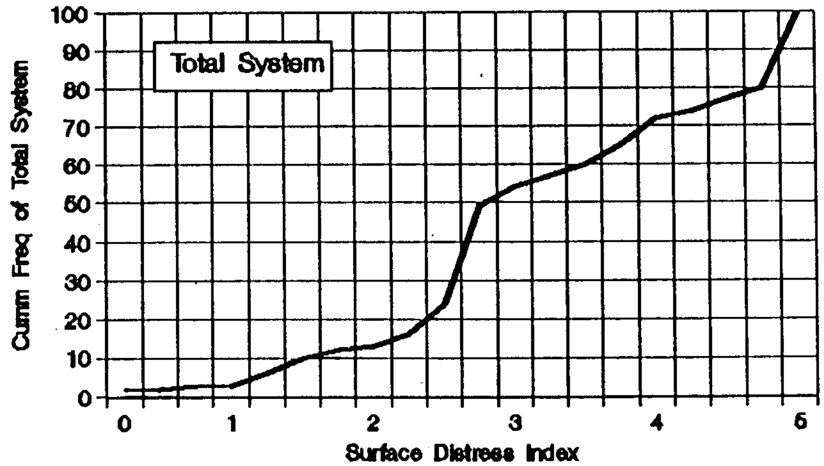
Percentage based on 3,043
Inventory Sections (0.2 miles)
on the Interstate System



Percentage based on 19,774
Inventory Sections (0.2 miles)
on the Non-Interstate System



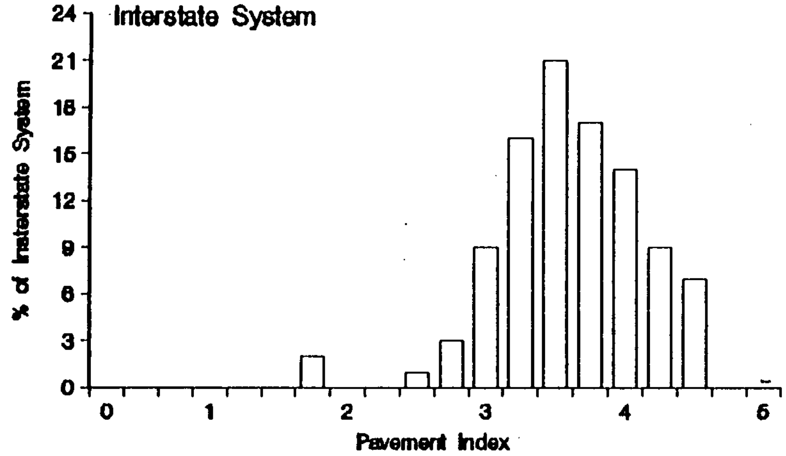
Percentage based on 22,817
Inventory Sections (0.2 miles)
on the Total System



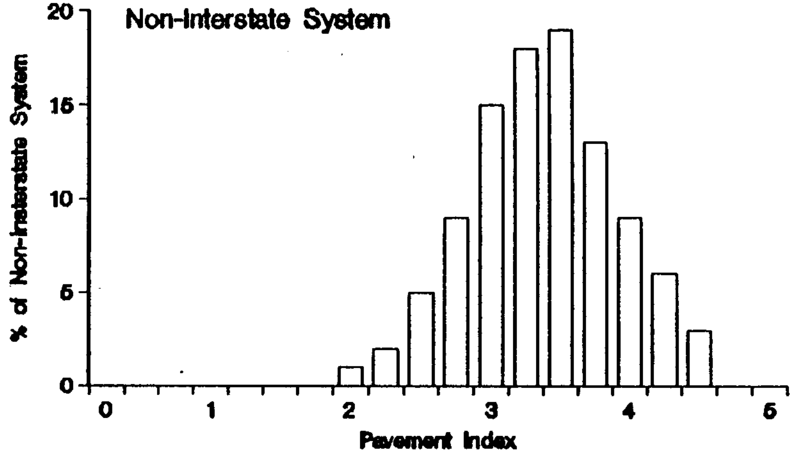
Percentage based on 22,817
Inventory Sections (0.2 miles)
on the Total System

Figure 26

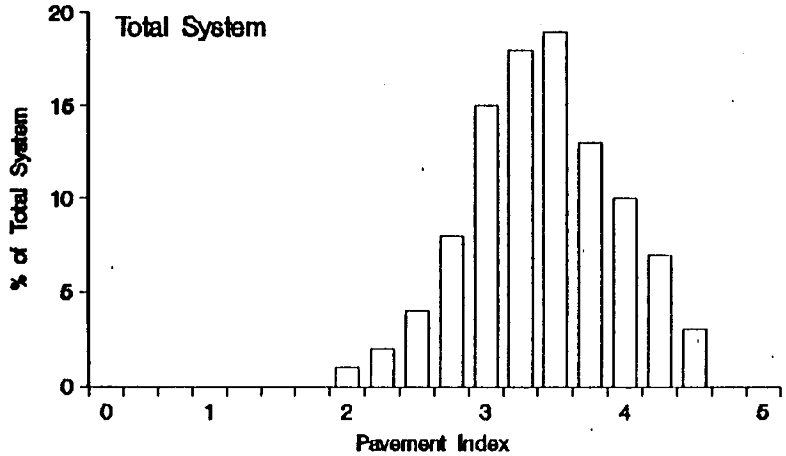
1988 PAVEMENT INDEX



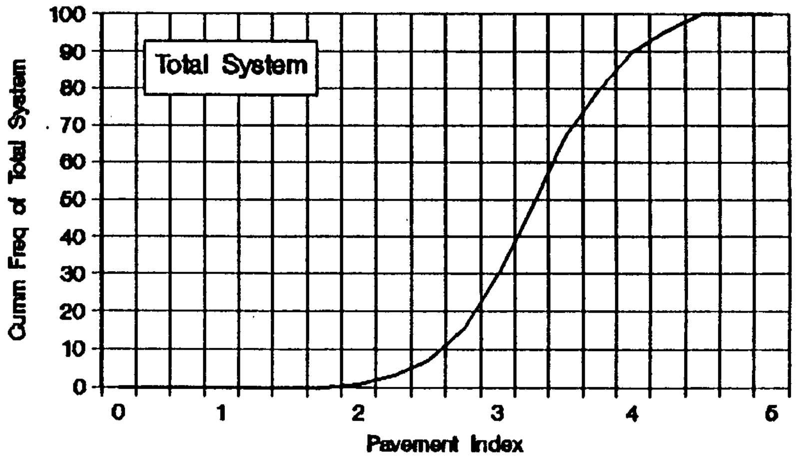
Percentage based on 2,891
Inventory Sections (0.2 miles)
on the Interstate System



Percentage based on 19,217
Inventory Sections (0.2 miles)
on the Non-Interstate System



Percentage based on 22,108
Inventory Sections (0.2 miles)
on the Total System



Percentage based on 22,108
Inventory Sections (0.2 miles)
on the Total System

Figure 27

1988 RUT DEPTH VALUES

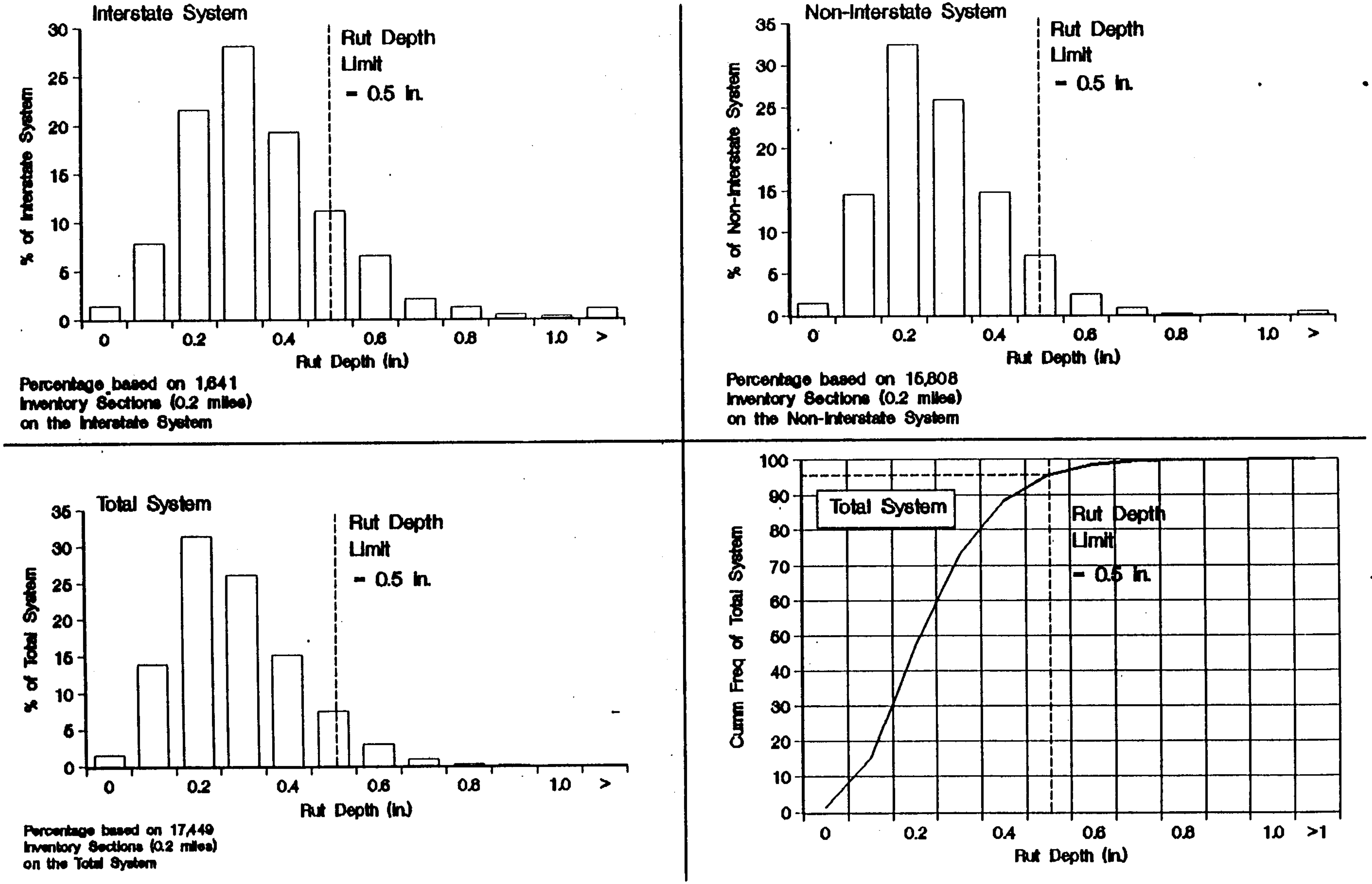
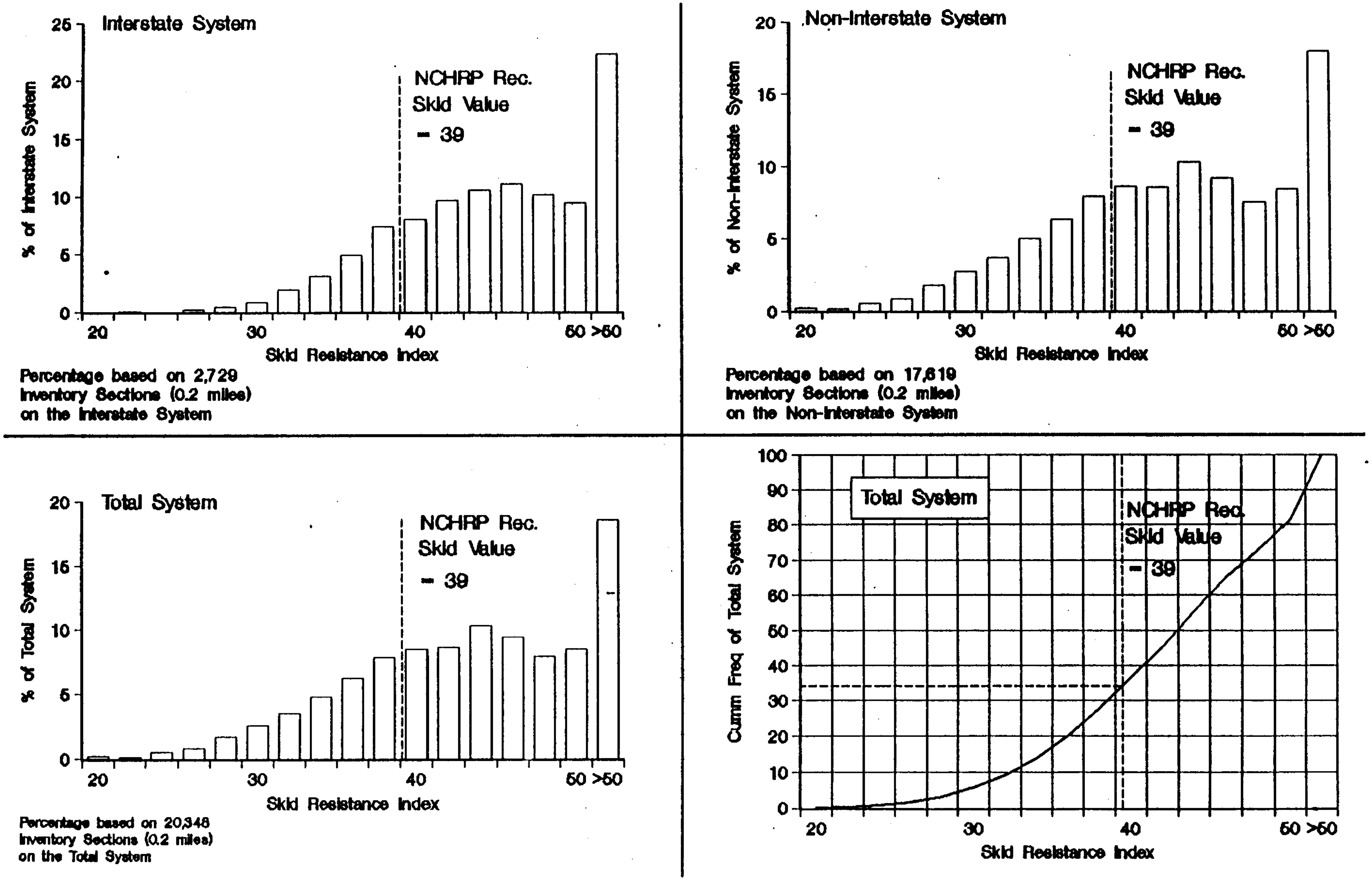


Figure 28

1988 SKID RESISTANCE INDEX



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APPENDICES

SATELLITE STUDIES

The following appendices describe the satellite studies conducted as part of the overall pavement management development process.

APPENDIX A - MILEPOST SYSTEM VERIFICATION

One of the first major satellite studies was the verification of the existing milepost system. This effort was given high priority in order to assure that all pertinent pavement information (e.g., serviceability, safety, and asbuilt data) for a given location, refers to the same pavement section.

The data collection starting point of each route was established and marked. Following this, vehicles equipped with distance measurement instruments (DMI), calibrated with an accurate fifth-wheel measurement device, were used to establish the location of the milepost signs in the primary directions (Northbound or Eastbound). The milepost signs in the secondary direction were located (approximately) directly opposite the primary direction sign. This convention was necessary because the length of many routes are different in the opposite direction. Existing milepost signs which were not located at the correct location were relocated. All milepost sign faces were replaced.

As part of the effort to ensure future reliability and repeatability of data, maintenance foreman responsible for maintaining the milepost signs were briefed on the operation and a procedure was established to restore damaged or missing milepost signs.

The milepost verification program was a joint effort conducted by the Division of Research and the Bureaus of Maintenance and Data Base Generation with the assistance of personnel from the Bureau of Construction and Maintenance's Winter Assignment Program.

APPENDIX B - MAYS-ARAN CORRELATION AND CALIBRATION STUDY

The PMTF emphasized pavement ride quality (roughness level) as the key parameter in assessing the pavement's overall condition. In 1985 an initial calibration procedure was developed for the Mays Ride Meter (Mays)(8). This procedure was developed to assess the repeatability and variability of the Mays output at various combinations of roughness, temperature, and speed levels. The procedure was designed to gain confidence in the Mays output, to periodically reevaluate the operating characteristics of the Mays, and to provide data necessary for correlation analyses of the various Mays units.

Twelve 1/2 to 1 mile test sections were established on bituminous and concrete pavements. These sites were selected to cover the range of road roughness expected to be encountered during normal road roughness surveys.

Each Mays unit was repeatedly driven over a single test site at 30, 40, and 50 m.p.h.. This process was repeated on each test site. The twelve sites were retested in this manner at low, moderate, and high temperature. Figure B-1 illustrates the experimental design schedule for testing.

The collective data was used to develop a calibration equation for each vehicle which incorporates speed and temperature corrections (to 40 m.p.h. at 70 °F). The corrected data was used to establish the correlation relationships between the Mays units.

The Mays units are presently driven over test sections used as a control site as standard practice, before roughness survey data is collected.

This same calibration and correlation procedure is now applied to our recently acquired ARAN unit. Both the Mays and ARAN units are being retested to provide data for inter-unit correlation.

Figure B-1

EXPERIMENTAL DESIGN

MINIMUM NUMBER OF REPETITIONS AT SPECIFIED TEMPERATURE AND SPEED

PAVEMENT TYPE	ROUGHNESS LEVEL	40 MPH			20 MPH			30 MPH			50 MPH		
		30	60	90	30	60	90	30	60	90	30	60	90
	Smooth	10	10	10	3	3	3	3	3	3	3	3	3
Bituminous	Medium	—	10	—	-	3	-	-	3	-	-	3	-
	High	10	10	10	3	3	3	3	3	3	3	3	3
	Smooth	10	10	10	3	3	3	3	3	3	3	3	3
Concrete	Medium	—	10	—	-	3	-	-	3	-	-	3	-
	High	10	10	10	3	3	3	3	3	3	3	3	3

APPENDIX C - FRICTION TESTER CALIBRATION

Pavement friction or skid resistance is measured as part of the network pavement condition evaluation. Four test units (truck and trailer), fabricated by Stevens Institute of Technology, are used to collect friction data on each pavement section. Prior to actual data collection these units are calibrated annually at the Eastern Field Test and Evaluation Center in East Liberty, Ohio.

Upon arrival at the Ohio test facility, the output of each friction tester is compared with the FHWA test unit which is maintained by the Bureau of Standards. This initial comparison is performed at 20, 40, and 60 m.p.h. on test pavements of various friction levels.

Each sub-system (water spray, speed and transducer output) is checked for compliance with the ASTM E-274 specification and adjusted as required. At the completion of these adjustments or modifications, the test units are retested against the standard.

A final report is prepared by the facility staff detailing the initial and final comparison tests, developing the correlation relationships, and listing the adjustments made to each unit.

APPENDIX D - NEW JERSEY PANEL STUDIES

The New Jersey panel studies (9) were conducted to complement the roughness equipment calibration procedures. The measurement of pavement roughness, regardless of the accuracy or repeatability of these measurements, is without meaning unless these values are correlated with the user's subjective opinion of the roads's roughness (ride quality).

The panel studies provided the means to establish the relationships between user opinion and measurements taken with the Mays Ride Meter, the ARAN, and the inertial profilometer. These relationships allow us to correlate the user's opinion of the pavement's ride quality to the output of the test vehicles. These panel studies also provided the data necessary for estimating the terminal serviceability index of each pavement type. Using the concept established at the AASHO Road Test, New Jersey defines a terminal serviceability index as the ride serviceability level at which point 50% of the panel members indicated that the pavement section should be rehabilitated based on road roughness alone.

Each of the two panel studies was conducted in three phases as described below.

OVERVIEW OF THE 1985 PANEL STUDY

Phase I - Preliminary Work

The preliminary work involved three major areas. First, it was necessary to review documentation on successful panel studies conducted by others (10) as models for our own effort. From this review, the Weaver-AASHO direct scale (Figure D-1) was selected to gauge the individual panelist's opinion of a pavement section's ride quality.

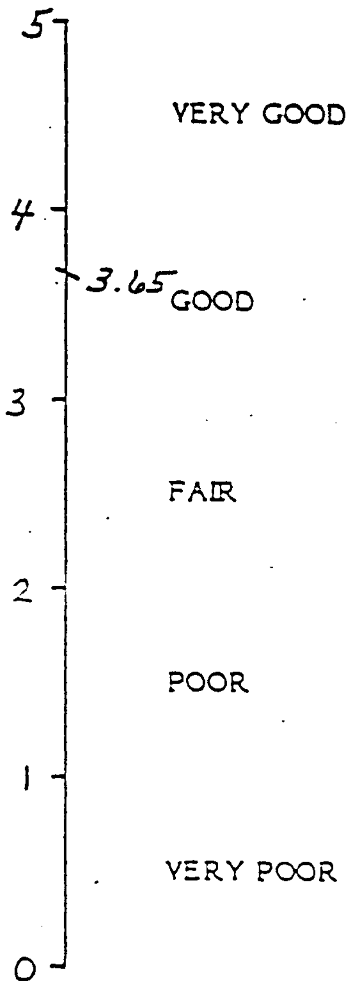
A second aspect of the work involved selection of quarter-mile test sections. A total of 28 test sites (14 bituminous and 14 concrete) were selected from over 40 potential sites. The sites were chosen to cover the full range of road roughness expected on the State highway network. The test sections were arranged in four test loops with a single pavement type within each loop. Two loops (one of each pavement type) were tested each day.

The third aspect of the work centered around the selection of panel members. It was determined that a panel size of 21 persons would provide the necessary volume of data based on the 28 test sites. The rating panel consisted of seven technical professionals (4 female and 3 male), seven non-technical males and seven non-technical females. For the purpose of this study, we distinguished the technical panelist as a person who had experience rating pavements and who had previous knowledge of New Jersey's Pavement Management System. The non-technical panelists were those persons not actively involved in rating pavements. One panelist from each of the three categories was randomly selected as a passenger in each test vehicle. Each was allowed to select his/her seat position in the car. However, once chosen, that

RIDE RATING PANEL

SECTION NUMBER 18 DATE ________ TIME ________

RATER (NAME) ________ VEHICLE NUMBER ________ POSITION IN VEHICLE ________



IS THIS RIDE ACCEPTABLE?

YES	
UNDECIDED	
NO	

Figure D-1 0-5 Scale

position became his/her assigned seat for the remainder of the experiment.

Phase II - Testing Phase

Prior to the actual testing, the panelists were given an orientation in which they were told the purpose of the experiment, provided with written instructions, and assigned to vehicles. After the orientation, the panelists were driven over two bituminous "calibration" sites (an extremely rough and an extremely smooth site) as a frame of reference for their ratings.

Among the key points stressed during the orientation was that each rater should record his/her own opinions, that there is no wrong answer, and that they should concentrate on the ride quality of the section alone. The two questions which they were to answer for each test section were, "How would you rate this section's pavement ride quality", and "Is the ride quality at an acceptable level or would you like to see the State spend your tax money to improve it".

Experimental Test Procedure:

-After their orientation and "calibration", panelists were driven along the bituminous and concrete pavement loops.

-At the beginning of each test site (the beginning and end were delineated by cones) the panelist were given the site's number. At the end of the section, the panelist were asked to rate the pavement's ride quality by placing a pencil mark on the scale. They were also asked to answer the question, "Is this ride quality acceptable?" by checking "yes", "no" , or "undecided" on the form.

Phase III - Data Analyses

The data was analyzed to calibrate the models (i.e., relationship or equation) which could be used for transforming the Mays Ride Meter measurements to PSR, the average user opinion of the road's roughness. In addition, estimates of the terminal serviceability index were determined.

Regression Analyses -

A scatter diagram of rater opinions and Mays Ride Meter values for each site is presented in Figure D-2. An analysis was subsequently performed to determine the relationships between the mechanical and subjective measurements of road roughness.

High variability of user opinion was immediately noticeable. The spread of 2.5 PSR units initially appeared to be excessively large, especially on a 0-5 scale. A reasonableness check with a 1983 Ketron study (reference 7) and a 1963 Purdue study revealed a similar degree of variability among raters.

One of the most critical aspects of the analysis was to determine the appropriate form of the model. Considerable

PANEL RATING vs MAYS METER

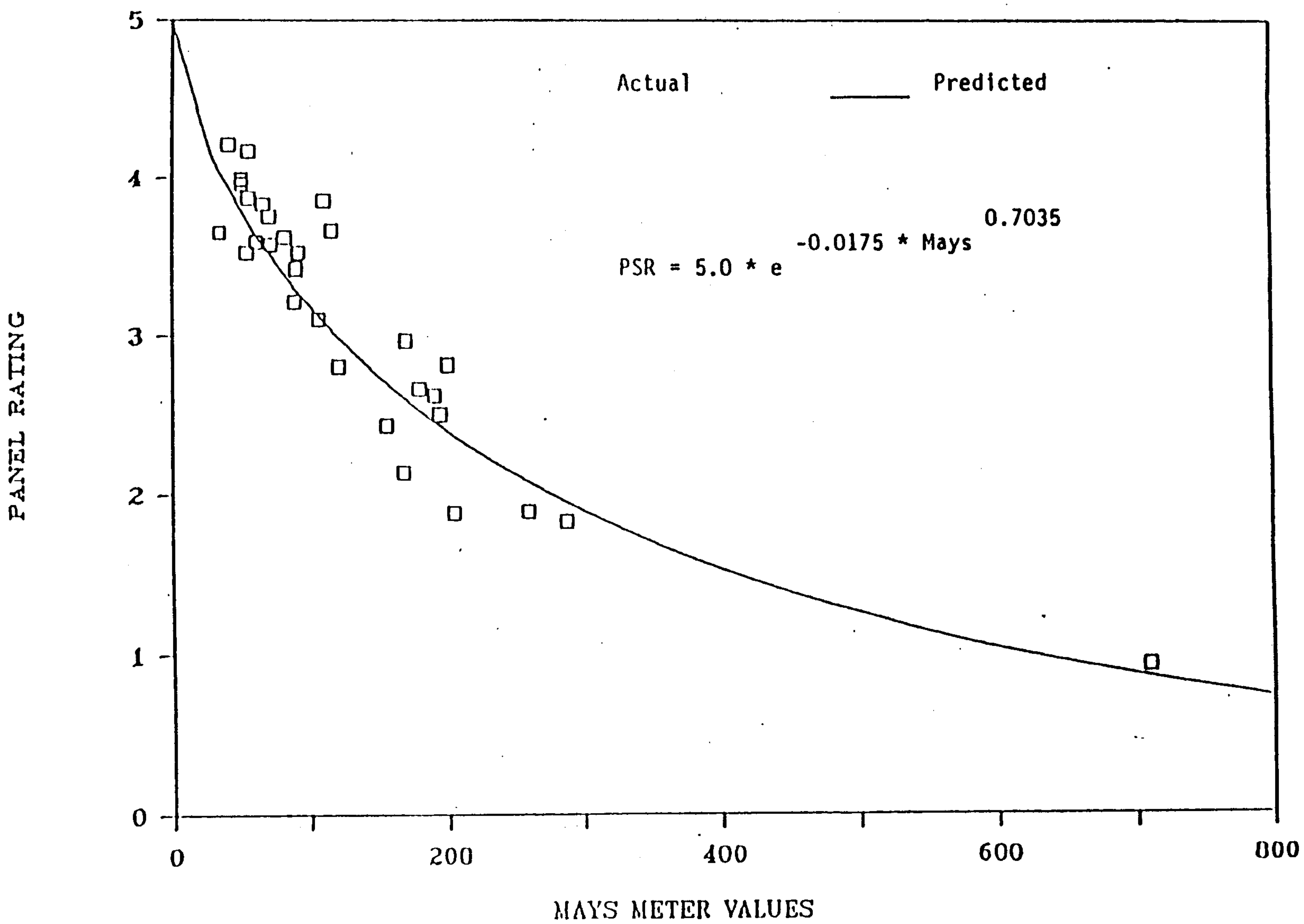


Figure D-2
Scatter Plot of (Mays,PSR) and Predicted Curve.

discussion addressed the merits of a straight line, a parabola, and an exponential function. Two boundary constraints were believed necessary to satisfy engineering judgment. First, both subjective and mechanical measurements of pavement roughness have known values for perfectly smooth pavements. For Mays Meter measurements, this value is 0.0 inches per mile and for user opinion the PSR value is 5.0. Secondly, since pavement roughness can increase infinitely, while the minimum PSR value is 0.0, the mathematical function must be asymptotic to the PSR-axis at infinity.

It was subsequently concluded that the following equation would approximately model the experimental data.

$$Y = 5.0 * e^{a * X^{b}} \qquad (3)$$

Nonlinear regression techniques contained in the Statistical Analysis System (SAS) were employed to estimate the constants a and b which provide the 'best fit' equation(s). After performing separate analyses, it was determined that unique curves for each pavement type were not justified.

The following equation (plotted in Figure D-3) is the 'best fit' curve for the combined data.

$$PSR = 5.0 * e^{-0.0175 * \text{Mays}^{0.7035}} \qquad (4)$$

This curve tends to obey 'Fechner's law' in which small increases in road roughness at the smooth end of the Mays scale cause greater decreases in the subjective rating than the same amount of change at the higher end; people are more sensitive to smaller differences of road roughness on the smoother roads than they are on rougher ones.

<u>Shortcomings and Questions of the 1985 Study</u>

A review of the results of the 1985 study revealed a number of shortcomings and questionable conclusions. The following is a summation of these problem areas.

1. The precision of NJ's user opinion was weaker than intuitively expected.
2. The available data supported only a single PSR= f(Mays) relationship for all pavement types. Since this result was unexpected, it was considered suspect at that time.
3. Raters who selected the "undecided" option on the ride acceptability question were disqualified from the logit analysis used to determine the terminal serviceability indices. Only a "yes" or "no" answer could be considered as a valid answer for the logit analyses. This constraint caused a severe reduction in the

amount of usable data.

4. The lack of Mays data in the 300 to 700 in./mile interval raised questions as to the adequacy of the estimated relationship in this range.

5. The use of a single type of roughness measurement device limited the generality of the developed relationships to that type of mechanical unit.

OVERVIEW OF 1986 PANEL STUDY - NCHRP 1-23 (2)

New Jersey was given the opportunity to participate in NCHRP 1-23 (2) along with four other states. This participation afforded the Department the opportunity to correlate its model(s) with those of four other states.

Objectives of the 1986 Panel Study -

The Department's specific objectives of this satellite study were:

1. To rectify the perceived shortcomings of the experimental design used in the earlier study.
2. To verify the PSR=f(Mays) relationship developed in the 1985 study and to develop similar relationships for the ARAN and Profilometer.
3. To determine the terminal serviceability level for bituminous, composite, and concrete pavements.

The tasks performed in the three phases of the 1985 study were repeated in this study. However, because the details of this study had to conform to the consultant's experimental design, certain modifications were required in each of the phases. The following sections outline these changes and the results obtained.

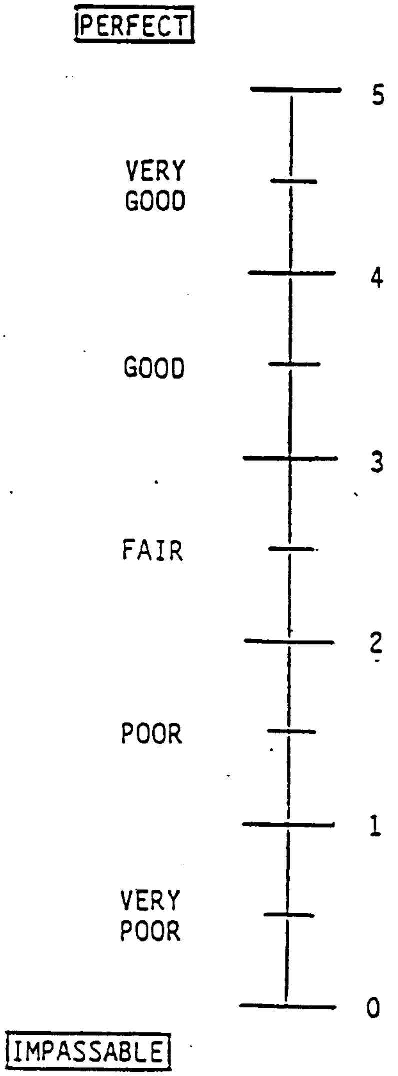
Phase I - Preliminary Work

The following changes to the 1985 experimental procedure were necessary to conform to the NCHRP experimental design.

The Weaver-AASHO direct scale (with minor changes) was again chosen to collect the user's opinion (Figure D-3). The "undecided" category was eliminated and the ride quality question was modified to determine at what point the users felt the pavement needed improvement.

The test site selection procedure was identical to the initial study with a few exceptions. Composite pavement sections (bituminous overlayed concrete pavements) were now included. The number of test sites increased from 48 in the 1985 study to 69. Of these, 62 sections were ultimately used in the analysis. Finally, the length of each test section was increased from 1/4 to approximately 1/2 mile.

From the list of verified test sections, a northern and a southern loop were created. The level of roughness and the pavement types were randomized as much as possible along the



☐ Ride quality does not need improvement

☐ Ride quality needs improvement

Site No. ________

Rater No. ________

Figure D-3

Weaver-AASHO Rating Scale

(bituminous overlayed concrete pavements) were now included. The number of test sites increased from 48 in the 1985 study to 69. Of these, 62 sections were ultimately used in the analysis. Finally, the length of each test section was increased from 1/4 to approximately 1/2 mile.

From the list of verified test sections, a northern and a southern loop were created. The level of roughness and the pavement types were randomized as much as possible along the route.

The 48 raters (plus alternates) were selected randomly from lists of available personnel submitted by various units within the Department. Panelists were assigned to test vehicles on a random basis. They were allowed to select their seat position but instructed to retain that position for the remainder of the test.

<u>Phase II - Testing Phase</u>

Prior to exposure to the test sites, the panelists were given oral and written instruction by Mr. Michael Janoff, the principal NCHRP 1-23 (2) investigator. The testing and experimental test procedures outlined earlier were also used in the 1986 study.

<u>Phase III - Data Analyses</u>

The roughness data was analyzed to determine the relationships necessary to transform Mays Meter, ARAN, and Profilometer values into estimates of user opinion. The data was analyzed to determine the terminal serviceability values for the three pavement types. The results of the 1985 and 1986 data analyses were also compared to verify the 1985 relationships.

Regression Analyses

The scatter diagrams (D-4, D-5, and D-6) of rater opinion vs. mechanical measurement device values (Mays, ARAN, and Profilometer) were plotted using the model fit by the SAS (nonlinear) computer package.

As cited earlier, the form of the model was considered critical in developing the appropriate relationships. After consideration of the physical constraints imposed by the model, and a scatter plot analysis, it was decided that the form of the model discussed earlier would be retained. It was subsequently determined that unique curves for each pavement type were not justified.

The equations plotted in Figures D-4, D-5, and D-6 are the 'best fit' curves for the combined pavement data for each roughness measuring device. These curves also obey Fechner's law cited earlier. A comparison of the 1985 and 1986 predictive models (see Figure D-7) indicate very close agreement.

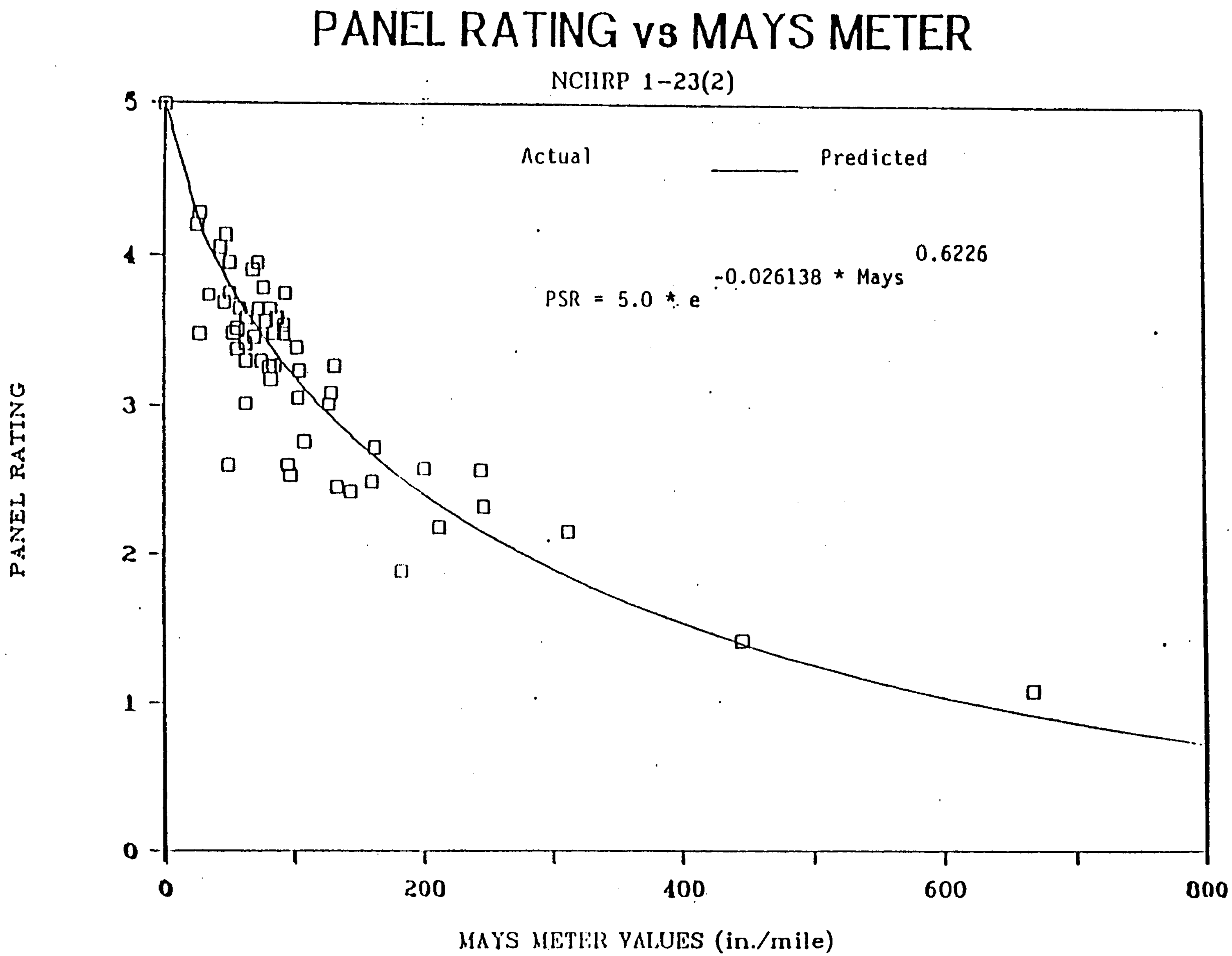


Figure D-4
Scatter Plot of (MAYS,PSR) and Predicted Curve.

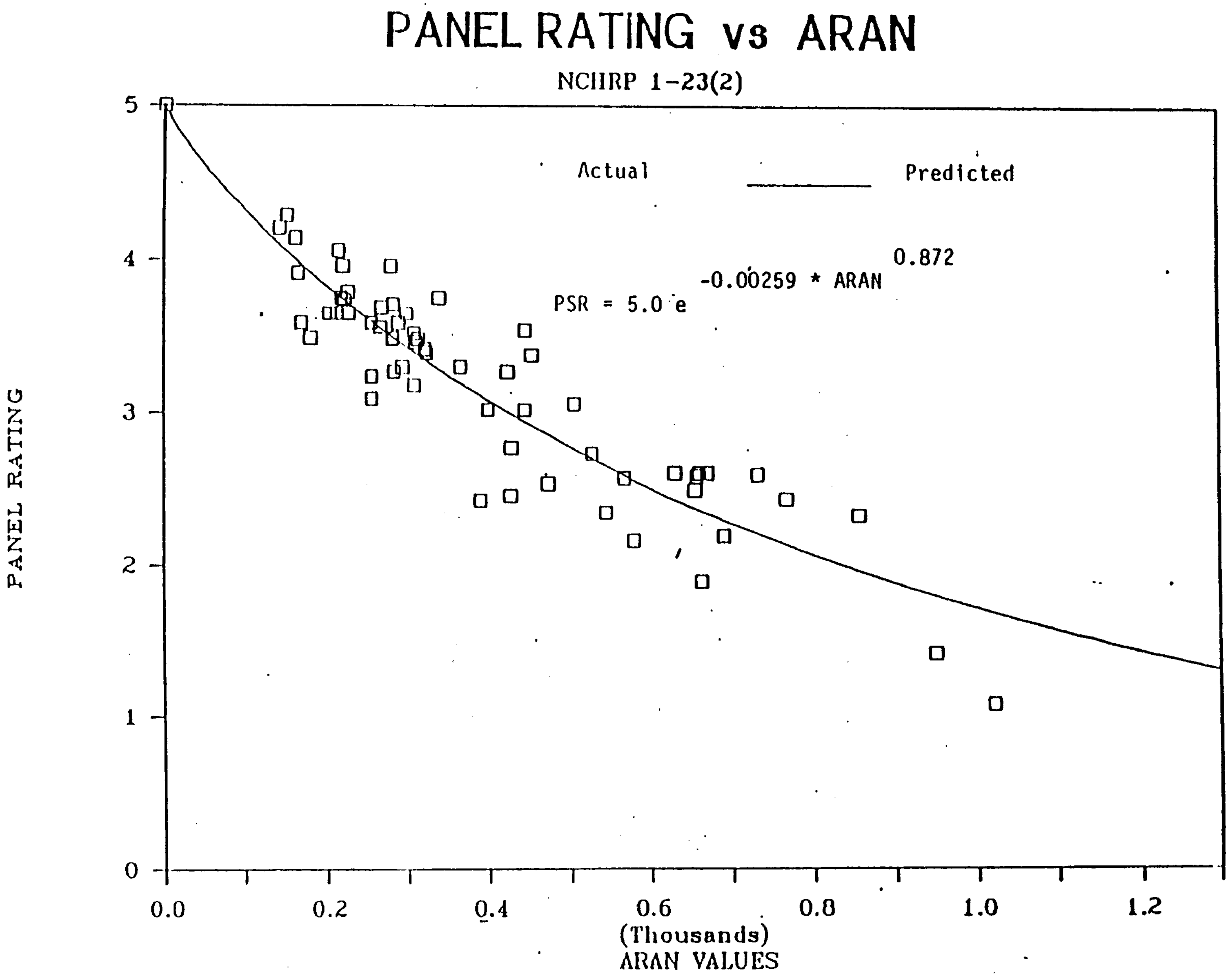


Figure D-5
Scatter Plot of (ARAN ,PSR) and Predicted Curve.

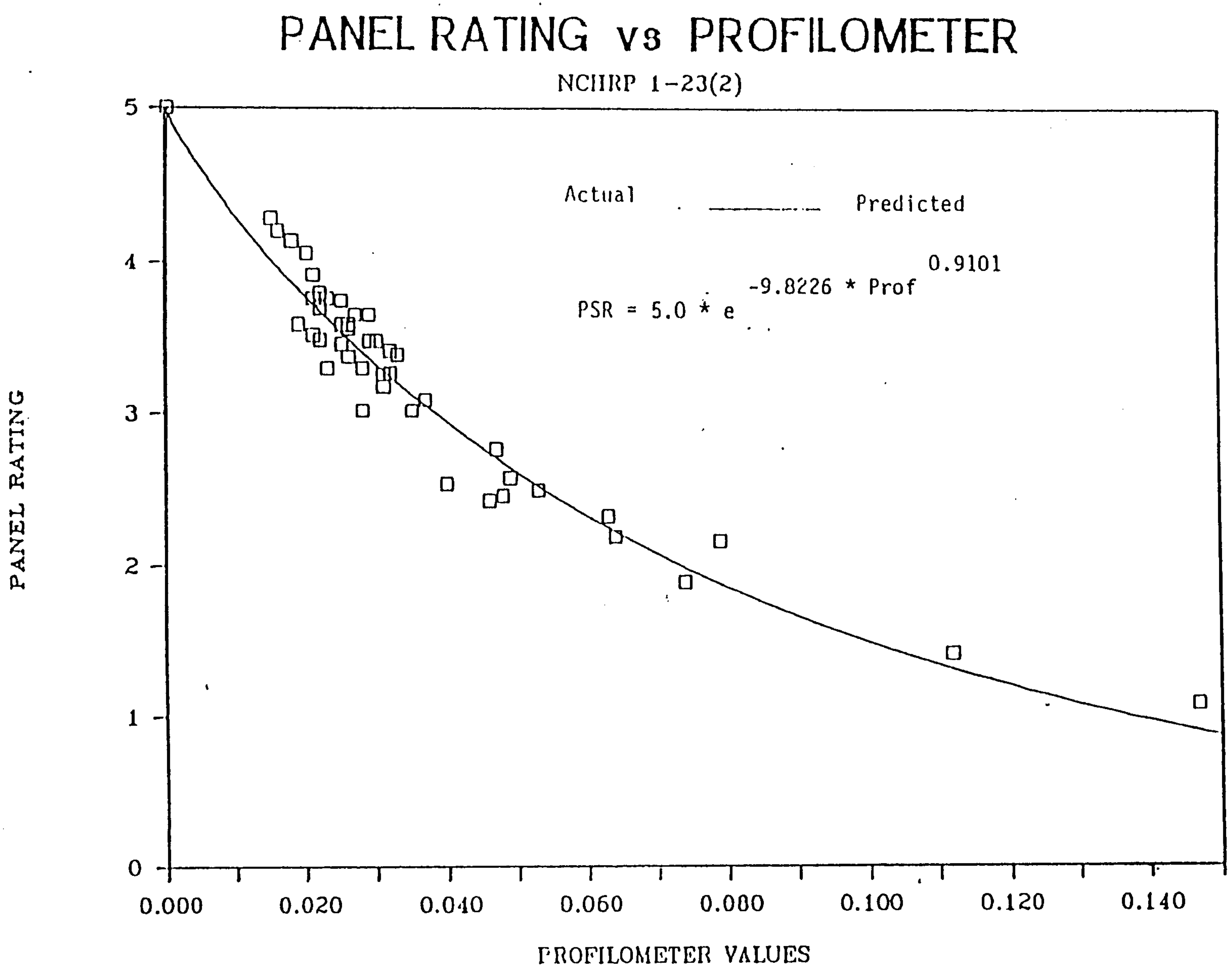


Figure D-6
Scatter Plot of (Profilometer,PSR) and Predicted Curve.

Terminal Serviceability Indices -

The third objective of this study was to determine the terminal serviceability index for each pavement type. Logit analyses were performed, regressing the proportion of the raters indicating pavement rehabilitation was required against the PSR value for each section. The analysis indicated that terminal serviceability of concrete and composite pavements were perceived without distinction, but that bituminous pavements were perceived differently. The terminal serviceability index for bituminous pavements is estimated to be a PSR of 2.0, while the TSI for concrete and composite pavements is approximately 2.5. The relative values of the bituminous and concrete composite pavement indices was unexpected. It had been assumed that the traveling public was more tolerant of roughness associated with the concrete and composite pavements. These results suggest just the opposite. Users are apparently more tolerant of the more uniformly distributed roughness, typical of the bituminous pavements, than they are of the sudden and more abrupt roughness associated with the joints of concrete pavements.

The combination of calibration procedure and panel study have provided New Jersey with a sound basis for evaluating the pavement network from the ride quality perspective. Modifications discussed in the future research section will enhance the value of this combination even further.

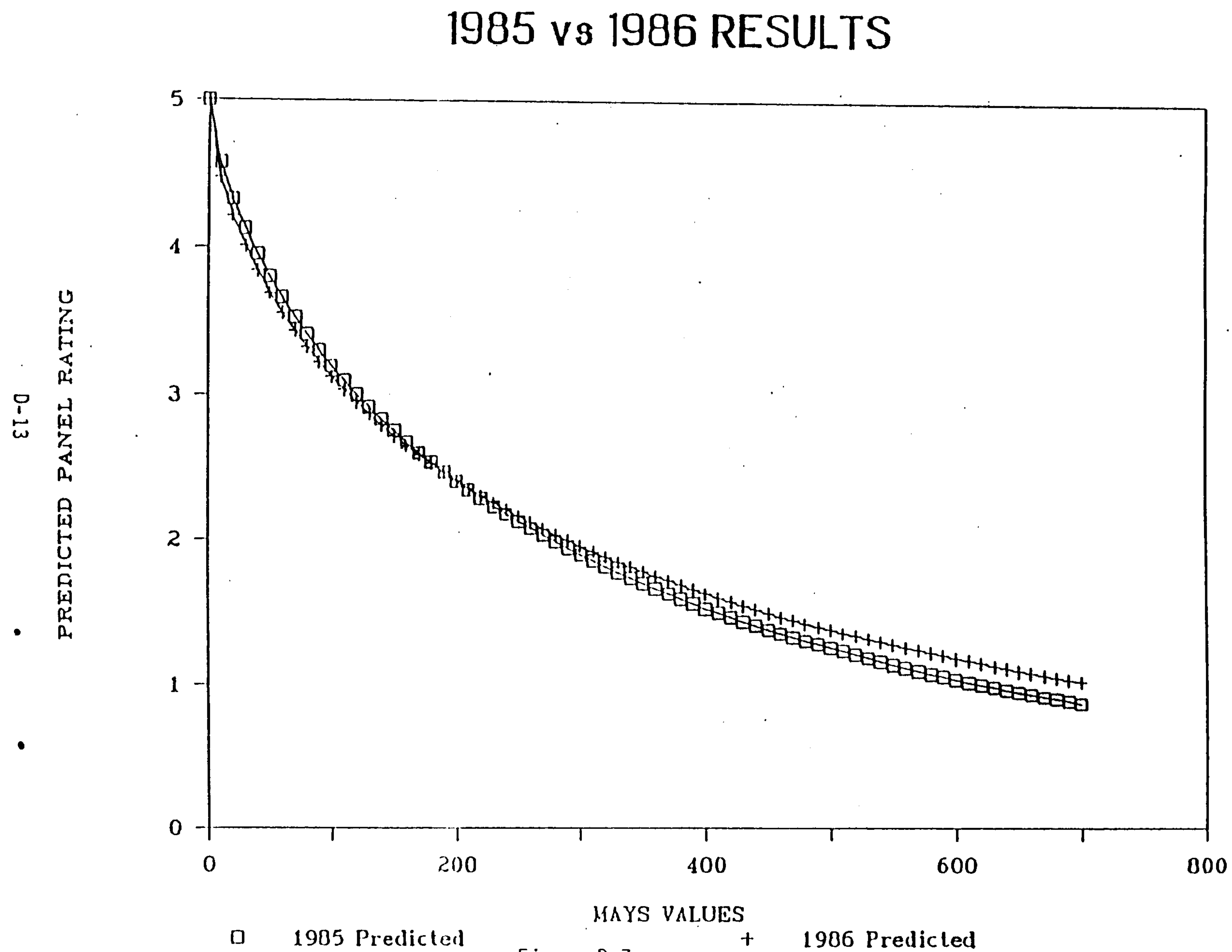


Figure D-7
Plot of 1985 and 1986 Mays Predicted Curves for All Pavement Types.

APPENDIX E

DEVELOPMENT OF RIDE QUALITY PERFORMANCE MODEL

Performance, in its simplest form, relates serviceability rendered to elapsed time. It was the objective of this phase of the pavement management study to develop such models for the ride quality serviceability parameter. Work on broader-scope models was deferred to subsequent studies so as to benefit from the experience of this first-stage attempt.

Ride Quality Performance Data

The best New Jersey data available to develop this ride quality performance model were the 1982 and 1985 systemwide Mays surveys. In these surveys a fleet of Mays vehicles measured the New Jersey pavement network, spanning a roughness range of approximately 10 to 600 inches per mile. Auxiliary descriptors of pavement characteristics, such as section age or design, were not available.

Use of this data required aggressive efforts to purge deleterious influences from the data base. These included sections which were re-mileposted and potentially mismatched, sections which were resurfaced between the two surveys and, whenever possible, eliminating measurements reported by Mays vehicles of uncertain calibration. It was not possible to distinguish the increase in roughness over time from possible trends in instrument bias. (Note that negative differences in roughness, in which pavements got "smoother" over time, were retained. The probability of observing a negative difference due to Mays instrument error alone was calculated to be 0.37.)

Summary statistics for the 1982 and 1985 mays surveys are presented in Figure E-1. For bituminous pavements, the systemwide average roughness increased from approximately 60 to approximately 77 inches per mile over this three year period. Note that while the number of pavement sections actually measured in 1982 and 1985 differed, only those 851 sections which could be paired between the two surveys were used in the following analysis. For this set of 851 paired measurements, the average annual difference was observed to be approximately 6 inches per mile per year.

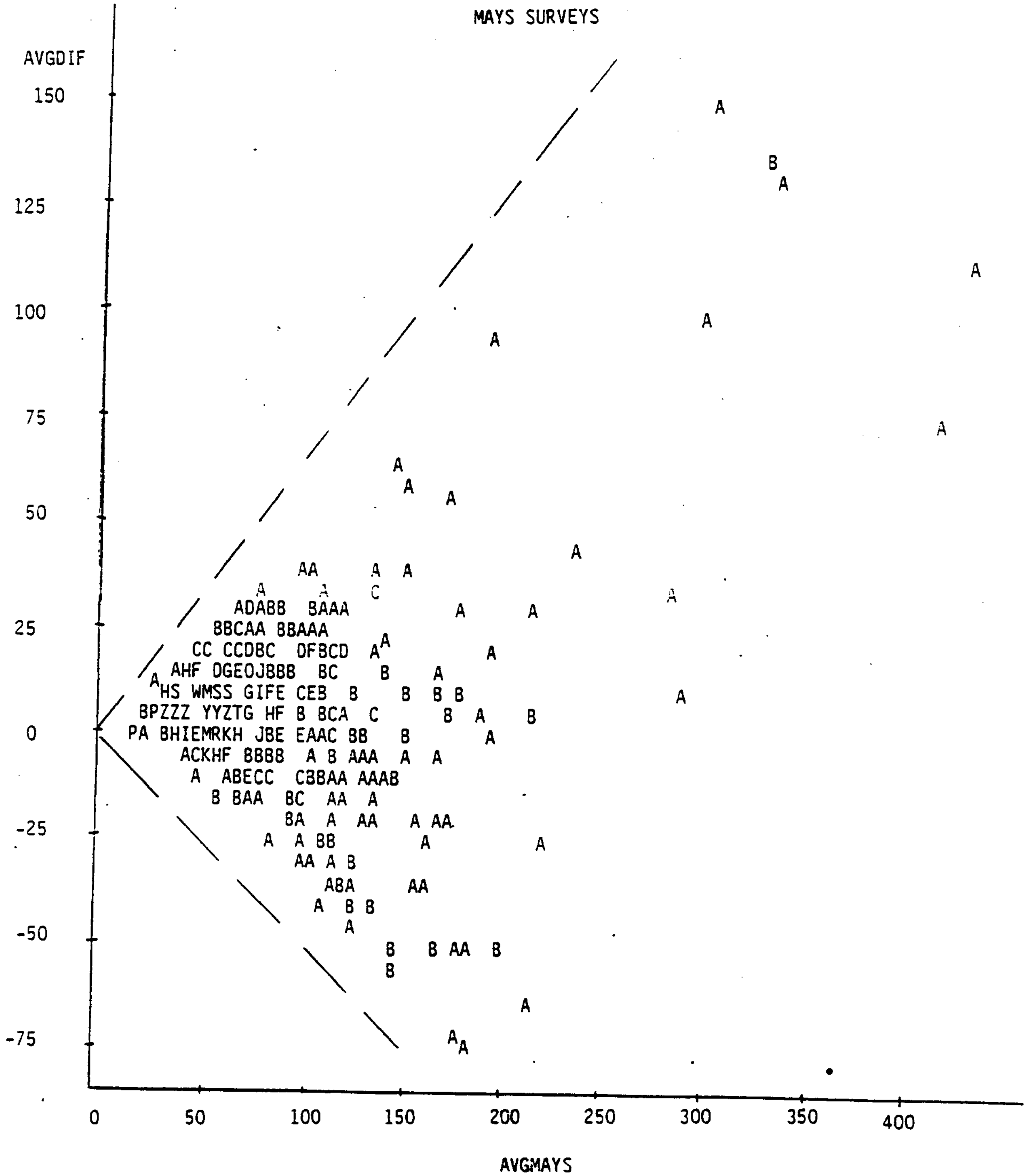
A plot of the average annual difference vs. average Mays for each pavement section is presented in Figure E-2. The conical spread of this scatterplot is partially attributable to the theoretical limits bounding plots of this type. In essence, the maximum difference of two values is limited by the absolute magnitude of the values. These limits plot as two lines symmetrically diverging from the origin. While the bulk of the data observations may be unaffected by these limits, those individual measurements most susceptible to random error apparently do approach these limits and delineate the domain's constraints.

Figure E-1

Summary Statistics
for the 1982 and 1985
Mays Surveys

Variable	N	Mean	Standard Deviation	Minimum Value	Maximum Value	Std Error of Mean
Mays82	874	61.56	47.59	8.59	316.77	1.60
Mays85	937	77.21	53.01	14.48	595.79	1.70
Avgmays	851	70.11	43.62	11.67	429.02	1.50
Avgdiff	851	5.84	16.98	-76.83	152.26	0.58

Figure E-2
PLOT OF AVGMAYS AND AVGDIFF
FOR 1982 AND 1985
MAYS SURVEYS



RIDE QUALITY PERFORMANCE MODELING

With this data it was only possible to develop a performance model on the basis of incremental change in ride quality. Two ride quality serviceability "snapshots" were available, and the elapsed time between them was three years. Had additional data been available, such as the ages of the various sections, then perhaps the full form of the performance model would have been revealed. Lack of additional information forced the developmental procedure to focus on the mechanism of observed roughness increases, and the procedure used this mechanism to determine the form of the model. Engineering judgement was used to assess the reasonableness of the end result.

Aside from the conical shape previously mentioned, a scatter plot of the 1982-1985 Mays differences vs. average Mays values did not reveal any obvious trends. (The average annual difference for this data is not suggested to be different for smooth pavements than it is for rough pavements.) This would suggest that a fixed average annual difference, i.e., a horizontal line, may fairly represent this data. The average annual difference for this overall data set of 851 paired observation is estimated to be approximately 6 inches per mile per year.

Close inspection of this data set revealed several average annual difference observations which were unreasonable. (For example, an average roughness increase of 150 inches per mile per year is simply not believable even if instrument error is taken into account.) While these data points could not be otherwise disqualified, it was decided on the basis of engineering judgement to exclude such extreme observations from this data. Analysis of the remaining data produced an estimated average annual roughness increase of approximately 10 inches per mile per year.

It is recognized that the rate of roughness increase may not be linear over time. The literature is unclear as to whether the increases are large at first and then gradually diminish, whether the opposite is true, or whether some form of a reversed "S" shaped curve is truly most appropriate. On the ground of little other choice, this analysis makes the simplifying assumption that the annual roughness increase, as measured by the Mays instrument, is indeed constant at the level of approximately 10 inches per mile per year. Similar analyses were also performed with composite and concrete pavement data. The increase in Mays roughness was approximately 14 and 13 inches per year for the composite and concrete pavements respectively.

Conversion of Mays to PSR (Reference Appendix D) or RQI re-expresses the same roughness increase but, because changes in roughness are perceived differently for rough pavements than for smooth pavements, the linear relationship is distorted. Thus the previous (linear) Mays vs. time relationship is now asymptotic to the abscissa when plotted as RQI vs. time.

Definition of a performance model simply requires this RQI vs. time relationship and an assumed starting point on the RQI scale. Given the initial value, all others are then determined. Performance models thus derived are presented in Figures E-3 to E-5 for bituminous, composite, and concrete pavements.

New Jersey's bituminous pavements typically start out with a RQI of approximately 4.0. Using the most reasonable rate of annual roughness increase, 10 inches per mile per year, this model suggests that bituminous pavements will last approximately 26 years on the basis of ride quality alone. Similarly, composite and concrete pavements are estimated to last 11 and 12 years, respectively.

These models admittedly incorporate a number of potentially significant simplifying assumptions. Two of the most critical are the initial RQI at time zero and the rate of roughness increase. While it was not possible to confirm the validity of these assumptions, it was possible to perform a sensitivity analysis and gage their potential impact.

The model for bituminous pavements was tested with initial RQI values ranging from 3.5 to 5.0. For each of these, the rate of annual roughness increase was assumed to be 5, 10, 15, and 20 inches per mile per year. Each of the pavements were "aged" until their RQI reached the terminal threshold (RQI=2.0) and the elapsed time was observed. In this way it was determined that the assumptions of initial RQI and deterioration rate did indeed have a significant influence on the estimated pavement longevity. At best (RQI_{init}=5.0 and DET RATE=5) pavements were estimated to last approximately 60 years, and at worst (RQI_{init}=3.5 and DET RATE=20) they were estimated to last 12 years. The spread of these extreme estimates suggests the order of magnitude of the precision associated with this model.

Recognizing a potentially large imprecision, this model still produces significant information. This model indicates that pavements have an adequate ride quality over a period of time substantially longer than the typical service life of a New Jersey pavement. Based on engineering judgment, New Jersey bituminous pavements fail overall after 10 or 11 years of service. The ride quality performance model indicates such an early failure would be extremely unlikely even with the margin of error suggested by the sensitivity analysis. Thus one concludes that New Jersey pavements are more likely to fail with respect to parameters other than ride quality. If so, future efforts in pavement management should be directed to the identification and modeling of these other parameters.

The ride quality models developed in this study have advanced the Department's understanding of pavement performance. While very much a prototype effort, the information learned will provide guidance in future developments of the Department's pavement management program.

Figure E-3

Ride Quality Performance Model For Bituminous Pavements

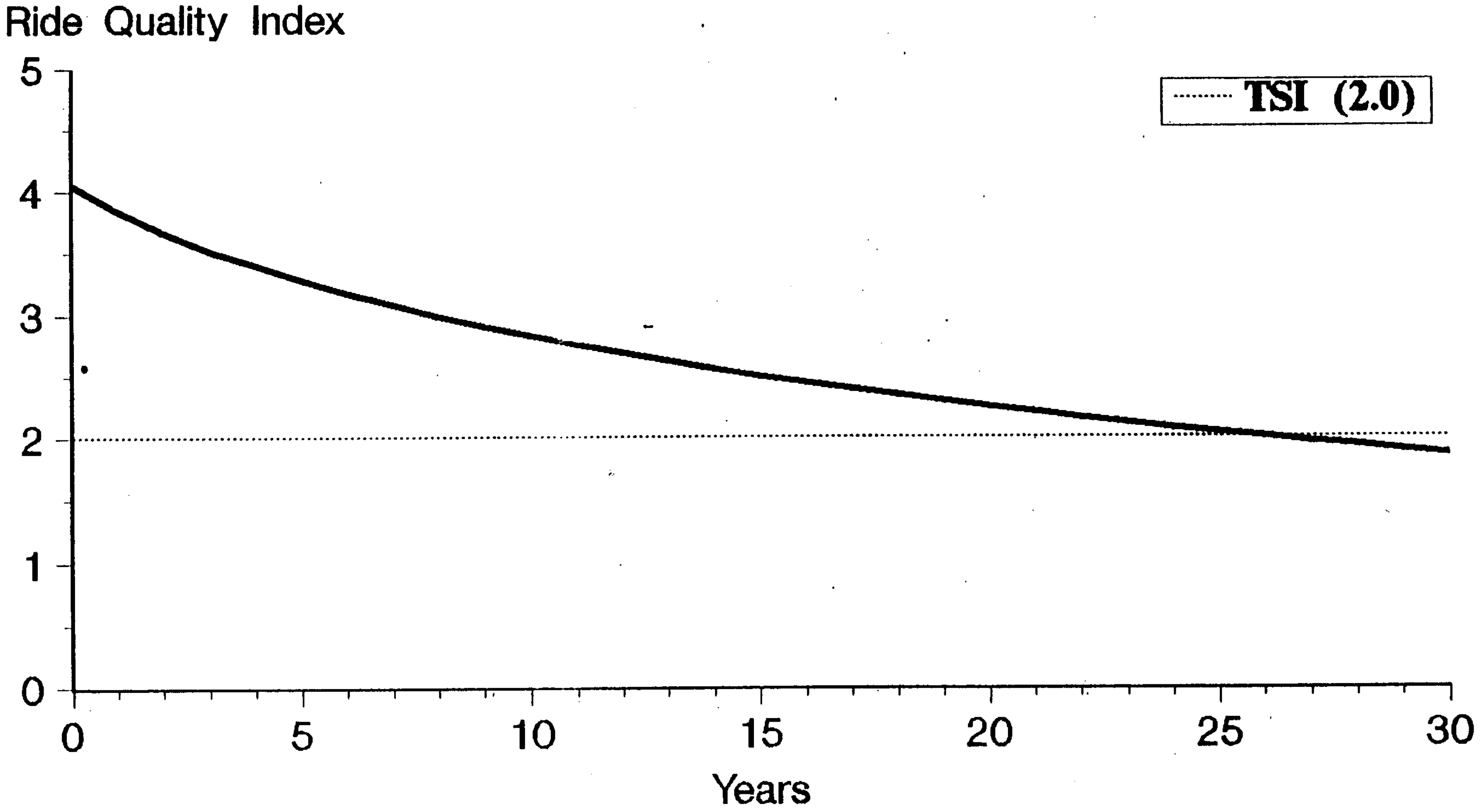


Figure E-4

Ride Quality Performance Model For Composite Pavements

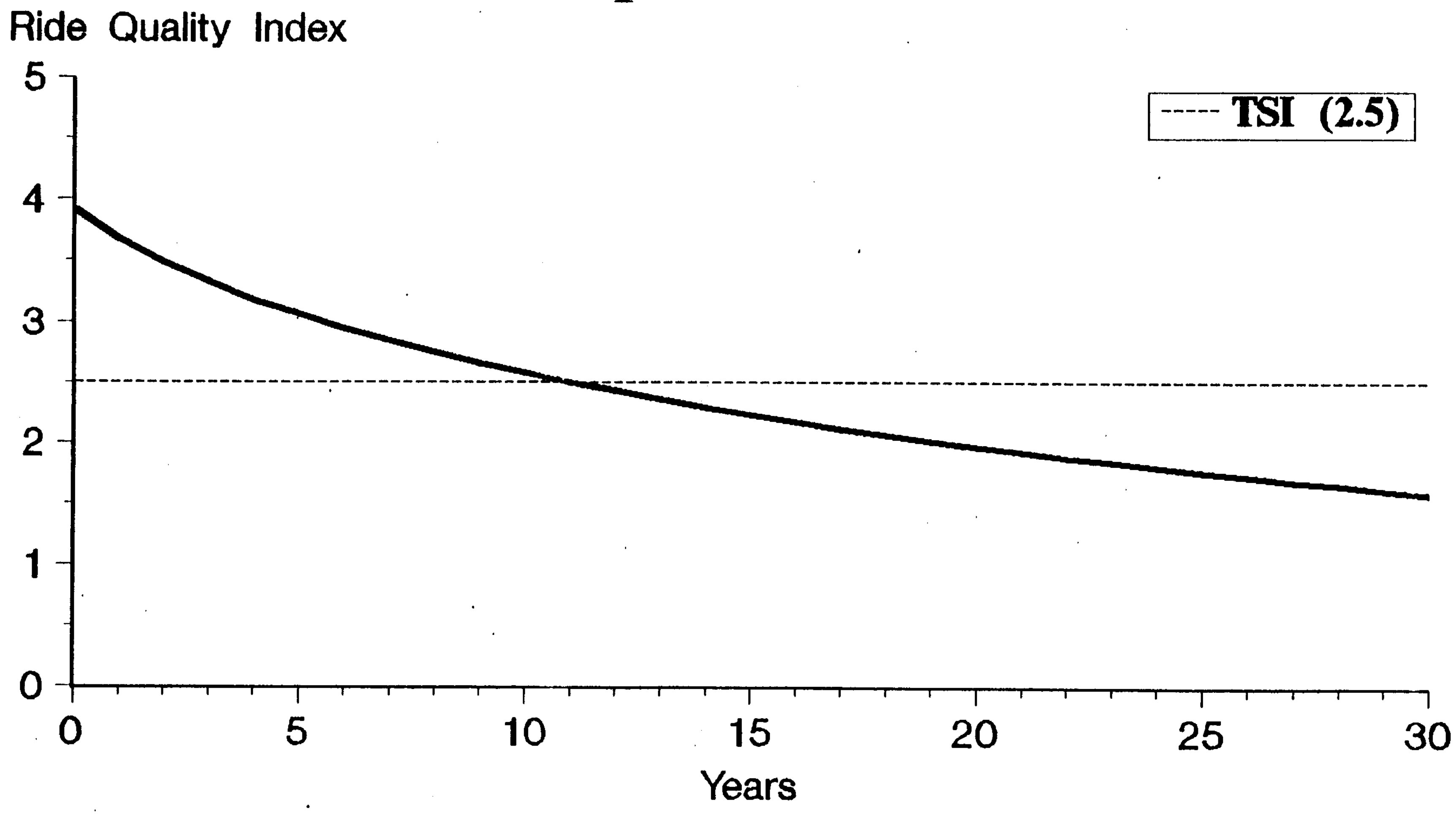
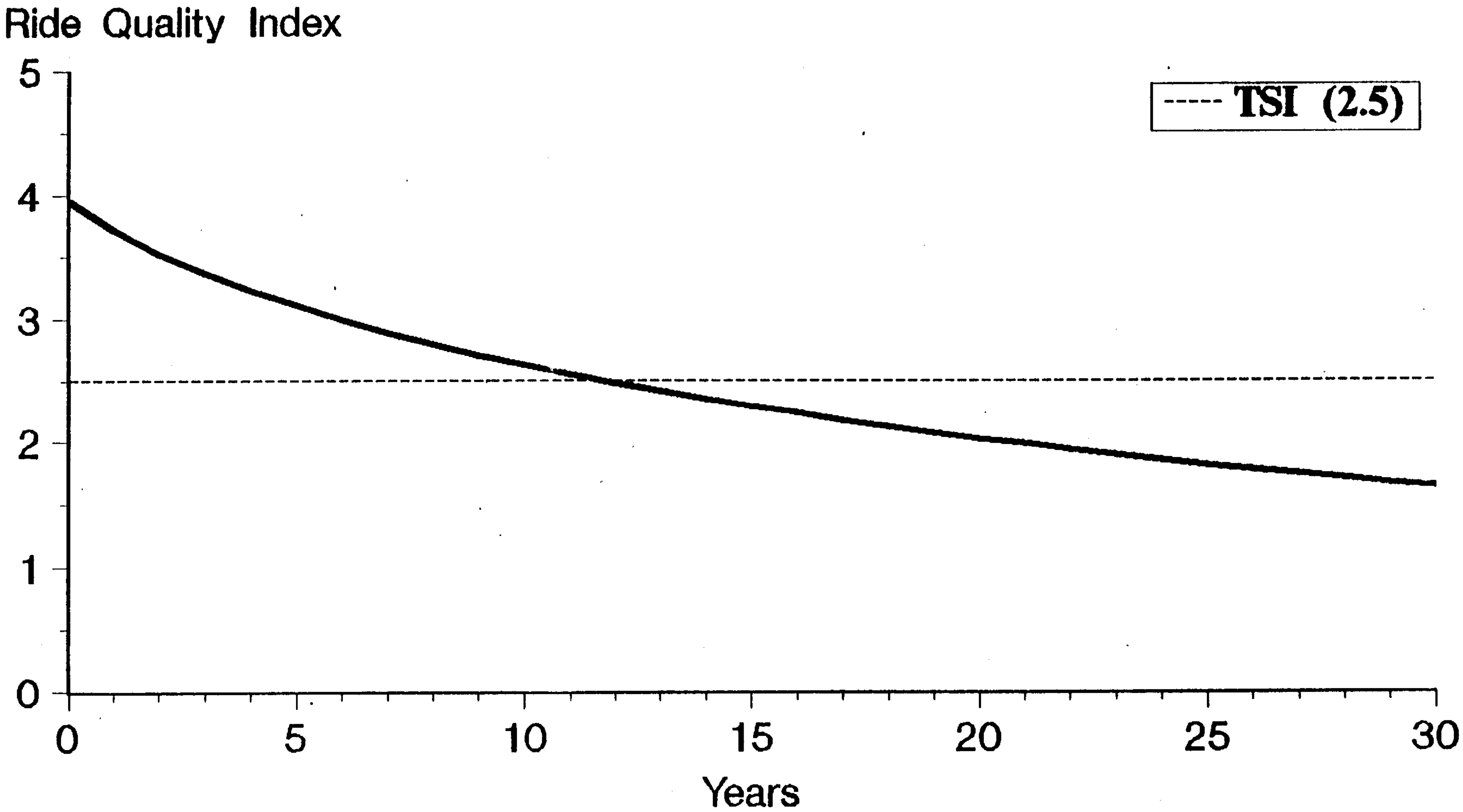


Figure E-5

Ride Quality Performance Model For Concrete Pavements



APPENDIX F - TYPICAL VALIDATION TEST OF THE ECONOMIC MODEL

In order to check that the computer model was working properly, a special data set was used that consisted of five pavement sections covering a range of conditions that assured that the various modes of operation would be tested. The checks consisted of two types, computational and operational. The computational checks confirmed that the various arithmetic steps were performed correctly. The operational checks confirmed that the proper actions occurred (resurfacing, routine maintenance, do nothing, etc.).

The following pages illustrate the input variables used in one computer run and the tables produced by the analysis.

ECONMOD8 VALIDATION

```
ENTER PERFORMANCE MODEL COEFFICIENTS A1 AND A2 OF
EPI= 5*E**(-A1*YEARS**A2)

? 0.00014 3

ENTER INTEREST AND INFLATION RATES (ANNUAL PERCENT) AND ANALYSIS
PERIOD (YEARS)

? 8 4 5

ENTER NUMBER OF LANE MILES IN SYSTEM

? 10000

ENTER INITIAL RESURFACING FUNDING ($MILLION/YEAR) AND PERCENT
ANNUAL INCREASE

? 500 4

ENTER INITIAL LIMITATION ON MAINTENANCE FUNDING ($MILLION/YEAR)
AND PERCENT ANNUAL INCREASE

? 10 4

ENTER REPAIR STRATEGY

 1. WORST FIRST
 2. BEST FIRST

? 1

ENTER EPI THRESHOLD BELOW WHICH REPAIR IS REQUIRED

? 2

SELECT TYPE OF OUTPUT DESIRED

 1. DETAILED PRINTOUT OF REPAIR ACTIVITIES
 2. ANNUAL SUMMARIES FOR ANALYSIS PERIOD

? 1

ENTER NUMBER OF PAVEMENT SECTIONS AND NUMBER OF YEARS FOR WHICH
DETAILED PRINTOUT IS DESIRED

? 5 5
```

Basic Model Information is printed at the begining of the analysis:

************************************** BASIC OPERATIONAL INFORMATION **************************************

PAVEMENT PERFORMANCE MODEL (ASSUMES NO MAINTENANCE OR REPAIRS)				COST MODELS ($1000/LANE MILE)				EFFECT MODELS (EPI)			
EPI = F(AGE)		ANNUAL DECAY (EPI)		RECONSTRUCTION OR RESURFACING		ROUTINE ANNUAL MAINTENANCE		RECONSTRUCTION OR RESURFACING		ROUTINE ANNUAL MAINTENANCE	
YEAR	EPI	YEAR(I)	YEAR(I+1)	EPI	COST	EPI	COST	BEFORE	AFTER	BEFORE	AFTER
0	5.00	0.0	0.0	0.0	400.0	0.0	10.000	0.0	4.00	0.0	0.25
5	4.91	0.5	0.38	0.5	252.3	0.5	4.972	0.5	3.78	0.5	0.72
10	4.35	1.0	0.80	1.0	184.3	1.0	3.386	1.0	3.64	1.0	1.20
15	3.12	1.5	1.25	1.5	139.9	1.5	2.468	1.5	3.56	1.5	1.67
20	1.63	2.0	1.71	2.0	108.6	2.0	1.867	2.0	3.56	2.0	2.15
25	0.56	2.5	2.20	2.5	85.7	2.5	1.448	2.5	3.62	2.5	2.62
30	0.11	3.0	2.70	3.0	68.4	3.0	1.143	3.0	3.76	3.0	3.10
35	0.01	3.5	3.22	3.5	55.1	3.5	0.916	3.5	3.96	3.5	3.57
40	0.00	4.0	3.76	4.0	44.7	4.0	0.742	4.0	4.24	4.0	4.05
45	0.00	4.5	4.33	4.5	36.5	4.5	0.607	4.5	4.58	4.5	4.52
50	0.00	5.0	5.00	5.0	30.0	5.0	0.500	5.0	5.00	5.0	5.00

A detailed summary of the actions performed on each pavement section is printed for each year:

************************* DETAILED LIST OF ACTIVITIES FOR YEAR 1 *************************

PAVEMENT SECTION	LENGTH (LANE MILES)	EPI RATING BEFORE	EPI RATING AFTER	TYPE OF REPAIR	PRIORITY SEQUENCE RANK	PRIORITY SEQUENCE R/R FUNDS AVAILABLE ($MILLION)	COST ($MILLION) FUTURE WORTH	COST ($MILLION) PRESENT WORTH
1	2000.00	0.80	3.69	RESURF	1	500.000	432.016	400.014
2	2000.00	1.25	1.43	MAINT	2	67.984	5.990	5.546
3	2000.00	1.71	1.88	MAINT	3	67.984	4.541	4.205
4	2000.00	2.20	2.34	MAINT	4	67.984	3.505	3.245
5	2000.00	2.70	2.81	MAINT	5	67.984	2.738	2.535

************************* DETAILED LIST OF ACTIVITIES FOR YEAR 2 *************************

PAVEMENT SECTION	LENGTH (LANE MILES)	EPI RATING BEFORE	EPI RATING AFTER	TYPE OF REPAIR	PRIORITY SEQUENCE RANK	PRIORITY SEQUENCE R/R FUNDS AVAILABLE ($MILLION)	COST ($MILLION) FUTURE WORTH	COST ($MILLION) PRESENT WORTH
1	2000.00	3.42	3.50	MAINT	5	234.937	2.051	1.759
2	2000.00	1.19	3.60	RESURF	1	593.423	358.485	307.344
3	2000.00	1.60	1.77	MAINT	2	234.937	5.045	4.325
4	2000.00	2.04	2.19	MAINT	3	234.937	3.960	3.395
5	2000.00	2.51	2.63	MAINT	4	234.937	3.119	2.674

************************* DETAILED LIST OF ACTIVITIES FOR YEAR 3 *************************

PAVEMENT SECTION	LENGTH (LANE MILES)	EPI RATING BEFORE	EPI RATING AFTER	TYPE OF REPAIR	PRIORITY SEQUENCE RANK	PRIORITY SEQUENCE R/R FUNDS AVAILABLE ($MILLION)	COST ($MILLION) FUTURE WORTH	COST ($MILLION) PRESENT WORTH
1	2000.00	3.22	3.31	MAINT	4	220.661	2.334	1.853
2	2000.00	3.33	3.41	MAINT	5	220.661	2.221	1.763
3	2000.00	1.49	3.57	RESURF	1	794.532	315.875	250.752
4	2000.00	1.89	3.56	RESURF	2	478.657	257.997	204.806
5	2000.00	2.33	2.46	MAINT	3	220.661	3.546	2.815

************************* DETAILED LIST OF ACTIVITIES FOR YEAR 4 *************************

PAVEMENT SECTION	LENGTH (LANE MILES)	EPI RATING BEFORE	EPI RATING AFTER	TYPE OF REPAIR	PRIORITY SEQUENCE RANK	PRIORITY SEQUENCE R/R FUNDS AVAILABLE ($MILLION)	COST ($MILLION) FUTURE WORTH	COST ($MILLION) PRESENT WORTH
1	2000.00	3.01	3.11	MAINT	2	800.745	2.660	1.955
2	2000.00	3.12	3.22	MAINT	3	800.745	2.529	1.859
3	2000.00	3.29	3.37	MAINT	5	800.745	2.352	1.729
4	2000.00	3.28	3.36	MAINT	4	800.745	2.363	1.737
5	2000.00	2.16	2.30	MAINT	1	800.745	4.019	2.954

************************* DETAILED LIST OF ACTIVITIES FOR YEAR 5 *************************

PAVEMENT SECTION	LENGTH (LANE MILES)	EPI RATING BEFORE	EPI RATING AFTER	TYPE OF REPAIR	PRIORITY SEQUENCE RANK	PRIORITY SEQUENCE R/R FUNDS AVAILABLE ($MILLION)	COST ($MILLION) FUTURE WORTH	COST ($MILLION) PRESENT WORTH
1	2000.00	2.81	2.92	MAINT	2	*******	3.034	2.065
2	2000.00	2.92	3.03	MAINT	3	*******	2.884	1.963
3	2000.00	3.08	3.18	MAINT	5	*******	2.679	1.823
4	2000.00	3.07	3.17	MAINT	4	*******	2.693	1.833
5	2000.00	2.00	2.15	MAINT	1	*******	4.537	3.088

Annual Cost Summaries are also printed:

AVERAGE ANNUAL PRESENT WORTH COSTS ($MILLION/YEAR)			PRESENT WORTH OF SURPLUS FUNDS AT END OF ANALYSIS PERIOD ($MILLION)
RECONSTRUCTION OR RESURFACING	ROUTINE ANNUAL MAINTENANCE	TOTAL	
232.583	11.024	243.607	986.666

** ANNUAL SUMMARIES FOR ANALYSIS PERIOD **

	FUTURE WORTH COSTS ($MILLION)			PRESENT WORTH COSTS ($MILLION)			EPI RATING AT END OF YEAR					
									PERCENT BELOW INDICATED VALUE			
YEAR	RESURF	MAINT	TOTAL	RESURF	MAINT	TOTAL	MINIMUM	AVERAGE	1.5	2.0	2.5	3.0
0	********	********	********	********	********	********	1.00	2.00	20.0	40.0	60.0	80.0
1	432.016	16.773	448.789	400.014	15.531	415.545	1.43	2.43	20.0	40.0	60.0	80.0
2	358.485	14.176	372.661	307.344	12.153	319.497	1.77	2.74	0.0	20.0	40.0	60.0
3	573.871	8.101	581.972	455.558	6.431	461.989	2.46	3.26	0.0	0.0	20.0	20.0
4	0.0	13.924	13.924	0.0	10.234	10.234	2.30	3.07	0.0	0.0	20.0	20.0
5	0.0	15.827	15.827	0.0	10.772	10.772	2.15	2.89	0.0	0.0	20.0	40.0