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AN LCCA PROCEDURE FOR SELECTING AND EVALUATING DURABLE PAVEMENT STRUCTURES USING SHRP-LTPP MECHANISTIC-EMPIRICAL RELATIONSHIPS.

By:

Patrick J. Prancl, P.E.

**A dissertation submitted to the Graduate Faculty in Engineering in partial fulfillment of the requirements for the degree of Doctor of Philosophy,
The City University of New York.**

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AN LCCA PROCEDURE FOR SELECTING AND EVALUATING DURABLE PAVEMENT STRUCTURES USING SHRP-LTPP MECHANISTIC-EMPIRICAL RELATIONSHIPS.

Patrick J. Prancl, P.E.

Dr. Neville A. Parker - Advisor

ABSTRACT

A *life-cycle cost mechanistic design-analysis procedure, utilizing* SHRP-LTPP relationships, is presented in this dissertation as a significant improvement upon the existing AASHTO-guided design procedures for selecting and evaluating durable pavements. In this procedure, the SHRP-LTPP equations are applied to predict pavement conditions, both roughness and distresses, throughout the pavement's analysis period. Using this type of analysis, the pavement's life-cycle performance and maintenance requirements are forecasted and the associated agency expenditures and road user costs are estimated. Finally, incremental benefit-cost analysis is used to assess the impact of increased agency spending on incurred road user costs, so that the most cost-effective alternatives may be determined as constrained by given system-wide requirements, including budget. The procedure is presented as a spreadsheet program.

The procedure is recommended to state highway agencies for the continuing revisions and updates of their catalog designs, including maintenance scheduling to ensure durability of pavements well into the newly propounded 50-70 year life. As an example, application of the procedure as a case study for New York State suggests, among others, the following:

1. There are lower cost maintenance and higher benefit-cost alternatives to the current catalogue of flexible pavement designs, which could be achieved by altering the asphalt mix

characteristics rather than increasing HMAC layer thickness, and which would meet the new durability requirements.

2. A single design standard should be used for rigid pavements. This may be varied for important or heavily traveled highways as dictated by agency policy based on return on investments.

3. Using both agency and user costs, rather than the conventional method of choosing the lowest agency cost, as economic decision criteria, will result in the most cost effective use of highway funds.

The procedure developed in this dissertation provides a new and improved method of analyzing pavement design alternatives. By examining the life-cycle implications of different design alternatives, in terms of both condition and cost, the highway engineer will make more informed project level management decisions. Finally, several topics are identified where there is a need for subsequent research to improve upon the ideas brought forth in this dissertation.

AN LCCA PROCEDURE FOR SELECTING AND EVALUATING DURABLE PAVEMENT STRUCTURES USING SHRP-LTPP MECHANISTIC-EMPIRICAL RELATIONSHIPS.

TABLE OF CONTENTS

Title Page
Copyright Page ii.
Approval Page iii.
Abstract iv.
Table of Contents vi.
List of Tables x.
List of Figures xiv.

CHAPTER 1 - INTRODUCTION. 1
1.1 Background and Motivation. 1
1.2 Problem Statement. 2
1.3 Dissertation Structure. 2

CHAPTER 2 - PROPOSED PAVEMENT DESIGN PROCEDURES 4
2.1 Background Information - SHRP-LTPP Pavement Studies. 4
2.2 Existing AASHTO Design Procedures. 4
2.3 Deficiencies of the AASHTO Design Procedures. 7
2.4 SHRP-LTPP Design Equations. 10
2.5 Total Cost Considerations. 11
2.6 Proposed Pavement Design Procedures. 12

CHAPTER 3 - TRAFFIC VOLUME AND AXLE LOADING COMPUTATIONS. 15
3.1 Background 15
3.2 Traffic Volume Analysis versus Axle Loading Analysis. 15
3.3 Traffic and Axle Loading Growth Rates. 16
3.4 Traffic Composition. 17
3.5 Load Equivalency Factors. 17
3.6 Traffic and Axle Load Computation Equations. 18
3.7 Need For Further Research 20

CHAPTER 4 - FLEXIBLE PAVEMENT MECHANISTIC DESIGN EQUATIONS. 22
4.1 SHRP-LTPP Flexible Pavement Studies. 22
4.2 Flexible Pavement Roughness Equations. 23
4.3 Flexible Pavement Distress Equations - Rutting. 27
4.4 Flexible Pavement Distress Equations - Thermal Cracking. 30
4.5 General Results and Observations. 34
4.6 Effects of Superpave Specifications. 35
4.7 Need For Further Research. 36

CHAPTER 5 - ADAPTING THE MECHANISTIC EQUATIONS TO IMPROVE THE EXISTING NYSDOT FLEXIBLE PAVEMENT DESIGN PROCEDURE. **37**
5.1 Existing NYSDOT Flexible Design Tables - AASHTO Methods. 37
5.2 Flexible Pavement Roughness Equation Calibration. 37
5.3 Flexible Pavement Distress Equation Calibration - Rutting. 39
5.4 Flexible Pavement Distress Equation Calibration- Thermal Cracking. 41
5.5 Recommended Improvements to Existing NYSDOT Design Equations. 43
5.6 Life Cycle Maintenance Requirements. 44
5.7 Need For Further Research. 46

CHAPTER 6 - RIGID PAVEMENT MECHANISTIC DESIGN EQUATIONS. **48**
6.1 SHRP-LTPP Rigid Pavement Studies. 48
6.2 Rigid Pavement Roughness Predictive Equations. 48
6.3 Rigid Pavement Distress Equations - Joint Faulting. 51
6.4 Rigid Pavement Distress Equations - Joint Spalling. 52
6.5 Rigid Pavement Distress Equations - Transverse Cracking. 54
6.6 General Results and Observations. 55
6.7 Effects of High Performance Concrete Specifications. 56
6.8 Need For Further Research. 56

CHAPTER 7 - ADAPTING THE MECHANISTIC EQUATIONS TO IMPROVE EXISTING NYSDOT RIGID PAVEMENT DESIGN PROCEDURE. **57**
7.1 Existing NYSDOT Rigid Pavement Design Tables. 57
7.2 Rigid Pavement Roughness Equation Calibration. 58
7.3 Rigid Pavement Distress Equation Calibration - Joint Faulting. 59
7.4 Rigid Pavement Distress Equation Calibration - Joint Spalling. 60
7.5 Recommended Improvements to Existing NYSDOT Design Equations. 62
7.6 Life Cycle Maintenance Requirements. 63
7.7 Need For Further Research. 65

CHAPTER 8 - AGENCY COST COMPUTATIONS. **67**
8.1 Definition and Components of Agency Costs. 67
8.2 Agency Costs - Flexible Pavement Construction and Maintenance. 68
8.3 Agency Costs - Rigid Pavement Construction and Maintenance. 69
8.4 Development of Regional Cost Factors. 71
8.5 Need For Further Research. 72

CHAPTER 9 - ROAD USER COST COMPUTATIONS. **73**
9.1 Background Information. 73
9.2 Historical Development of Road User Cost Models. 73
9.3 Existing User Cost Analysis by NYSDOT. 75
9.4 Development of Road User Cost Model. 77
9.5 Need For Further Research. 83

CHAPTER 10 - ECONOMIC ANALYSIS **84**
10.1 Life Cycle Analysis. 84
10.2 Present Worth Method (Agency Costs). 84
10.3 Total Road User Costs and Societal Benefits. 86
10.4 Economic Analysis Methodology 86
10.5 Need For Further Research. 88

CHAPTER 11 - SAMPLE APPLICATIONS OF THE DESIGN PROCEDURE. **89**
11.1 Choice of Micro-Computer Program. 89
11.2 Description of Design Spreadsheets. 89
11.3 Case Study - NYSDOT - Flexible Pavement. 92
11.4 Case Study - NYSDOT Rigid Pavement. 95
11.5 Need For Further Research. 99

CHAPTER 12- IMPLICATIONS FOR NEW CATALOGUE DESIGNS **100**
12.1 The Need For Design Optimization. 100
12.2 Flexible Pavement Design. 100
12.3 Rigid Pavement Design. 103

CHAPTER 13 - CONCLUSIONS. **108**
13.1 General Conclusions. 108
13.2 Recommendations. 111
13.3 General Need For Additional Research. 112

NOTES & COMMENTS **114**

APPENDICES **116**
APPENDIX A Sensitivity Analysis - SHRP Flexible Pavement Equations. 116
APPENDIX B Sensitivity Analysis - SHRP Rigid Pavement Equations. 120
APPENDIX C NYSDOT Flexible Pavement Specifications. 124
APPENDIX D Lane Distribution For Trucks. 127
APPENDIX E Flexible Pavement - Predicted Roughness & Distress Data. 130
APPENDIX F Flexible Pavement - Predicted Life Cycle Maintenance Plans. 134
APPENDIX G Rigid Pavement - Predicted Roughness & Distress Data. 140
APPENDIX H Rigid Pavement - Predicted Life Cycle Maintenance Plans. 144
APPENDIX I Predicted Service Life - One Course Overlay - Rigid Pavement. 148
APPENDIX J Predicted Service Life - One Course Overlay - Flexible Pavement. 151
APPENDIX K Flexible Pavement - Typical Line Items - Initial Construction Costs. 155
APPENDIX L Flexible Pavement - Typical Line Items - Maintenance Costs. 161
APPENDIX M Rigid Pavement - Typical Line Items - Initial Construction Costs. 164
APPENDIX N Rigid Pavement - Typical Line Items - Maintenance Costs. 168
APPENDIX O Typical Network Level Construction Costs. 170
APPENDIX P Sample Application - NYSDOT Flexible Pavement. 172
APPENDIX Q Sample Application - NYSDOT Rigid Pavement. 180
APPENDIX R Initial Agency Cost Matrices. 187
APPENDIX S NYSDOT Flexible Pavement - Economic Optimization Trials. 192
APPENDIX T NYSDOT Flexible Pavement - Performance Optimization Trials. 205

APPENDICES (CONTINUED). 218
APPENDIX U NYSDOT Rigid Pavement - Economic Optimization Trials. 218
APPENDIX V NYSDOT Rigid Pavement - Performance Optimization Trials. 227
APPENDIX W Climate Information, New York State. 236

REFERENCES 242

TABLE OF CONTENTS - LIST OF TABLES

Table	**Description**	**Page**
Table 2-1	Pavement Condition Indices.	8
Table 3-1	Typical Traffic Volume and Axle Growth Rates.	16
Table 3-2	Typical Traffic Composition on U.S. Highways.	18
Table 3-3	Regression Parameters For Lane Distribution Equations.	20
Table 4-1	Flexible Pavement Equations - Roughness.	24
Table 4-2	Regression Data For Flexible Pavement Equations - Roughness.	26
Table 4-3	Flexible Pavement Equations - Rutting.	28
Table 4-4	Regression Data For Flexible Pavement Equations - Rutting.	30
Table 4-5	Flexible Pavement Equations - Thermal Cracking.	31
Table 4-6	Regression Data For Flexible Pavement Equations - Thermal Cracking.	33
Table 5-1	NYSDOT Flexible Pavement Design.	38
Table 5-2	Flexible Pavement : Roughness Prediction.	39
Table 5-3	Flexible Pavement : Rutting Prediction.	41
Table 5-4	Flexible Pavement : Thermal Crack Spacing Distress.	42
Table 5-5	Flexible Pavement : Predicted Maintenance Schedule	45
Table 6-1	Regression Data For Rigid Pavement Equations - Roughness.	50
Table 6-2	Regression Data For Rigid Pavement Equations - Faulting.	52
Table 6-3	Regression Data For Rigid Pavement Equations - Spalling.	53
Table 6-4	Regression Data For Rigid Pavement Equations - Transverse Cracking.	55
Table 7-1	NYSDOT Rigid Pavement Design.	57
Table 7-2	Rigid Pavement - Roughness Equation Calibration.	58
Table 7-3	Rigid Pavement - Faulting Equation Calibration.	60
Table 7-4	Rigid Pavement - Spalling Equation Calibration.	61
Table 7-5	Improved NYSDOT Rigid Pavement Design Table.	63
Table 7-6	Rigid Pavement - Predicted Maintenance Schedule	65
Table 8-1	Flexible Pavement - Initial Construction Costs.	68
Table 8-2	Flexible Pavement - Maintenance Costs.	69
Table 8-3	Rigid Pavement - Initial Construction Costs.	70
Table 8-4	Rigid Pavement - Maintenance Costs.	70
Table 8-5	NYSDOT Regional Cost Factors.	71
Table 9-1	Calibrated Constants For Vehicle Operating Cost Equations.	75
Table 9-2	Vehicle Operating Costs as Related to Pavement Condition.	78
Table 9-3	Vehicle Registration in New York State.	79
Table 9-4	NYSDOT V.O.C. versus Pavement Condition.	80
Table 9-5	Regression Equation Relating NYSDOT V.O.C. to IRI.	81
Table 9-6	Accident Costs versus Pavement Condition.	81
Table 9-7	Regression Equation Relating Accident Cost to IRI.	83

TABLE OF CONTENTS - LIST OF TABLES (CONTINUED).

Table	**Description**	**Page**
Table 11-1	Pavement Performance - Case Study - NYSDOT Flexible Pavement.	93
Table 11-2	Incremental B/C Analysis - Case Study - NYSDOT Flexible Pavement.	95
Table 11-3	Pavement Performance - Case Study - NYSDOT Rigid Pavement.	97
Table 11-4	Incremental B/C Analysis - Case Study - NYSDOT Rigid Pavement.	98
Table 12-1	Sample Economic Analysis - NYSDOT Flexible Pavement Trials.	101
Table 12-2	NYSDOT Flexible Pavement - Design Optimization.	102
Table 12-3	Sample Economic Analysis - NYSDOT Rigid Pavement Trials.	104
Table 12-4	NYSDOT Rigid Pavement - Design Optimization.	106
Table C-1	NYSDOT Flexible Pavement Specifications - Asphalt Viscosity.	125
Table C-2	NYSDOT Flexible Pavement Specifications - HMAC Aggregate Grad.	125
Table C-3	NYSDOT Flexible Pavement Specifications - Subbase Aggregate Grad.	125
Table C-4	NYSDOT Flexible Pavement Specifications - HMAC Asphalt Content.	126
Table C-5	NYSDOT Flexible Pavement Specifications - HMAC Air Voids.	126
Table D-1	Lane Distribution Data - 4 Lane Highway.	128
Table D-2	Lane Distribution Data - 6 Lane Highway.	129
Table E-1	Flexible Pavement - Predicted Roughness with Improved Mix Design.	131
Table E-2	Flexible Pavement - Predicted Rutting with Improved Mix Design.	132
Table E-3	Flexible Pavement - Predicted Thermal Cracking with Improved Mix.	133
Table F-1	Flexible Pavement - Life Cycle Maintenance Plan - Case 1.	135
Table F-2	Flexible Pavement - Life Cycle Maintenance Plan - Case 2.	135
Table F-3	Flexible Pavement - Life Cycle Maintenance Plan - Case 3.	136
Table F-4	Flexible Pavement - Life Cycle Maintenance Plan - Case 4.	136
Table F-5	Flexible Pavement - Life Cycle Maintenance Plan - Case 5.	137
Table F-6	Flexible Pavement - Life Cycle Maintenance Plan - Case 6.	137
Table F-7	Flexible Pavement - Life Cycle Maintenance Plan - Case 7.	138
Table F-8	Flexible Pavement - Life Cycle Maintenance Plan - Case 8.	138
Table F-9	Flexible Pavement - Life Cycle Maintenance Plan - Case 9.	139
Table G-1	Rigid Pavement - Predicted Roughness with Improved Design.	141
Table G-2	Rigid Pavement - Predicted Joint Faulting with Improved Design.	142
Table G-3	Rigid Pavement - Predicted Joint Spalling with Improved Design.	143
Table H-1	Rigid Pavement - Life Cycle Maintenance Plan - Case 1.	145
Table H-2	Rigid Pavement - Life Cycle Maintenance Plan - Case 2.	145
Table H-3	Rigid Pavement - Life Cycle Maintenance Plan - Case 3.	146
Table H-4	Rigid Pavement - Life Cycle Maintenance Plan - Case 4.	146
Table H-5	Rigid Pavement - Life Cycle Maintenance Plan - Case 5.	147
Table H-6	Rigid Pavement - Life Cycle Maintenance Plan - Case 6.	147

TABLE OF CONTENTS - LIST OF TABLES. (CONTINUED)

Table	Description	Page
Table I-1	Predicted Life - One Course, 2" HMAC Overlay - Rigid Pavement.	149
Table J-1	Predicted Life - One Course, 1.5" HMAC Overlay - Flexible Pavement.	152
Table J-2	Predicted Life - One Course, 2.0" HMAC Overlay - Flexible Pavement	152
Table J-3	Predicted Life - One Course, 2.5" HMAC Overlay - Flexible Pavement	153
Table K-1	Flexible Pavement - Initial Construction Cost Computations.	156
Table L-1	Flexible Pavement - Maintenance Cost Computations.	162
Table M-1	Rigid Pavement - Initial Construction Cost Computations.	165
Table N-1	Rigid Pavement - Maintenance Cost Computations.	169
Table O-1	Flexible Pavement -Network Level Pavement Construction Costs.	171
Table O-2	Rigid Pavement - Network Level Pavement Construction Costs.	171
Table R-1	NYSDOT Flexible Pavement - Initial Agency Cost Matrix.	188
Table R-2	NYSDOT Rigid Pavement - Initial Agency Cost Matrix.	190
Table S-1	NYSDOT Flexible Pavement - Economic Optimization - 3" HMA.	193
Table S-2	NYSDOT Flexible Pavement - Economic Optimization - 4" HMA.	194
Table S-3	NYSDOT Flexible Pavement - Economic Optimization - 5" HMA.	195
Table S-4	NYSDOT Flexible Pavement - Economic Optimization - 6" HMA.	196
Table S-5	NYSDOT Flexible Pavement - Economic Optimization - 7" HMA.	197
Table S-6	NYSDOT Flexible Pavement - Economic Optimization - 8" HMA.	198
Table S-7	NYSDOT Flexible Pavement - Economic Optimization - 9" HMA.	199
Table S-8	NYSDOT Flexible Pavement - Economic Optimization - 10" HMA.	200
Table S-9	NYSDOT Flexible Pavement - Economic Optimization - 11" HMA.	201
Table S-10	NYSDOT Flexible Pavement - Economic Optimization - 15" HMA.	202
Table S-11	NYSDOT Flexible Pavement - Economic Optimization - 20" HMA.	203
Table S-12	NYSDOT Flexible Pavement - Economic Optimization - 25" HMA.	204
Table T-1	NYSDOT Flexible Pavement - Performance Optimization - 3" HMA.	206
Table T-2	NYSDOT Flexible Pavement - Performance Optimization - 4" HMA.	207
Table T-3	NYSDOT Flexible Pavement - Performance Optimization - 5" HMA.	208
Table T-4	NYSDOT Flexible Pavement - Performance Optimization - 6" HMA.	209
Table T-5	NYSDOT Flexible Pavement - Performance Optimization - 7" HMA.	210
Table T-6	NYSDOT Flexible Pavement - Performance Optimization - 8" HMA.	211
Table T-7	NYSDOT Flexible Pavement - Performance Optimization - 9" HMA.	212
Table T-8	NYSDOT Flexible Pavement - Performance Optimization - 10" HMA.	213
Table T-9	NYSDOT Flexible Pavement - Performance Optimization - 11" HMA.	214
Table T-10	NYSDOT Flexible Pavement - Performance Optimization - 15" HMA.	215
Table T-11	NYSDOT Flexible Pavement - Performance Optimization - 20" HMA.	216
Table T-12	NYSDOT Flexible Pavement - Performance Optimization - 25" HMA.	217

TABLE OF CONTENTS - LIST OF TABLES. (CONTINUED)

Table	Description	Page
Table U-1	NYSDOT Rigid Pavement - Economic Optimization - 7" PCC.	219
Table U-2	NYSDOT Rigid Pavement - Economic Optimization - 8" PCC.	220
Table U-3	NYSDOT Rigid Pavement - Economic Optimization - 9" PCC.	221
Table U-4	NYSDOT Rigid Pavement - Economic Optimization - 10" PCC.	222
Table U-5	NYSDOT Rigid Pavement - Economic Optimization - 11" PCC.	223
Table U-6	NYSDOT Rigid Pavement - Economic Optimization - 12" PCC.	224
Table U-7	NYSDOT Rigid Pavement - Economic Optimization - 13" PCC.	225
Table U-8	NYSDOT Rigid Pavement - Economic Optimization - 15" PCC.	226
Table V-1	NYSDOT Rigid Pavement - Performance Optimization - 7" PCC.	228
Table V-2	NYSDOT Rigid Pavement - Performance Optimization - 8" PCC.	229
Table V-3	NYSDOT Rigid Pavement - Performance Optimization - 9" PCC.	230
Table V-4	NYSDOT Rigid Pavement - Performance Optimization - 10" PCC.	231
Table V-5	NYSDOT Rigid Pavement - Performance Optimization - 11" PCC.	232
Table V-6	NYSDOT Rigid Pavement - Performance Optimization - 12" PCC.	233
Table V-7	NYSDOT Rigid Pavement - Performance Optimization - 13" PCC.	234
Table V-8	NYSDOT Rigid Pavement - Performance Optimization - 15" PCC.	235
Table W-1	Annual Weather Parameters: New York State.	237
Table W-2	Climate Information: New York, New York.	237
Table W-3	Climate Information: Islip, New York.	238
Table W-4	Climate Information: Binghamton, New York.	238
Table W-5	Climate Information: Buffalo, New York.	239
Table W-6	Climate Information: Rochester, New York.	239
Table W-7	Climate Information: Syracuse, New York.	240
Table W-8	Climate Information: Albany, New York.	240
Table W-9	Climate Information: Plattsburg, New York.	241
Table W-10	Climate Information: Potsdam, New York.	241

TABLE OF CONTENTS - LIST OF FIGURES

Figure	Description	Page
Figure 2-1	Environmental Zones for SHRP-LTPP Studies.	10
Figure 2-2	Proposed Flexible Pavement Design Procedure.	13
Figure 2-3	Proposed Rigid Pavement Design Procedure.	14
Figure 9-4	Vehicle Operating Cost versus Roughness.	80
Figure 9-6	Accident Costs versus Roughness.	82
Figure 11-1	Flexible Pavement Algorithm - Lotus 1-2-3 Spreadsheet Layout.	90
Figure 11-2	Rigid Pavement Algorithm - Lotus 1-2-3- Spreadsheet Layout.	91
Figure 12-2	Flexible Pavement: HMA Thickness versus Allowable Loading.	102
Figure 12-4A	Rigid Pavement: Total Cost Minimization.	106
Figure 12-4B	Rigid Pavement: Incremental B/C Analysis	106
Figure A-1	Sensitivity Analysis - Flexible Pavement - Roughness.	117
Figure A-2	Sensitivity Analysis - Flexible Pavement - Rutting.	118
Figure A-3	Sensitivity Analysis - Flexible Pavement - Thermal Cracking.	119
Figure B-1	Sensitivity Analysis - Rigid Pavement - Roughness.	121
Figure B-2	Sensitivity Analysis - Rigid Pavement - Joint Faulting.	122
Figure B-3	Sensitivity Analysis - Rigid Pavement - Joint Spalling.	123
Figure D-1	Lane Distribution - 4 Lane Highway.	128
Figure D-2	Lane Distribution - 6 Lane Highway.	129
Figure E-1	Flexible Pavement - Predicted Roughness.	131
Figure E-2	Flexible Pavement - Predicted Rutting.	132
Figure E-3	Flexible Pavement - Predicted Thermal Cracking.	133
Figure G-1	Rigid Pavement - Predicted Roughness.	141
Figure G-2	Rigid Pavement - Predicted Joint Faulting.	142
Figure G-3	Rigid Pavement - Predicted Joint Spalling.	143

AN LCCA PROCEDURE FOR SELECTING AND EVALUATING DURABLE PAVEMENT STRUCTURES USING SHRP-LTPP MECHANISTIC-EMPIRICAL RELATIONSHIPS.

Patrick J. Prancl, P.E.

CHAPTER 1 : INTRODUCTION

1.1 - Background and Motivation.

The ratifying of the Intermodal Surface Transportation Efficiency Act (ISTEA) mandated state governments to generate pavement management systems in order to better utilize limited highway funds. As stated in the goals of the Strategic Highway Research Program (SHRP)[45], one of the most effective ways to enhance pavement management is to improve the ability of the highway engineer to design new pavement structures and maintenance strategies. Therefore, as part of the Long Term Pavement Performance (LTPP) studies [44], the federal government has collected data and developed mechanistic equations which will assist in the prediction of life cycle pavement condition in terms of pavement roughness and pavement distresses. The SHRP data will be implemented to establish mechanistic design procedures which will be used to predict pavement condition and required maintenance strategies. As well, the proposed mechanistic design methodology may be used to enhance existing design procedures used by state highway agencies throughout North America, many which presently rely upon the AASHTO design procedures [2].

A deficiency of many pavement management systems, particularly at the project level, is the lack of consideration of societal cost impacts as a result of pavement design and maintenance decisions. Current practice [23] is to select the design alternative which "minimizes" agency construction and maintenance costs during the analysis period. Factors such as service life, road deterioration, and user costs are considered only implicitly; relying upon the interpretation and experience of the designer. Although practical experience is both valuable and essential, reliance upon individual opinion may lead to inconsistent and inefficient use of funds. The proposed design procedure will assist highway engineers to evaluate the influence that design and maintenance decisions have on both total societal costs and agency spending.

The goal of this dissertation will be to develop mechanistic based design equations and utilize them to improve existing procedures for newly constructed pavements. The proposed procedure will implement SHRP studies [45] to calibrate mechanistic design equations which relate pavement age to pavement condition. The proposed procedure will consider total cost evaluation in order to improve the efficiency of pavement design and maintenance strategy choice. Finally, the dissertation will utilize data gathered during associated university research [30] to illustrate how the proposed design procedure can be implemented to improve the design procedure currently employed by the New York State Department of Transportation [34], a lead state in the implementation of SHRP products.

1.2 - Problem Statement.

The objective of this dissertation is to advance the state of the art by using the data gathered during SHRP studies [44][45] to improve upon existing pavement design procedures used by state highway agencies. The procedure proposed in this dissertation will implement the mechanistic pavement performance relationships to predict pavement condition during the pavement's analysis period. Pavement performance will dictate the required maintenance strategies and life-cycle costs associated with each design alternative. The incurred road user costs of each design alternative of the design choice will be evaluated as a function of the pavement condition. The end result will be a total cost algorithm which will assist the highway engineer in making the most effective pavement design and management choice.

1.3 - Dissertation Structure.

The dissertation is arranged into 12 chapters. Each chapter is presented in the basic format described below:

A. The background of the proposed theory is described.

B. The potential design application of developed equations is explained and evaluated.

C. The need for subsequent investigation and improvements is discussed.

Chapter 1 describes the background and motivation for this dissertation, including the problem statement and dissertation structure. Chapter 2 summarizes and evaluates the SHRP-LTPP studies and how their conclusions may be utilized to improve upon existing pavement design methodologies. Chapter 3 defines the relationship between traffic and axle loading for pavement structures including contemporary methods for data collection and computation of load equivalency factors, growth rates, and traffic composition and distribution. Chapter 4 presents the mechanistic design equations developed to predict pavement roughness and distresses for flexible pavements including the influences of new Superpave mixes on pavement performance. Chapter 5 exemplifies how the mechanistic equations may be adapted to improve the existing flexible pavement design procedure used by New York. Chapter 6 introduces the design equations developed to predict pavement roughness and distress propagation for rigid pavements, including the consequences that high performance concrete mixes have on pavement performance. Chapter 7 demonstrates how the mechanistic equations may be adapted to improve the present rigid pavement design procedure employed by New York. Chapter 8 computes the fixed and variable agency costs associated with capital construction and maintenance policies for the design alternatives to be studied. Chapter 9 generates road user costs, including vehicle operating cost and accident cost, as a function of pavement condition. Chapter 10 explains how incremental benefits to cost analysis are used to evaluate alternative design and maintenance choices. Chapter 11 exhibits the micro-computer model which is used to implement the proposed design procedure and shows case studies for both flexible and rigid pavement structures. Chapter 12 examines the implications the proposed mechanistic analysis has on design optimization. Chapter 13 draws conclusions regarding the proposed procedure and identifies areas where subsequent study is needed.

CHAPTER 2 - PROPOSED PAVEMENT DESIGN PROCEDURES.

2.1 Background Information - SHRP-LTPP Pavement Studies.

One of the primary objectives of the Strategic Highway Research Project - Long Term Pavement Performance (SHRP-LTPP) study is to improve the ability of the highway engineer to design new and overlaid pavement structures. Since 1985, SHRP has been collecting and analyzing data for 770 in-service pavements throughout the United States and Canada. The data has been used to construct the National Pavement Performance Data Base (later titled the LTPP Data Base) which has been used to achieve the study's goals such as:

- Evaluating existing design methodologies.
- Developing improved design methods and strategies for pavement management.
- Developing improved design procedures for new and reconstructed pavements.
- Determining the effects of axle loading, environment, material properties, construction quality, and maintenance levels on pavement performance.
- Establish a long-term pavement data base to support SHRP objectives and future needs.

Beginning in 1993, SHRP began the dissection of pavement data collected to date and publishing the results in a series of design reports. These reports represent state of the art design methodology for pavement management and will serve as the source of the design procedures presented in this dissertation.

2.2 Existing AASHTO Design Procedures.

The most commonly utilized design procedure accepted by most state highway agencies in North America is the AASHTO Guide For Design of Pavement Structures [2]. The AASHTO design procedure is the product of the road tests conducted in the 1950's by the federal government. The resulting design methodology consists of empirical equations which have been extrapolated and calibrated to represent the varied climatic and loading conditions found throughout North America. The original equations have been modified numerous times to account for additional design factors such as drainage, load transfer, and mix strength.

Pavement Condition Index.

The pavement condition index used by the AASHTO flexible and rigid pavement design method is the present serviceability index (PSI). The PSI is a combined index which quantifies pavement condition as a function of pavement roughness, permanent deformation (rutting), and cracked / patched areas. As shown in AASHTO [2] the PSI equations are as follows:

Flexible Pavement

$PSI = 5.03 - 1.91 \log(1 + SV) - 1.38\ RD^2 - 0.01\ (C+P)^{0.5}$

Where: PSI = Present Serviceability Index (no units)

SV = Slope Variance as collected by the CHLOE Profilograph.

RD = Average Rut Depth (inches)

C = Square Feet of Class 2 and 3 Cracks per 1000 Square Feet.

P = Square Feet of Patching per 1000 Square Feet.

Rigid Pavement

$PSI = 5.41 - 1.80 \log(1 + SV) - 0.09\ (C+P)^{0.5}$

Where: PSI = Present Serviceability Index (No Units)

SV = Slope Variance as collected by the CHLOE Profilograph.

C = Square Feet of Class 3 and 4 Cracks per 1000 Square Feet.

P = Square Feet of Patching per 1000 Square Feet.

Through statistical analysis it is computed that the correlation coefficient only increases by 5 percent due to pavement distresses. Thus, pavement distresses, especially, cracks and patches are not sensitive variables in the serviceability equation.

Existing AASHTO Flexible Design Procedure.

The AASHTO flexible design procedure is based upon the principles of layered design theory. It consists of an empirical equation and design nomograph developed during the AASHTO Road Tests concluded in 1960. Pavement layer thicknesses are determined as a function of traffic axle loading, subgrade resilient modulus, factor of safety (reliability and standard deviation), allowable loss of PSI, material property, and drainage characteristics. The design equation, as shown in AASHTO [2], is as follows:

$$\log W_{18} = Z_R S_o + 9.36 \log(SN+1) - 0.20 + \log[\Delta PSI/(4.2-1.5)]/[0.4+1094/(SN+1)^{5.19}]$$
$$+ 2.32 \log M_R - 8.07$$

where: W_{18} = Cumulative 18 kip Standard Axle Loads (ESAL).

M_R = Resilient Modulus (pound per square inch).

ΔPSI = Change in Present Serviceability Index.

SN = Structural Number.

Z_R = Normal Deviate for Reliability Level.

S_o = Standard Deviation for Loading Prediction Errors.

$$SN = \Sigma\, a_x m_x d_x$$

where: SN = Structural Number.

a_x = Layer Coefficient of layer x.

m_x = Drainage Coefficient of layer x.

D_x = Thickness of layer x (inches).

In performing layered design analysis, it is assumed that the Elastic Modulus (strength) of each layer decreases from the surface course down to the subgrade ($E_{AC} > E_{BASE} > E_{SUBBASE} > M_R$). The design equation is most sensitive to changes in axle loading and subgrade Resilient Modulus. Other variables such as factor of safety, material properties, and drainage properties are usually fixed by the specifications of the state highway agency.

Existing AASHTO Rigid Design Procedure.

The AASHTO rigid design procedure is based upon the principles of finite element analysis. The rigid design equation was also developed during the original road tests and has been updated numerous times to include design additions for drainage, load transfer, and concrete mix properties. Design is an iterative process which can be accomplished by using the empirical equation or design nomograph. The thickness of the pavement slab is determined as a function of traffic axle loading, factors of safety (reliability and standard deviation), allowable loss of PSI, load transfer between slabs, material properties of concrete and subgrade, and drainage properties. The design equation, as shown in AASHTO [2], is as follows:

$$\log W_{18} = Z_R S_o + 7.35 \log (D+1) - 0.06 + \log[\Delta PSI/(4.5-1.5)]/[1 + 1.624 * 10^7/(D+1)^{8.46}]$$
$$+ (4.22 - 0.32p_t)\log\{[S_c C_d(D^{0.75}-1.132)]/[215.63J[D^{0.75}-18.42(E_c/k)^{0.75}]]\}$$

Where: W_{18} = Cumulative 18 kip Standard Axle Loads (ESALs).

Z_R = Normal Deviate of Reliability Level.

S_o = Standard Deviation for Loading Prediction Errors.

D = Pavement Slab Thickness (inches).
ΔPSI = Change in Present Serviceability Index.
p_t = Terminal Serviceability (PSI).
S_c = Concrete Modulus of Rupture (psi).
C_d = Drainage Coefficient.
E_c = Elastic Modulus of Concrete (psi).
J = Load Transfer Coefficient.
K = Modulus of Subgrade Reaction (pci).

The design equation is most sensitive to changes in axle loadings, most other variables including material properties, factors of safety, allowable loss of PSI, drainage properties and load transfer properties are commonly fixed by the specifications of the state highway agency.

2.3 Deficiencies of the AASHTO Procedures.

Initial investigation, referenced in SHRP-P-394, Evaluation of the AASHTO Design Equations and Recommended Improvements [45], shows that although many improvements have been made to the original AASHTO design equations, the equations still do not adequately represent North American pavements.

Pavement Condition Index.

Initial studies conducted by SHRP [45] echo the results of previous World Bank studies [52] regarding pavement condition indices. Most international and state highway agencies agree that pooling roughness and all distress types into a composite index is not desirable. The PSI measure employed by the AASHTO design procedure is an example of a composite index. Of all the variables which contribute to the prediction of PSI, only slope variance (roughness) contributes in a statistically meaningful manner.

There are also additional problems with PSI that render it ineffective as an accurate, overall measurement of pavement condition. The qualitative portion of the PSI equation was based on the public's perception of the highway pavements over 40 years ago. Since that time, travel speeds, vehicle characteristics, and highway design standards have changed dramatically. Quantitatively, the instrumentation used to collect the pavement roughness data for the PSI equation, the CHLOE Profilograph, is no longer in use. Contemporary equipment which measure pavement roughness in IRI, such as the Law profilometer, are not calibrated to collect slope variance data needed for the PSI equation and no study has been conducted which establishes a statistically reliable relationship between the slope variance and IRI measurements.

SHRP [45] advocates utilizing the International Roughness Index (IRI) as the primary measurement unit for pavement roughness. The IRI is a quantitative measurement developed by the World Bank [52] and measured by a profilometer. IRI is a measurement of vertical distortions in the pavement surface which are caused by deformations in the pavement structure due to settlement and distresses, and therefore, may be considered an indicator of both structural capacity and surface condition. Patterson [40], Archondo-Faiz [4], and SHRP [45] have developed both quantitative and qualitative relationships between IRI, PSI, and other common

Table 2-1 : Pavement Condition Indexes.

AASHTO PSI (no units)	English IRI (in./mile)	Metric IRI (met./km)	NYSDOT SRS (no units)	Canadian RCI (No units)	AASHTO Qualitative Description	World Bank Qualitative Description
5.0	0.00	0.00	10	10	—	"New"
4.5	25.70	0.41	9	9	"Initial"	"New"
4.0	54.43	0.86	8	8	—	"Smooth"
3.5	86.99	1.37	7	7	—	"Smooth"
3.0	124.59	1.96	6	6	"HP Terminal"	"Smooth"
2.5	169.06	2.67	5	5	"Terminal"	"Reasonable"
2.0	223.49	3.52	4	4	"LP Terminal"	"Reasonable"
1.5	293.65	4.63	3	3	"Failure"	"Rough"
1.0	392.55	6.19	2	2	—	"Rough"
0.5	561.61	8.86	1	1	—	"Rough"

Notes:
1. Quantitative relationship $PSI = 5 * e^{(-0.0041*IRI)}$ IRI = Inch/mile.
2. Quantitative relationship $PSI = 5 * e^{(-0.26*IRI)}$ IRI = meter/km.
3. Quantitative relationship PSI = SRS / 2
4. Quantitative relationship PSI = RCI / 2
5. "HP Terminal" = Terminal serviceability for a high-priority, high volume facility.
6. "LP Terminal" = Terminal serviceability for a low-priority, low volume facility.

Source: Archondo [5], Patterson [40], SHRP [45].

pavement indexes utilized in the United States and Canada. These relationships are shown in Table 2.1 : Pavement Condition Indexes.

SHRP [45] also advocates predicting individual distresses and roughness separately, and therefore, a pavement design process can be optimized to meet a given agency's needs. Since road user cost is most closely related to roughness, as shown by Patterson [40], many agencies already rely on roughness as the primary measure of pavement condition. Traditionally, pavement distress data has been shown to have a small contribution to overall roughness and distress data is arduous and expensive to collect. However, using the models produced by SHRP, other important distresses such as rutting, thermal cracking, fatigue cracking, and surface skid resistance for flexible pavement and joint faulting, spalling, thermal cracking, and surface skid resistance for rigid pavements can be quickly predicted and included as a check to ascertain that unacceptable levels of distress do not occur during the pavement's analysis period.

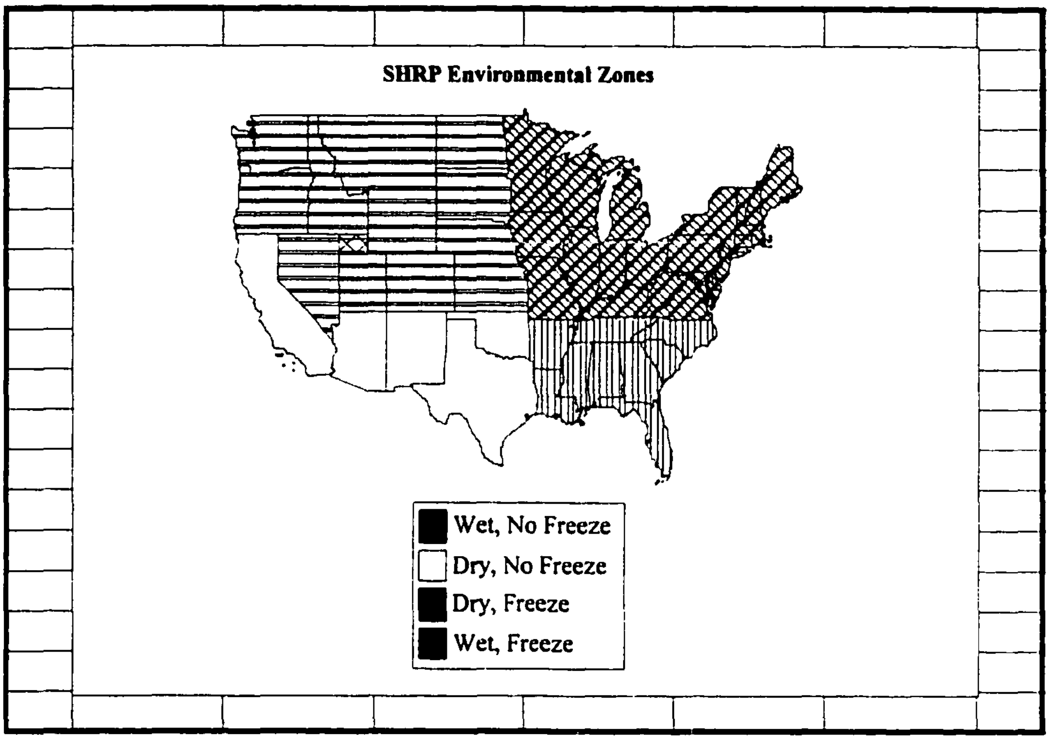
AASHTO Flexible Pavement Design Procedure.

Initial studies conducted by SHRP [45] show that the form of the 1986 AASHTO design equation does not fit the observed data for North American pavements. Analysis confirms that the flexible design equation generally represents a serious extrapolation outside the inference space from which the design equation was derived. The use of this equation leads to under-designing the pavement structure and pre-mature failure prior to the intended design life. In many cases, the design equation predicted 100 times the estimated ESALs to produce the observed loss of pavement serviceability. In fitting the observed data to the flexible design equation, the coefficient of determination (R squared) never exceeded 0.25 indicating a very poor fit. Overall, the 1986 AASHTO equation does not provide an adequate design for the majority of test sections represented in the SHRP study.

AASHTO Rigid Pavement Design Procedure.

Initial studies conducted by SHRP [45] show that the form of the 1993 AASHTO design equation does not fit the observed data for North American pavements. The original 1960 design equation has been extended many times to include additional design factors such as drainage, load transfer and concrete strength properties. While these changes slightly improve the

Figure 2-1 : Environmental Zones for SHRP-LTPP Studies.



reliability of the design equation, the equation generally over-estimates the number of 18 kip ESALs needed to cause a given loss of serviceability. In fitting the observed data to the rigid design equation, the results of a t-test show that the data distributions may be statistically similar at 50 percent reliability but not at 90 percent. Overall, the 1993 AASHTO equation provides a very conservative design for the majority of test sections represented in the SHRP studies.

2.4 SHRP-LTPP Design Procedures.

A number of equations have been developed from LTPP data in the SHRP Studies [45]. These equations predict distresses and roughness propagation for flexible and rigid pavements under various traffic loading and environmental conditions. SHRP has divided North America into 4 broad climate zones as shown in Figure 2-1, Environmental Zones For SHRP-LTPP Studies. These zones are wet-freeze, wet-no freeze, dry-freeze, and dry-no freeze.

For flexible pavements, SHRP identifies the following pavement condition indices as the primary causes of deterioration which contribute to agency and road user costs:

1. Roughness (International Roughness Index {IRI}).
2. Permanent Deformation (Wheelpath Rutting).
3. Thermal Cracking (Low Temperature or Transverse Cracking).
4. Fatigue Cracking (Alligator Cracking).
5. Pavement Surface Friction (Skid Resistance).

Mechanistic based, flexible design equations have been developed which relate the pavement material properties to the predicted roughness and distresses as a function of both traffic loading and environmental conditions. Presently, although considered an important distress, sufficient data does not exist to support a statistically accurate predictive equation for fatigue cracking. As well, the data collected by SHRP [45] was not adequate to determine a model for the loss of surface friction for flexible pavements.

For rigid pavements, SHRP identifies the following pavement condition indices as the primary causes of deterioration which contribute to agency and road user costs:

1. Roughness (International Roughness Index {IRI}).
2. Permanent Deformation (Joint Faulting).
3. Thermal Cracking (Low Temperature or Transverse Cracking).
4. Spalling (Expansion Cracking).
5. Pavement Surface Friction (Skid Resistance).

Mechanistic based, rigid design equations have been developed which relate the pavement material properties to the predicted roughness and distresses as a function of both traffic loading and environmental conditions. Presently, although predictive equations have been developed for thermal cracking, the relationships do not prove to be meaningful due to poor statistical fits. As with flexible pavements, the present data collected by SHRP [45] was not adequate to determine a model for the loss of surface friction for rigid pavements.

2.5 Total Cost Considerations.

In order for any pavement design process to be complete, the total cost of each design alternative must be considered. The total cost includes the agency costs and road user costs. The agency costs consist of outlays by the highway agency to construct and maintain the pavement structure throughout its analysis period. Road user costs are the societal costs borne by the highway users throughout its analysis period and are directly related to the condition of the highway pavement. The proposed SHRP predictive equations are utilized to find the minimum pavement structure which can satisfy the roughness and distress criteria set by a given highway agency through the pavement's design life. Total cost economic analysis may then be used to justify additional investment in the pavement structure or maintenance which could prove beneficial to overall societal savings. Such total cost consideration leads to the most prudent spending of limited highway funds during the design life of a pavement structure and is an integral tool in efficient pavement management.

2.6 Proposed Pavement Design Procedures.

Figures 2-2 and 2-3 show the proposed pavement design procedure for flexible and rigid pavements to be utilized in this dissertation. The given set of inputs include pavement characteristics such as pavement materials, environmental factors, subgrade properties, and traffic loadings; a specified degree of risk; and trial pavement thickness and composition. For the given inputs, mechanistic analysis will be used to analyze specific pavement deterioration modes against the terminal criteria as specified by the highway agency for each mode. For flexible pavements, roughness, rutting, and thermal cracking will be considered; while for rigid pavements, roughness, joint faulting, and spalling will be considered. Life cycle maintenance needs will be forecasted and both agency and user costs will be estimated for the design alternative. Finally, economic analysis will be conducted to aid in the selection of the final pavement thickness and materials to be utilized in the newly constructed pavement structure.

It is noted that SHRP [45] acknowledges that the present data limitations preclude the use of the developed equations for design use at sufficient confidence levels. It is recommended that the predictive equations be used as a check for pavement structures designed using other procedures. This dissertation attempts to advance the state of the art by utilizing these equations to conduct mechanistic analysis which, in turn, will improve the existing design procedure used by many state agencies. Since New York is a lead state in implementing SHRP products, and the state in which the author practices, New York's is utilized as a case study of how mechanistic analysis may be implemented to improve present pavement design practices.

Figure 2-2: Proposed Flexible Pavement Design Procedure.

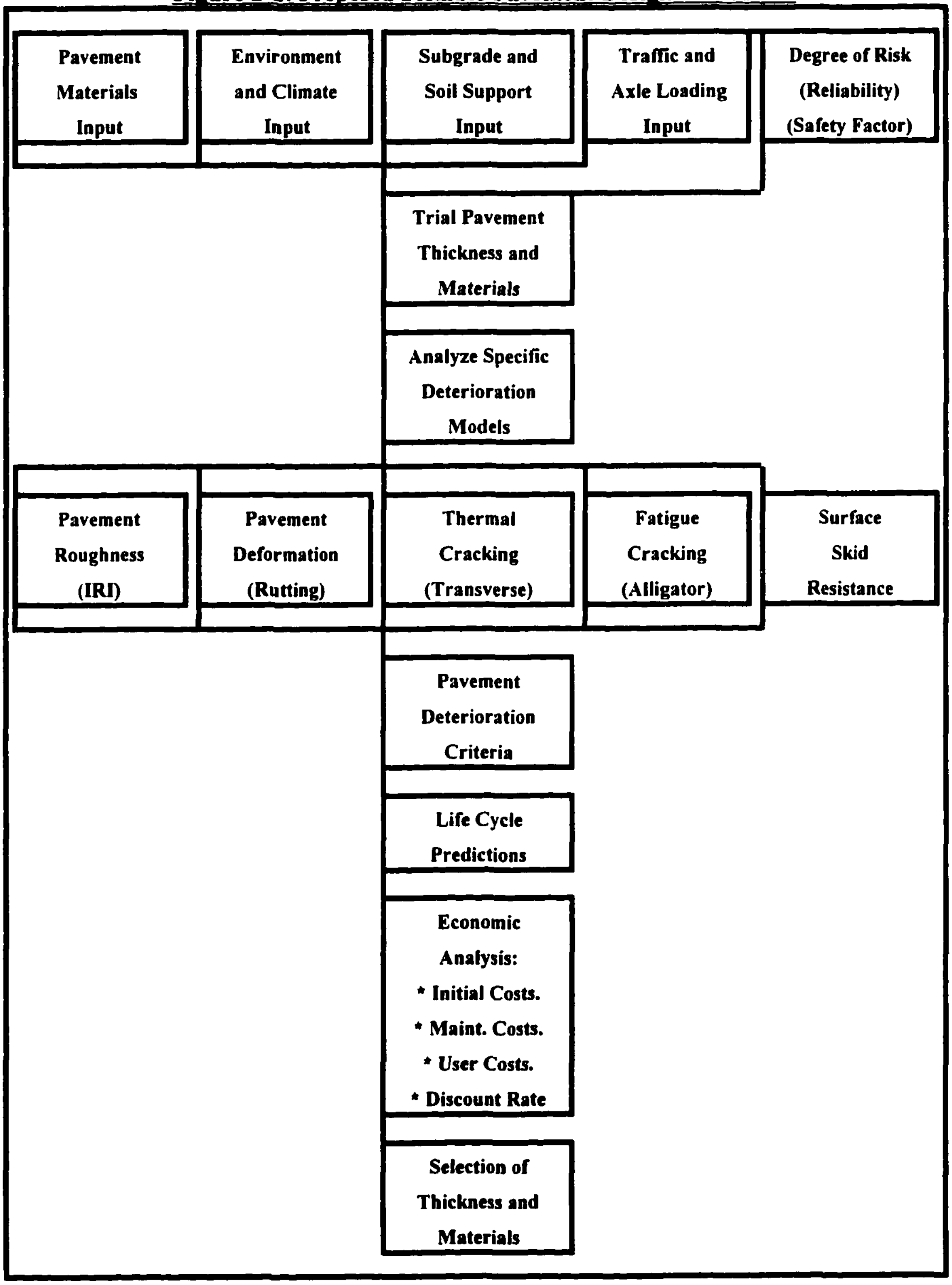
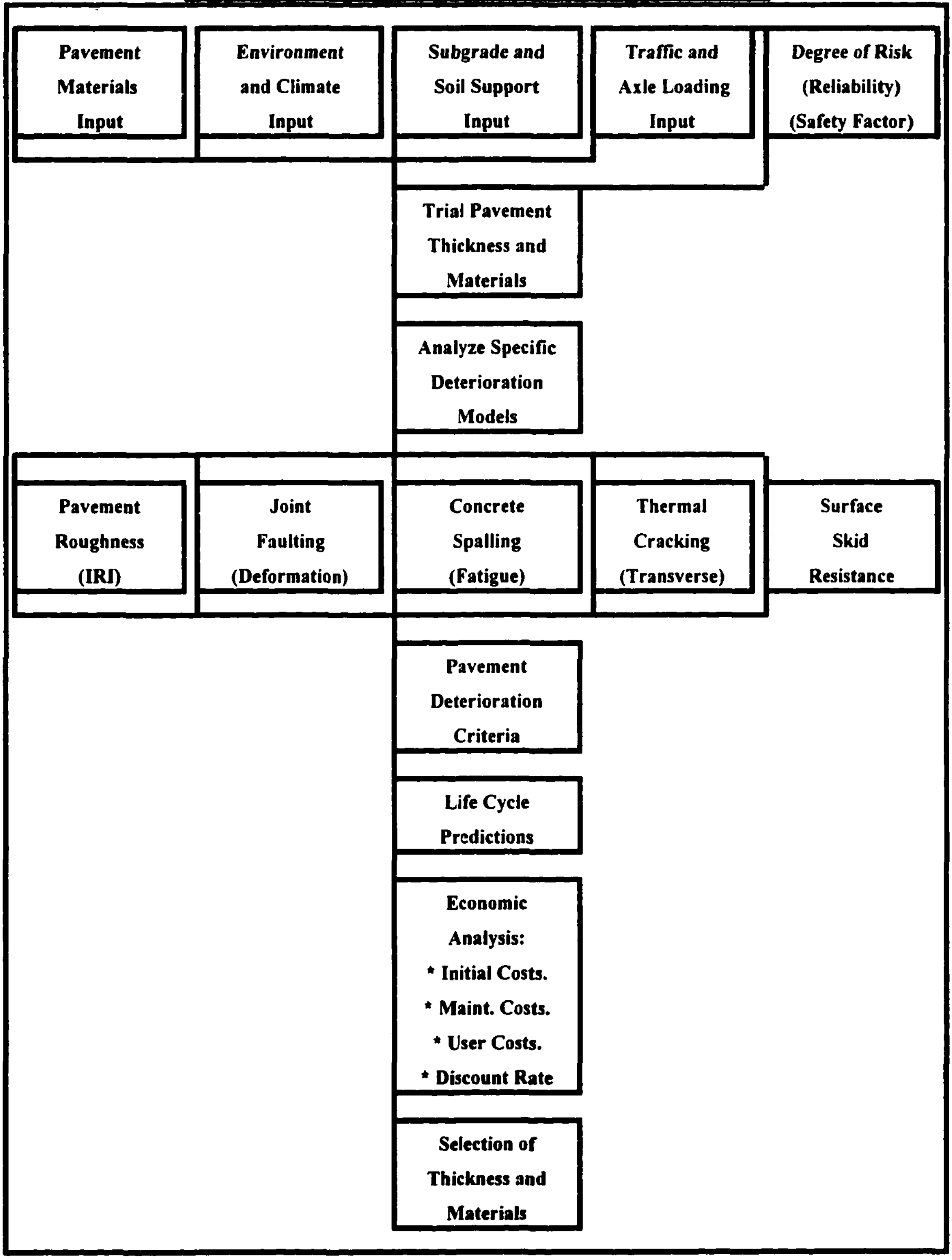


Figure 2-3: Proposed Rigid Pavement Design Procedure.



CHAPTER 3 - TRAFFIC VOLUME AND AXLE LOADING COMPUTATIONS.

3.1 Background.

The prediction of future traffic loadings is a very sensitive and consequential parameter in pavement design and management. Errors in this prediction may lead to premature pavement failure if estimated too liberally and wasteful spending of highway funds if forecasted too conservatively. The following procedure, as described by AASHTO [2] and United States Department of Transportation (USDOT) [51] will be used to estimate the axle loading during the analysis period of a newly constructed pavement.

3.2 Traffic Volume Analysis Versus Axle Loading Analysis.

When conducting pavement analysis, the engineer must be cognizant of the two types of traffic data, traffic volume and axle loading.

Traffic volume analysis, associated with traffic engineering, is the study of how the vehicle volume and composition affects parameters such as capacity, density, flow rate, and level of service. Traffic volume is the total number of vehicles which pass a specific point on a highway facility in a given day. Traffic volume is measured in terms of average daily traffic (ADT). Traffic volume and composition data is usually gathered and compiled annually at the network level by the planning units of state highway agencies. In this dissertation, annual traffic volume data will be utilized in the estimation of road user costs.

Axle loading analysis, correlated with pavement engineering, is the investigation of how axle weights affect highway pavement parameters such as damage ratio, pavement degradation, and remaining service life. An axle load can be converted to a standardized 18-kip Equivalent Single Axle Loads (ESAL). ESAL for a given axle is the number of 18 kip single axles that will cause similar damages as the given axle. Axle loading data is gathered at weigh stations and load equivalency factors are calibrated for various vehicle classes by planning units of state highway agencies. In this dissertation, the annual axle loading data is used to design the initial pavement structure and to predict pavement performance throughout the design life.

3.3 Traffic and Axle Loading Growth Rates.

Growth rate is the variable utilized to forecast the future traffic volume and axle loading during the proposed analysis period of newly constructed pavements. The USDOT [50] reports a trend that both traffic volume and axle loading are increasing annually. The deregulation of the trucking industry, demands from new population centers, and advancements in truck aerodynamic and tire design technology has caused axle weights to increase dramatically. Table 3-1 shows the annual growth rate for both traffic volume and axle loading on typical highways in the Western United States. Due to the disparity between the traffic loading and axle loading growth rates, it is prudent to consider both rates when projecting future traffic.

Table 3-1 : Typical Annual Traffic Volume and Axle Growth Rates.

Location	Traffic Volume (%)	Truck Volume (%)	Trailer Volume (%)	18 Kip Axle Weight (%)
MT I-94, Wilbaux	3.4	5.4	6.3	10.3
MT I-94, Billings	4.0	8.1	13.1	18.3
MT I-94, Butte	2.6	4.2	9.9	9.5
MT I-94, Superior	3.9	9.5	10.4	10.4
WA I-94, Cle Elum	2.1	4.3	5.6	8.5
WA I-5, Vancouver	3.6	6.5	10.1	13.2
OR I-5, Ashland	4.1	8.8	11.7	12.6
OR I-5, Border	4.4	8.0	10.4	11.1
Average Value	3.5	6.8	9.7	11.8

Source : USDOT [51].

Traffic Volume Annual Growth Rate.

The traffic volume growth rate is the anticipated proportion by which average daily traffic is projected to increase during the analysis period. The USDOT [51] states that the nationwide traffic growth rate for mixed vehicular traffic ranges from 2 to 5 percent with a mean value of 3 percent. NYSDOT [25] indicates that the statewide traffic volume growth rate is roughly 3 percent. However, the New York State Thickness Design Manual [33] specifies that Regional Planning Units should be consulted for project level data for specific facilities.

Axle Weight Growth Rate

The axle weight growth rate is the anticipated proportion by which the truck axle weights expand over time. This variable is sensitive in the design equations for both rigid and flexible pavements as stipulated by AASHTO. The USDOT Manual [51] suggests the use of a 3 percent annual growth rate but advises that growth rates up to 10 percent have been observed in recent years. The NYSDOT Thickness Design Guide [33] specifies that the annual axle weight growth rate varies from 0 to 4 percent, compounded continuously. NYSDOT advocates consulting the appropriate Regional Planning Unit in forecasting this value for specific highways.

3.4 Traffic Composition.

Traffic composition is the categorization of vehicles in the traffic stream by class. The USDOT Manual [51] classifies traffic using the grouping system initiated by the Federal Highway Administration (FHWA) listed below:

FHWA Vehicle	Vehicle Description
1	Motorcycles
2	Passenger Cars
3	Utility Vehicles (2 axle, 4 tire)
4	Buses
5	2 Axle, 6 Tire Single Unit Trucks
6	3 Axle Single Unit Trucks
7	4 Axle (or more) Single Unit Trucks
8	4 Axle (or less) Single Trailer Trucks
9	5 Axle Single Trailer Trucks
10	6 Axle (or more) Single Trailer Trucks
11	5 Axle (or Less) Multiple Trailer Trucks
12	6 Axle Multiple Trailer Trucks
13	7 Axle (or more) Multiple Trailer Trucks

Presently, most state agencies do not collect detailed traffic composition data at either the planning or project level. However, it is customary to collect simple traffic data such as ADT and percent heavy vehicles for state highway facilities. Table 3-2 illustrates the typical traffic composition on highways in the United States.

3.5 Load Equivalency.

The load equivalency factor is the variable which converts traffic volume to equivalent axle loads for individual vehicle types. As each vehicle passes over a specific point in the pavement structure, the load causes the pavement to deflect and generates stresses in the

Table 3-2 : Typical Traffic Composition On U.S. Highways.

Vehicle Type	Rural Highway (%)	Urban Highway (%)	Total Highway (%)
Passenger Car	88.90	95.20	92.60
Bus	0.40	0.20	0.30
Single Unit Truck	3.50	2.00	2.60
Trailer Truck	7.20	2.60	4.50

Source : Traffic Engineering Handbook [14].

pavement structure. The magnitude of the induced stresses is a function of the axle weight, axle configuration, tire pressure, and pavement strength. Load equivalency factors, also known as truck factors, are used to convert the stresses caused by different vehicles into a standard load unit. The standard axle load utilized by the AASHTO Guide [2] and USDOT Manual [51] is the 18 kip Standard Axle Loads (ESAL).

Load equivalency factors are calibrated by state highway agencies from data amassed at weigh stations situated throughout the United States and Canada. The NYSDOT Design Manual [33] designates the following load equivalency factors to be utilized for heavy vehicles, FHWA class 5 through 13, on state highways:

Flexible Pavements : 1.85 ESAL / truck.

Rigid Pavement : 1.35 ESAL / truck.

It should be noted that FHWA class 1 through 4 vehicles, which includes motorcycles, passenger cars, utility vehicles, and buses, have negligible load equivalency factors. Due to the insignificant damage as compared to the standard truck, these vehicle types are not considered in the analysis of the pavement structure except for the case of a parkway.

3.6 Traffic Volume and Axle Loading Computation Equations.

Traffic Loading Computations.

The annual traffic volume during any year of the analysis period is calculated using the following equation:

$$ADT_n = (ADT_i * 365)(1 + g_{tv})^n$$

where: ADT_n Annual Yearly Traffic in year n. (veh/year)
ATD_i Initial Year ADT. (vehicles per day).

g_{tv}	Growth Rate - Traffic Volume. (decimal)
n	Years after Initial Construction. (years)

Axle Loading Computations.

The total axle loading is the sum of the 18-kip equivalent axle loads utilizing the design lane of the highway pavement throughout the analysis period. New York [33][34] presently specifies a 50 year analysis period for both flexible and rigid pavements. The design lane, as defined by AASHTO [2], is the most heavily traveled lane of the highway pavement.

Directional Distribution

The directional distribution factor accounts for variations of vehicular volume or axle weight by direction. The USDOT [51] advises that, under normal circumstances, this factor is 50 percent. However, in distinctive circumstances where one direction has a heavier loading, the directional distribution factor should be modified. Examples of such circumstances would include highways leading to quarries or port facilities where heavily laden trucks depart and empty trucks arrive.

Lane Distribution

On a multi-lane highway, truck traffic will occupy all travel lanes, but the highest proportion of trucks ordinarily utilize the right lane. The percentage of trucks traveling in the design lane is a function of the highway volume and number of lanes in each direction. The following mathematical relationships are used in the prediction of the lane distribution factor:

2 Lane Highway	$D_{lane} = 1.00$
4 Lane Highway	$D_{lane} = \{(ADT^{-0.11})(10^{2.36})\}/100$
6 Lane Highway	$D_{lane} = \{(ADT^{-0.13})(10^{2.39})\}/100$
Greater than 6 Lanes	$D_{lane} = \{(ADT^{-0.13})(10^{2.39})\}/100$

where:

ADT	Average Daily Traffic (vehicles/day)
D_{lane}	Lane Distribution Factor (decimal)

These relationships are developed in Appendix D of this dissertation. As shown in Table 3-3, the relationships, which take the form of the power equation, are statistically good fits of the observed data.

Table 3-3 : Regression Parameters For Lane Distribution Equations.

$$D_{lane} = ADT^{a} * (10^{b})$$

Facility Type	b	a	R^2	r	Fit
4 Lane Highway	2.36	-0.11	0.998	0.999	"Good"
6 Lane Highway	2.39	-0.13	0.995	0.997	"Good"

Initial Axle Loading Computation

The axle loading in the initial year of the analysis period is computed using the following equation:

$$W_{18i} = ADT * HV_{\%} * LEF * D_d * D_l * 365$$

where: W_{18i} Initial Year Axle Loading (ESAL)
$HV_{\%}$ Percent Heavy Vehicles (decimal)
LEF Load Equivalency Factor (ESAL/vehicle)
D_d Directional Distribution (decimal)
D_l Lane Distribution (decimal)
365 Number of days per year.

Cumulative Axle Weight Loading

The final step in the computation of axle loading is to calculate the number of cumulative axle loads during any year of the analysis or performance period. The cumulative axle loading at any time during the analysis period is computed using the following equation:

$$W_{18c} = W_{18i} \left[(1+g_{ax})^{n}-1/g_{ax}\right]$$

where: W_{18c} Cumulative Axle Loads in year "n" (ESAL)
W_{18i} Initial Year Axle Loads (ESAL)
g_{ax} Annual Axle Weight Growth Rate (decimal)
n Number of Years into analysis period (Years)

3.7 Need For Further Study.

The current methodologies used to compute traffic volume and axle loading is described in the AASHTO Guide For Design of Pavement Structures [2]. Due to the significance and sensitivity of traffic data in most design equations, researchers are striving to improve the present technologies used to collect and predict traffic and axle loading data.

Vehicle Classification.

Many state highway agencies, including the NYSDOT [33], presently utilize the "simple" method for computing load equivalency factors. This method considers a single load equivalency factor for all trucks in FHWA class 5 through 13. It is commonly used because adequate planning level data is not available regarding traffic composition. However, the USDOT [50] has initiated compiling specific vehicle composition data in order to develop individual load equivalency factors for all 13 FHWA vehicle classifications. Upon completion, it will be feasible to implement the "rigorous" method of traffic loading prediction as proposed in the USDOT [51] and 1993 NYSDOT Thickness Design Manual [32]. This alternative procedure has the potential to make traffic and axle loading predictions more precise.

Advanced Technologies.

Traffic data is a sensitive variable in pavement design equations, therefore, current and accurate data are essential in pavement design. Traditionally, axle weight information used to compute load equivalency factors has been gathered at weigh stations, thus, the monitoring process is time consuming, unreliable, and costly. Advanced technologies, such as weigh-in-motion scales, are now being implemented by state highway agencies to maintain an accurate, reliable record of loading information. This versatile equipment monitors and records traffic data using high speed micro-processors without interfering with the flow of the traffic stream. Traffic data assembled using this apparatus may be used to verify past design assumptions and re-evaluate initial design and maintenance needs based upon real-time data.

CHAPTER 4 - FLEXIBLE PAVEMENT MECHANISTIC DESIGN EQUATIONS.

4.1 SHRP-LTPP Flexible Pavement Studies.

Full depth flexible pavement studies were conducted by SHRP [44] during General Pavement Studies (GPS) 1 and 2. In total 386 full depth asphalt pavements were constructed, 253 test projects consisting of asphalt concrete over granular base and subbase materials and 133 test projects consisting of asphalt concrete over bound base, treated asphalt or Portland cement concrete. Data collected from the test sections includes pavement roughness and primary distress data including rutting, thermal cracking, and fatigue cracking.

Initial SHRP [45] studies attempted to develop models with an inference space that included all of the United States and Canada. The results of these studies showed that it is not possible to develop a single, predictive model across such diverse environmental conditions which would adequately address the effects of the variation of independent variables. Therefore, separate equations were developed for a combination of pavement types, distress types, and environmental regions. Specific models were developed to predict pavement roughness, rutting, and thermal cracking for the four environmental regions shown in Figure 2-1.

Regarding flexible pavements, SHRP [45] has developed mechanistic equations to model pavement roughness, rut depth, and thermal cracking for each of the four climate zones. Each predictive equation was the best of several hundred trial equations in terms of statistical parameters which minimized the colinearities between independent variables. The quantitative analysis in determining the correlation coefficient for the predictive equations was completed by SHRP as referenced in manual SHRP P-394 [45]. From a purely statistical point of view, if the correlation coefficient is greater than 0.85, the equation represents a good statistical fit of the data points [8][16]. However, additional statistical methods are needed to make a qualitative judgement as to the equation's applicability in this dissertation. These methods include comparing SHRP regional to local data ranges, studying the sensitivity analysis of independent variables with respect to available data, and weighing the implications of the computed correlation coefficients. For example, Table 4-2, shows a correlation coefficient of 0.933 for roughness in the wet-freeze zone, indicating that the predictive equation is a statistically good fit of the observed data. Figure A-1 of Appendix A shows that axle loading, air voids, asphalt viscosity, HMA layer thickness, and freeze index are particularly sensitive variables in the predictive equation for the wet-freeze zone. For the New York case study, the data inputs representing these variables are obtainable, therefore, the predictive equation is appropriate for use. Results of this analysis are shown in Tables 4-2, 4-4, and 4-6 for flexible pavement and, Tables 6-1, 6-2, 6-3, and 6-4 for rigid pavement.

4.2 Flexible Pavement Roughness Equations.

Pavement roughness is defined as unevenness of the pavement surface or general distortions of the pavement profile caused by settlement, construction variability, pavement surface distresses, traffic loading, and environmental factors. Roughness is measured in terms of International Roughness Index (IRI) in units of inches per mile. The equations developed to predict flexible pavement roughness are detailed in Table 4-1. The predictive equations take the form of the power equation:

$$IRI = N^{B}\,10^{C}$$

where:		
	IRI	International Roughness Index (inch/mile).
	N	Number of Cumulative KESAL.
	B	b_o (Calibrated Constant).
	C	$c_o + c_1x_1 + ... + c_nx_n$.

The coefficients in the linear equation to determine the value of variable C are a function of pavement design, mix properties, and regional climate factors.

Statistical Analysis

Table 4-2 shows the correlation coefficients for the predictive roughness equations developed for the four climatic regions. The correlation constant is greater than 0.85 for each of the regional equations, indicating that the equations are a good statistical fit of the data. Overall, as the data set is reduced from the entire set to the regional equations, the value of the correlation constant increases, indicating that the regional equations are better data fit. Since the regional equations are more statistically sufficient, they will be used for mechanistic analysis in this dissertation.

Table 4-1 : Flexible Pavement Equations - Roughness

4-1A. Entire Data Set.

Explanatory Variable (xi)	Units	Bi	Ci
Constant Term	---	0.153	-0.000543
Asphalt Content	% Weight	0	-0.016
Annual Precipitation	Inches	0	0.000359
Asphalt Viscosity at 140 degrees (F).	Poise	0	0.000036
Base Thickness	Inches	0	-0.00335
Base Compaction (AASHTO)	% Density	0	0.0113
Subgrade < No. 200 Sieve	% Weight	0	0.00062
Freeze Index	Degree-Day	0	0.000081
Annual Days > 90 degrees (F) * HMAC Thickness	Number Inches	0	-0.000437
Annual Days > 90 Degrees (F) * Air Voids in HMAC	Number % Volume	0	0.000178

Note : Stars (*) represent multiplication in these tables.

4-1B. Wet - No Freeze Data Set.

Explanatory Variable (xi)	Units	Bi	Ci
Constant Term	---	0.21	0.0233
Base Thickness	Inches	0	-0.0372
Annual number of Days > 90 degrees (F).	Days	0	0.00249
Annual Precipitation.	Inches	0	0.0214
HMAC Thickness * Base Compaction (AASHTO)	Inches % Density	0	-0.000761
Log (Air Voids in HMAC) * Daily Temperature Range	% Volume Degrees	0	0.0322
Asphalt Viscosity at 140 degrees (F) * Log (Annual Freeze-Thaw Cycles+ 1)	Poise Number	0	-0.000299
Asphalt Viscosity at 140 degrees (F) * Daily Temperature Range	Poise Degrees	0	0.000017

4-1C. Wet - Freeze Data Set.

Explanatory Variable (xi)	Units	Bi	Ci
Constant Term	---	0.25	0.0403
Asphalt Viscosity at 140 degrees (F)	Poise	0	0.00014
Air Voids in HMAC	% Volume	0	0.0704
Log (HMAC Thickness)	Inches	0	0.314
Base Thickness	Inches	0	-0.00162
Annual Number of Days > 90 degrees (F)	Days	0	-0.00165
Freeze Index * Air Voids in HMAC	Degree-Days % Volume	0	0.000016

4-1D. Dry - No Freeze Data Set.

Explanatory Variable (xi)	Units	Bi	Ci
Constant Term	---	0.406	-0.00994
HMAC Thickness	Inches	0	0.0255
Asphalt Viscosity at 140 degrees (F).	Poise	0	0.00024
Base Thickness	Inches	0	-0.0329
Annual Precipitation	Inches	0	0.0124
Annual Number of Days > 90 degrees * HMAC Thickness	Days Inches	0	-0.00114
Subgrade < No. 200 Sieve * Annual Precipitation	% Weight Inches	0	0.000268

4-1E. Dry - Freeze Data Set.

Explanatory Variable (xi)	Units	Bi	Ci
Constant Term	---	0.271	0.00393
Asphalt Viscosity at 140 degrees (F)	Poise	0	0.000317
Base Thickness	Inches	0	0.024
Annual Number of Days > 90 degrees (F)	Days	0	-0.0125
Log (Air Voids in HMAC) * HMAC Thickness	% Volume Inches	0	-0.00197
Freeze Index * Annual Number of Days > 90 degrees (F)	Degree-Days Days	0	0.000015

Table 4-2 : Regression Data For Flexible Pavement Equations, Roughness.

Data Set	Equation Form	n	R^2	r	Statistical Fit	NYSDOT Adequacy
1. Entire Set.	Power	108	0.650	0.806	"Marginal"	---
2. Wet, No Freeze Zone.	Power	32	0.850	0.922	"Good"	---
3. Wet, Freeze Zone.	Power	35	0.870	0.933	"Good"	Adequate
4. Dry, No Freeze Zone.	Power	27	0.950	0.975	"Good"	---
5. Dry, Freeze Zone.	Power	14	0.940	0.970	"Good"	---

Source : Adapted from SHRP [45].

Sensitivity Analysis

Sensitivity analysis reflects the different ways in which the independent variables manifest themselves in the various predictive equations. This type of analysis shows how the dependent variable in the predictive equation is affected by varying the value of the independent variables throughout their expected range of values. The Engineer may use this information to establish the importance of each variable in the prediction of a specific distress and can qualitatively judge if assumptions can be tolerated in the case of missing data. Appendix A shows the sensitivity analysis for flexible pavement roughness and distresses, while Appendix B does the same for the rigid pavement predictive equations. In this dissertation, the sensitivity analysis performed proves the importance of climatic and environmental factors in the prediction of distresses for pavements in New York State.

The sensitivity analysis for roughness models is shown in Figure A-1 of Appendix A. Roughness is most sensitive to changes in traffic loading in the wet, freeze and dry, no freeze regions; most sensitive to changes in the freeze index in the dry, freeze region; and most sensitive to changes in the number of daily freeze cycles in the wet, no freeze region. Basic trends in other design variables which change the pavement structure are HMAC thickness and base thickness.

An increase in the thickness of the HMAC layer will result in:

- Substantial decrease in roughness in the wet, no freeze region.
- Substantial decrease in roughness in the dry, no freeze region.
- Increased roughness in the wet, freeze region.

- Very slight decrease in the dry, freeze region.

An increase in the thickness of the base and subbase layer will result in:

- Substantial decrease in roughness in the wet, no freeze region.
- Substantial decrease in roughness in the dry, no freeze region.
- Slight decrease in roughness in the wet, freeze region.
- Substantial increase in roughness in the dry, freeze region.

These basic trends help the engineer in making design decisions which best suit the pavement in his region of the country.

4.3 Flexible Pavement Distress Equations - Rutting.

Rutting is longitudinal surface depressions in the pavement wheel paths caused by insufficient pavement thickness, unstable base, insufficient base compaction, excessive tire pressures, or permanent wear due to traffic abrasion. Rut depth is measured in units of inches in the centerline of each wheel path. The equations developed to predict flexible pavement rutting are shown in table 4-3. The predictive equations take the form of the power equation:

$$RD = N^{B} 10^{C}$$

where:
RD Rut Depth (inches).
N Number of Cumulative KESAL.
B $b_0 + b_1x_1 + ... + b_nx_n$.
C $c_0 + c_1x_1 + ... + c_nx_n$.

The coefficients in the linear equations to determine the values of variables B and C are a function of pavement design, mix properties, and regional climate factors.

Statistical Analysis

Table 4-4 shows the correlation coefficients for the predictive equations developed for the four climate regions and for the entire data set. The correlation constant for each of the climate regions is greater than 0.85 indicating that predictive equation is a good statistical fit for

Table 4-3 : Flexible Pavement Equations - Rutting.

4-3A. Entire Data Set.

Explanatory Variable (xi)	Units	Bi	Ci
Constant Term	---	0.151	-0.00475
Log (HMAC Aggregate < No. 4 Sieve)	% Weight	0	-0.596
Log (Air Voids in HMAC)	% Volume	-726	0
Log (Base Thickness)	Inches	0	0.19
Subgrade < No. 200 Sieve	% Weight	0	0..00582
Freeze Index	Degree-Days	0.000008	0
Log (HMAC Thickness) * Log (Base Thickness)	Inches Inches	0	-0.161

4-3B. Wet - No Freeze Data Set.

Explanatory Variable (xi)	Units	Bi	Ci
Constant Term	---	0.0739	0.00998
Log (HMAC Aggregate < No. 4 Sieve)	% Weight	0	-0.373
Log (Air Voids in HMAC)	% Volume	0	-0.215
Subgrade < No. 200 Sieve	% Weight	-0.00056	0
Annual Number of Days > 90 Degrees (F)	Days	0	-0.00022
Log (Annual Freeze-Thaw Cycles + 1)	Number	0	0.0337
Log (HMAC Thickness) * Log (Base Thickness)	Inches Inches	0	-0.135

4-3C. Wet - Freeze Data Set.

Explanatory Variable (xi)	Units	Bi	Ci
Constant Term	---	0.183	0.0289
Log (Air Voids in HMAC)	% Volume	0	-0.189
Log (HMAC Thickness)	Inches	0	-0.181
Log (HMAC Aggregate < No. 4 Sieve)	% Weight	0	-0.592
Asphalt Viscosity at 140 Degrees (F)	Poise	0	0.000018
Log (Base Thickness)	Inches	0	-0.436
Annual Precipitation * Freeze Index	Inches Degree-Days	0	0.000002

4-3D. Dry - No Freeze Data Set.

Explanatory Variable (xi)	Units	Bi	Ci
Constant Term	---	0.156	-0.00163
Log (HMAC Aggregate < No. 4 Sieve)	% Weight	0	-0.628
Log (HMAC Thickness)	Inches	0	0.0918
Log (Air Voids in HMAC)	% Volume	-0.0988	0
Base Thickness	Inches	0	0.00257
Subgrade < No. 200 Sieve	% Weight	0	0.00153
Annual Precipitation * Annual Number of Days > 90 Degrees (F)	Inches Days	0	0.0000066

4-3E. Dry - Freeze Data Set.

Explanatory Variable (xi)	Units	Bi	Ci
Constant Term	----	0.0349	0.00451
Log (HMAC Thickness)	Inches	0	0.06
Base Compaction (AASHTO)	% Density	0	-0.00849
Base Thickness * Log (HMAC Thickness)	Inches Inches	0	0.00875
Log (Subgrade < No. 200 Sieve) * Log (Freeze Index +1)	% Weight Degree-Days	0	0.0107
Log (Subgrade < No. 200 Sieve) * Log (Air Voids in HMAC)	% Weight % Volume	0	-0.00567

the observed data. Similar to flexible pavement roughness, there is less variance for the regional equations than for the entire data set. The regional rutting equations are statistically sufficient for the limited use proposed in this dissertation.

Sensitivity Analysis.

The sensitivity analysis for the developed rutting equations are shown in Figure A-2 of Appendix A. The plots illustrate the change in rut depth achieved by varying the value of each independent variable throughout its expected range. Flexible pavement rutting is most sensitive to variance in traffic loading except in the dry, freeze region where it is most sensitive to changes

Table 4-4 : Regression Data For Flexible Pavement Equations, Rutting.

Data Set	Equation Form	n	R^2	r	Statistical Fit	NYSDOT Adequacy
1. Entire Set	"Power"	152	0.450	0.671	"Marginal"	---
2. Wet, No Freeze Zone.	"Power"	41	0.720	0.849	"Good"	---
3. Wet, Freeze Zone.	"Power"	41	0.730	0.854	"Good"	Adequate
4. Dry, No Freeze Zone.	"Power"	36	0.750	0.866	"Good"	---
5. Dry, Freeze Zone.	"Power"	44	0.850	0.922	"Good"	---

Source : Adapted from SHRP [45].

in the base compaction. With regard to pavement thickness design variables, the following trends are observed.

An increase in the thickness of the HMAC layer will lead to:

- * A decrease in rutting in the wet, no freeze region.
- * A slight increase in rutting in the dry, no freeze region.
- * A decrease in rutting in the wet, freeze region.
- * An increase in rutting in the dry, freeze region.

An increase in the thickness of the base and subbase layers will lead to:

- * A slight decrease in rutting in the wet, no freeze region.
- * A slight decrease in rutting in the dry, no freeze region.
- * A slight decrease in rutting in the wet, freeze region.
- * An increase in rutting in the dry, freeze region.

4.4 Flexible Pavement Distress Equations - Thermal Cracking.

Thermal cracks are visible fractures or separations of the pavement surface perpendicular to the pavement centerline caused by pavement shrinkage, frost action, or base settlement. Thermal cracking is measured as the number of cracks per mile of pavement. The equations which relate thermal cracking to pavement age in flexible pavements are shown in Table 4-5. The predictive models again take the form of a power equation:

$$CS = N^B 10^C$$

Where: CS Crack Spacing (feet).
N Pavement Age (years).
B $b_o + b_1x_1 + ... + b_nx_n$.
C $c_0 + c_1x_1 + ... + c_nx_n$.

The coefficients in the linear equations to determine the values of variable B and C are functions of pavement design, mix properties, and regional climate factors.

Table 4-5 : Flexible Pavement Equations - Thermal Cracking

4-5A. Entire Data Set.

Explanatory Variable (xi)	Units	Bi	Ci
Constant Term	---	-0.205	0.282
Log (HMAC Thickness)	Inches	0	0.341
Air Voids in HMAC	% Volume	0	0.00686
Log (Base Thickness + 1)	Inches	0	-0.0031
Base Compaction (AASHTO)	% Density	0	0.00646
Asphalt Viscosity at 140 Degrees (F)* Log (Base Thickness + 1)	Poise Inches	0	0.00013
Log (Annual Precipitation) * Log (Base Thickness +1)	Inches Inches	0	0.301

4-5D. Dry - No Freeze Data Set.

Explanatory Variable (xi)	Units	Bi	Ci
Constant Term	---	-0.241	-0.00155
HMAC Thickness	Inches	0	-0.0282
Log (Base Thickness +1)	Inches	-0.147	0
Log (Annual Precipitation)	Inches	0	1.89

4-5B. Wet - No Freeze Data Set.

Explanatory Variable (xi)	Units	Bi	Ci
Constant Term	---	-1.12	0.0131
Log (Freeze Index + 1)	Degree-Days	0	0.733
Log (Annual Precipitation)	Inches	0	0.534
HMAC Thickness * Log (Asphalt Viscosity at 140 Degrees (F))	Inches Poise	0	0.0109
Base Thickness * Asphalt Content	Inches % Weight	0	-0.00587
Base Compaction (AASHTO) * Daily Temperature Range	% Density Degrees	0	0.000295

4-5C. Wet - Freeze Data Set.

Explanatory Variables (xi)	Units	Bi	Ci
Constant Term	---	-0.106	-0.0201
HMAC Aggregate < No. 4 Sieve	% Weight	0	-0.0131
HMAC Thickness	Inches	-0.00474	0
Log (Annual Precipitation)	Inches	0	1.84
Annual Number of Days > 90 Degrees (F)	Days	-0.054	0
Base Thickness * Log (Annual Precipitation)	Inches Inches	0	-0.0159
Base Thickness * Annual Number of Days > 90 Degrees (F)	Inches Days	0	0.0024
Subgrade < No. 200 Sieve * Log (Annual Precipitation)	% Weight Inches	0	0.00408

4-5E. Dry - Freeze Data Set.

Explanatory Variables (xi)	Units	Bi	Ci
Constant Term	---	-0.425	0.0468
Log (Annual Traffic)	KESAL	0	0.854
Base Thickness	Inches	0	-0.00853
Freeze Index	Degree- Days	0	0.00013
HMAC Thickness * Base Thickness	Inches Inches	0	0.00398
HMAC Thickness * Asphalt Viscosity at 140 Degrees (F)	Inches Poise	0	0.000016
HMAC Thickness * Log (Subgrade < No. 200 Sieve)	Inches % Weight	0	-0.035

Explanatory Variables (xi)	Units	Bi	Ci
Asphalt Viscosity at 140 Degrees (F) * Log (Subgrade < No. 20 0 Sieve)	Poise %Weight	0	0.00011

Statistical Analysis.

Table 4-6 shows the correlation coefficients for the predictive equations developed for the four environmental regions and for the entire data set. The correlation constant for each of the climate regions is greater than 0.85 indicating that the equation is a good statistical fit of the observed distress data. The regional equations are an improvement over the entire data set as indicated by the reduction in variance. Overall, the regional thermal cracking equations are statistically sufficient for the limited use proposed in this dissertation.

Table 4-6 : Regression Data For Flexible Pavement Equations, Thermal Cracking.

Data Set	Equation Form	n	R^2	r	Statistical Fit	NYSDOT Adequacy
1. Entire Set.	"Power"	118	0.370	0.608	"Marginal"	---
2. Wet, No Freeze Zone.	"Power"	17	0.850	0.922	"Good"	---
3. Wet. Freeze Zone.	"Power"	44	0.860	0.927	"Good"	Adequate
4. Dry, No Freeze Zone.	"Power"	23	0.860	0.927	"Good"	---
5. Dry, Freeze Zone.	"Power"	34	0.780	0.883	"Good"	---

Source : Adapted from SHRP [45].

Sensitivity Analysis.

The sensitivity analysis for the crack spacing equations are shown in Figure A-3 of Appendix A. Crack spacing is most sensitive to pavement age in the wet, no freeze region; most sensitive to annual precipitation in the dry, no freeze region; most sensitive to annual days above 90 degrees Fahrenheit in the wet, freeze region; and most sensitive to asphalt viscosity in the dry, freeze region. The following trends are observed relative to pavement thickness variables.

An increase in HMAC layer thickness will lead to:

* A decrease in crack spacing in the wet, no freeze region.
* An increase in crack spacing in the dry, no freeze region.
* A slight increase in crack spacing in the wet, freeze region.

- A decrease in crack spacing in the dry, freeze region.

An increase in the base and subbase thickness will lead to:

- An increase in crack spacing in the wet, no freeze region.
- A slight increase in crack spacing in the dry, no freeze region.
- An increase in crack spacing in the wet, freeze region.
- A decrease in crack spacing in the dry, freeze region.

4.5 General Results and Observations.

As shown in Chapter 5, the results of the mechanistic design analysis show that the AASHTO [2] design procedure for flexible pavement over-estimates the number of loads required to cause a specific loss of serviceability, especially for cases of higher axle loading. Therefore, using the AASHTO equation may result in pre-mature aging and failure of the pavement structure.

The sensitivity analysis shows that environmental factors have a significant effect upon the performance of a flexible pavement structure. The AASHTO equation fails to incorporate specific environmental factors including average annual precipitation, freeze index, average days below freezing (32 degrees Fahrenheit), and average days above 90 degrees Fahrenheit into the design equation. As per the above referenced sensitivity analysis, these design variables have a statistically significant effect on pavement roughness, rutting, and thermal cracking.

Layered design theory, the basic assumption underlying the AASHTO [2] flexible design theory, is shown to be invalid by mechanistic analysis. Layered design theory combines the strength properties, drainage properties, and thickness of each layer into a composite variable, the structural number. Mechanistic analysis shows that simply increasing layer thickness of HMAC and base courses as per AASHTO [2] will not improve pavement performance, and in some climate regions will lead to increased distress. However, mechanistic analysis completed in this dissertation does show that altering the properties of individual layers and the design mix has a positive impact on roughness, rutting, and thermal cracking. Material properties such as gradation, compaction, and moisture content may be adjusted so that pavement performance is optimized. Additionally, HMAC mix design properties such as percent of air voids, asphalt content, asphalt viscosity, and aggregate gradation, may be modified to meet climate and loading conditions.

4.6 Effects of Superpave Specifications.

The mechanistic analysis completed in this dissertation shows that Superpave specifications, issued by many state highway agencies, will have a positive effect on flexible pavement design in terms of improved mix design and construction quality.

Superpave asphalt concrete mixes are designed to address specific pavement problems and distresses such as rutting and thermal cracking. In New York, Superpave mixes make adjustments to the aggregate gradation and asphalt cement properties depending on the predicted level of traffic and climate region. For pavements expected to carry higher traffic loadings, larger aggregate is specified for the binder and top courses to stabilize the mix thereby reducing wheel path rutting. As well, changes in the performance grade of asphalt cement content and viscosity are based on the predicted environmental conditions and help to reduce thermal cracking in the HMAC structure.

Superpave asphalt concrete mixes have specifications designed to improve construction quality. Laboratory testing of the Superpave mix is conducted using the gyratory compactor, rather than the traditional Marshall hammer. The gyratory compactor better represents the field loading conditions which are encountered by a flexible pavement structure throughout its design life. As well, many state highway agencies have developed quality assurance or quality control (QA/QC) specifications designed to improve the quality of construction of superpave mixes. When implementing QA/QC specifications, contractors are given additional payment for high quality paving operations or less payment for a poor product. The nuclear density gauge is used to measure the overall quality of paving with the idea that a better product will lead to a longer serviceable pavement life.

New York State Department of Transportation (NYSDOT) is presently considered a lead state in the implementation of SHRP and superpave products and specifications [24].

4.7 Need For Further Study.

It is expected that the collection of additional data will lead to more refinement and betterment of the predictive equations developed for flexible pavement roughness, rutting, and thermal cracking.

Fatigue Cracking.

SHRP has been collecting data regarding fatigue cracking, a primary distress in flexible pavements. Fatigue cracking, also called alligator cracking, are connected cracks located within the pavement wheel paths which form multi-sided, sharp angled pieces in a pattern resembling the skin of an alligator. This distress is caused by fatigue due to the cyclic loads over the life of the pavement and is often the result of unstable base materials, inadequate drainage, or insufficient pavement thickness. This is a significant distress because its presence signifies the failure of the pavement structure. In cold climates, it is assumed that fatigue cracks propagate from the bottom bound layer towards the surface, therefore, is difficult to quantify in its initial stages. To-date, very few of the flexible pavement test sections have been observed to develop this distress. Therefore, statistically accurate predictive equations for this distress could not be developed and future analysis is warranted.

Skid Resistance of Pavement Surface.

SHRP has also been collecting data which will be used to predict the loss of surface friction. Loss of surface friction occurs as continual traffic loading wears the pavement surface. The loss of surface texture is a serious problem because it affects the safety of a given pavement. Presently, the data collected is not adequate to determine an accurate, meaningful model.

CHAPTER 5 - ADAPTING THE MECHANISTIC EQUATIONS TO IMPROVE THE EXISTING NYSDOT FLEXIBLE PAVEMENT DESIGN PROCEDURE.

5.1 Existing NYSDOT Flexible Pavement Design Tables - AASHTO Methods.

The present pavement design methodology used by the New York State Department of Transportation (NYSDOT) for the design of flexible pavements is outlined in the New York State Thickness Design Manual For New and Reconstructed Pavements [33][34]. The design is based upon the layered analysis theory described by AASHTO [2]. Independent design variables such as materials, subgrade, and construction practices have been calibrated to reflect statewide conditions [9]. The selection of HMAC thickness is dependent upon two primary independent variables, the predicted traffic loading in standard 18 kip axles (ESAL) and the Resilient Modulus of the subgrade soil. To improve drainage, a 4 inch layer of permeable asphalt treated base material is placed below the HMAC layer. To improve subbase support, a 12 inch layer of granular subbase is standard in design. Where very heavy traffic loads are anticipated, or locations where subgrade improvement is warranted, a layer of select granular fill may be placed below the subbase material. The present design chart, as specified by NYSDOT [34], is shown in Table 5-1.

5.2 Flexible Pavement Roughness Equation Calibration.

The predictive equation for flexible pavement roughness takes the following form:

$$IRI = N^{0.25}\,10^{C}$$

$$C = 0.0403 + 0.00014AC_{visc} + 0.0704\ AC_{void} + 0.314\ \log(AC_{thick}) - 0.00162\ B_{thick} - 0.00165\ DGT + 0.00001628\ (FI*AC_{void})$$

Where: IRI	Roughness (International Roughness Index) (inch/mile)
N	Cumulative KESAL (1000 ESAL)
AC_{visc}	Asphalt Viscosity (Poise)
AC_{void}	Asphalt Air Voids (% Volume)
AC_{thick}	HMAC Layer Thickness (inch)
B_{thick}	Base Layer Thickness (inch)
DGT	Annual Days Greater Than 90 Degrees (days)
FI	Freeze Index.

Table 5-1 : NYSDOT Flexible Pavement Design.

Mr 4000 psi			Mr 5000 psi			Mr 6000 psi		
18 Kip ESAL (10^6))	HMAC Thick. (Inch)	Fill Thick. (Inch)	18 Kip ESAL (10^6))	HMAC Thick. (Inch)	Fill Thick. (Inch)	18 Kip ESAL (10^6)	HMAC Thick. (Inch)	Fill Thick (Inch)
0-1	5	0	0-2	5	0	0-3	5	0
1-2	6	0	2-4	6	0	3-6	6	0
2-4	7	0	4-7	7	0	6-11	7	0
4-8	8	0	7-13	8	0	11-20	8	0
8-13	9	0	13-23	9	0	20-35	9	0
13-23	10	0	23-40	10	0	35-60	10	0
23-45	10	6	40-70	10	6	60-110	10	6
45-80	10	12	70-130	10	12	110-200	10	12
80-140	10	18	130-235	10	18	200-360	10	18
140-240	10	24	235-400	10	24	360-500	10	24
240-400	10	30	400-500	10	30	-----	-----	-----
400-500	10	36	-----	-----	-----	-----	-----	-----

Mr 7000 psi			Mr 8000 psi			Mr 9000 psi		
18 Kip ESAL (10^6)	HMAC Thick. (Inch)	Fill Thick. (Inch)	18 Kip ESAL (10^6)	HMAC Thick. (Inch)	Fill Thick. (Inch)	18 Kip ESAL (10^6)	HMAC Thick. (Inch)	Fill Thick. (Inch)
0-4	5	0	0-6	5	0	0-8	5	0
4-8	6	0	6-12	6	0	8-15	6	0
8-16	7	0	12-20	7	0	15-30	7	0
16-30	8	0	20-40	8	0	30-50	8	0
30-50	9	0	40-65	9	0	50-90	9	0
50-85	10	0	65-115	10	0	90-150	10	0
85-160	10	6	115-215	10	6	150-280	10	6
160-290	10	12	215-395	10	12	280-500	10	12
290-500	10	18	395-500	10	18	-----	-----	-----

Notes:

1. 500 million ESAL is practical limit of traffic volume.
2. Regional Soils Engineer should be contacted to determine proper value of Mr.

Table 5-2 shows the design input and predicted roughness for the existing NYSDOT flexible pavement design alternatives resulting from mechanistic analysis. The table shows that the predicted roughness will exceed the terminal roughness of 170.00 inch per mile for 10 inch HMAC pavements above 85 million axle loads during the 50 year analysis period. Therefore, for the more heavily loaded pavements, the present NYSDOT catalog design table does not provide an adequate cross-section to support the number of load applications to terminal serviceability. Mechanistic analysis also has proven the expected trend that increasing the HMAC thickness, given the same axle loading, will increase the predicted roughness for flexible pavements in the wet-freeze climate zone. Finally, it is noted that although the NYSDOT [33] design table considers two primary independent variables in flexible pavement design , axle loading and soil resilient modulus, the predictive equation for roughness does not consider soil strength as an independent variable.

Table 5-2 : Flexible Pavement : Roughness Prediction.

HMA Layer Thick. (inch)	Base Layer Thick. (inch)	Input					Output			
		Asphalt Visc. (Poise)	HMAC Voids (%Vol)	Days > 90 Deg. (day)	Freeze Index (d-days)	Traffic Volume KESAL	B	C	Change IRI (in/mi)	Final IRI (in/mi)
5	14	1600	4.0	9	925	4000	0.25	0.79	48.82	74.82
6	14	1600	4.0	9	925	8000	0.25	0.81	61.48	87.48
7	14	1600	4.0	9	925	16000	0.25	0.83	76.74	102.74
8	14	1600	4.0	9	925	30000	0.25	0.85	93.64	119.64
9	14	1600	4.0	9	925	50000	0.25	0.87	110.40	136.40
10	14	1600	4.0	9	925	85000	0.25	0.88	130.30	156.30
10	19	1600	4.0	9	925	160000	0.25	0.87	149.81	175.81
10	24	1600	4.0	9	925	290000	0.25	0.87	170.61	196.61
10	29	1600	4.0	9	925	500000	0.25	0.86	191.89	217.89

Notes:

1. Base layer thickness includes permeable AC base, subbase course, and select fill (Adjusted by layer coefficients).
2. Initial roughness (IRI) = 26.00 inch/mile.
3. Terminal roughness (IRI) = 170.00 inch/mile.

5.3 Flexible Pavement Distress Equation Calibration - Rutting.

The predictive equation for flexible pavement rutting takes the following form:

$$RD = N^{0.183}\,10^{C}$$

$$C = 0.0289 - 0.189 \log(AC_{void}) - 0.181 \log(AC_{thick}) - 0.592 \log(AGG) + 0.0000180\, AC_{visc} - 0.0436 \log(B_{thick}) + 0.0000323\,(PRE * FI)$$

Where :		
	RD	Predicted Rut Depth (inch).
	AC_{void}	Voids in HMAC Layer (% Volume).
	AC_{thick}	HMAC Layer Thickness (inch).
	AGG	HMAC Aggregate passing Number 4 Sieve (% Weight).
	AC_{visc}	Asphalt Viscosity (Poise).
	B_{thick}	Base Layer Thickness (inch).
	PRE	Annual Precipitation (inch).
	FI	Freeze Index (degree-days).

The NYSDOT Pavement Condition Guide [28] defines wheelpath rutting as longitudinal surface depressions in the wheelpath due to insufficient pavement thickness, unstable base, insufficient compaction, and pavement wear due to traffic abrasion. Rutting has the following levels of severity:

Low Severity - Less than 0.38 inch.

Medium Severity - 0.38 inch through 0.75 inch.

High Severity - Greater than 0.75 inch.

Low severity rutting may be effectively repaired by shimming in the wheel ruts [30]. Medium to high severity rutting is corrected by milling the entire pavement surface and overlaying with a single course overlay [30]. If high severity, frequent rutting is most likely a sign of subgrade failure and usually warrants pavement reconstruction.

Table 5-3 displays the design variable input and predicted rutting for the existing NYSDOT flexible pavement design alternatives based upon mechanistic design analysis. As per the table, low severity rutting is expected for design alternatives 1 to 3, and medium severity rutting is for design alternatives 4 to 9, during the analysis life of the flexible pavement. Mechanistic analysis has also been used to verify the trend that increasing the HMAC thickness, given a fixed axle loading, will slightly decrease the rutting distress. As seen in the table, the present NYSDOT design does not increase the pavement thickness to limit rutting in proportion to the axle loading. Heavy duty asphalt, rut avoidance asphalts, and Superpave asphalt mixes will lessen the affects of rutting by adjusting aggregate size to improve mix stiffness.

Table 5-3 : Flexible Pavement : Rutting Distress.

HMA Layer Thick. (Inch)	Base Layer Thick. (Inch)	Input						Output		
		Asphalt Visc. (Poise)	HMAC Voids (% Vol)	Aggreg. Pass #4 (% Wt.)	Annual Precip. (Inch)	Freeze Index (d-day)	Traffic Vol. KESAL	B	C	Rut Depth (Inch)
5	14	1600	4.0	65.0	38	925	4000	0.183	-1.19	0.29
6	14	1600	4.0	65.0	38	925	8000	0.183	-1.21	0.32
7	14	1600	4.0	65.0	38	925	16000	0.183	-1.22	0.36
8	14	1600	4.0	65.0	38	925	30000	0.183	-1.23	0.39
9	14	1600	4.0	65.0	38	925	50000	0.183	-1.24	0.42
10	14	1600	4.0	65.0	38	925	85000	0.183	-1.25	0.45
10	19	1600	4.0	65.0	38	925	160000	0.183	-1.25	0.50
10	24	1600	4.0	65.0	38	925	290000	0.183	-1.26	0.55
10	29	1600	4.0	65.0	38	925	500000	0.183	-1.26	0.61

Notes:

1. Base layer thickness includes permeable AC base, subbase, and select fill layer (adjusted by layer coefficients).
2. Low severity rutting - less than 0.38 inches. [28]
3. Medium severity rutting - 0.38 to 0.75 inches. [28]
4. High severity rutting - more than 0.75 inches. [28]

5.4 Flexible Pavement Distress Equation Calibration - Thermal Cracking.

The predictive equation for thermal cracking takes the following form:

$$CS = N^{B}\, 10^{C}$$

$$B = -0.106 - 0.0074\, AC_{thick} - 0.0504\, DGT$$

$$C = -0.0201 - 0.0131\, AGG + 1.84\, PRE - 0.0159\, (AC_{thick} * \log(PRE)) + 0.0024\, (AC_{thick} * DGT) + 0.00408\, (SUB * \log(PRE))$$

Where:		
	CS	Predicted Crack Spacing (feet).
	Ac_{thick}	HMAC Layer Thickness (inch).
	DGT	Annual Days Greater Than 90 Degrees (days).
	AGG	Aggregate Passing Number 4 Sieve (% Weight).
	PRE	Annual Precipitation (inch).
	SUB	Subbase Passing Number 200 Sieve (% Weight).

The NYSDOT Pavement Condition Guide [28] defines full width transverse cracking as fractures or separations of the pavement surface due to shrinkage, frost action, or base settlement. There are three levels of thermal crack severity:

* Low Severity Cracking - A single crack.

* Medium Severity Cracking - Multiple Cracks that have been raveling.

* High Severity Cracking - Multiple Cracks that have formed potholes.

Low and medium severity cracking is treated with bituminous crack filler as part of preventative maintenance. High severity cracking is treated by asphalt pothole patching. A flexible pavement which exhibits frequent, high severity cracks indicates pavement failure and should be reconstructed. The above referenced equation only predicts low to medium severity thermal cracking.

Table 5-4 : Flexible Pavement : Transverse Crack Spacing Distress.

HMA Layer Thick. (Inch)	Base Layer Thick. (Inch)	Input					Output		
		Subbase > #200 (% Wt.)	Aggreg. Pass #4 (% Wt.)	Annual Precip. (Inch)	Days > 90 deg. (Days)	Pave. Age (years)	B	C	Crack Spacing (feet)
5	14	10	65	38	9	50	-0.616	2.05	10.10
6	14	10	65	38	9	50	-0.620	2.05	9.91
7	14	10	65	38	9	50	-0.625	2.05	9.73
8	14	10	65	38	9	50	-0.630	2.05	9.55
9	14	10	65	38	9	50	-0.635	2.05	9.38
10	14	10	65	38	9	50	-0.639	2.05	9.21
10	19	10	65	38	9	50	-0.639	2.03	8.84
10	24	10	65	38	9	50	-0.639	2.02	8.49
10	29	10	65	38	9	50	-0.639	2.00	8.15

Notes:

1. Base thickness includes permeable AC base, subbase, and select fill thickness (adjusted by layer coefficient).
2. Includes low, medium, and high severity cracks.

Table 5-4 shows the input variables and predicted thermal cracking for the existing NYSDOT flexible pavement design alternatives based upon mechanistic analysis. The table indicates that crack spacing would be frequent by the time the flexible pavement reaches its 50 year design life. Performance grade asphalt mixes, used with Superpave technologies, adjust the liquid asphalt content in the overall mix in order to minimize thermal cracking.

5.5 Recommended Improvements to the Existing NYSDOT Flexible Design Equations.

Mechanistic analysis was utilized to recommend improvements to the present flexible pavement design tables [34] utilized by NYSDOT. Based on sensitivity analysis, the following general trends are observed:

1. The predictive equations for roughness, rutting, and thermal cracking are sensitive to changes in HMAC thickness, but not very sensitive to changes in base thickness.
2. Increasing the HMAC layer thickness will increase the predicted roughness.
3. Increasing the HMAC layer thickness will slightly decrease the quantity of predicted rutting.
4. Increasing the HMAC layer thickness will slightly increase the quantity of predicted thermal cracking.

Based on mechanistic analysis performed in this dissertation, the following design changes are recommended to improve flexible pavement performance.

1. Decrease the percentage of aggregate passing the number 4 sieve (0.25 inch) from 65 percent to 40 percent. A greater percent of larger aggregate in the asphalt mix will increase the stability and stiffness. This improvement will vastly decrease thermal cracking and while having negligible adverse effects on roughness and rutting.
2. Adjust the viscosity of the asphalt cement based on the regional climate. A decrease from 1600 poise to 1200 poise is made in this dissertation. The result will be improved performance of the mix causing a decrease in both roughness and rutting. It should be noted that NYSDOT [24] already has guidelines in place which specify different performance grades for asphalt cement based on climate to be utilized with Superpave mixes.
3. Decrease the percent of air voids in the mix from 4 to 6 percent to 4 percent by volume. The result will be a denser HMAC layer which will reduce pavement roughness while having an inconsequential negative effect on rutting. It should be noted that NYSDOT [24] already has specifications in place for heavy duty and Superpave asphalt mixes which allow contractors a plant production bonus based on the air void content by volume of the asphalt concrete mix. As well, NYSDOT [24] has specifications in place for heavy duty and Superpave mixes which allow contractors a density quality adjustment based on the field measured density of the asphalt concrete as determined by non-destructive testing. Both adjustments bonuses are paid upon verification that proper paving techniques have been used and that distresses due to improper paving techniques such as bleeding and raveling are not present.

5.6 Life Cycle Maintenance Requirements.

Figures E-1, E-2, and E-3 of Appendix E plot the predicted propagation of pavement roughness, rutting, and thermal cracking, respectively, for the improved flexible pavement design alternatives during their 50 year analysis period. Figure E-1 shows that, for flexible pavement, roughness increasing rapidly at first then leveling to a steady state increasing rate. Figure E-2 shows that a similar relationship exists between rut depth and pavement age. Figure E-3 displays that there is similar, but inverted, relationship between the number of thermal cracks and pavement age. The curve is inverted because crack spacing, rather than number of cracks, is modeled. An unexpected trend of the prediction equations, observed for the flexible pavement design alternatives, is that roughness and distress propagation increases as the HMAC layer thickness is increased. It is expected that as the strength of the pavement structure is increased (by increasing the HMAC layer thickness), that the pavement deterioration will be decreased. However, it is noted that this trend only occurs in the wet-freeze climate region.

The predictive equations may also be utilized to forecast the life cycle maintenance requirements of a flexible pavement structure. As per the present NYSDOT manual [34], it is expected that periodic preventative pavement maintenance will be required throughout the 50 year analysis period, however, no specific maintenance treatment is mandated. Based on the roughness and distresses calculated using the predictive equations, it is possible to determine the combination of periodic corrective treatments that are needed. In this dissertation, preventative maintenance consists of treatments which correct minor defects and may slow down the rate of deterioration for up to 8 years. Corrective maintenance is correcting distresses and upgrading the pavement surface including improving strength, friction, ride quality and appearance for 8 years or until more extensive treatments are needed.

The maintenance treatments in this dissertation represent the theoretical, scheduled maintenance needs in response to the distresses predicted by mechanistic analysis. The individual strategies are implemented at fixed intervals, at which time the predicted distresses will be corrected. The following treatments will be employed as part of the overall flexible pavement maintenance strategy.

1. Crack Filling. Using improved asphalt cements and placement equipment, crack filling has an expected service life of 5 years [38]. This treatment is scheduled maintenance to be implemented at 5 year intervals throughout the pavement analysis period to remedy thermal cracking.

2. *Patching and Shimming.* Milling, patching, and shimming is used to correct low severity rutting, medium severity rutting, and high severity thermal cracking. This flexible pavement repair has an expected service life of 10 years and will be implemented at 10 year intervals as a responsive maintenance dictated by predicted pavement condition.

3. *Single Course Overlay.* Milling the pavement surface and paving a single course overlay is required to repair high severity rutting. The required thickness and predicted service life of 1.5, 2.0, and 2.5 inch thick HMAC overlays is calculated in Appendix J. A 1.5 inch HMAC Overlay is adequate to achieve a 10 year service life for flexible pavements where the original HMAC layer thickness ranges from 5 to 10 inches. A 2.0 inch HMAC Overlay is required to achieve a 10 year service life for flexible pavements with original HMAC layer thickness of 10 inches with composite base thicknesses of 19 and 24 inches. Finally, a 2.5 inch HMAC Overlay is required

Table 5-5: Flexible Pavement: Predicted Maintenance Schedule.

Year	Case 1 5" AC	Case 2 6" AC	Case 3 7" AC	Case 4 8" AC	Case 5 9" AC	Case 6 10"AC	Case 7 10"AC	Case 8 10"AC	Case 9 10"AC
0	I	I	I	I	I	I	I	I	I
5	C	C	C	C	C	C	C	C	C
10	C,S	C,S	C,S	C,S	C,S	C,S	C,S	C,S	C,S
15	C	C	C	C	C	C	C	C	C
20	C,S	C,S	C,S	C,S	C,S	C,S	C,S	C,S	2.5"
25	C	C	C	C	C	C	C	C	C
30	C,S	C,S	C,S	C,S	C,S	C,S	C,S	2.0"	2.5"
35	C	C	C	C	C	C	C	C	C
40	C,S	C,S	C,S	C,S	C,S	C,S	C,S	2.0"	2.5"
45	C	C	C	C	C	C	C	C	C
50	E	E	E	E	E	E	E	E	E

Notes:

1. I = Initial Construction.
2. C = Crack Filling.
3. S = Shimming.
4. 2" = 2 Inch HMAC Overlay preceded by crack filling and shimming.
5. 2.5" = 2.5 Inch HMAC Overlay preceded by crack filling and shimming.
6. E = End of pavement structure's service life.
7. See tables F-1 through F-9 for estimated quantities.

to attain a 10 year service life for flexible pavements with HMAC thickness of 10 inches and composite base thickness of 29 inches.

Tables F-1 through F-9 of Appendix F show the maintenance strategies required for each of the proposed flexible pavement design alternatives in the NYSDOT design alternatives. The predicted maintenance strategies are summarized in Table 5-5. The combination of maintenance treatments are scheduled in response to the predicted distress propagation at specific intervals during the pavement analysis period. The analysis shows the following:

1. Crack filling is scheduled maintenance to be implemented at 5 year intervals.
2. Patching and shimming is required at 10 year intervals in order to meet the pavement maintenance specifications shown in the NYSDOT rehabilitation manual [29].
3. Overlaying, in addition to shimming, is required for design alternatives 8 and 9, the most heavily loaded flexible pavements. For alternative 8, the 10 inch HMAC pavement with 24 inch composite base, a 2 inch, single course HMAC Overlay will be required in years 30 and 40 of the design period. For alternative 9, the 10 inch HMAC pavement with 29 inch composite base, a 2.5 inch, single course HMAC Overlay will be placed in years 20, 30 , and 40 of the analysis period.

It is to be noted that the life-cycle maintenance predictions in Appendix F for flexible pavements and Appendix H for rigid pavements are differential, not cumulative. As per the NYSDOT Pavement Rehabilitation Manual [29], and as stated in subsections 5.6 and 7.6 of this dissertation, the expected service life of each maintenance treatment is known. The scheduled maintenance periods were chosen so as not to exceed the expected service life of the specific treatment to be implemented. At this time, mechanistic relationships have not yet been developed to model the performance of various maintenance treatments. However, when such predictive equations are made available, they will further enhance the mechanistic design procedure proposed in this thesis.

5.7 The Need For Future Research.

As maintained in Chapter 4 of this dissertation, two important predictive models which are missing for the effective analysis of flexible pavement are fatigue (alligator) cracking and skid resistance. Initial studies indicate that alligator cracks begin to form in the flexible pavement structure after 20 years of traffic loading. A predictive model for this distress is very important because high severity alligator cracking indicates failure of the lower pavement layers and overall structure. Preliminary skid resistance studies show that polishing of the asphalt pavement surface varies with traffic loading, aggregate gradation, and material type. A predictive model for skid resistance may further alter the asphalt mix design and pavement treatment strategy to be implemented during the flexible structure's analysis period. In conclusion, additional SHRP studies are expected to develop the mechanistic equations which model the performance of maintenance treatments during their expected service life.

CHAPTER 6 - RIGID PAVEMENT MECHANISTIC DESIGN EQUATIONS.

6.1 SHRP-LTPP Rigid Pavement Studies.

Full depth rigid pavement studies were conducted by SHRP [45] during the General Pavement Studies (GPS) 3, 4, and 5. In total, 282 pavement test sections were constructed throughout the United States and Canada. Test strips for concrete pavements are divided as follows:

* GPS 3 - 126 sections of Jointed Plain Concrete Pavement (JPCP).
* GPS 4 - 71 sections of Jointed Reinforced Concrete Pavement (JRCP).
* GPS 5 - 85 sections of Continuously Reinforced Concrete Pavement (CRCP).

Data collected from the test sections includes pavement roughness and primary distresses including joint faulting, spalling, and fatigue (transverse) cracking.

Unlike flexible pavements, which are divided into four distinct environmental regions, SHRP [45] classifies rigid pavements by pavement type. Four types of concrete pavement are considered; JPCP (doweled), JPCP (non-doweled), JRCP (doweled), and CRCP. The following predictive equations have been developed by SHRP:

<u>Rigid Pavement Roughness</u>

* JPCP (doweled)
* JPCP (non-doweled)
* JRCP (doweled)
* CRCP

<u>Rigid Pavement Joint Faulting</u>

* JPCP (doweled)
* JPCP (non-doweled)
* JRCP (doweled)

<u>Rigid Pavement Spalling</u>

* JPCP (both types)
* JRCP (doweled)

<u>Rigid Pavement Fatigue Cracking</u>

* JPCP (both types)
* JRCP (doweled).

6.2 Rigid Pavement Roughness Predictive Equations.

The predictive equations for rigid pavement roughness are listed below. Rigid pavement roughness has been observed to increase linearly with increases in traffic loading. An important observation is that doweled JPCP, JRCP, and CRCP is not sensitive to changes in axle loading, only the age of pavement since construction. Therefore, in the inference space of the model, age represents a combination of axle loading and environmental factors.

Jointed Plain Concrete Pavement (JPCP) with Doweled Joints.

$$IRI = 105.9 + (AGE/K_{static}) + (2.17*JT_{spacing}) - (7.13 * THICK) + (13.50*EDGE)$$

Where:

IRI	International Roughness Index (inches/mile)
AGE	Pavement age since construction (years)
THICK	Concrete Slab Thickness (inches)
K_{static}	Mean Static Modulus of Subgrade Reaction (pci/inch)
JT_{space}	Mean Transverse Joint Spacing (feet)
EDGE	1 if Tied Concrete Shoulder, 0 if other

Jointed Plain Concrete Pavement (JPCP) with Non-Doweled Joints.

$$IRI = 38.85 + (12.9*CESAL) + (0.222*FT) + (1.50*PRECIP) - (10.97*BASE) - (13.7*SUB)$$

Where:

IRI	International Roughness Index (inches/mile)
CESAL	Cumulative 18 kip ESAL (million ESAL)
FT	Mean Annual Air Freeze-Thaw Cycles (Number)
PRECIP	Mean Annual Precipitation (inches)
BASE	1 if treated AC or PCC, 0 if untreated.
SUB	1 if course grained (AASHTO), 0 if fine grained (AASHTO)

Jointed Reinforced Concrete Pavement (JRCP) with Doweled Joints.

$$IRI = 141.4 + (0.8488*AGE) + (0.3469*PRECIP) + (1388*[1/K_{static}]) + (21.24*THICK) + (15.09*EDGE)$$

Where:

IRI	International Roughness Index (inches/mile)
AGE	Pavement age since construction (years)
THICK	Concrete Slab Thickness (inches)
K_{static}	Mean Static Modulus of Subgrade Reaction (pci/inch)
PRECIP	Mean Annual Precipitation (inches)
EDGE	1 if Tied Concrete Shoulder, 0 if other

Continuously Reinforced Concrete Pavement

$$IRI = 262.0 + (1.47*CESAL) - (2.94*THICK) - (232.3*P_{STEEL}) - (29.79*WIDE) - (16.82*SUB)$$

Where:

IRI	International Roughness Index (inches/mile)
CESAL	Cumulative 18 kip ESAL (millions ESAL)
THICK	Concrete Slab Thickness (inches)
P_{STEEL}	Percentage of Steel (Longitudinal Reinforcement)
WIDE	1 if widened lane, 0 if normal width lane.
SUB	1 if course grained (AASHTO), 0 if fine grained (AASHTO)

Statistical Analysis - Rigid Pavement Roughness.

Table 6-1 shows the correlation coefficient for each of the predictive equations developed for the roughness mechanism for various pavement types. The correlation coefficient, computed by SHRP [45], indicates how well the predictive equation statistically fits the observed data. Quantitatively, a correlation coefficient greater than 0.85 indicates a good statistical fit [8][16], while a value less than 0.70 indicates a poor fit. However, applicability of the predictive equation to any given case study is a qualitative judgement based upon the availability and relative sensitivity of the required data. The JRCP equation has an R value of 0.88, indicating a good statistical fit of the observed data. The JPCP and CRCP equations have R values ranging from 0.74 to 0.80, a marginal statistical fit of observed data, indicating that there is room to improve the reliability of the predictive equation. For the case study in New York, where doweled, plain concrete pavements are used, the most sensitive variables are joint spacing, slab thickness, edge support, age, and modulus of subgrade reaction. Since all these variables are known, the roughness predictive equations are assumed to be adequate for use in this dissertation.

Table 6-1 : Regression Data For Rigid Pavement Equations, Roughness.

Pavement Type	n	R^2	r	Statistical Fit	NYSDOT Adequacy
JPCP Doweled Joints.	21	0.548	0.740	"Marginal"	Adequate
JPCP Non-Doweled Joints.	28	0.644	0.802	"Marginal"	---
JRCP Doweled Joints.	32	0.782	0.884	"Good"	---
CRCP	42	0.546	0.739	"Marginal"	---

Notes:
1. "Marginal" means there is sufficient room for improvement. [8].
2. Source : Adapted from SHRP [45].

Sensitivity Analysis - Rigid Pavement Roughness.

The sensitivity analysis for the proposed rigid pavement roughness equations is shown in Figure B-1 of Appendix B. The plots of sensitivity analysis reveal that the different type of rigid pavement are affected by input variables in different ways. For example:

* Doweled JPCP is most sensitive to changes in joint spacing.

* Non-doweled JPCP is most sensitive to changes in traffic loading.

* JRCP is most sensitive to changes in pavement slab thickness.

* CRCP is most sensitive to changes in the percent of steel reinforcement.

With regards to rigid pavement design, an increase in slab thickness will lead to:

* A decrease in roughness for Doweled JPCP slabs.

* No change in roughness for Non-Doweled JPCP slabs.

* A slight increase in roughness for JRCP slabs. This increase is due to the fact that longer PCC slabs are usually utilized when pavement thickness is increased. These longer slabs are subject to thermal curling and joint failure over time, all of which will increase roughness.

* A slight decrease in roughness for CRCP structures.

6.3 Rigid Pavement Distress Predictive Equations - Joint Faulting.

Joint faulting is the differential vertical displacement of abutting concrete slabs at the transverse joint creating a step deformation on the pavement structure. Joint faulting is expressed in units of inches and is generally measured one foot from the edge of the pavement lane. The predictive equations for joint faulting are listed below. The general trend for joint faulting is to increase rapidly then to level off in the future.

Jointed Plain Concrete Pavement (JPCP) & Jointed Reinforced Concrete Pavement (JRCP) with Doweled Joints.

$$\mathrm{FAULT} = \mathrm{CESAL}^{0.25} * [0.0238 + (0.0006*\{\mathrm{JT}_{\mathrm{SPACE}}/10\}^2) + (0.0037 * \{100/\mathrm{K}_{\mathrm{STATIC}}\}^2) + (0.0039 * \{\mathrm{AGE}/10\}^2) - (0.0037*\mathrm{EDGE}) - (0.0218 * \mathrm{DOW}_{\mathrm{DIA}})]$$

Where:

FAULT	Mean Transverse Joint Faulting (inches).
CESAL	Cumulative 18 kip ESAL (million ESAL).
$\mathrm{JT}_{\mathrm{SPACE}}$	Mean Transverse Joint Spacing (feet).
$\mathrm{K}_{\mathrm{STATIC}}$	Mean Static Modulus of Subgrade Reaction (psi/inches).
AGE	Age since pavement construction (years).
EDGE	1 if tied concrete, 0 if other.
$\mathrm{DOW}_{\mathrm{DIA}}$	Diameter of Transverse Dowels (inches)

Jointed Plain Concrete Pavement (JPCP) with Non-Doweled Joints.

$$\mathrm{FAULT} = \mathrm{CESAL}^{0.25} * [-0.0757 + (0.0251*\{\mathrm{AGE}\}^{0.5}) + (0.0013*\{\mathrm{PRECIP}/10\}^2) + (0.0012*\{\mathrm{FI}*\mathrm{PRECIP}/100\}) - (0.0378 * \mathrm{DRAIN})]$$

Where:

FAULT	Mean Transverse Joint Faulting (inches).
CESAL	Cumulative 18 kip ESAL (million ESAL).
AGE	Age since pavement construction (years).

PRECIP	Mean Annual Precipitation (inches).
FI	Mean Freezing Index (Degree-days).
DRAIN	1 if longitudinal edge drain exists, 0 if not.

Statistical Analysis - Rigid Pavement Joint Faulting.

Table 6-2 shows the correlation coefficients for the predictive equations for joint faulting in rigid pavements for doweled and non-doweled slabs. The R value for both models is roughly 0.74, indicating a marginal fit to the observed data, and that there is room for improvement in the reliability of the equations.

Table 6-2 : Regression Data For Rigid Pavement Equations, Joint Faulting.

Pavement Type	n	R^2	r	Statistical Fit	NYSDOT Adequacy
JPCP Non-Doweled Joints.	25	0.550	0.742	"Marginal"	---
JPCP / JRCP Doweled Joints	59	0.534	0.731	"Marginal"	Adequate

Source: Adapted from SHRP [45].

Sensitivity Analysis - Rigid Pavement Joint Faulting.

The sensitivity analysis for joint faulting equations for rigid pavements is illustrated in Figure B-2 of Appendix B. Joint faulting is most sensitive to changes in traffic loading for both the doweled and non-doweled prediction equations. Both models are also sensitive to the age variable which represents cycles of climatic change including thermal curling, joint opening and closing, and freeze-thaw cycles.

The non-doweled joint faulting model is subject to failure due to pumping, therefore, independent variables such as precipitation, freeze index, and drainage play an important role in the predictive equation. For the doweled model, joint failure is due to bearing stresses in the pavement dowels and adjoining pavement, therefore, independent variables such as subbase stiffness, dowel diameter, and joint spacing are integral in the predictive equation. Neither model is sensitive to the thickness of the concrete pavement slab.

6.4 Rigid Pavement Distress Predictive Equations - Spalling.

Transverse joint spalling is defined as pieces of concrete joint edge which have cracked and broken away from the slab due to stresses caused by internal corrosion or external infiltration of incompressible materials. Joint spalling is measured as percent of spalled length along the linear dimension of the transverse joint. The predictive equations for joint spalling are listed below. In general, spalling increases slowly at first, then increases more rapidly after several years.

Jointed Plain Concrete Pavement (JPCP).

$$SPALL = 9.79 + 10.01 * [-1.227 + (0.0022 * \{0.985*AGE + 0.171\ FT\})]$$

Where :

SPALL	Percentage of Joint Spalling (%).
AGE	Age since pavement construction (years).
FT	Mean Annual Air Freeze-Thaw Cycles (Number).

Jointed Reinforced Concrete Pavement (JRCP).

$$SPALL = -79.01 + (0.603 * AGE^{1.5}) + (0.129 * T_{RANGE}{}^{1.5})$$

Where:

SPALL	Percentage of Joint Spalling (%).
AGE	Age since Pavement Construction (years).
T_{RANGE}	Mean Monthly Temperature Range (Number)

(Mean Daily Maximum - Mean Daily Minimum averaged for each month).

Statistical Analysis - Rigid Pavement Spalling.

Table 6-3 shows the correlation coefficients for the predictive equations generated for joint spalling for both JPCP and JRCP pavements. The R value is 0.58 for JPCP indicating a poor statistical fit of the existing data. The r value for JRCP is 0.80, a marginal statistical fit of the observed data. In general, there is considerable room for improvement of the predictive equations for spalling.

Table 6-3 : Regression Data for Rigid Pavement Equations, Spalling.

Pavement Type	n	R^2	r	Statistical Fit	NYSDOT Adequacy
JCPC (All types)	56	0.335	0.579	"Poor"	Adequate
JRCP (All types)	25	0.644	0.802	"Marginal"	---

Notes:

1. "Marginal" means there is sufficient room for improvement.
2. Source: Adapted from SHRP [45].

Sensitivity Analysis - Rigid Pavement Spalling.

The sensitivity analysis for rigid pavement joint spalling is illustrated in Figure B-3 of Appendix B. There are only two independent variables which affect the joint spalling; pavement age and climate changes. Pavement age represents the effects of thermal curling and joint opening and closing in relation to potential spalling mechanisms. Climate changes include annual freeze-thaw cycles for JPCP and average temperature range for JRCP. Spalling is not sensitive to pavement slab thickness.

One variable which is not considered in the predictive equations, yet is known to contribute to joint spalling, is the impact of pavement maintenance. Joint expansion and contraction due to seasonal climate change causes the joint sealant to fail. A joint which is not well maintained will fill up with incompressible materials, causing additional stresses and failures of the concrete adjacent to the joint. This problem will not affect well maintained pavements as much as poorly maintained ones.

6.5 Rigid Pavement Distress Predictive Equations - Transverse Cracking.

Transverse cracking, also known as fatigue cracking, are cracks in the pavement slab which occur later in pavement life due to the action of traffic loading and environmental fluctuation. Fatigue cracking is measured as the number of cracks per mile of pavement. The predictive equations developed for fatigue (transverse) cracking are listed below. Fatigue cracking in rigid pavements is normally modeled on an "S" curve, cracking increases slowly at first, then rapidly increases to a critical value, then levels off.

Jointed Plain Concrete Pavement (JPCP).

$$P_{CRACK} = 1 / [0.01 + 10 * 100^{-\log(n/N)}]$$

Where:

P_{CRACK}	Percentage of Cracked Slabs (%)
N	Mean Number of Allowable Edge Stress Loads.
n	Expected number of applied edge stresses based on traffic and thermal curling.

Jointed Reinforced Concrete Pavement (JRCP).

$$P_{CRACK} = -72.59 + (1.907*CESAL) + 0.182(1/P_{STEEL}^2) + 2474(1/K_{STATIC}) + (0.697*PRECIP)$$

Where:

P_{CRACK}	Number of Transverse Cracks (high to medium severity) per mile.

CESAL	Cumulative 18 kip ESAL (million ESAL).
P_{STEEL}	Percentage of Steel (Longitudinal Reinforcement).
K_{STATIC}	Mean Modulus of Subgrade Reaction (psi/inch)
PRECIP	Mean Annual Precipitation (inches).

Statistical Analysis - Rigid Pavement Fatigue Cracking.

Table 6-4 shows the correlation coefficients developed for the relationships between JPCP and JRCP and fatigue cracking. The R values for JPCP and JRCP indicate a poor fit to observed data and that more comprehensive fatigue damage analysis needs to be developed and applied. It has been noted that very few test sections presently exhibit fatigue cracking at any severity.

Table 6-4 : Regression Data For Rigid Pavement Equations, Thermal Cracking.

Pavement Type	n	R^2	r	Statistical Fit	NYSDOT Adequacy
JPCP (All types)	N/A	N/A	N/A	"Poor"	Not Adequate
JRCP (All types)	27	0.480	0.693	"Poor"	---

Notes:
1. The model developed for JPCP is not reliable, further study is needed.
2. Source: Adapted from SHRP [45].

Sensitivity Analysis - Rigid Pavement Fatigue Cracking.

As per the design equation for jointed, plain concrete pavement, the two independent variables are mean number of allowable edge stress loads and expected number of applied edge stress loads based upon traffic and thermal curling. Since this data is not collected in New York, even if the predictive equation had been a statistically good fit, the equation would not be adequate for use in the New York case study.

6.6 General Results and Observations.

As shown in Chapter 7, preliminary results of mechanistic analysis reveal that the finite element methods used by the present AASHTO [2] design procedure for rigid pavements provides an adequate, but generally conservative, design. As with the 1986 and 1993 updates of the design formulas to include additional independent variables such as drainage factors, load transfer coefficients, and concrete strength parameters, it is expected that the rigid design procedure may be further improved by incorporating environmental factors such as freeze-thaw cycles, annual precipitations, and number of days below freezing into the existing design methodology. As proven through sensitivity analysis in Appendix B, climatic factors have a statistically significant affect upon rigid pavement performance.

Regional models have not yet been developed for rigid pavement analysis, rather, specific predictive models have been developed for different rigid pavement types. The equations used to predict rigid pavement roughness, joint faulting, and joint spalling are marginal fits of the observed data, and improvements are expected as additional regional data is collected and calibrated. Therefore, for the purposes of this dissertation, the present predictive equations for roughness, joint faulting and joint spalling are sufficient to act as a comprehensive check of another design methodology. The equations which have been developed for rigid pavement fatigue cracking, however, are poor and can not be utilized.

6.7 Effects of High Performance Concrete Specifications.

Analogous to Superpave initiatives, many state highway agencies have been adapting high performance concrete specifications to improve the pavement performance during the analysis period. High performance concrete specifications, such as that proposed by the New York State Department of Transportation [32], utilize admixtures such as fly-ash and silica fume to improve the density of the concrete mix. The increased density, combined with concrete sealants, will decrease the infiltration of water and other substances which lead to the deterioration of the structure, especially pavement joints, in the form of spalling and joint faulting. Qualitatively, the utilization of high performance concrete will assist in decreasing the initiation and propagation of the primary rigid pavement distresses such as faulting and spalling, however, it is not anticipated to have a significant effect on pavement roughness.

6.8 The Need For Further Research.

It is anticipated that the collection of additional data will enhance the existing predictive equations developed for rigid pavement roughness, joint faulting, and joint spalling.

Skid Resistance.

SHRP [45] studies have been amassing data which may be used to predict the loss of surface friction for concrete pavements. Presently, the data collected is not adequate to determine a model for this distress which greatly effects motorist safety.

CHAPTER 7 - ADAPTING THE MECHANISTIC EQUATIONS TO IMPROVE THE EXISTING NYSDOT RIGID PAVEMENT DESIGN PROCEDURE.

7.1 Existing NYSDOT Rigid Design Tables - AASHTO Methods.

The present methodology used by the New York State Department of Transportation (NYSDOT) for the design of rigid pavements is outlined in the New York State Thickness Design Manual For New and Reconstructed Pavements [33][34] adapted in 1993 and revised in 1994. Rigid pavement design is based upon the finite element procedure described by AASHTO [2] with the design variables adjusted for conditions encountered in New York [9]. In 1993, New York modified the standard design of rigid pavement from jointed, reinforced concrete pavement structures (9 inch thick, mesh reinforced PCC slab over 10 inch sandy subbase for commercial traffic; 8 inch thick, mesh reinforced PCC slab over 10 inch sand subbase for parkways) to jointed, plain concrete pavement (unreinforced PCC slab varying in thickness from 8 to 13 inches). Standard slab length was reduced from 60 feet to 16 or 18 foot slabs, depending on the required pavement thickness. To improve pavement drainage and subbase stiffness, a 4 inch layer of permeable base is placed below the pavement slab atop a 12 inch layer of granular subbase material. Predicted axle loading is the primary independent variable used to determine

Table 7-1 : NYSDOT Rigid Pavement Design

18 Kip (80KN) ESAL (millions)	PCC Slab Thickness (inch)	Treated Base Thickness (inch)	Subbase Course Thickness (inch)	PCC Slab Length (feet)	Dowel Bar Diameter (inch)
0-35	8	4	12	16	1.25
35-65	9	4	12	16	1.25
65-125	10	4	12	16	1.25
125-220	11	4	12	18	1.38
220-380	12	4	12	18	1.50
380-500	13	4	12	18	1.63

Notes :

1. Add 1 inch to pavement thickness with applicable slab length and diameter where there is curbing.
2. Transverse dowel bar length is 18 inches spaced at 12 inches on center.
3. 500 million is the practical limit for traffic volume.
4. Effective modulus of subgrade reaction (k) is 200 pci. (Appendix B - Subgrade Improvement.)

Source: NYSDOT Pavement Design Manuals [33][34].

required pavement slab thickness. The present design table, as specified by NYSDOT [33][34], is shown in Table 7-1.

7.2 Pavement Roughness Equation Calibration.

When calibrated for use in New York, the predictive equation for rigid pavement roughness takes the following form:

$$IRI = 105.9 + 159\ (AGE/K_{ST}) + 2.17\ JS + 7.13\ TH + 13.50$$

Where:

IRI	Roughness (International Roughness Index) (inch/mile)
AGE	Pavement Age (Years)
K_{ST}	Modulus of Subgrade Reaction (pounds/cubic inch)
JS	Joint Spacing (feet)
TH	Pavement Thickness (inch)

Table 7-2 displays the input variables and predicted roughness for the existing NYSDOT rigid pavement design alternatives as computed by mechanistic analysis. The table confirms that roughness will not exceed the terminal serviceability of 170.00 inch per mile for any of the proposed alternatives during the 50 year analysis period. It is noted that while axle loading is the most sensitive variable in the AASHTO [2] design equation, the mechanistic equation does not include traffic loading as an independent variable for predicting roughness. Instead, age since initial construction is included in the mechanistic equation.

Table 7-2 : Rigid Pavement - Roughness Equation Computations.

PCC	Input			Computed
Slab Thickness (inch)	Pavement Age (years)	Subgrade Reaction (pci)	Joint Spacing (feet)	Roughness IRI (inch/mile)
8	50	200	16	136.83
9	50	200	16	129.70
10	50	200	16	122.57
11	50	200	18	119.78
12	50	200	18	112.65
13	50	200	18	105.52

Note : Terminal serviceability is IRI = 170.00 inch/mile.

7.3 Pavement Distress Equation Calibration - Joint Faulting.

When adapted for use in New York, the predictive equation for joint faulting is as follows:

$$FAULT=CESAL^{0.25}\left[0.0201+0.0006(JS/10)^2+0.0037(100/K_{ST})^2+0.0039(AGE/10)^2-0.0218\,DD\right]$$

Where :		
	FAULT	Predicted Joint Faulting (inch).
	JS	Joint Spacing (feet).
	K_{ST}	Modulus of Subgrade Reaction (pound per cubic inch).
	AGE	Pavement Age (years).
	DD	Transverse Dowel Diameter (inch).

The NYSDOT Pavement Condition Guide [28] defines transverse joint faulting to be differential vertical displacement of abutting slabs at joints creating a step deformation on the pavement surface. Faulting, measured one foot from the edge of the pavement slabs, has the following levels of severity:

Low Severity - Less than 0.38 inch.

Medium Severity - 0.38 inch through 0.75 inch.

High Severity - Greater than 0.75 inch.

Critical faulting, defined as any faulting greater than 0.19, is that which affects the measurement of pavement roughness, therefore, must be repaired promptly. Low severity faulting is addressed by milling and shimming the faulted joint [35]. Medium severity faulting is corrected by milling the entire pavement surface and placing a single course overlay [30]. High severity faulting indicates failure of the pavement joint and must be corrected by full depth pavement repairs [30]. If high severity joint faulting is observed at high frequencies, the pavement structure warrants reconstruction.

Table 7-3 utilizes mechanistic analysis to compute the forecasted joint faulting for the existing slab thickness alternatives used by NYSDOT [33][34]. The table indicates that low severity faulting is expected during the analysis period for pavements ranging in slab thickness from 8 to 11 inches. For 12 and 13 inch pavement slab thicknesses, medium severity faulting will be reached during the latter years of the 50 year analysis period. However, for all rigid pavement alternatives, corrective maintenance will be required during the analysis period as triggered by faulting exceeding the critical value of 0.19 inch.

Table 7-3: Rigid Pavement - Faulting Distress.

PCC Slab Thickness (inch)	Input					Computed Joint Faulting (inch)
	Traffic Loading (Mil. ESAL)	Pavement Age (years)	Subgrade Reaction (pci)	Joint Spacing (feet)	Dowel Diameter (inch)	
8	35	50	200	16	1.25	0.23
9	65	50	200	16	1.25	0.26
10	125	50	200	16	1.25	0.31
11	220	50	200	18	1.25	0.35
12	380	50	200	18	1.25	0.39
13	500	50	200	18	1.25	0.40

Notes:
1. Critical faulting, which effects roughness, is greater than 0.19 inches. [20].
2. Low severity faulting - less than 0.38 inches. [28]
3. Medium severity faulting - 0.38 inches to 0.75 inches. [28]
4. High severity faulting - greater than 0.75 inches. [28]

7.4 Pavement Distress Equation Calibration - Joint Spalling.

When considered for use in New York, the predictive equation for joint spalling becomes:

$$SPALL = 9.79 + 10.01\ [-1.23 + 0.022\{(0.985*AGE) + (0.171*FT)\}]$$

Where:		
	SPALL	Predicted Percent of Joints Spalled.
	AGE	Pavement Age (years).
	FT	Annual Air Freeze-Thaw Cycles (number).

The NYSDOT Pavement Condition Guide [28] classifies transverse joint spalling as sections of concrete joint edges which have cracked and broken away from the slab due to internal corrosion stresses or external infiltration stresses. There are three classifications of joint spalling severity:

Low Severity Spalling - No spall with any dimension greater than 3 inches.

Medium Severity Spalling - 2 or less spalls per joint with dimensions greater than 3 inches.

High Severity Spalling - 3 or more spalls per joint with dimensions greater than 3 inches.

Low severity joint spalling is treated with joint sealer when the joints are cleaned and sealed as part of preventative maintenance. Medium to high severity spalling is treated by removing the unsound concrete and patching the area using rapid setting concrete. If the spalls are found to be very deep, the partial depth repair is superseded by a full-depth joint repair. The above referenced equation predicts medium to high severity joint spalling.

Table 7-4 displays the predicted joint spalling for all six design alternatives considered in the existing NYSDOT rigid pavement design as determined by mechanistic analysis. Results indicate that joint spalling does not vary by pavement thickness or traffic loading, but, with pavement age and air freeze-thaw cycles. For all design alternatives, approximately 12 percent of the pavement joints are forecasted to exhibit medium to high severity faulting by the end of the 50 year analysis period. In addition, it is qualitatively known that the frequency of joint sealing treatments has an effect on joint spalling. However, the exact quantitative impact has not been modeled at the present time in the predictive equation. Additional SHRP studies are being conducted which will model the performance of various, common maintenance strategies.

Table 7-4 : Rigid Pavement - Spalling Distress.

PCC Slab Thickness (inch)	Design Input: Pavement Age (years)	Design Input: Air Freeze Thaw Cycles (#)	Computed Spalled Percentage (%)
8	50	80	11.34
9	50	80	11.34
10	50	80	11.34
11	50	80	11.34
12	50	80	11.34
13	50	80	11.34

Notes:
1. SHRP Model [45] predicts spalling of medium and high severity.
2. Low severity spalling (less than 3 inches) is treated using joint sealant.
3. Medium severity spalling - 2 or less spalls per joint with dimensions greater than 3 inches.
4. High severity spalling - 3 or more spalls per joint with dimensions greater than 3 inches.

7.5 Recommended Improvements to the Existing NYSDOT Design Equations.

Mechanistic design analysis was utilized to recommend improvements to the present pavement design tables [34] utilized by NYSDOT. Based on sensitivity analysis the following general trends are observed:

1. The predictive equation for roughness is most sensitive to changes in joint spacing, slab thickness, edge support, and pavement age.
2. The predictive equation for joint faulting is most sensitive to changes in traffic loading, joint spacing, pavement age and dowel diameter.
3. The predictive equations for joint spalling is most sensitive to changes in age and number of freeze-thaw cycles.
4. Increasing the slab thickness will decrease the predicted roughness.
5. Increasing the slab thickness has no effect on joint faulting and joint spalling.

Based on the mechanistic analysis performed in this dissertation, the following design changes are recommended to improve rigid pavement performance.

1. Increase transverse joint dowel diameter to 2 inches, the largest commercially available size, in order to reduce joint faulting.
2. Decrease transverse joint spacing to 16 feet for slab thickness of 11, 12, and 13 inches.

Increasing dowel diameter and reducing slab length will reduce thermal and curling stresses in the transverse joint. The reduction in stresses will lead to a decrease in joint faulting (from medium to low severity) for the most heavily traveled pavements. However, increasing the dowel diameter to more than 2 inches is not recommended because the reduction in concrete cover will cause higher stresses in the concrete slab, resulting in additional joint spalling. Reducing the slab length to shorter than 16 feet will result in increased maintenance costs for cleaning and sealing, offsetting the benefits incurred due to the slight improvement in roughness. The recommendations for improvements to the contemporary NYSDOT rigid pavement design procedure are summarized in Table 7-5.

Table 7-5 : Improved NYSDOT Rigid Pavement Design Table.

18 Kip (80 kN) ESAL (millions)	PCC Slab Thickness (inch)	Treated Base Thickness (inch)	Subbase Course Thickness (inch)	PCC Slab Length (feet)	Dowel Bar Diameter (inch)
0-35	8	4	12	16	2.00
35-65	9	4	12	16	2.00
65-125	10	4	12	16	2.00
125-220	11	4	12	16	2.00
220-380	12	4	12	16	2.00
380-500	13	4	12	16	2.00

7.6 Life Cycle Maintenance Requirements.

The mechanistic predictive equations are utilized to generate the expected rigid pavement conditions throughout the 50 year analysis period. Figures G-1, G-2, and G-3 of Appendix G illustrate the predicted pavement roughness, joint faulting, and joint spalling, respectively, for the improved NYSDOT rigid pavement design alternatives. Pavement roughness increases linearly with pavement age. Joint faulting initiates at year 20, then increases at an exponential rate during the remainder of the analysis period. The predicted joint faulting is reduced to low severity for all pavement thickness alternatives by using the improved NYSDOT rigid pavement design table. Joint spalling increases linearly with pavement age and is shown to be independent of slab thickness.

The predictive equations are then utilized to forecast the life cycle maintenance needs for each design alternative of the rigid pavement structure. In its design manual [34], NYSDOT acknowledges that pavement maintenance will be required to reach the 50 year analysis period, but does not specify the frequency or type maintenance required. Based on the roughness and distresses predicted by mechanistic analysis, a combination of preventative and corrective treatments can be scheduled to maintain the pavement structure throughout the analysis period. NYSDOT [29] defines preventative maintenance as treatments which correct minor defects and slow down deterioration for up to 8 years. Corrective maintenance is defined as correcting deficiencies regarding ride quality, friction, and appearance and upgrading the roadway surface for 8 years or until more extensive treatments are needed.

The following treatments will be utilized as part of the overall rigid pavement maintenance strategy. As stated in Chapter 5, the life-cycle maintenance predictions are differential, not cumulative, and are based upon the expected service life of the treatment as defined by NYSDOT [29] policy.

1. Joint and Crack Sealing. Using enhanced silicone sealants, joint sealing has an expected service life of 10 years. This treatment is scheduled maintenance to be implemented at fixed 10 year intervals to correct low severity spalling.

2. Spall Patching. Patching spalls with rapid setting concrete has an expected service life of 10 years when completed as specified in the NYSDOT Pavement Rehabilitation Manual [29]. This treatment will be used to repair medium to high severity joint spalling.

3. Grinding and Shimming. Grinding faulted joints then patching with shim asphalt has an expected service life of 5 years. This maintenance treatment will be used to repair low severity faulting at 5 year intervals as needed. Joints must be resealed after grinding.

4. Single Course Overlay. Milling the concrete slab surface and placing a single course, 2 inch thick HMAC overlay has an expected service life of 10 to 12 years, as computed in Appendix I. This treatment will be utilized to repair faulted rigid pavements which have deteriorated to medium to high severity levels. The joints in the HMAC overlay must be cleaned and filled every 5 years after placement to minimize reflective cracking damage.

Tables H-1 through H-6 of Appendix H show the proposed maintenance strategies required for each of the proposed pavement slab thickness design alternatives in the improved NYSDOT design table. Table 7-6 summarizes the predicted maintenance strategies for rigid pavement. The maintenance treatments chosen are dictated by the predicted distress propagation at specific intervals within the pavement analysis period.

1. Joint sealing and spall repair will be implemented at 10 year intervals throughout the analysis period.
2. Grinding and shimming will be implemented at 5 year intervals as triggered by predicted joint faulting exceeding 0.19 inches. For rigid pavement slab thicknesses of 8, 9 and 10 inches, faulting is limited to below the critical value of 0.19 inches throughout the 50 year cycle, thus, no grinding is required. For a rigid pavement slab thickness of 11 inches, grinding, shimming, and

resealing will be required at year 45. For rigid pavement slab thicknesses of 12 and 13 inches, grinding, shimming, and resealing will be required in years 40 and 45. No single course overlay will be required for rigid pavement structures designed using the improved NYSDOT design table.

Table 7-6: Rigid Pavement - Predicted Maintenance Schedule.

Year	Case 1 8" PCC	Case 2 9" PCC	Case 3 10" PCC	Case 4 11" PCC	Case 5 12" PCC	Case 6 13" PCC
0	I	I	I	I	I	I
10	J,S	J,S	J,S	J,S	J,S	J,S
20	J,S	J,S	J,S	J,S	J,S	J,S
30	J,S	J,S	J,S	J,S	J,S	J,S
40	J,S	J,S	J,S	J,S	J,S	J,G,S
45	---	---	---	G,R	G,R	G.R
50	E	E	E	E	E	E

Notes:
1. I = Initial Construction.
2. J = Seal Joints.
3. S = Repair Spalls.
4. G = Grinding and shimming transverse joint faults.
5. R = Resealing joints.
6. 1.5" = 1.5" HMAC Overlay preceded by repairing spalls and sealing joints.
7. 2.0" = 2.0" HMAC Overlay preceded by repairing spalls and sealing joints.
8. 2.5" = 2.5" HMAC Overlay preceded by repairing spalls and sealing joints.
9. E = End of pavement structure's service life.
10. See tables H-1 to H-6 for estimated quantities.

7.7 The Need For Future Research.

As stated in Chapter 6 of this dissertation, the development of prediction models for fatigue cracking and skid resistance will help to improve the ability of pavement engineers to better design and maintain pavements throughout their intended life cycle. Fatigue cracks begin to initiate and propagate in rigid pavements after roughly 60 percent of the design loading has occurred. A predictive model for fatigue cracking may indicate that additional crack routing and sealing is required during the analysis period. Preliminary studies exhibit that polishing of a rigid pavement surface occurs due to repeated traffic loading. A predictive model may demonstrate that pavement grooving or retexturing is required to maintain skid resistance during the pavement design life. Finally, SHRP [44] is developing mechanistic, predictive equations for determining the service life and failure modes of various corrective treatments which can be used in tandem with the present models to better understand the condition of the pavement and maintenance requirements.

CHAPTER 8 : AGENCY COST COMPUTATIONS.

8.1 Definition and Components of Agency Cost.

Agency costs are the tangible costs incurred by state highway agencies for pavement construction and maintenance. Highway agencies customarily maintain an accurate record of these costs for estimating and accounting practices at both the project and network management level. At the network level, annual pavement maintenance expenses are employed in the regional planning and budgeting process. At the project level, cost information is used in estimating project costs for pavement maintenance contracts. In this dissertation, project level cost data is utilized to estimate baseline costs for pavement designs and maintenance treatments, while network level cost statistics is used to determine regional cost factors depicting variance in statewide bidding trends.

Fixed and Variable Costs.

Pavement maintenance expenditures can be classified as either fixed or variable costs. Fixed cost is directly related to the surface area of the pavement. Examples of fixed cost include the initial construction of pavement, overlays (not including preparations), and reconstruction. Variable cost is a function of the pavement surface condition; the quantity of work to be done and the cost of the work is a function of the predicted condition of the pavement structure. Examples of variable cost repairs include crack sealing and shimming for flexible pavements and joint and crack sealing, patching, and grinding faults for rigid pavements. The total agency cost of pavement treatment is sometimes a combination both fixed and variable costs.

Line Item Budget.

State highway agencies often utilize a line item budget for pavement construction and improvement contracts. Each line item number corresponds to a particular construction operation and has its own work specifications as designated in the agency's specifications. The item specification defines the exact work description, required materials, construction details, method of measurement, and basis of payment associated with each item. Generally, the unit price bid for each item must include the cost of all requisite manpower, equipment, materials to perform the work as well as the contractor's overhead costs such as insurance, contingencies, and profit. The aggregate of all the line item costs comprises the contract cost.

Agency Overhead Costs.

In addition to the estimated total bid price, which comprises the contract cost of pavement management work, there are additional overhead costs associated with pavement management work which are incurred by the state highway agency. Typical agency expenses include preliminary and support engineering, mobilization, traffic protection, and construction inspection. NYSDOT [29] and USDOT [51] define the overhead costs as a fixed percentage of estimated contract costs as follows:

Preliminary Engineering	8%
Mobilization	4%
Maintenance and Protection of Traffic	10%
Construction Inspection	12%
Total Agency Overhead	34%

Therefore, the total agency cost of pavement construction is inflated by approximately one-third to account for predicted overhead expenditures.

8.2 Typical Agency Costs - Flexible Pavement Construction and Maintenance.

Initial costs for flexible pavement are fixed costs affiliated with the new construction or reconstruction of the pavement structure. These costs include excavation, subgrade preparation, subbase course, and asphalt paving. Table K-1 of Appendix K shows the typical line items used

Table 8-1 : Flexible Pavement - Initial Construction Costs.

Case Number	HMAC Layer Thickness (Inch)	Select Fill Thickness (Inch)	Estimated Cost per Lane-mile ($)	Estimated Cost per Square Ft. ($)	Cost per Lane-mile w/ OH ($)	Cost per Square Ft. W/ OH ($)
1	5	0	160606	2.53	215211	3.39
2	6	0	173129	2.73	231993	3.66
3	7	0	185656	2.93	248779	3.93
4	8	0	198184	3.13	265566	4.19
5	9	0	210711	3.33	282353	4.46
6	10	0	223238	3.52	299139	4.72
7	10	6	245355	3.87	328776	5.19
8	10	12	267473	4.22	358414	5.65
9	10	18	289590	4.57	388051	6.12

Source: NYSDOT [36][37]

by NYSDOT for the construction of a flexible pavement for the nine design cases proposed in the pavement design manual [34]. Table 8-1 is a summary of these typical costs given in cost per lane-mile and cost per square foot of construction. As anticipated, unit agency costs escalate as pavement thicknesses increase.

Maintenance costs for flexible pavement are variable costs associated with alternative pavement treatments required to preserve the pavement facility at the desired level. Variable costs are a function of the pavement condition, with costs multiplying as pavement condition worsens. Table L-1 of Appendix L demonstrates the standard line items used by NYSDOT to pay for the various maintenance treatment strategies. Table 8-2 shows the mechanistic cost functions developed in this dissertation to predict the costs of each flexible pavement maintenance treatment. The cost equations are linear in form and express total cost in terms of dollars per lane mile.

Table 8-2 : Flexible Pavement - Maintenance Costs

Maintenance Treatment	Variable Cost ($/Lane-mile)	Variable Cost w/ OH ($/Lane-mile)
Crack Filling	1.63 * LFC	2.18 * LFC
Patching & Shimming	13006 + (80.15*Tac)	17428 + (107.40*Tac)
1.5" HMAC Overlay	34644 + (80.15*Tac)	46423 + (107.40*Tac)
2.0" HMAC Overlay	41223 + (80.15*Tac)	55238 + (107.40*Tac)
2.5" HMAC Overlay	47837 + (80.15*Tac)	64101 + (107.40*Tac)

Notes:
1. LFC = Linear feet of thermal cracking.
2. Tac = Tons of asphalt shim course required.
Data Source : NYSDOT [36][37].

8.3 Typical Agency Costs - Rigid Pavement Construction and Maintenance.

Initial costs for rigid pavement construction are fixed costs related to the new construction or reconstruction of the pavement structure. These costs consist of excavation, subgrade preparation, subbase course, concrete paving including joints and ties, and sawing and sealing the new pavement. Table M-1 of Appendix M shows the common line items used by NYSDOT in construction contracts for the six alternative slab thicknesses proposed in the design manual [33][34]. Table 8-3 is a summary of these costs expressed in terms of cost per lane-mile and cost per square foot of new pavement. The unit cost increases as slab thickness is increased.

Table 8-3 : Rigid Pavement - Initial Construction Costs.

Case Number	PCC Slab Thickness (inch)	Transverse Joint Spacing (feet)	Estimated Cost per Lane-mile ($)	Estimated Cost per Square Ft. ($)	Cost per Lane-mile w/ OH ($)	Cost per Square Ft. w/ OH ($)
1	8	16	413726	6.53	554393	8.75
2	9	16	435652	6.88	583774	9.22
3	10	16	461448	7.28	618340	9.76
4	11	16	487243	7.69	652907	10.30
5	12	16	513039	8.10	687473	10.85
6	13	16	538835	8.50	722039	11.39

Data Source: NYSDOT [36][37].

Maintenance costs for rigid pavement are variable costs associated with the alternative treatments proposed to maintain the pavement structure throughout the design life. Variable costs rise as the pavement condition, represented as roughness and distresses, deteriorates. Table N-1 of Appendix N illustrates the typical line items used by NYSDOT to pay for contractual maintenance work which includes joint and crack sealing, spall patching, joint grinding and shimming, and single course HMAC overlay. Table 8-4 shows the mechanistic cost functions

Table 8-4: Rigid Pavement - Maintenance Costs.

Maintenance Treatment	Variable Cost ($/Lane-mile)	Variable Cost w/OH ($/Lane-Mile)
Joint & Crack Sealing	2.53 * LFS	3.39 * LFS
Spall Patching	10.43 * Asp	13.98 * Asp
Grinding & Shimming	0.64 * Agr	0.86 * Agr
2.0" HMAC Overlay	41716	55899

Notes:
1. LFS = Linear feet of joint spalling.
2. Asp = Area of spall repairs required.
3. Agr = Area of grinding required.
Data Source: NYSDOT [36][37].

developed in this dissertation to predict the costs of each rigid pavement maintenance treatment. The cost equations are linear in form and express total cost in terms of dollars per lane mile. The single course overlay for rigid pavement is a fixed cost.

8.4 Development of Regional Cost Factors.

The cost of construction, including pavement maintenance expenses, varies from location to location. During the project design stage, state highway agencies desire to have an accurate estimate of costs for each contemplated project using local data. However, many times, adequate and accurate local data is not available. To account for the disparity in data, regional cost factors are generated and used to adapt available statewide costs to a particular region. State highway agencies utilize network level data to predict regional factors.

Table 8-5: NYSDOT Regional Cost Factors.

NYSDOT Region Number	Flexible Pavement Factor	Rigid Pavement Factor
1	0.79	0.75
2	0.77	0.85
3	0.87	0.84
4	0.92	0.78
5	0.83	0.81
6	0.92	1.02
7	0.73	0.66
8	0.87	0.91
9	0.89	0.96
10	1.27	1.41
11	2.11	2.01
Statewide	1.00	1.00

Appendix O is an example of how network level pavement management data is utilized for determining regional cost factors. At the network level, NYSDOT [26] gathers annual cost data for various pavement maintenance strategies including; routine maintenance, preventative maintenance, corrective maintenance, rehabilitation, high cost rehabilitation, and reconstruction.

Table O-1 shows the regional cost factors calculated in this dissertation for flexible and rigid pavement construction and maintenance based upon network level costs in New York state. The table shows two rows of data for each maintenance treatment for flexible and rigid pavement. The top row is the weighted average cost factor for each maintenance treatment. The bottom row, entitled "percent of statewide" is the unit-less factor obtained by dividing the regional weighted average cost by the statewide average cost for each region. The final regional factor is the mean of the individual maintenance treatment factors for each region. Table 8-5 is a summary of the regional cost factors to be applied to adjust agency costs for flexible and rigid pavement construction for each of the eleven administrative regions in NYSDOT.

8.5 Need For Further Study.

State highway agencies maintain precise records of agency construction costs at both the network and project management level. Annual weighted average bid price books [36] and annual network level cost reports [26] are valuable in estimating contract costs and planning budgetary needs. However, rarely do such documents consider the fluctuation of item unit costs with estimated contract quantity. It is common economic knowledge that unit bid prices normally decrease as contract demand (quantity) increases. Economic demand functions, if established for individual items, may provide a more accurate contract cost estimate than the average weighted bid price, which is insensitive to item quantity.

CHAPTER 9 : ROAD USER COST COMPUTATIONS.

9.1 - Background Information.

For efficient pavement management the impact of design decisions on total societal costs should be considered. Total societal cost is the sum of agency cost outlays for capital construction and maintenance and user costs incurred by the motorists. User costs are directly influenced by the condition of highway pavements, consisting of vehicle operating costs and accident costs. Vehicle operating costs include fuel and lubricant consumption, vehicle maintenance, vehicle depreciation, and travel time delays incurred by the driver, passenger, and freight using the highway. Accident costs include the costs of personal injuries or fatalities, as well as property damage as related to the pavement condition.

There is evidence that user costs comprise a large portion of overall societal costs of highway operations. The Organization for Economic Cooperation and Development reports that maintenance outlays by government agencies account for only two percent of total vehicle operating costs in the United States [38]. Gichaga and Parker [11] cite studies which maintain that while more than 10 trillion dollars are spent annually on highway construction and maintenance in developing countries, the costs borne by the road users might be on the order of ten times that amount. More recently, the New Jersey Times Union [48] reported that drivers spend six times more on vehicle maintenance than New Jersey Department of Transportation spends on highway maintenance. It can be deduced that the condition of highway pavements has a direct effect on the economy of a region. Therefore, the consideration of total societal costs will give a better idea as to the utility of different pavement design strategies.

9.2 - Historical Development of Road User Costs.

World Bank Models

The pioneer organization in realizing the impact of highway investment decisions on road user costs is the World Bank. Initiated in 1969 and continuing through the present, the World Bank has conducted studies in Brazil, Kenya, India, and the Caribbean to construct mathematical relationships which can predict road construction costs, road deterioration rates, and road user costs. The resulting models are utilized in the 1985 Highway Design and Maintenance Standards Model (HDM-III) [52] which is employed by many road agencies around the world. Finally, the Highway Design and Maintenance Standards Model, Version 4, now commercially available, has further refined road user costs to include rigid pavements and cold weather applications which were not included in the HDM-III study.

The road user cost submodel, developed for the HDM-Model, is discussed in detail by Archondo-Callao and Diaz [4] and Patterson [40]. The submodel computes the average operating speed for various vehicle types based on the pavement roughness, gradient, and curvature. The submodel then computes and sums the cost components for each vehicle type as a function of operating speed; these components include fuel consumption, lubricant consumption, tire wear, crew time, passenger time, cargo holding time, labor and parts cost of maintenance, depreciation, interest, and overhead. It should be noted that since vehicle operating speed is a function of roughness, all operating costs are implicitly a function of roughness.

Saskatchewan Pavement Information System

The user cost functions proposed by the World Bank, HDM-III studies have been calibrated for use in North America. As reported by Bein [6], the Saskatchewan Pavement Management Information System (Saskatchewan PMIS) integrates agency and user cost models in order to conduct life cycle analysis in the maintenance strategy selection for provincial highways. In the Saskatchewan PMIS, vehicle operating cost components such as fuel and lubricant consumption, tire wear, vehicle maintenance and labor, user travel delay, and administrative costs were gathered and compared to roughness in terms of International Roughness Index (IRI) and riding comfort index (RCI). The results of this study yielded the following models for vehicle costs.

$$\mathrm{VOC}_x = \{\acute{\alpha}_x\, e^{(Ax + Bx*IRI)}\}/1000$$

$$\mathrm{IRI} = 1.44 + 29.8*10^{-0.2278RCI}$$

where: VOC_x : Vehicle Operating Cost for vehicle type x. (Canadien $/km)

α_x : administrative cost parameter for vehicle type x.
A_x, B_x : calibrated constants for vehicle type x.
IRI : International Roughness Index (m/km).
RCI : Saskatchewan Riding Comfort Index (Scale 1 to 10)

Table 9-1, shows the calibrated constants formulated for the Saskatchewan PMIS in terms of financial and economic cost analysis.

Table 9-1 : Calibrated Constants For Vehicle Operating Cost Equations.

Vehicle Type	Financial			Economic		
	a	A	B	a	A	B
Small Car	1.00	5.77	0.0186	1.00	5.45	0.0129
Medium Car	1.00	5.88	0.0206	1.00	5.56	0.0213
Large Car	1.00	5.99	0.0196	1.00	5.67	0.0203
Utility Vehicle	1.00	5.96	0.0216	1.00	5.62	0.0228
2 Axle Truck	1.10	6.14	0.0564	1.10	5.79	0.0604
3 Axle Truck	1.10	6.39	0.0394	1.10	6.04	0.0417
5 Axle Truck	1.10	6.35	0.0343	1.10	5.98	0.0387
7 Axle Truck	1.10	6.60	0.0421	1.10	6.24	0.0465
3 Axle Bus	1.10	7.67	0.0115	1.10	7.33	0.0118

Source : Adapted from Bein [6].

9.3 - Existing User Cost Analysis By NYSDOT.

NYSDOT presently addresses the subject of road user costs in two of its highway management models. The first model, the Highway User Cost Accounting Model, is employed by traffic engineers in the appraisal of various highway capacity projects. The second reference to road user costs is employed during network level pavement management in an annual report which rates overall condition of the pavement network in the state.

NYSDOT Highway User Cost Accounting Model

The NYSDOT Highway User Cost Accounting Model, known as HUCA, is used to estimate the impacts of highway improvements on road user costs. This model defines road user costs as vehicle operating costs, user delay costs, and reduced accident costs. The main objective of the model is to compute project benefits as the result of capacity improvements for various facilities such as freeways, arterials, two lane highways, multi-lane highways, and signalized intersections. The model also appraises the impact of capacity reductions due to lane closures, night time construction, and detour roads on road user costs. Given specific highway capacity improvement projects, their costs, projected analysis periods, and discount rates, the model estimates life cycle reductions in user cost compared to the no-build condition.

Although the HUCA model is a valuable tool, it is suited to the analysis of highway capacity improvement projects. Presently, this model can not be employed to estimate road user costs due to the condition of a highway pavement along a given facility. Therefore, this model may not be implemented to project road user costs in the context of this dissertation.

Network Level Road User Cost Estimation

Presently, NYSDOT produces an annual report entitled Pavement Condition of New York's Highways [26] as part of its network level pavement management activities. The annual report summarizes the overall condition of the state highway system. Pavements are classified according to their surface rating and categorized into groups ranging from "excellent" to "poor". Table 13 of the Pavement Condition Report [27] estimates the road user costs which would be redeemed if all pavements were improved to "excellent" conditions. The following relationships are utilized by NYSDOT to predict the excess operating costs based on pavement surface conditions.

PSR Rating	Excess Operating Cost ($/mile)
1 to 5	0.035
6	0.016
7 to 8	0.006
9 to 10	0.000

These correlations were generated by Irwin [15] based on rough estimates of road user costs calibrated from World Bank models. Although these operating cost figures are employed by NYSDOT in network level planning activities and management policy adjustments, their qualitative nature renders them unsuitable for project level implementation.

9.4 - Development of Road User Costs For NYSDOT.

The road user cost submodel developed for NYSDOT will model vehicle operating costs and accident costs as a function of International Roughness Index (IRI). Since NYSDOT has not published any relationship between these parameters, models developed and utilized in regions with similar demographics will be borrowed.

Financial Cost Analysis or Economic Cost Analysis.

World Bank models as well as those calibrated for the Saskatchewan PMIS express vehicle operating costs in terms of both financial and economic cost analysis. Financial cost analysis deals with the actual accounting costs incurred by various parties involved with the highway, including government and taxpayers. This type of analysis is commonly utilized in budget planning since the computed costs represent the true accounting costs. Economic cost analysis is the financial cost minus the market distortions such as taxes, foreign exchange, duties, tariffs, government subsidies, and external impacts such as pollution. This type of analysis is commonly employed at the planning level since policies resulting from the studies will reflect overall societal impacts. Adler [3] recommends that transport projects should only be undertaken if they are both financially and economically justified. However, with pavement management projects, it might be more appropriate to utilize economic cost analysis because the road users incur vehicle operating costs directly and agency costs indirectly as a taxpayer. Using financial costs, although more conservative, may double count for the governmental agency costs being indirectly absorbed by the taxpayer.

NYSDOT Vehicle Operating Cost Submodel.

The Saskatchewan Pavement Management Information System (PMIS) study, as sited by Bein [6], will be utilized to formulate a vehicle operating cost submodel for NYSDOT. The Saskatchewan PMIS, rather than World Bank HDM-III, was selected because the vehicles utilized, time value of money, and pavement structures are analogous to those found in the NYSDOT highway system.

The Saskatchewan PMIS data expressed vehicle operating costs in units of 1986

Canadian dollars. To convert to 1999 United States dollars, an exchange rate of CA$1.00 to US$0.75 was used, along with a 4 percent annual rate of inflation. Table 9-2 shows the relationship between vehicle operating costs and pavement condition assuming the use of economic cost analysis. As anticipated, vehicle operating costs increase as pavement condition declines. A distinct observation involves the three axle bus. The high operating cost incurred by the bus is due to the travel time delay costs incurred by the passengers on the bus.

Table 9-2 : Vehicle Operating Costs as Related to Pavement Condition (Economic).

		Veh. Type	Small Car	Med. Car	Large Car	Utility Veh.	2 Axle Truck	3 Axle Truck	5 Axle Truck	7 Axle Truck	3 Axle Bus
		a	1.00	1.00	1.00	1.00	1.10	1.10	1.10	1.10	1.10
		A	5.77	5.88	5.99	5.96	6.14	6.39	6.35	6.60	7.67
USA PSI	Can. RCI	B	0.019	0.021	0.020	0.022	0.056	0.040	0.034	0.042	0.012
		IRI (m/km)	$/mile	$/mile	$/mile	$/mile	$/mile	$/mile	$/mile	$/mile	$/mile
0.5	1	8.85	0.62	0.70	0.78	0.75	1.37	1.49	1.37	1.90	4.17
1.0	2	6.19	0.59	0.66	0.73	0.71	1.17	1.34	1.24	1.68	4.04
1.5	3	4.63	0.57	0.64	0.71	0.69	1.06	1.25	1.16	1.56	3.96
2.0	4	3.54	0.56	0.63	0.70	0.67	0.99	1.20	1.11	1.49	3.91
2.5	5	2.67	0.55	0.61	0.68	0.66	0.94	1.15	1.05	1.43	3.87
3.0	6	1.96	0.54	0.61	0.67	0.64	0.91	1.12	1.05	1.38	3.84
3.5	7	1.37	0.53	0.60	0.67	0.64	0.87	1.09	1.03	1.34	3.81
4.0	8	0.86	0.53	0.59	0.66	0.63	0.85	1.07	1.01	1.31	3.79
4.5	9	0.41	0.52	0.59	0.65	0.62	0.82	1.05	0.99	1.29	3.77

Source : Adapted from Bein [6].

NYSDOT does not gather the detailed traffic composition information for which the Saskatchewan PMIS is calibrated. At the planning level, NYSDOT only maintains average annual daily traffic (AADT) volumes and percentage of heavy vehicle utilization. More specific traffic composition collections are carried out at the project level when designing a particular project. For this dissertation, it is assumed that the composition of vehicles registered in New

York reflect the traffic composition utilizing the state highways. This information was obtained from the New York State Department of Motor Vehicles [21] (NYSDMV) and is displayed in Table 9-3. The NYSDMV records the number of passengers cars, rental cars, taxis, single unit trucks, trailer trucks, ambulances, farm vehicles, buses, motorcycles, and mopeds registered in each county of the state.

Table 9-3 : Vehicle Registration in New York State.

Vehicle Classification	Vehicles Registered (#)	Overall Composition (%)	Passenger Composition (%)	Commercial Composition (%)
Passenger Car	7408033	81.12	98.81	-----
Rental Car	33607	0.37	0.45	-----
Livery Car	55257	0.61	0.74	-----
Ambulance	2752	0.03	-----	0.19
Farm Vehicle	8723	0.10	-----	0.59
Single Unit Truck	960202	10.51	-----	65.19
Trailer Truck	484399	5.30	-----	32.89
Bus	16775	0.18	-----	1.14
Motorcycle	162691	1.78	-----	-----
Total	9132439	100.00	100.00	100.00

Source : Adapted from NYSDMV Records [21].

Regression analysis executed on the data in Table 9-4 indicates that there is a statistically significant relationship between the vehicle operating costs and roughness index (IRI). The mathematical function takes the linear form:

$$VOC = a(IRI) + b$$

where: VOC = Vehicle Operating Costs ($/mile).

IRI = International Roughness Index (inch/mile).

a,b = Regression parameter constants.

Figure 9-4 : Vehicle Operating Cost vs. Roughness

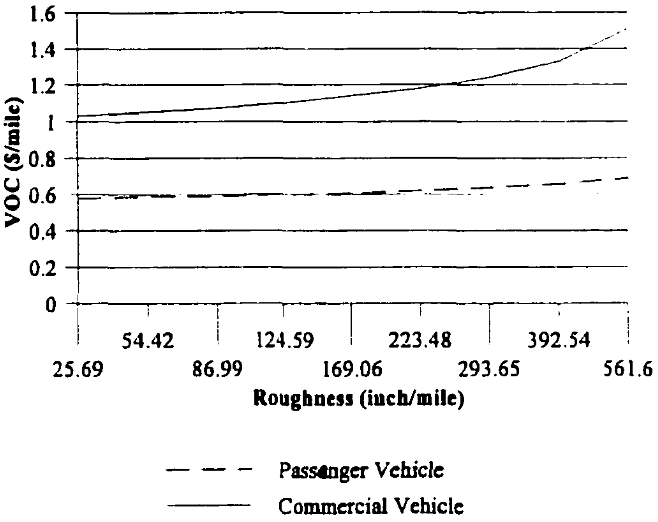


Table 9-4 : NYSDOT VOC versus Pavement Condition.

Pavement Condition AASHTO PSI	Pavement Condition IRI (Inch/mile)	Passenger Vehicle V.O.C. ($/mile)	Commercial Vehicle V.O.C. ($/mile)
4.5	25.69	0.58	1.03
4.0	54.42	0.59	1.05
3.5	86.99	0.59	1.07
3.0	124.59	0.60	1.10
2.5	169.09	0.61	1.14
2.0	223.48	0.62	1.18
1.5	293.65	0.64	1.24
1.0	392.54	0.66	1.33
0.5	561.60	0.69	1.51

Source : Adapted from NYSDMV [21] and USDOT [51].

Table 9-5 displays the regression parameter constants, a and b, for the various vehicle types and analysis methods as well as the correlation coefficients. The table shows that the computed functions are statistically good fits as indicated by the correlation coefficients.

Table 9-5 : Regression Equations Relating NYSDOT VOC to IRI.

Analysis Type	Vehicle Type	a	b	R^2	r	Goodness of Fit
Economic	Passenger Car	0.00021	0.576	0.9993	0.9996	"Good"
Economic	Commercial	0.00088	0.995	0.9962	0.9981	"Good"

NYSDOT Accident Cost Submodel.

Little information exists correlating accident costs directly with pavement conditions. McFarland [19] reports that the Texas Highway Department completed an AASHTO research project which integrated various road user cost components and pavement conditions. McFarland's study defines the total road user cost as the sum of operating cost, travel time cost, discomfort cost, and accident cost. Since it was an AASHTO project, the road user costs are directly related to the present serviceability index (PSI) for pavement condition. The highway facility types included in this research are the two lane highway, undivided multi-lane highway, and divided multi-lane highway.

Table 9-6 : Accident Cost versus Pavement Condition.

Pavement Condition AASHTO PSI	Pavement Condition IRI (inch/mile)	2 Lane Undivided Highway ($/mile)	Undivided Multi-Lane Highway ($/mile)	Divided Multi-Lane Highway ($/mile)	Average Accident Cost ($/mile)
4.5	25.69	0.016	0.026	0.008	0.017
4.0	54.42	0.016	0.027	0.008	0.017
3.5	86.99	0.016	0.029	0.008	0.018
3.0	124.59	0.017	0.033	0.009	0.020
2.5	169.06	0.018	0.041	0.009	0.023
2.0	223.48	0.020	0.055	0.010	0.028
1.5	293.65	0.023	0.075	0.012	0.037

Source: Adapted from McFarland [19].

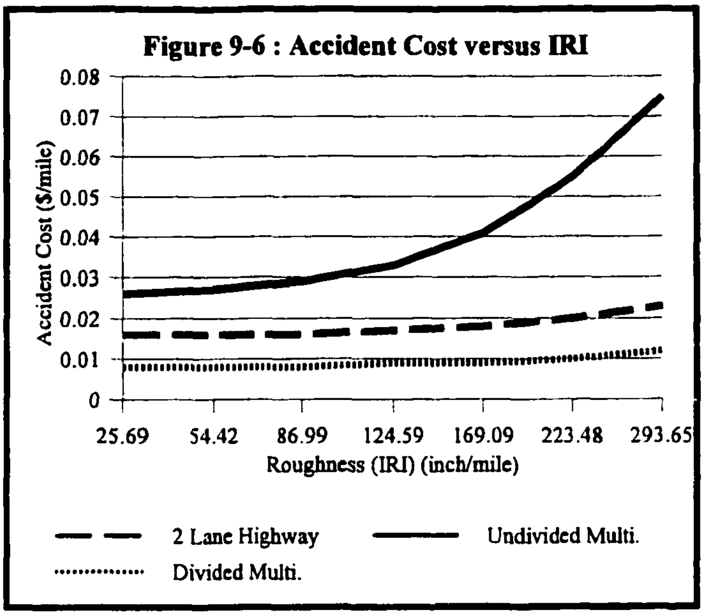


Figure 9-6 : Accident Cost versus IRI

Table 9-6 computes the accident costs to be utilized by NYSDOT as a function of pavement condition. These costs were adapted from McFarland's 1972 data by applying an annual inflation rate approximated at 4 percent. Figure 9-6 exhibits the accident costs versus IRI for the 2 lane highway, undivided multi-lane highway, and divided multi-lane highway. As expected, the data shows that as pavement roughness increases so do accident costs. However, as shown by McFarland's data, other elements such as traffic volume and lateral clearance also influence the accident cost for the different highway facility types.

Regression analysis executed on the data contained in Table 9-6 indicates that there is a statistically significant relationship between accident cost and pavement condition for the assorted highway facility types. The mathematical function takes on the following exponential form:

$$AC = e^{a(IRI)+b}$$

where: AC = Accident Cost ($/mile).

IRI = International Roughness Index (inch/mile).

a,b = Regression parameter constants.

Table 9-7 presents the computed regression parameter constants, a and b, for the various highway facility types and the correlation coefficients. It is apparent that the computed functions are statistically good fits as indicated by the values correlation coefficients.

Table 9-7 : Regression Equation Relating Accident Cost to IRI.

Facility Type	**a**	**b**	**R^2**	**r**	**Goodness of Fit**
Two Lane Highway	0.0014	-4.222	0.9379	0.9685	"Good"
Undivided Multi-Lane	0.0041	-3.848	0.9771	0.9885	"Good"
Divided Multi-Lane	0.0015	-4.916	0.9239	0.9612	"Good"
Average Cost	0.0030	-4.254	0.9675	0.9836	"Good"

9.5 - Need For Further Research.

In order to accurately employ road user costs as related to pavement condition, NYSDOT would have to complete studies such as those by Bein [6] and McFarland [19]. However, the methodologies used to generate correlations between the vehicle operating costs and roughness index and accident costs and roughness index are adequate in the context of this dissertation. In practice, the Saskatchewan and McFarland studies were performed over a decade ago in different geographical regions. Independent research by NYSDOT would produce the data needed to adapt and calibrate models with the desired accuracy to be implemented at the project level.

CHAPTER 10 : ECONOMIC ANALYSIS.

10.1 Life Cycle Analysis.

The analysis period of a highway pavement is defined as the design life of the pavement structure. In the past, state highway agencies used an analysis period of 30 years as recommended by the AASHTO [2] guide. However, in recent years, the trend amongst state highway agencies is to design thicker pavement structures capable of sustaining an analysis period of 50 years. This chapter designates how both agency costs and user costs will be computed and analyzed during the life cycle of a newly designed highway pavement.

Typical life cycle cost analysis [29] for highway pavements, both flexible and rigid, involves the following steps:

1. Selection of an adequate initial pavement design based on predicted loading and environmental conditions.
2. Designation of a suitable maintenance strategy of treatments selected based on the prediction of pavement roughness and primary distresses.
3. Estimating the agency costs of the initial construction and maintenance strategies.
4. Comparison of alternative design options using the Present Worth method.
5. Conducting sensitivity analysis for primary independent variables in the design equation.
6. Designation of optimal design and maintenance strategy to be implemented based upon lowest life cycle cost.

At the discretion of the pavement engineer, other considerations such as budgetary constraints, non-pavement construction activities, and traffic volumes may also influence the choice of treatment selection.

10.2 Present Worth Method (Agency Cost Computation).

The components of pavement construction and maintenance costs for flexible and rigid pavements have been discussed in Chapter 8 of this dissertation. Total agency expenditures for the pavement life cycle are evaluated for each design alternative using the present worth method.

Salvage Values.

When an individual maintenance treatment's performance life does not coincide with the end of the pavement structure's analysis period, a salvage value will be assigned for the unused portion of the treatment. USDOT [51] recommends calculating the salvage value using the straight line depreciation method as follows:

$$S_n = C_n * (RSL_n / ESL_n)$$

Where : S_n Salvage Value of treatment n ($).
C_n Agency Cost of treatment n ($).
RSL_n Remaining Service Life of treatment n (years).
ESLn Expected Service Life of treatment n (years).

Discount Rate.

The discount rate, or time value of money, is the difference between the rate of return on public investments and the rate of inflation. Return on public investments is the outcome of improved infrastructure and its impacts on employment, income, sales tax, and other exogenous benefits to local economy. Adler [3] maintains that the prediction of the discount rate is a complex process because it involves the economic concept of shadow pricing. However, he recommends that discount rates ranging from 2 to 10 percent are typical for transport projects, depending upon the local economy. NYSDOT [29] and other state highway agencies in the United States utilize a discount rate of 4 percent on pavement and highway projects.

Present Worth Method.

Present worth of pavement treatment strategies is interpreted as the amount of money that would have to be invested currently to fund future treatments when required. The present worth factor, which discounts future costs to the present, is calculated using the following mathematical function:

$$PWF = (P/F,r,N) = 1 / (1+r)^N$$

Where: r Discount Rate (percent, in decimal, typically 0.04)
N Pavement age when treatment is applied (years).

The present worth value of the treatment "n" applied in year "N" is calculated by multiplying the estimated treatment cost per lane mile by the present worth factor, as shown:

$$P_n = C_n * PWF = C_n * (P/F,r,N)$$

Where : P_n Present value of estimated agency cost of treatment n ($).
C_n Estimated agency cost of treatment n ($).

The total agency cost for each alternative design is the sum of all discounted agency costs including initial construction and life cycle maintenance subtracted by the discounted salvage value of unused portions of maintenance treatments.

10.3 Total Road User Costs and Societal Benefits.

Road user benefits are the savings incurred by highway travelers as an effect of improved pavement conditions. Chapter 9 of this dissertation establishes that road user costs are directly correlated with pavement roughness; as pavement roughness deteriorates, road user costs escalate.

Present Worth Method

Road user benefits are incurred annually during the 50 year analysis life of the pavement structure. The following process is used to estimate road user benefits for alternative design strategies by employing the present worth method:

1. Determine the present worth of road user costs for each of the design strategies to be considered for a particular pavement project. It should be noted that only design alternatives which meet the minimum strength requirements as specified in the design tables should be considered.
2. Select the base case alternative. This is the alternative with the lowest, discounted agency cost by the present worth method.
3. Compute the road user benefit for each alternative design using the following equation:

$$B_n = RUC_{bc} - RUC_n$$

Where :	B_n	Road user benefit of alternative n ($).
	RUC_{bc}	Discounted road user cost of base case ($).
	RUC_n	Discounted road user cost of alternative n ($).

10.4 Economic Analysis Methodology.

There are two stages of economic analysis to be completed, strategy examination and rejection, and incremental cost analysis.

Strategy Examination and Rejection.

Strategy examination and rejection consists of conducting benefit-to-cost evaluations for each design alternative and rejecting those which are not economically sound. The benefit to cost ratio for each design alternative is calculated using the following equation:

$$B/C_n = B_n / C_n$$

Where : B/C_n Benefit to Cost Ratio of improved alternative n (no units).
B_n Discounted road user benefits of improved alternative n ($).
C_n Discounted agency cost of improved alternative n ($).

According to Adler [3], a transport project is justified if its benefits outweigh its costs, thus, the benefit to cost ratio is greater than 1. Economically, any alternative with a benefit to cost ratio of less than 1 will be rejected from consideration. It is also recognized that the benefit to cost ratio of the base case alternative will be zero by definition, therefore, the base case alternative is exempt from having to be greater than 1 to avoid rejection.

Incremental Cost Analysis.

Incremental benefit to cost analysis enables the pavement engineer to assess the societal impacts of agency investment decisions. In this type of analysis, the engineer is evaluating if the additional benefits incurred by choosing an improved design justify the higher agency cost. The incremental benefit is the difference in road user benefit between the present alternative and the prior, lower cost alternative. The incremental functions are shown below:

$$IC_n = C_n - C_{n-1}$$

$$IB_n = B_n - B_{n-1}$$

Where: IC_n Incremental Cost of alternative n ($).
C_n Discounted agency cost of alternative n ($).
C_{n-1} Discounted agency cost of prior, lower cost alternative to n ($).
IB_n Incremental Benefit of alternative n ($).
B_n Discounted road user benefit of alternative n ($).
B_{n-1} Discounted road user benefit prior, lower cost alternative to n ($).

The World Bank [45] advocates that improved alternatives which possess an incremental benefit to cost ratio of 1 or greater be considered for implementation. Incremental ratios of less than 1 indicate that government expenditure necessary to implement the higher cost alternative exceeds its supplementary incurred benefits. In practice, highway engineers could utilize incremental analysis to plan pavement maintenance projects which maximize road user benefits given a fixed budget.

10.5 Need For Further Research.

The discount rate is a sensitive variable in the determination of present worth and slight modification may have profound effects on the overall computations. Foreign governments usually consider the ramifications of external factors on the shadow pricing of the discount rate with transportation projects [3]. Domestic highway agencies may wish to consider factors such as environmental issues as associated with newly constructed pavements when determining the appropriate discount rate for analysis.

CHAPTER 11 : SAMPLE APPLICATIONS OF PROPOSED DESIGN PROCEDURE.

11.1 - Choice of Micro-Computer Program.

A computer spreadsheet is adequate to perform computations to show the potential utility of the design procedure proposed in this dissertation. The spreadsheet utilized is Lotus 1-2-3 of the Lotus Smartsuite 97 software for the purposes of this dissertation. The spreadsheet was prepared using NYSDOT pavement specifications and environmental data gathered in the various state regions. Therefore, the flexible pavement spreadsheet is only valid for the wet-freeze region, and the rigid pavement spreadsheet is only valid for jointed, plain concrete pavement. However, using the guidelines proposed in the design algorithm, similar spreadsheet applications may be calibrated for any region as a function of the climate, pavement type, and local data available.

11.2 - Description of Design Spreadsheets.

The spreadsheet developed for the proposed design procedure, as calibrated for NYSDOT flexible pavements, is shown in Appendix P and summarized in Figure 11-1 The spreadsheet generated for NYSDOT rigid pavements is shown in Appendix Q and is outlined in Figure 11-2.

Spreadsheet Input.

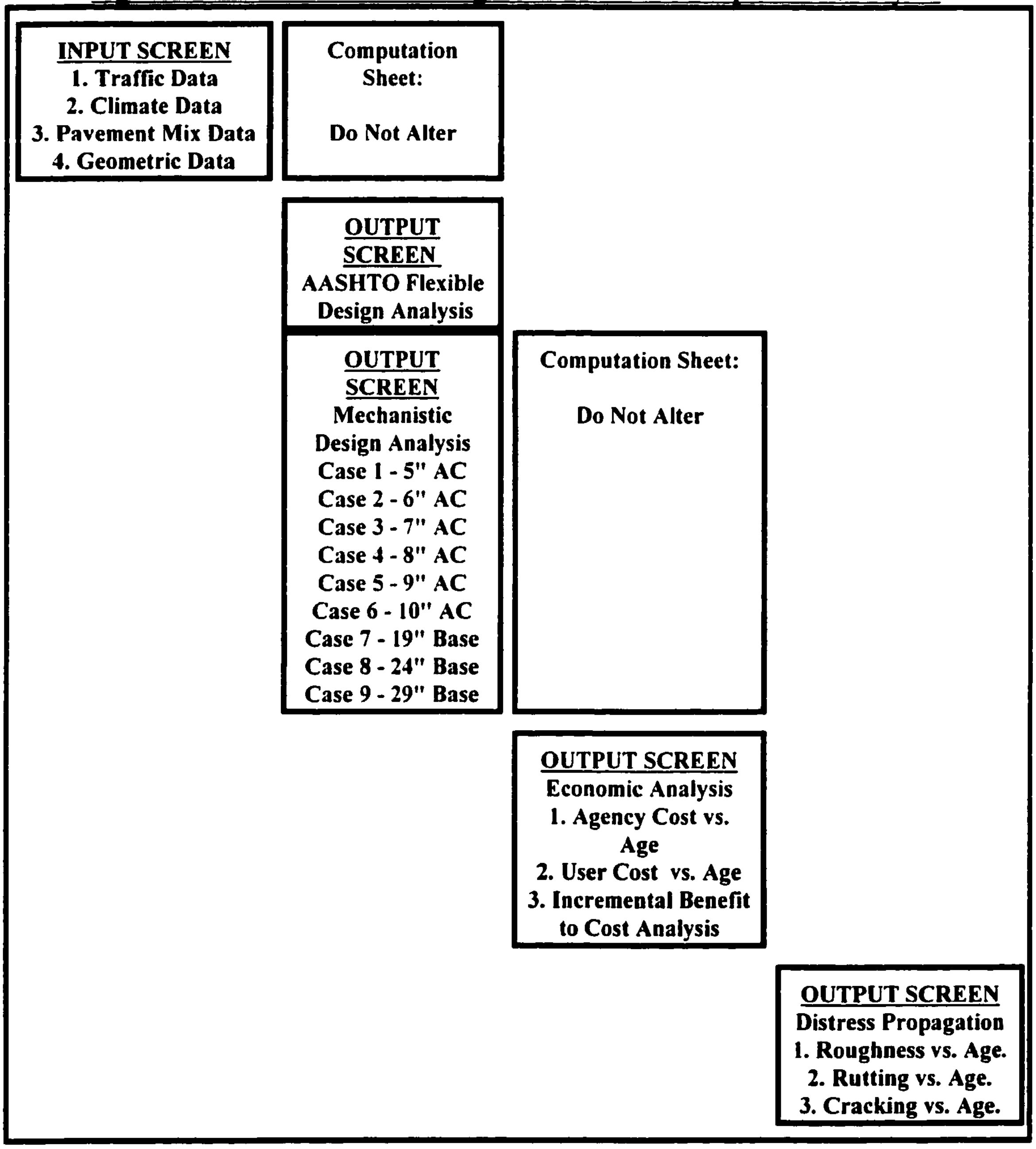
The input for the spreadsheet application consists of the following requirements:

1. Traffic Data: Data entails average daily traffic, percent commercial vehicles, load equivalency factor, directional and lane distribution, and forecasted growth rate.

2. Environmental Data: Data consists of annual number of freeze-thaw cycles, annual number of days greater than 90 degree Fahrenheit, freeze index, and annual precipitation.

3. Pavement Mix Characteristics: Data required for flexible pavements includes asphalt viscosity, percent air voids, asphalt aggregate gradation, and subbase aggregate gradation. Needed data for rigid pavements entails modulus of subgrade reaction, joint spacing and dowel diameter.

Figure 11-1: Flexible Pavement Algorithm - Lotus 1-2-3 Spreadsheet Layout



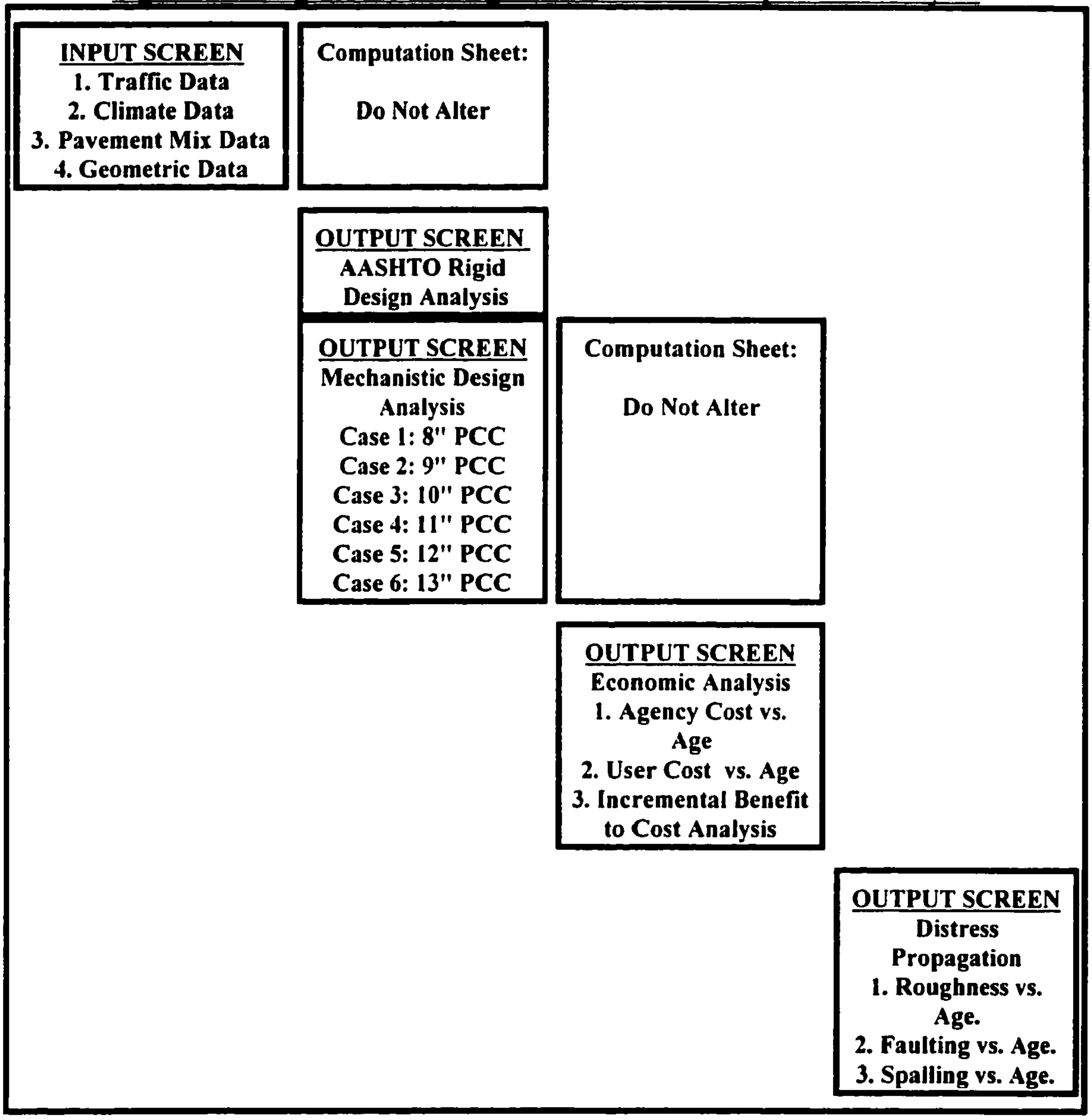
4. Highway Geometry Information: Required data input is lane width, shoulder width, and project length.

5. Economic Data: The discount rate to be used in economic study must be entered.

Spreadsheet Output.

The output generated by the spreadsheet consists of the following information:

Figure 11-2: Rigid Pavement Algorithm - Lotus 1-2-3 Spreadsheet Layout



1. AASHTO Design Analysis: Calculates if each design alternative is feasible or overloaded based on the present NYSDOT Design Manual [34] and AASHTO [2] methodology.

2. Mechanistic Design Analysis: Predicts roughness and primary distress propagation throughout the 50 year pavement analysis period for each design alternative. For flexible pavement, primary distresses are rutting and thermal cracking; for rigid pavement, primary distresses are joint faulting and spalling. The predicted, responsive maintenance strategies required for each design alternative are also determined.

3. Agency and User Cost Computations: The agency expenditures for initial capital investment and maintenance is computed for each design alternative. The annual vehicle user cost due to pavement roughness and distresses is estimated. Finally, the incremental benefit to cost ratio is plotted so that the consequences of supplementary agency investment may be examined.

4. Distress Propagation: The propagation of roughness and individual distresses is predicted and charted throughout the analysis period so that the implications of choosing different alternatives may be explored.

11.3 - Case Study - NYSDOT Flexible Pavement.

The case study for flexible design considers a typical, rural, two lane highway pavement reconstruction. The forecasted average daily traffic is 22000 vehicles, with 10 percent commercial traffic, increasing at a combined growth rate of 2.0 percent. The pavement structure will be constructed using a standard AC-20 mix. The highway geometry will consist of 1 travel lane in each direction and will be constructed to the standard width of 12 feet per travel lane with full depth outer shoulders of 8 feet width over the proposed 1 mile project.

AASHTO Design Analysis.

Assuming the median soil resilient modulus of 7000 pounds per square inch, using the NYSDOT table [34], the pavement thickness required would be design alternative four; 7 inches of HMAC over a 4 inch permeable drainage course and 12 inches of subbase material.

Mechanistic Design Analysis.

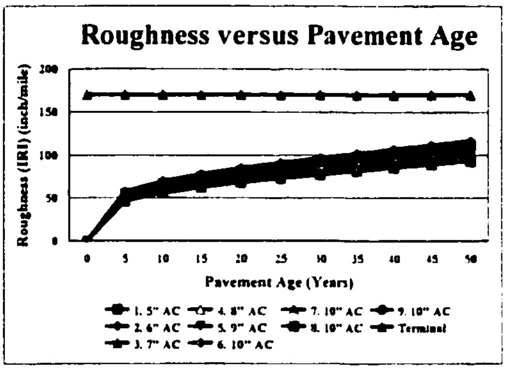
Mechanistic analysis of the proposed flexible pavement yields the following results as shown in Table 11-1.

1. Roughness: Roughness does not exceed the terminal limit of 170.00 inches per mile throughout the 50 year design life for any alternative. Roughness increases as the HMAC thickness increases from 5 to 10 inches, then, decreases slightly as the base thickness is increased from 0 to 29 inches.

Table 11-1: Pavement Performance - Case Study - NYSDOT Flexible Pavement.

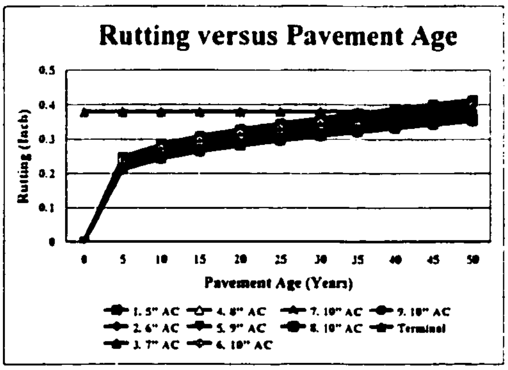
OUTPUT - PREDICTED ROUGHNESS

Year	Alt 1 5" AC 14" Base inch/mile	Alt 2 6" AC 14" Base inch/mile	Alt 3 7" AC 14" Base inch/mile	Alt 4 8" AC 14" Base inch/mile	Alt 5 9" AC 14" Base inch/mile	Alt 6 10" AC 14" Base inch/mile	Alt 7 10" AC 19" Base inch/mile	Alt 8 10" AC 24" Base inch/mile	Alt 9 10" AC 29" Base inch/mile	Terminal Roughness inch/mile
0	0	0	0	0	0	0	0	0	0	170
5	46	49	52	54	56	58	57	56	55	170
10	56	59	62	65	67	70	68	67	66	170
15	63	66	70	73	75	78	77	75	74	170
20	68	72	76	79	82	85	83	82	80	170
25	73	78	81	85	88	91	89	88	86	170
30	78	82	86	90	93	97	95	93	91	170
35	82	87	91	95	98	102	100	98	96	170
40	86	91	95	99	101	107	105	103	101	170
45	90	95	100	104	108	111	109	107	105	170
50	93	99	104	108	112	116	114	112	110	170
Total	—	—	—	—	—	—	—	—	—	—


Roughness versus Pavement Age

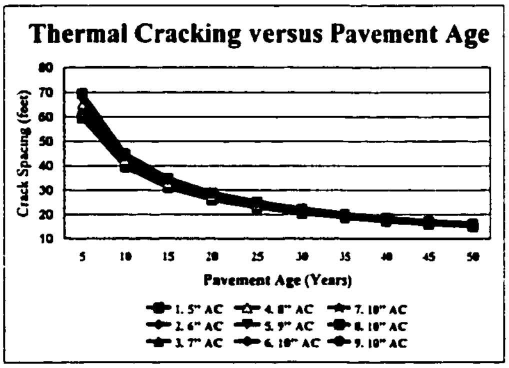
OUTPUT - PREDICTED RUTTING

Year	Alt 1 5" AC 14" Base (inch)	Alt 2 6" AC 14" Base (inch)	Alt 3 7" AC 14" Base (inch)	Alt 4 8" AC 14" Base (inch)	Alt 5 9" AC 14" Base (inch)	Alt 6 10" AC 14" Base (inch)	Alt 7 10" AC 19" Base (inch)	Alt 8 10" AC 24" Base (inch)	Alt 9 10" AC 29" Base (inch)	Terminal Rutting (inch)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38
5	0.25	0.24	0.23	0.23	0.22	0.22	0.22	0.21	0.21	0.38
10	0.28	0.27	0.27	0.26	0.26	0.25	0.25	0.24	0.24	0.38
15	0.31	0.30	0.29	0.28	0.28	0.27	0.27	0.27	0.26	0.38
20	0.33	0.32	0.31	0.30	0.30	0.29	0.29	0.28	0.28	0.38
25	0.35	0.33	0.32	0.32	0.31	0.30	0.30	0.30	0.30	0.38
30	0.36	0.35	0.34	0.33	0.32	0.32	0.31	0.31	0.31	0.38
35	0.37	0.36	0.35	0.34	0.34	0.33	0.33	0.32	0.32	0.38
40	0.39	0.38	0.36	0.36	0.35	0.34	0.34	0.33	0.33	0.38
45	0.40	0.39	0.38	0.37	0.36	0.35	0.35	0.35	0.34	0.38
50	0.41	0.40	0.39	0.38	0.37	0.36	0.36	0.36	0.35	0.38
Total	—	—	—	—	—	—	—	—	—	—


Rutting versus Pavement Age

OUTPUT - PREDICTED THERMAL CRACKING

Year	Alt 1. 5" AC 14" Base (feet)	Alt 2. 6" AC 14" Base (feet)	Alt 3. 7" AC 14" Base (feet)	Alt 4. 8" AC 14" Base (feet)	Alt 5. 9" AC 14" Base (feet)	Alt 6. 10" AC 14" Base (feet)	Alt 7 10" AC 19" Base (feet)	Alt 8 10" AC 24" Base (feet)	Alt 9 10" AC 29" Base (feet)
0	—	—	—	—	—	—	—	—	—
5	59.55	61.39	63.30	65.26	67.29	69.38	69.38	69.38	69.38
10	39.38	40.39	41.43	42.50	43.60	44.72	44.72	44.72	44.72
15	30.92	31.62	32.34	33.07	33.82	34.59	34.59	34.59	34.59
20	26.04	26.58	27.12	27.68	28.24	28.82	28.82	28.82	28.82
25	22.80	23.22	23.66	24.11	24.56	25.02	25.02	25.02	25.02
30	20.45	20.80	21.17	21.54	21.91	22.29	22.29	22.29	22.29
35	18.65	18.95	19.26	19.58	19.89	20.22	20.22	20.22	20.22
40	17.22	17.49	17.75	18.02	18.30	18.58	18.58	18.58	18.58
45	16.05	16.28	16.52	16.76	17.00	17.24	17.24	17.24	17.24
50	15.08	15.28	15.49	15.70	15.91	16.13	16.13	16.13	16.13
Total	—	—	—	—	—	—	—	—	—


Thermal Cracking versus Pavement Age

2. Rutting: Rutting exceeds 0.38 inch for design alternatives 1, 2, and 3, therefore, higher cost maintenance efforts will be required to maintain the pavement for these options. Rut depth decreases as the pavement thickness, both HMAC and select base, is increased.

3. Thermal Cracking. The number of thermal cracks in the HMAC layer of the pavement structure increases as the thickness of the HMAC layer is decreased.

Maintenance Requirements.

The predicted, life-cycle pavement maintenance requirements for all nine pavement design alternatives consist of filling of thermal cracks at 5 year intervals and grinding and shimming wheel path ruts at 10 year intervals throughout the design life of the pavement. The estimated quantity of crack filling and shimming required varies by design alternative. Generally, as the thickness of the pavement structure is increased, the quantity of maintenance repairs is decreased.

Economic Analysis.

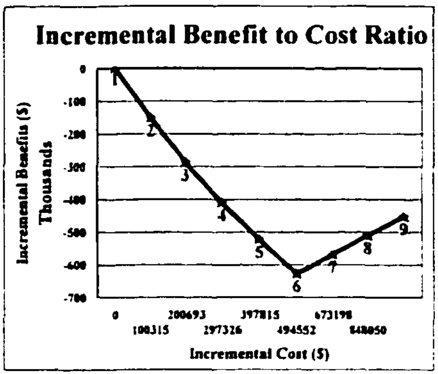
As expected, the initial capital cost incurred by the highway agency increases as does the thickness of the pavement structure. Maintenance costs decrease as the pavement thickness is increased. It is observed that the incurred road user costs are tangibly larger than the forecasted agency expenditures for all nine alternatives.

Incremental benefit to cost analysis is shown and plotted in Table 11-2. From alternatives 1 to 6, as the agency increases spending to increase HMAC thickness, the user costs increase. From alternative 6 to 9, increased agency spending to increase base thickness will result in slightly decreased road user costs. However, since the incremental benefit to cost ratio never exceeds 1, it is economically justified to choose the lowest cost alternative available. Therefore, for the given two lane highway, as per mechanistic analysis, the minimum feasible alternative as limited by rutting distress, is alternative 4; 8 inches of HMAC over 4 inches permeable base and 12 inches of granular subbase material.

Table 11-2: Incremental B/C Analysis - Case Study - NYSDOT Flexible Pavement.

OUTPUT - INCREMENTAL B/C ANALYSIS

Alternative Number	Agency Cost ($)	User Cost ($)	Incremental Cost ($)	Incremental Benefit ($)	Incremental B/C Ratio
1	1517509	100975435	0	0	—
2	1617824	101127411	100315	-151976	-1.51
3	1718202	101262869	100378	-135459	-1.35
4	1814836	101385627	96633	-122758	-1.27
5	1915324	101498264	100488	-112636	-1.12
6	2012062	101602611	96738	-104348	-1.08
7	2190707	101543360	178646	59251	0.33
8	2365559	101485204	174851	58156	0.33
9	2544216	101428122	178657	57082	0.32



General Observations and Recommendations.

The final cross section required by mechanistic analysis is less than what is required by the present AASHTO [2] methodology utilized by NYSDOT. For this case study, mechanistic analysis refutes the contemporary layer design theory for flexible pavement which assumes that increases in HMAC thickness will result in a stronger, better performing pavement. As per mechanistic analysis, the HMAC layer thickness should be limited to the minimum required to satisfy rutting requirements in order to minimize pavement roughness and associated road user costs.

11.4 - Case Study - NYSDOT Rigid Pavement.

The case study for rigid pavement considers a reconstructed suburban expressway with average daily traffic of 64000 vehicles, consisting of 12 percent commercial traffic, forecasted to increase at a combined growth rate of 2.0 percent. Standard 3000 pound per square inch concrete will be used to construct the concrete slab. The highway geometry will be reconstructed to consist of two lanes in each direction with full depth rigid shoulders. Existing right-of-way will allow standard travel lanes of 12 foot width, inner shoulder of 4 feet, and outer shoulder of 8 feet along the 1 mile project.

AASHTO Design Analysis.

Using the recommended modulus of subgrade reaction of 200 pounds per cubic inch shown in the NYSDOT Design Manual [34], the minimum allowable pavement thickness for the proposed suburban expressway would be alternative 4, a 11 inch thick concrete slab over 4 inches of permeable base and 12 inches of granular subbase.

Mechanistic Design Analysis.

Mechanistic analysis of the proposed rigid pavement yields the following results as shown in Table 11-3.

1. Roughness: Roughness is not expected to exceed the terminal value of 170.00 inch per mile during the analysis period for any design alternative. The predicted roughness increases as the thickness of the pavement structure decreases.

2. Joint Faulting. Predicted faulting is expected to exceed the terminal value of 0.19 inches at 43 years for all design alternatives. Since faulting is not a function of slab thickness, increasing the slab thickness will not decrease the presence of this distress.

3. Joint Spalling. Predicted spalling increases linearly as pavement age increases. Since this distress is dependent upon weather parameters, increasing the pavement thickness will not have any positive affect.

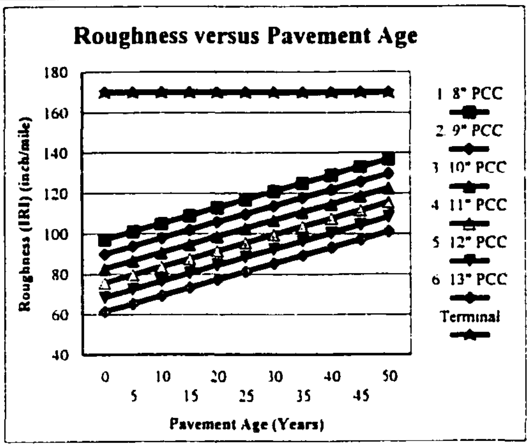
Maintenance Requirements.

The forecasted, life-cycle pavement maintenance requirements for all six pavement design alternatives consist of joint sealing and spall repairs at 10 year intervals and grinding, shimming, and resealing of joints at year 45. Generally, increasing the thickness of the pavement structure will decrease pavement roughness, but will not affect the predicted quantity of primary distresses. No structural overlays are required during the design life of the suburban expressway.

Table 11-3: Pavement Performance - Case Study - NYSDOT Rigid Pavement.

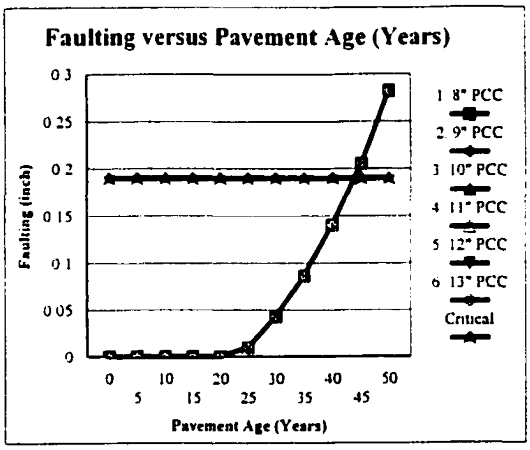
OUTPUT - PREDICTED ROUGHNESS

Year	Alt 1. 8" PCC (inch/mile)	Alt 2. 9" PCC (inch/mile)	Alt 3. 10" PCC (inch/mile)	Alt 4. 11" PCC (inch/mile)	Alt 5 12" PCC (inch/mile)	Alt 6 13" PCC (inch/mile)	Terminal Roughness (inch/mile)
0	97.08	89.95	82.82	75.69	68.56	61.43	170.00
5	101.06	93.93	86.80	79.67	72.54	65.41	170.00
10	105.03	97.90	90.77	83.64	76.51	69.38	170.00
15	109.01	101.88	94.75	87.62	80.49	73.36	170.00
20	112.98	105.85	98.72	91.59	84.46	77.33	170.00
25	116.96	109.83	102.70	95.57	88.44	81.31	170.00
30	120.93	113.80	106.67	99.54	92.41	85.28	170.00
35	124.91	117.78	110.65	103.52	96.39	89.26	170.00
40	128.88	121.75	114.62	107.49	100.36	93.23	170.00
45	132.86	125.73	118.60	111.47	104.34	97.21	170.00
50	136.83	129.70	122.57	115.44	108.31	101.18	170.00
Total	---	---	---	---	---	---	---



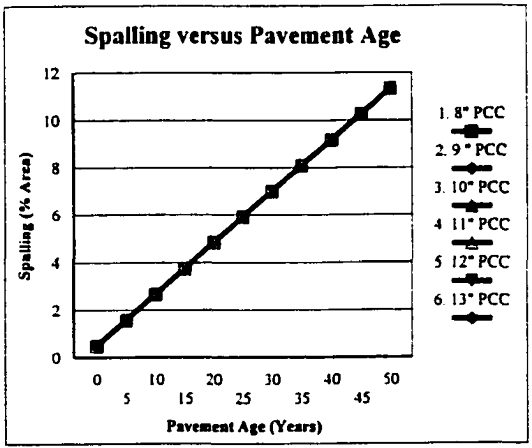
OUTPUT - PREDICTED FAULTING

Year	Alt 1 8" PCC (inch)	Alt 2 9" PCC (inch)	Alt 3. 10" PCC (inch)	Alt 4 11" PCC (inch)	Alt 5. 12" PCC (inch)	Alt 6 13" PCC (inch)	Critical Faulting (inch)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.19
5	0.00	0.00	0.00	0.00	0.00	0.00	0.19
10	0.00	0.00	0.00	0.00	0.00	0.00	0.19
15	0.00	0.00	0.00	0.00	0.00	0.00	0.19
20	0.00	0.00	0.00	0.00	0.00	0.00	0.19
25	0.01	0.01	0.01	0.01	0.01	0.01	0.19
30	0.04	0.04	0.04	0.04	0.04	0.04	0.19
35	0.09	0.09	0.09	0.09	0.09	0.09	0.19
40	0.14	0.14	0.14	0.14	0.14	0.14	0.19
45	0.21	0.21	0.21	0.21	0.21	0.21	0.19
50	0.28	0.28	0.28	0.28	0.28	0.28	0.19
Total	---	---	---	---	---	---	---



OUTPUT - PREDICTED SPALLING

Year	Alt 1. 8" PCC (%)	Alt 2. 9" PCC (%)	Alt 3. 10" PCC (%)	Alt 4. 11" PCC (%)	Alt 5 12" PCC (%)	Alt 6. 13" PCC (%)
0	0.49	0.49	0.49	0.49	0.49	0.49
5	1.57	1.57	1.57	1.57	1.57	1.57
10	2.66	2.66	2.66	2.66	2.66	2.66
15	3.74	3.74	3.74	3.74	3.74	3.74
20	4.83	4.83	4.83	4.83	4.83	4.83
25	5.91	5.91	5.91	5.91	5.91	5.91
30	7.00	7.00	7.00	7.00	7.00	7.00
35	8.08	8.08	8.08	8.08	8.08	8.08
40	9.17	9.17	9.17	9.17	9.17	9.17
45	10.25	10.25	10.25	10.25	10.25	10.25
50	11.34	11.34	11.34	11.34	11.34	11.34
Total	---	---	---	---	---	---



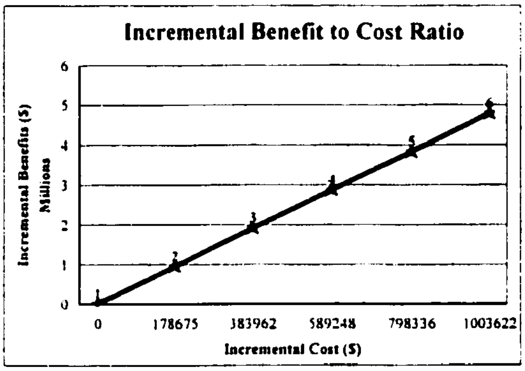
Economic Analysis.

The initial capital expenditure increases as does the thickness of the pavement structure. The maintenance costs are similar for each alternative. The incurred road user costs are substantially greater than the predicted agency expenditures.

Table 11-4: Incremental Benefit to Cost Analysis - Case Study - NYSDOT Rigid Pavement.

OUTPUT - INCREMENTAL B/C ANALYSIS

Alternative Number	Agency Cost ($)	User Cost ($)	Incremental Cost ($)	Incremental Benefit ($)	Incremental B/C Ratio
1	3968622	305045031	0	0	---
2	4147297	304085845	178675	959186	5.37
3	4352583	303126659	205286	959186	4.67
4	4557870	302167473	205286	959186	4.67
5	4766958	301208287	209088	959186	4.59
6	4972244	300249100	205286	959186	4.67



Incremental benefit to cost analysis is shown and plotted in Table 11-4. For this case study, as the agency invests more funds for a thicker pavement structure, the road user benefits increase. Since the ratio of benefits to cost is greater than one, it would be economically viable to select alternatives other than the minimum allowable design. In this case, interpreting the plot of the incremental benefit to cost ratio indicates that alternative two provides the maximum return on agency investment at a ratio of 1.34. However, the plot also implies that there still may be a more costly design alternative which would optimize total cost. For the given suburban expressway, as per mechanistic analysis, the minimum feasible design would be alternative one as limited by roughness requirements. However, the agency would incur maximum societal benefits by increasing agency spending to the limit of the project budget.

General Observations and Recommendations.

The pavement cross section required by mechanistic analysis is less than what is required by the present NYSDOT catalog design based on AASHTO [2] methods. In this case, mechanistic analysis has proven that the contemporary AASHTO [2] formulae produced a very conservative design in regards to the rigid pavement structure. However, as per economic analysis, the concrete slab thickness should be maximized, with the parameters of the project budget, in order to optimize total societal benefit incurred by better pavement performance.

11.5 - Need For Further Research.

For the purpose of this dissertation, the use of a spreadsheet is adequate to exhibit the benefits of the proposed design procedure. In practice, a more user friendly program, similar to the HDM-IV Model [54] developed by the World Bank, must be developed for commercial use. The commercial model would be capable of receiving a larger number of inputs, as required for all 4 climatic regions. As well, the commercial model should be able to conduct sensitivity analysis on independent variables in order to help the pavement engineer in making design decisions as to an input's importance.

CHAPTER 12 : IMPLICATIONS FOR NEW CATALOGUE DESIGNS.

12.1 - The Need For Design Optimization.

The purpose of this chapter is to employ the proposed pavement design procedure and spreadsheet model to redefine the design alternatives in terms of incremental cost of initial pavement structure plus maintenance strategies in order to identify the optimal design. The ideal result would be a cost effectiveness curve with a shape which rises to a maximum then decreases, thus, providing a rational catalogue of increasingly costly structures. This chapter utilizes the proposed mechanistic analysis to explore the recommendations given for flexible and rigid pavements given in chapters 5, 7, and 11. To illustrate the utility of the proposed methodology, modifications will be made to the state catalogue design used by New York as a case study. Improvements to the design catalogues represent the advancement of the state of the art technology and further contribute to the validity of the design procedure proposed in this dissertation.

12.2 - Flexible Pavement Design.

General trends to be examined are the economic and performance impacts of altering the thickness of the HMA and subbase layers of the flexible pavement structure. A matrix of possible thickness combinations will be tested in order to determine the optimal design. HMA layer thickness will be varied from 3 to 25 inches. For each of the HMA layer thicknesses, granular subbase thickness will be tested at intervals of 0, 6, 12, 18, 24, 30, and 36 inches thick. As per present specifications [32], the minimum practical HMA layer thickness which may be properly placed during new construction is 3 inches. The minimum design thickness to be considered for the granular subbase, with respect to practical construction practice, will be 6 inches. A 4 inch permeable asphalt drainage layer will be placed between the HMA and granular subbase layers to facilitate drainage. The maximum number of axle loadings for a given HMA thickness will be determined by governing values of roughness as 170.00 inches per mile or rut depth of 0.38 inches. Therefore, the need for high-cost maintenance treatments will be eliminated during the pavement's analysis period.

Results of the mechanistic analysis performed on the matrix of flexible design alternatives are shown in the following tables and appendices:

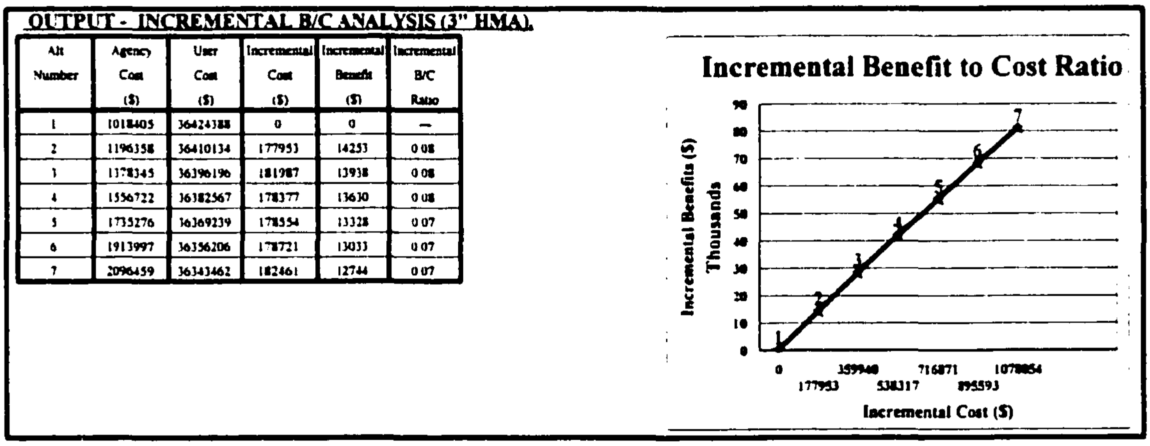
* Table R1, Appendix R, shows the initial cost estimates for each of the alternatives to be considered.

* Tables S1 through S12, Appendix S, display the results of economic analysis for each trial HMA thickness.

* Tables T1 through T12, Appendix T, forecast the performance of each design alternative during the analysis period.

Table 12-1 is an illustration of the results of economic analysis performed for the 3 inch HMA flexible pavement structure. As per the analysis, 19.4 million equivalent 18 kip axle loads is the maximum allowable in order to limit rut depth to the governing value of 0.38 inches.

Table 12-1: Sample Economic Analysis - NYSDOT Flexible Pavement Trials.



OUTPUT - INCREMENTAL B/C ANALYSIS (3" HMA)

Alt Number	Agency Cost ($)	User Cost ($)	Incremental Cost ($)	Incremental Benefit ($)	Incremental B/C Ratio
1	1018405	36424388	0	0	—
2	1196358	36410134	177953	14253	0.08
3	1378345	36396196	181987	13938	0.08
4	1556722	36382567	178377	13630	0.08
5	1735276	36369239	178554	13328	0.07
6	1913997	36356206	178721	13033	0.07
7	2096459	36343462	182461	12744	0.07

Incremental benefit-to-cost analysis shows a nearly uniform, incremental benefit to cost ratio less than 1 indicating that, although increasing granular subbase thickness from 6 to 36 inches will slightly improve roughness, the additional expenditure to attain this improvement is not economically justified. Therefore, for the 3 inch HMA trial thickness, the depth of subbase which minimizes total cost is the minimum value of 6 inches. This procedure was repeated for other trial HMA layer thicknesses ranging from 4 to 25 inches.

The results of economic benefit-to-cost analysis show that for all feasible flexible pavement trial thicknesses examined, increasing granular subbase thickness, while slightly

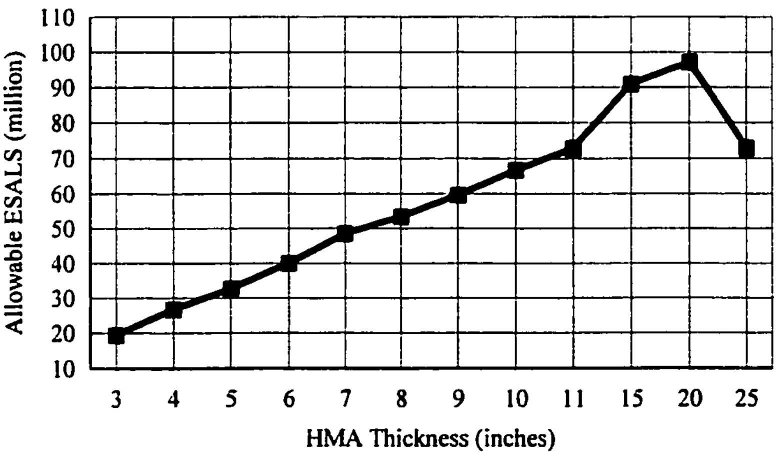
Table 12-2: NYSDOT Flexible Pavement - Design Optimization.

HMAC Thickness (inch)	HMAC Drainage (inch)	Subbase Thickness (inch)	Maximum ESAL * (millions)	Governing Distress
3	4	6	19.4	Rutting
4	4	6	26.7	Rutting
5	4	6	32.7	Rutting
6	4	6	40.0	Rutting
7	4	6	48.5	Rutting
8	4	6	53.4	Rutting
9	4	6	59.5	Rutting
10	4	6	66.7	Rutting
11	4	6	72.8	Rutting
15	4	6	91.0	Rutting
20	4	6	97.1	Equal
25	4	6	72.8	Roughness

Notes:

1. Shaded regions represent designs which were examined but are not economically justified.
2. Assumed soil Resilient Modulus is 7000 psi.
3. Assumed traffic: 10% truck volume at 2% combined growth rate.

Figure 12-2: HMA Thickness versus Allowable Loading



improving roughness and rutting, is not economically justified. Therefore, the recommended thickness of granular subbase is 6 inches. Table 12-2 summarizes the results of the economic and mechanistic analysis and also represents the revised flexible pavement design catalogue for NYSDOT. Rutting is the governing distress from 3 to 15 inches HMA thicknesses. For HMA thickness of 15 to 20 inches, rutting still governs, but roughness also is near to the maximum allowable criteria. For HMA thickness exceeding 20 inches, roughness governs. Therefore, an HMA layer thickness of 20 inches is the point of diminishing returns, when increasing the layer thickness will no longer improve the ability of the pavement structure to carry axle loads within accepted performance and economic criteria. Therefore, based upon mechanistic analysis, 97 million ESAL is the maximum number of axle loads which may be considered during the 50 year analysis period for flexible pavement. However, based upon economic analysis, increasing the HMA layer thickness any more than 11 inches is not justified. For thicknesses greater than 11 inches, a flexible pavement structure becomes more expensive to construct than a rigid structure which would support the same number of axle loads. Therefore, the maximum number of axle loads which should be considered for flexible pavement design is 72.8 million at an HMA layer thickness of 11 inches.

12.3 Rigid Pavement Design.

General trends to be explored are the economic and performance impacts of altering concrete slab thickness, granular subbase thickness, and joint spacing of the rigid pavement structure. A matrix of possible input combinations will be tested in order to determine the optimal design values including:

* Varying PCC layer thickness from 7 to 15 inches.

* Varying depth of granular subbase from 6 to 18 inches.

* Varying transverse joint spacing from 16 to 20 feet.

The minimum pavement slab thickness for construction purposes, as recommended by both AASHTO [2] and the Portland Cement Association [13], is 7 inches. The minimum subbase thickness, which allows a k-static value of 200 pounds per cubic inch [33], is 6 inches. A 4 inch thick permeable asphalt drainage layer will be installed between the pavement slab and granular subbase to facilitate drainage. The maximum number of standard, 18 kip load application allowed for any trial thickness will be chosen as to limit roughness to 170.00 inches per mile and joint faulting to 0.38 inches. Therefore, maintenance requirements will be limited to lower cost treatments such as sealing, patching, grinding, and shimming throughout the analysis period.

Results of the mechanistic analysis performed on the matrix of rigid design alternatives are shown in the following tables and appendices:

* Table R2, Appendix R, shows the initial cost computations for the alternatives to be tested.

* Tables U1 through U8, Appendix U, display the results of economic analysis for each trial concrete slab thickness.

* Tables V1 through V8, Appendix V, forecast the performance of each design alternatives during the analysis period.

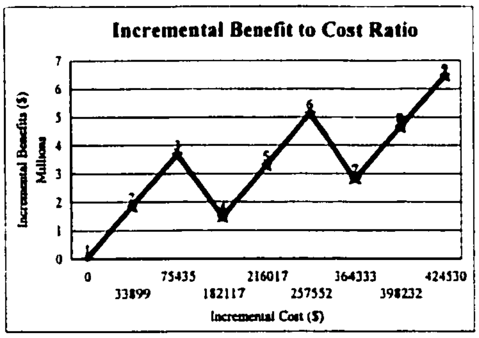
Table 12-3 is a typical sample of the economic analysis performed, illustrating the results for the 8 inch PCC slab thickness trial.

Table 12-3: Sample Economic Analysis - NYSDOT Rigid Pavement Trials.

OUTPUT - INCREMENTAL B/C ANALYSIS (8" PCC)

Alt No.	Agency Cost ($)	User Cost ($)	ncrementa Cost ($)	Incremental Benefit ($)	Incr B/C Ratio	Incr B/C Ratio**
1	3624115	991042106	0	0	---	—
2	3658014	989214739	33899	1827366	53.91	53.91
3	3699550	987387373	41536	1827366	44.00	44.00
4	3806232	989586785	106682	-2199412	-20.62	—
5	3840132	987759419	33899	1827366	53.91	—
6	3881667	985932053	41536	1827366	44.00	7.99
7	3988448	988243413	106781	-2311360	-21.65	—
8	4022347	986416047	33899	1827366	53.91	—
9	4048645	984588681	26298	1827366	69.49	8.05

** Considering viable options.



The table and adjacent plot illustrate the following points:

A. Design alternatives 4, 5, 7, and 8 are not economically feasible based on incremental benefit-to-cost analysis showing that increased investment results in the loss of incurred benefits.

B. Increasing agency investment from alternative 1 to 2 and 2 to 3, by decreasing joint spacing, is economically justified since the increase in agency costs due to additional discounted maintenance costs is outweighed by the additional incurred road user savings.

C. Increasing agency investment from alternative 3 to 6 and 6 to 9, by increasing granular subbase thickness, is also economically justified because the additional costs are outweighed by the projected extra benefits of such action.

D. The alternative which results in the greatest return on investment for this slab thickness is alternative 2, an 8 inch pavement slab with drainage course over 6 inches of granular subbase with transverse joints spaced at 18 feet on center.

The results of economic analysis for all trial thicknesses of rigid pavements yields similar results. Decreasing joint spacing from 20 to 18 feet will slightly increase initial construction costs and future maintenance requirements, but is economically justified due to the magnitude of the incurred benefits. Increasing subbase thickness from 6 to 18 inches is also feasible, but, will not provide as much return on investment as decreasing joint spacing.

Table 12-4 summarizes the results of the mechanistic analysis for the proposed matrix of rigid pavement alternatives. Joint faulting is the governing distress and manifests itself in all trial thicknesses to a point where it must be addressed by the fortieth year of the analysis period, after 40.6 million 18 kip axle loads. Analysis also shows that joint spacing is at the optimal condition; decreasing joint spacing from 60 to 18 feet greatly improves faulting, however, decreasing the spacing to less than 16 feet will result in minimal returns. However, by limiting faulting to year 40, the affects of the discounted maintenance treatment costs have little impact on the total cost optimization for the pavement.

Table 12-4 : NYSDOT Rigid Pavement - Design Optimization.

PCC Thickness (inch)	HMAC Drainage (inch)	Subbase Thickness (inch)	Joint Spacing (feet)	Critical Faulting (Year)	Agency Cost (million $)	User Cost (million $)	Total Cost (million $)	Incr. B/C Ratio
7	4	6	18	40	3.45	992.22	995.67	---
8	4	6	18	40	3.66	989.21	992.87	14.33
9	4	6	18	40	3.87	986.21	990.08	14.29
10	4	6	18	40	4.08	983.21	987.29	14.29
11	4	6	18	40	4.3	980.21	984.51	13.64
12	4	6	18	40	4.51	977.21	981.72	14.29
13	4	6	18	40	4.73	974.2	978.93	13.68
14	4	6	18	40	4.94	971.2	976.14	14.29
15	4	6	18	40	5.15	968.2	973.35	14.29

Figure 12-4A: Total Cost Minimization NYSDOT Rigid Pavement

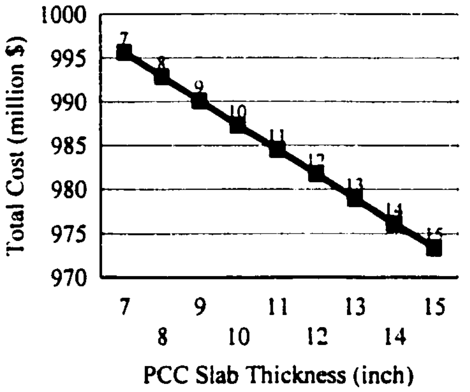
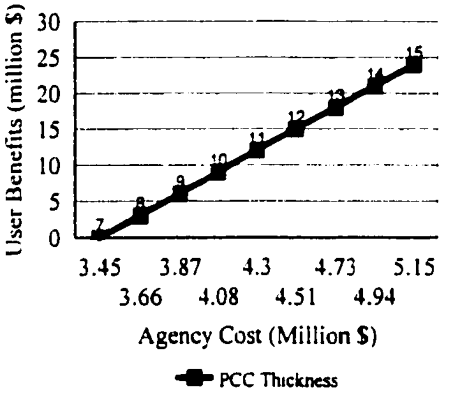


Figure 12-4B: Incremental B/C Analysis NYSDOT Rigid Pavement



For jointed, plain concrete pavements used in New York, the predictive equation for roughness is dependent upon age since construction, not axle loading. As shown in Table V1 through V8, all slab thicknesses limit roughness to below the allowable maximum value of 170 inch per mile. As well, all pavement thicknesses have similar deterioration predictions for both faulting and joint spalling, an indication that joint faulting is not terribly sensitive to changes in slab thickness. Therefore, the choice of rigid pavement thickness shall not be based upon traffic loading, but rather, based upon economic analysis and allowable budget constraints.

Figure 12-4A plots the total cost versus slab thickness for the trial thicknesses of rigid pavements considered. As computed, the total cost is minimized by selecting the thickest available slab thickness. Figure 12-4B illustrates the incremental benefit-to-cost analysis and indicates that, in all cases, increased agency investment is outweighed by the additional benefits which will result from such spending. Quantitatively, both figures may be interpreted to mean that rigid pavement slab thickness may be increased to 30 to 40 inches, to a point where roughness will be reduced to negligible value. At this point of diminishing returns, additional investment to increase pavement thickness would not further improve performance. However, qualitatively, it is known that pavement design, at the project level, is limited by the budgetary constraints governed by network level needs.

Therefore, based on this analysis, New York should revise their present project level catalogue [33] from the present method, which is based solely on axle loading, to a policy where a single design standard is used for rigid pavement regardless of axle loading. Prior to the present design tables [33], New York had utilized a standard thickness of a 9 inch thick, jointed, reinforced, concrete slab over 10 inches of granular subbase for commercial highways and an 8 inch thick, jointed, reinforced, concrete slab over 10 inches of granular subbase for parkways, both, with 60 foot transverse joint spacing. Based upon the completed mechanistic analysis, an 8 inch thick, plain, jointed concrete slab over a 4 inch thick asphalt drainage course and 6 inch granular subbase, with transverse joints spaced at 18 feet, is recommended for all rigid pavement in New York. The 8 inch slab thickness is the minimum required in order to provide enough depth to accommodate the recommended 2 inch diameter transverse dowel with 3 inches of concrete cover above and below the steel. As well, it is recommended that network level policy be revised in order to optimize investment in rigid pavement structures. In order to accomplish this task, a new specification would be developed which would allow the pavement designer to increase rigid pavement thickness for highways which are very high volume or are of particular importance to a region. The increase in spending for these facilities will be offset by the additional incurred benefits resulting from the improved pavement performance.

CHAPTER 13 : CONCLUSIONS AND RECOMMENDATIONS.

13.1 - General Conclusions.

This dissertation advances the pavement design state of the art by demonstrating that existing design procedures used for flexible and rigid highway pavements can be improved by utilizing mechanistic equations to predict life-cycle pavement condition and required maintenance strategies. The major contributions brought forth include the following:

1. Illustrating the utility of the mechanistic models in an improved design methodology.
2. Demonstrating the effects of mechanistic analysis on present flexible and rigid pavement design methods.
3. Demonstrating the utilization of the proposed mechanistic analyses to optimize flexible and rigid pavement design.

The referenced contributions are illustrated by applied case studies of both flexible and rigid pavements in New York State in Chapters 11 and 12.

Utility of Mechanistic Analysis in Pavement Design.

The mechanistic models developed by SHRP [45] are equations that relate pavement strength, mix properties, and environmental conditions to predicted conditions including roughness, rutting, and thermal cracking for flexible structures and roughness, faulting, and spalling for rigid structures. At the stage of data collection and development, SHRP only recommends utilizing these models to improve upon more established design models, such as AASHTO [2], that are utilized by most state highway agencies in North America. However, as demonstrated by the case studies of this dissertation, the use of mechanistic models of roughness and distress is shown to improve design in the following aspects:

A. Forecast pavement performance throughout the design period. This is shown to be an improvement over the present, catalog type AASHTO [2] methodology which fails to predict the pavement condition throughout the design period and its economic impacts.

B. Forecast maintenance needs during the design period. This allows the highway agency greater flexibility in budgetary and policy decisions by enabling the engineer to examine impact of initial design choices against future maintenance needs.

Both of the above mentioned advantages of mechanistic analysis shown in this dissertation, are then combined to develop optimized pavement design tables in terms of life-cycle total costs, the most significant contribution of this dissertation.

Flexible Pavement Design.

The SHRP mechanistic relationships invalidate some of the basic assumptions of standard design procedure regarding flexible pavement. For example, contrary to the impact of layered design theory, the basic assumption underlying the AASHTO procedure, analysis using the SHRP relationships indicates that increasing the thickness of the HMAC layer, without adjusting the mix properties, as in Superpave, will worsen pavement performance by increasing roughness, resulting in greater maintenance requirements and higher user costs. The following points illustrate the results of analysis completed in this dissertation, and how it may be used to alter contemporary design practices and policy decisions:

1. Pavement Thickness versus Axle Loading. Mechanistic analysis illustrates that the present NYSDOT [33][34] design table is inadequate. As per the tables in Chapter 5, the present design catalogue will result in overloading for flexible pavements at higher levels of axle loading as per the excessive roughness exhibited for design alternatives 7 through 10. Based on the analysis completed in Chapter 12, the maximum number of axle loads which can be adequately supported and limit roughness and rutting to acceptable levels is approximately 73 million.

2. Economic Impacts. Economic analysis for the flexible pavement case study in New York State shows that increasing agency spending to increase the initial flexible pavement structure's thickness is not economically justified. As per the economic analysis in Chapter 12, increasing the depth of base material, while slightly improving the pavement's ability to resist deterioration, is not economically feasible.

Rigid Pavement Design.

The application of mechanistic distress relationships may also be used to improve the standard design procedures regarding rigid pavement. These relationships already suggest that increasing the thickness of the pavement slab will decrease predicted roughness and distresses throughout the analysis period for doweled, plain concrete pavement. However, they also indicated that jointed, plain concrete pavement thickness is less dependent upon axle loading than on age of the pavement since construction. This clearly leads to the suggestion that the AASHTO equations may be deficient in considering the effects of environmental conditions. The following points illustrate how this type of analysis may alter design practice:

1. Governing Distress. Mechanistic analysis shows that joint faulting, rather than pavement roughness, is the governing factor limiting rigid pavement design. As per analysis performed in chapters 7 and 12, improvements such as decreasing joint spacing will significantly improve the performance of a rigid pavement, rather than increasing slab thickness. Table 7-5 illustrates how the present New York State catalog may be modified to achieve improved performance. However, as indicated in Table 12-4, as per mechanistic and economic analysis, NYSDOT may be better served by adopting a uniform, minimal design standard for rigid pavement and policy allowing for increasing the pavement thickness for heavily traveled and other important highways where increased thickness will result in an increased return on the agency investment.

2. Conservative Design. Mechanistic analysis confirms that the present methodology in the AASHTO Design Guide [2] produces a conservative design regarding rigid pavement thickness. As shown in the Chapter 11 case study, using the present design table, a slab thickness of 11 inches would be chosen, however, as per mechanistic analysis in Chapters 11 and 12, any of the design trial alternatives would be sufficient to limit roughness to an acceptable value throughout the design period.

3. Economic Impacts. Economic analysis shows that increasing pavement thickness, thereby

increasing agency spending, will produce an economically feasible return on investments. As interpreted from the incremental benefit to cost analysis, although there may be a quantitative optimal design, this design is qualitatively limited by the project's budget.

13.2 - Recommendations.

Based on the results of this analysis, the following would be recommended to NYSDOT:

In respect of flexible pavement design:

1. Revisit the decisions made in the 1993 Design Manual [33] which base flexible pavement thickness on axle loading and soil resilient modulus. The designs selected by using this methodology neither optimize pavement performance nor maximize road user benefits. However, as shown in Table 12-2, mechanistic analysis may be used to predict improved flexible pavement alternatives based on a rational catalogue of increased agency investments to minimize total societal costs, including the agency and road user.
2. Continue to implement Superpave specifications as they will improve performance of asphalt pavement by adjusting mix design to loading and climate conditions.

In respect of rigid pavement design:

1. Revisit the 1993 Design Manual [33] which yields a conservative design in terms of pavement thickness. Mechanistic analysis demonstrates that the pavement thickness may be reduced without compromising performance.
2. Improve load transfer design and decrease joint spacing, the result of which will be better performing and more economical pavements.

More generally, as pavement designers adapt to the use of SHRP-LTPP mechanistic-empirical relationships to specific localities, it is recommended that:

1. In addition to correlation coefficient, the models be evaluated qualitatively for "adequacy" of applicability, in terms of the availability and feasibility of acquiring the data that represent those

independent variables to which the roughness and distress measure are sensitive.

2. Design methodology shift away from the "closed-form" analytical approach of the current AASHTO procedure, to an "open-form" evaluative approach of selected pavement structures, in terms of predicted roughness and distress.
3. Life-cycle cost analysis, considering both agency and road user costs, be integral to the design process.
4. In considering the life-cycle maintenance costs of durable pavement structures, major rehabilitation, such as overlays, be avoided during the analysis period.
5. Benefit-cost ratios and return on investment be used as explicit criteria for determining the subset of feasible pavement structures to be entered into the design catalogues.
6. Spreadsheet models, such as the one developed for this dissertation (Chapter 11), be developed as the analysis procedure for improved design outcomes.

13.3 - General Need For Further Research.

Although the design procedure introduced in this dissertation is sound, a number of additional factors should be resolved before the methodology can be considered complete.

Fatigue Cracking.

Fatigue cracking is considered to be a primary distress for both flexible and rigid pavement structures. It is an important indicator of pavement condition because frequent occurrences of high severity fatigue cracking indicates a failure of the subgrade support and of the pavement structure in general. Initial SHRP-LTPP [45] studies have indicated that many of the test pavement sections are just beginning to exhibit this distress. It is expected that future studies will have adequate data to produce a statistically meaningful mechanistic equation for this distress.

Skid Resistance.

Skid resistance is an important indicator of pavement condition and is directly related to highway safety. Initial studies have proven unfruitful in producing a statistically meaningful model for pavement surface skid resistance. A potential problem is that skid resistance is related to the type of materials used to construct the pavement surface course. Since available paving materials vary widely from region to region, it is difficult to generate a model which accurately predicts skid resistance as a function of loading, climate, or material composition. Some state highway agencies, such as NYSDOT, have conducted their own studies showing which native paving materials are appropriate for use assuming regional loading and environmental conditions.

Maintenance Strategies.

Initial published SHRP [47] studies did not include mechanistic models for pavement maintenance strategies. General pavement studies [44], have commenced to mechanistically quantify the performance of pavement maintenance strategies including crack sealing (rigid pavement), crack filling (flexible pavement), patching, resealing (thin overlay), and structural overlays (thick overlay). Maintenance models will be used to evaluate the performance of selected maintenance strategies and guide agencies in establishing policy relating pavement management decisions on predicted pavement condition and road user costs.

Road User Costs.

The road user costs were calculated based upon past studies [6][19][40]. Analysis in this dissertation proves that changes in pavement design and maintenance policy significantly impact road user costs which are substantial when compared to agency highway spending. Since vehicle operating cost factors are very sensitive, it is beneficial to develop accurate local factors rather than relying on past studies. Although such a study is beyond the scope of this dissertation, it may be feasible at the network level for state highway agencies to implement such research.

NOTES AND COMMENTS:

NOTES AND COMMENTS:

APPENDIX A :

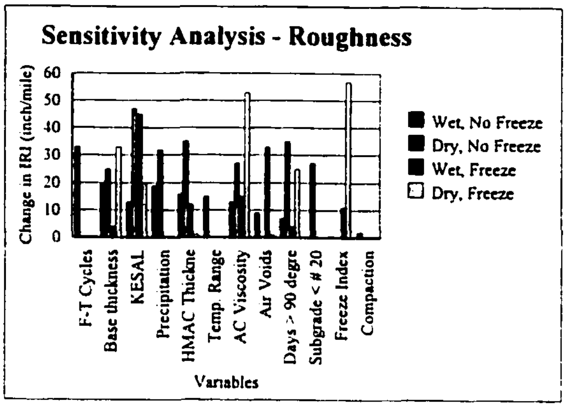
Sensitivity Analysis - Flexible Pavement Equations.

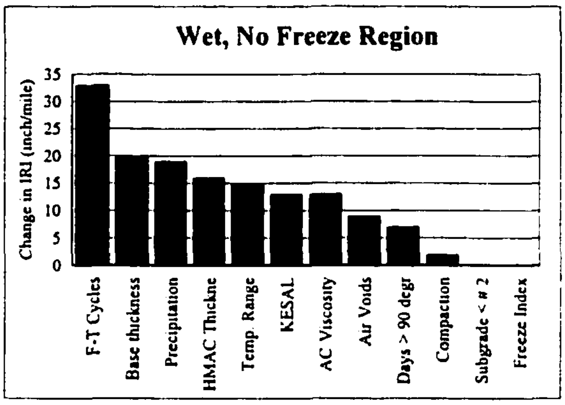
Contents:

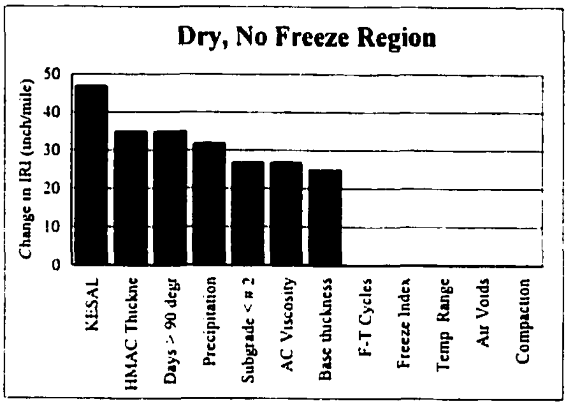
Figure A-1 : Sensitivity Analysis - Flexible Pavement - Roughness.
Figure A-2 : Sensitivity Analysis - Flexible Pavement - Rutting.
Figure A-3 : Sensitivity Analysis - Flexible Pavement - Thermal Cracking.

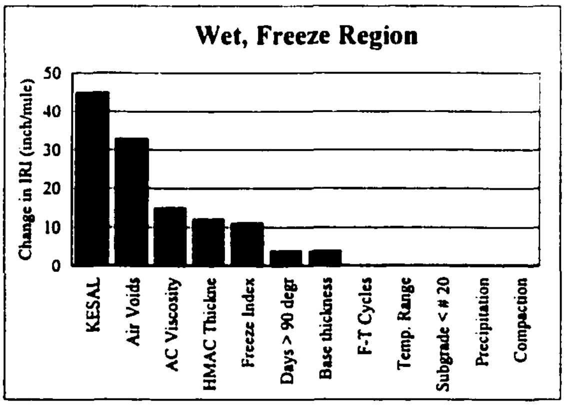
Figure A-1: Sensitivity Analysis - Flexible Pavement - Roughness - Change in IRI (inch/mile).

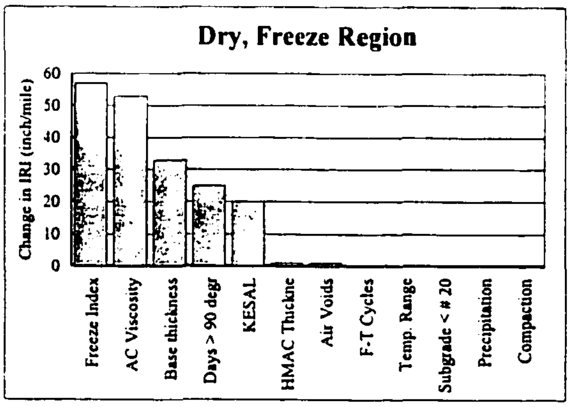
Independent Variable	Wet, No Freeze	Dry, No Freeze	Wet, Freeze	Dry, Freeze
F-T Cycles	33	0	0	0
Base thickness	20	25	4	33
KESAL	13	47	45	20
Precipitation	19	32	0	0
HMAC Thickness	16	35	12	1
Temp. Range	15	0	0	0
AC Viscosity	13	27	15	53
Air Voids	9	0	33	1
Days > 90 degrees	7	35	4	25
Subgrade < # 200	0	27	0	0
Freeze Index	0	0	11	57
Compaction	2	0	0	0







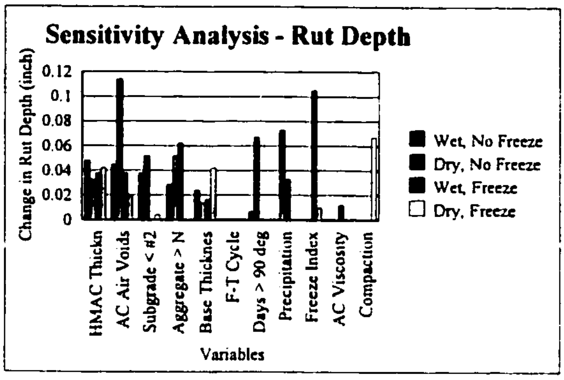


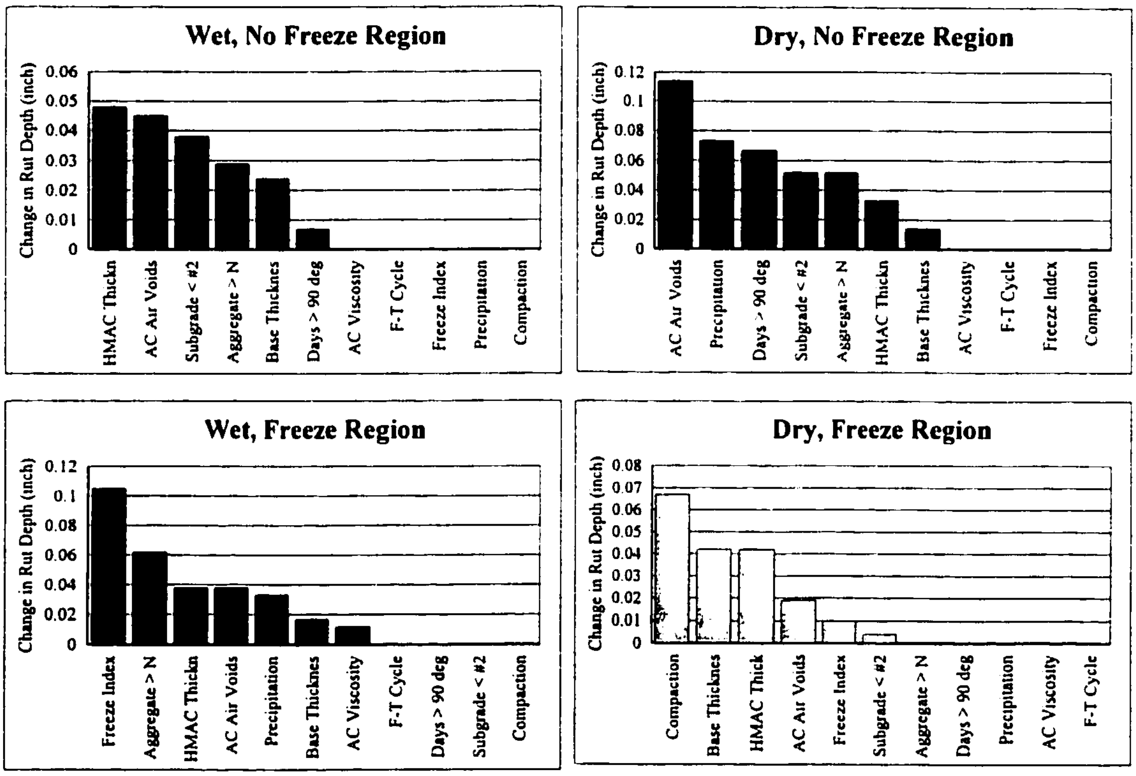


Source : Adapted from SHRP [45].

Figure A-2: Sensitivity Analysis - Flexible Pavement - Rutting - Change in Rut Depth (inch).

Independent Variable	Wet, No Freeze	Dry, No Freeze	Wet, Freeze	Dry, Freeze
HMAC Thickness	0.048	0.033	0.038	0.042
AC Air Voids	0.045	0.114	0.038	0.019
Subgrade < #200	0.038	0.052	0.000	0.004
Aggregate > No4.	0.029	0.052	0.062	0.000
Base Thickness	0.024	0.014	0.017	0.042
F-T Cycle	0.000	0.000	0.000	0.000
Days > 90 degrees	0.007	0.067	0.000	0.000
Precipitation	0.000	0.073	0.033	0.000
Freeze Index	0.000	0.000	0.105	0.010
AC Viscosity	0.000	0.000	0.012	0.000
Compaction	0.000	0.000	0.000	0.067

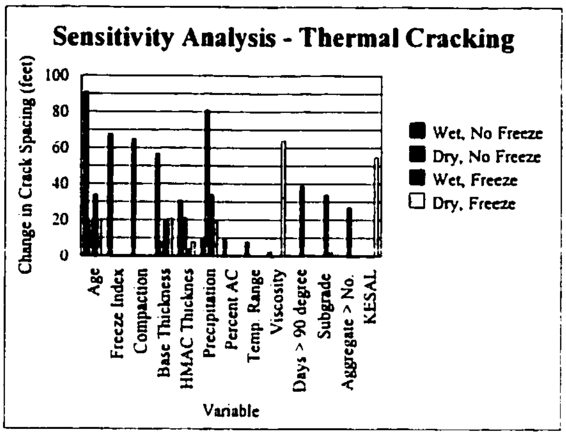


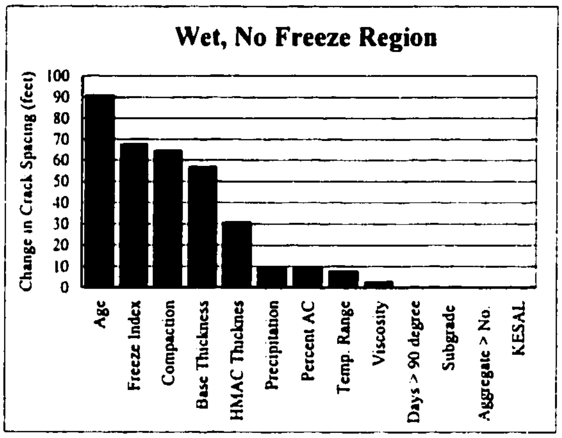


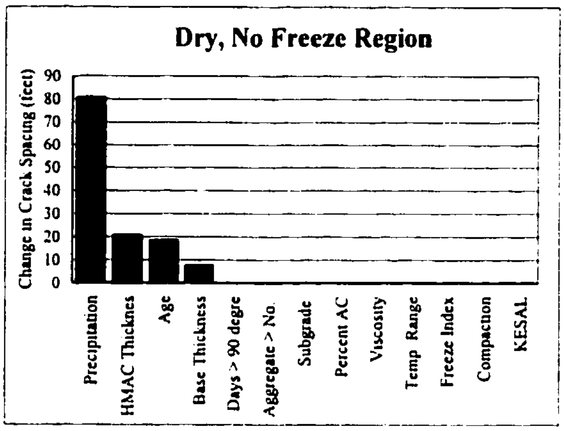
Source : Adapted from SHRP [45].

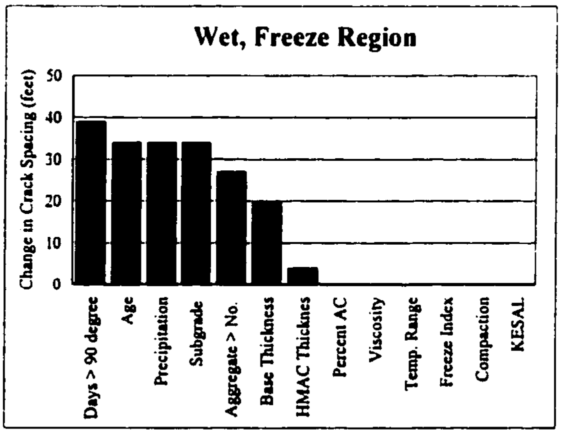
Figure A-3: Sensiivity Analysis - Flexible Pavement - Thermal Cracking - Change in Crack Spacing (feet).

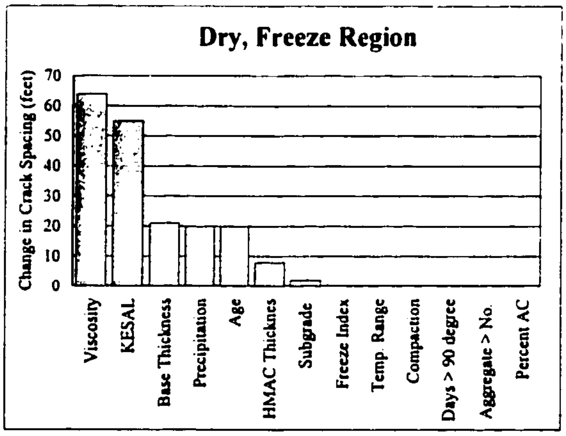
Independent Variable	Wet, No Freeze	Dry, No Freeze	Wet, Freeze	Dry, Freeze
Age	91	19	34	20
Freeze Index	68	0	0	0
Compaction	65	0	0	0
Base Thickness	57	8	20	21
HMAC Thickness	31	21	4	8
Precipitation	10	81	34	20
Percent AC	10	0	0	0
Temp. Range	8	0	0	0
Viscosity	3	0	0	64
Days > 90 degrees	0	0	39	0
Subgrade	0	0	34	2
Aggregate > No. 4	0	0	27	0
KESAL	0	0	0	55











Source : Adapted from SHRP [45].

APPENDIX B :

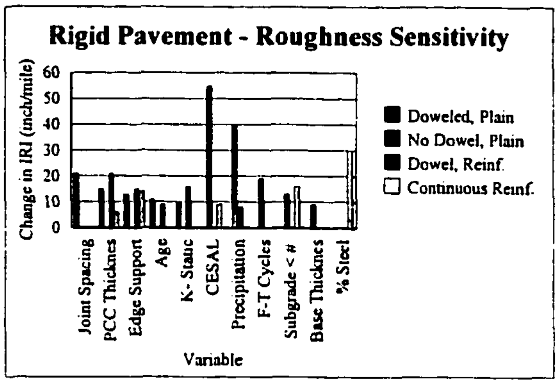
Sensitivity Analysis - Rigid Pavement Equations.

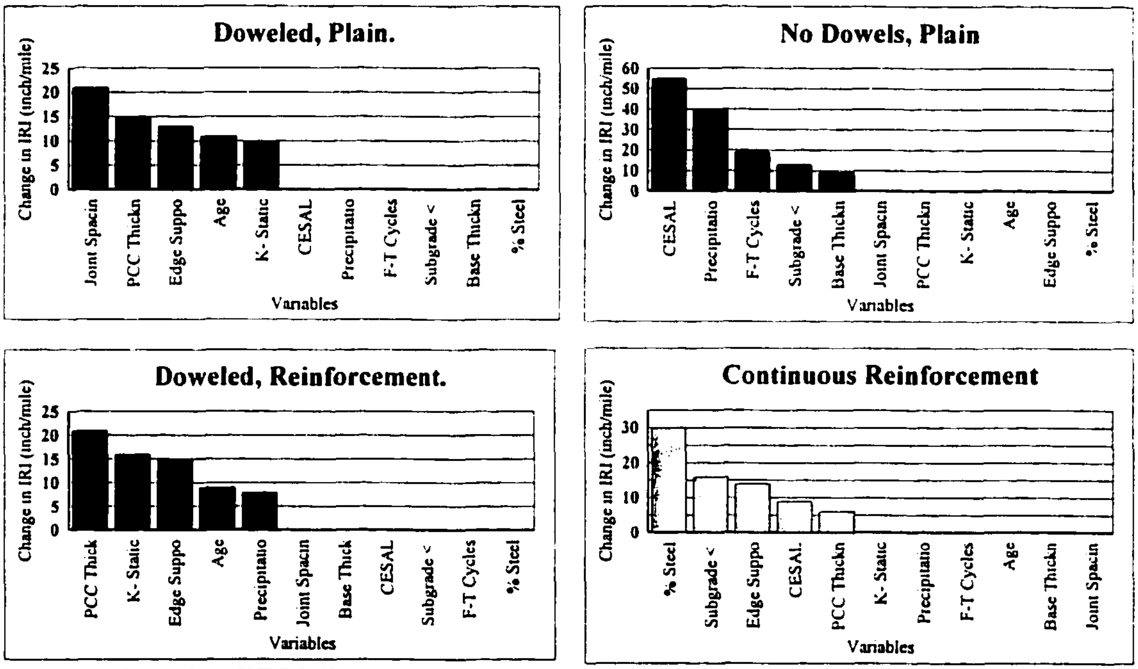
Contents:

Figure B-1 : Sensitivity Analysis - Rigid Pavement - Roughness.
Figure B-2 : Sensitivity Analysis - Rigid Pavement - Joint Faulting.
Figure B-3 : Sensitivity Analysis - Rigid Pavement - Joint Spalling.

Figure B-1 : Sensitivity Analysis : Rigid Pavement - Roughness - Change in IRI (inch/mile).

Independent Variable	Doweled, Plain	No Dowels, Plain	Doweled, W/ Reinf.	Continuous Reinf.
Joint Spacing	21	0	0	0
PCC Thickness	15	0	21	6
Edge Support	13	0	15	14
Age	11	0	9	0
K- Static	10	0	16	0
CESAL	0	55	0	9
Precipitation	0	40	8	0
F-T Cycles	0	19	0	0
Subgrade < # 200	0	13	0	16
Base Thickness	0	9	0	0
% Steel	0	0	0	30

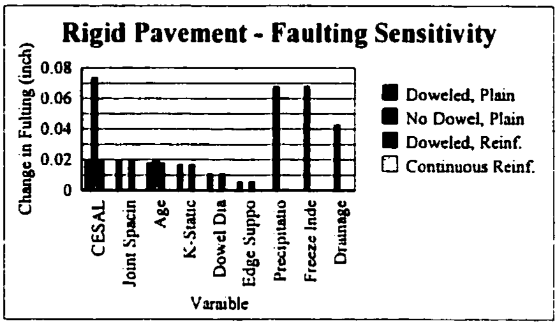


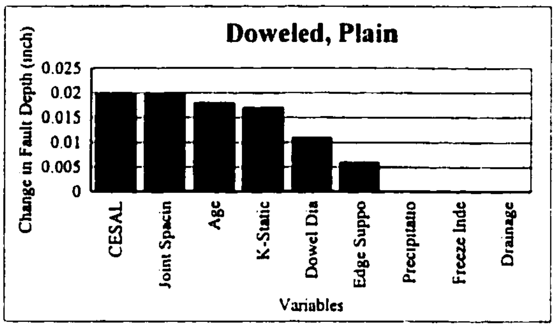


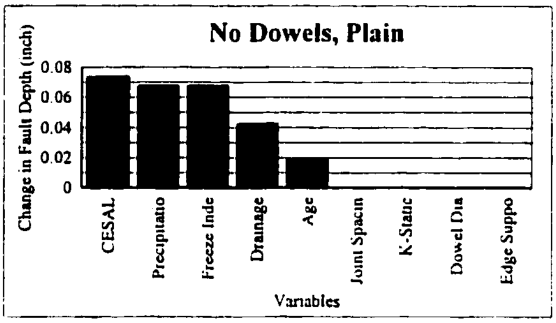
Source : Adapted from SHRP [45].

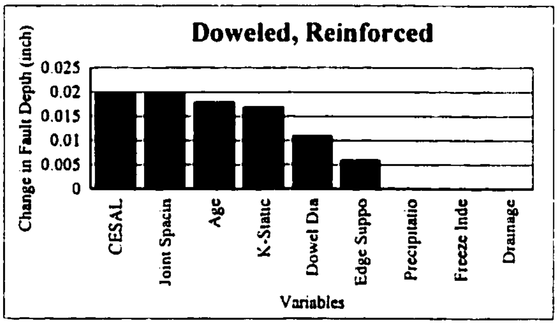
Figure B-2 : Sensitivity Analysis - Rigid Pavement - Joint Faulting - Change in Faulting (inch).

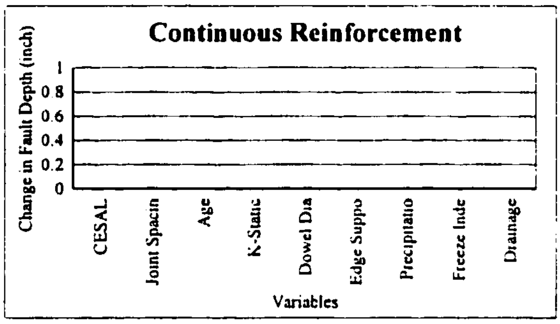
Independent Variable	Doweled, Plain	No Dowels, Plain	Doweled, W/ Reinf.	Continuous Reinf.
CESAL	0.020	0.074	0.020	0.000
Joint Spacing	0.020	0.000	0.020	0.000
Age	0.018	0.020	0.018	0.000
K-Static	0.017	0.000	0.017	0.000
Dowel Diameter	0.011	0.000	0.011	0.000
Edge Support	0.006	0.000	0.006	0.000
Precipitation	0.000	0.068	0.000	0.000
Freeze Index	0.000	0.068	0.000	0.000
Drainage	0.000	0.043	0.000	0.000







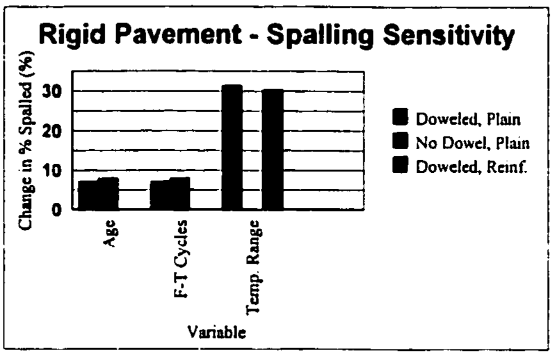


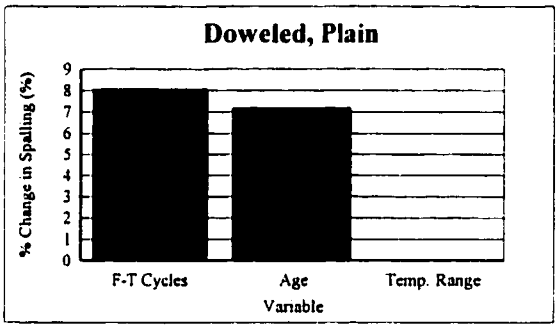


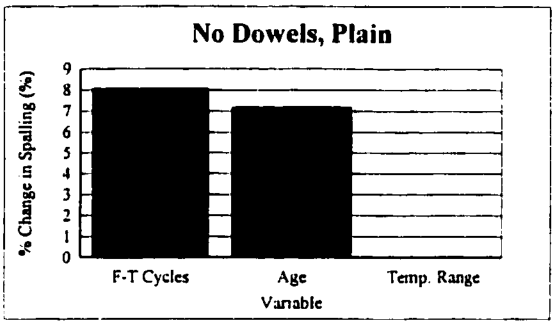
Source : Adapted from SHRP [45].

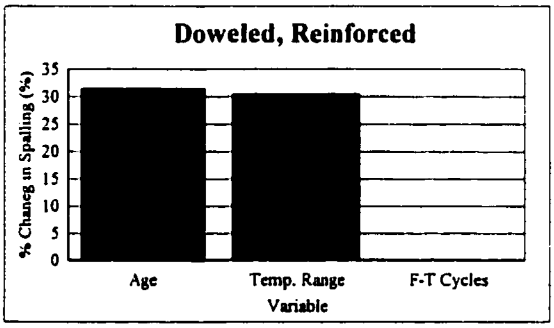
Figure B-3: Sensitivity Analysis - Rigid Pavement - Joint Spalling - Change in Percent Spalls(%).

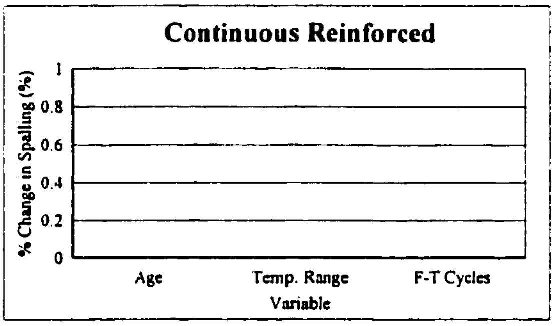
Independent Variable	Doweled, Plain	No Dowels, Plain	Doweled, W/ Reinf.	Continuous Reinf.
Age	7.20	7.20	31.50	0.00
F-T Cycles	8.08	8.08	0.00	0.00
Temp. Range	0.00	0.00	30.50	0.00











Source : Adapted from SHRP [45].

APPENDIX C :

NYSDOT Flexible Pavement Specifications.

Contents:

Table C-1 : NYSDOT Flexible Pavement Specifications - Asphalt Viscosity.
Table C-2 : NYSDOT Flexible Pavement Specifications - HMAC Aggregate Gradation.
Table C-3 : NYSDOT Flexible Pavement Specifications - Subbase Aggregate Gradation.
Table C-4 : NYSDOT Flexible Pavement Specifications - HMAC Asphalt Content.
Table C-5 : NYSDOT Flexible Pavement Specifications - HMAC Air Voids.

Table C-1 : NYSDOT Flexible Pavement Specifications - Asphalt Viscosity.

Asphalt Cement Grade	NYSDOT Material Spec. No.	Minimum Viscosity (Poise)	Maximum Viscosity (Poise)	Mean Viscosity (Poise)	General Use of Asphalt
AC 2.5	702-0100	200	300	250	Recycle Mixes
AC 5.0	702-0200	400	600	500	Extreme Cold Climate
AC 10	702-0300	800	1200	1000	Very Cold Climate
AC 15	702-0400	1200	1800	1600	Moderate Climate
AC 20	702-0500	1600	2400	2000	Standard Mixes.

Source: Adapted from NYSDOT Standard Specifications [31][32].

Table C-2 : NYSDOT Flexible Pavement - HMA Aggregate Gradation.

HMA Type	Minimum Passing No. 4 Sieve (% Weight)	Maximum Passing No. 4 Sieve (% Weight)	Mean Passing No. 4 Sieve (% Weight)	Job Mix Tolerance (% Weight)	NYSDOT General Use Of Mix
1	40	72	56	7	Dense Base
2	5	20	13	6	Open Base
3	48	74	61	7	Dense Binder
5	100	100	100	0	Shim
6F	65	85	75	7	Top (Urban Arterial)
7F	90	100	95	0	Top (One Course)
8F	90	100	95	0	Top (Street w/Curb)
9F	48	64	56	5	Permeable Top

Source : Adapted from NYSDOT Standard Specifications [31][32].

Table C-3 : NYSDOT Flexible Pavement - Subbase Aggregate Gradation.

Subbase Type	Minimum Passing No. 200 Sieve (% Weight)	Maximum Passing No. 200 Sieve (% Weight)	Mean Passing No. 200 Sieve (% Weight)	General Materials
1	0	10	5	Blast slag, stone, sand, gravel.
2	0	10	5	Blast slag, stone
3	0	10	5	Blast slag, stone, sand.
4	0	10	5	Blast slag, stone, sand.

Source: Adapted from NYSDOT Standard Specifications [31][32].

Table C-4 : NYSDOT Flexible Pavement Specifications - HMA Asphalt Content.

Asphalt Type	Minimum Asphalt Content (% Weight)	Maximum Asphalt Content (% Weight)	Mean Asphalt Content (% Weight)	Job Mix Tolerance (% Weight)	General Use
1	4.0	6.4	5.0	0.40	Dense Base
2	2.5	4.5	3.5	0.40	Open Base
3	4.5	6.5	5.5	0.40	Dense Binder
5	7.0	9.5	8.3	0.40	Shim
6F	5.8	7.0	6.4	0.40	Dense Top
7F	6.0	8.0	7.0	0.40	Dense Top
8F	6.2	8.0	7.1	0.40	Dense Top
9F	5.5	7.0	6.3	0.40	Permeable Top

Source: Adapted from NYSDOT Standard Specifications [31][32].

Table C-5 : NYSDOT Flexible Pavement Specifications - HMAC Air Voids.

Asphalt Design Mix Method	Minimum Air Voids (% Volume)	Maximum Air Voids (% Volume)	Mean Air Voids (% Volume)	NYSDOT General Use
Marshall	2.0	4.0	3.0	No adjustments made.
Superpave	2.0	6.0	4.0	Quality adjustment for value closer to 4.0.

Source : Adapted from NYSDOT Standard Specifications [31][32] and EI-98.041 [24].

APPENDIX D :

Lane Distribution For Trucks.

Contents:

Table D-1 Lane Distribution - 4 Lane Highway.
Figure D-1 Lane Distribution - 4 Lane Highway.
Table D-2 Lane Distribution - 6 Lane Highway.
Figure D-2 Lane Distribution - 6 Lane Highway.

Table D-1 Lane Distribution - 4 Lane Highway.

ADT Total (Veh/day)	Left Lane (%)	Right Lane (%)	Log (X)	Log (Y)	Regression Data
4000	6	94	3.602	1.973	
8000	12	88	3.903	1.944	Form:
12000	15	85	4.079	1.929	$y = x^a (10^b)$
16000	18	82	4.204	1.914	
20000	20	80	4.301	1.903	a = -0.105628
30000	23	77	4.477	1.886	b = 2.357387
40000	25	75	4.602	1.875	R^2 = 0.9977668
50000	27	73	4.699	1.863	N = 11
60000	29	71	4.778	1.851	
70000	30	70	4.845	1.845	
80000	31	69	4.903	1.839	
100000	33	67	5.000	1.826	
120000	34	66	5.079	1.820	

Figure D-1: Lane Distribution For Trucks

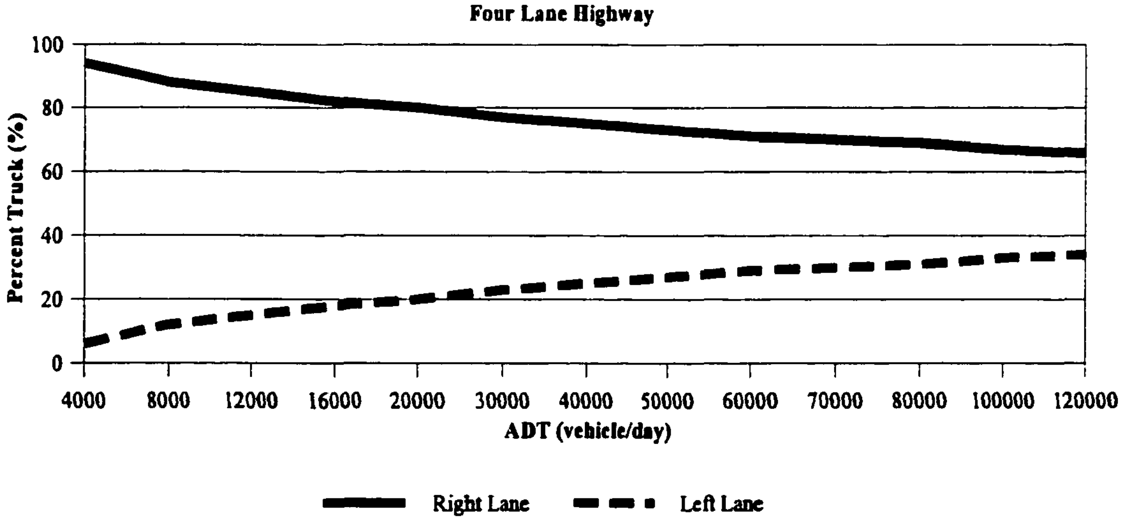
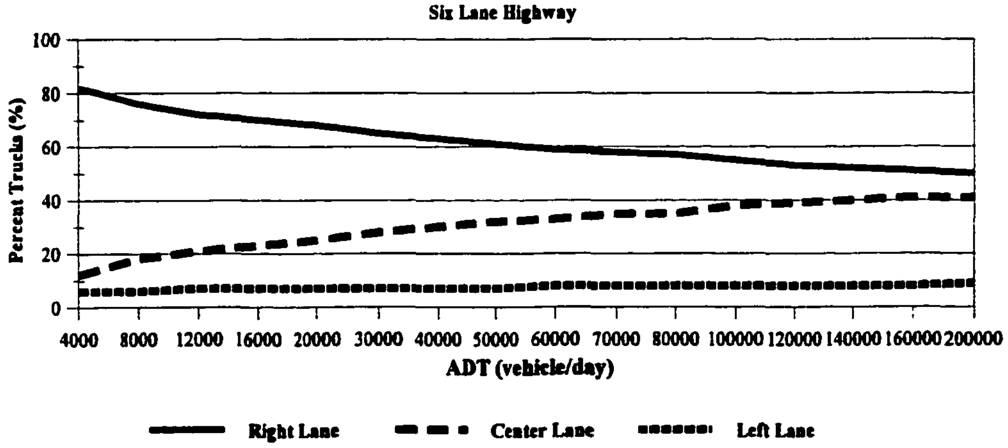


Table D-2 Lane Distribution - 6 Lane Highway.

ADT Total (Veh/day)	Left Lane (%)	Center Lane (%)	Right Lane (%)	Log (X)	Log (Y)	Regression Data
4000	6	12	82	3.602	1.914	
8000	6	18	76	3.903	1.881	Form:
12000	7	21	72	4.079	1.857	$y = x^a (10^b)$
16000	7	23	70	4.204	1.845	
20000	7	25	68	4.301	1.833	a = -0.130035
30000	7	28	65	4.477	1.813	b = 2.389957
40000	7	30	63	4.602	1.799	R^2 = 0.9948281
50000	7	32	61	4.699	1.785	N = 14
60000	8	33	59	4.778	1.771	
70000	8	34	58	4.845	1.763	
80000	8	35	57	4.903	1.756	
100000	8	37	55	5.000	1.736	
120000	8	39	53	5.079	1.724	
140000	8	40	52	5.146	1.716	
160000	8	41	51	5.204	1.708	
200000	9	41	50	5.301	1.699	

Figure D-2: Lane Distribution For Trucks



APPENDIX E :

Flexible Pavement - Predicted Roughness& Distress Data with Improved Design.

Contents:

Table E-1	Flexible Pavement - Predicted Roughness with Improved Mix Design.
Figure E-1	Flexible Pavement - Predicted Roughness.
Table E-2	Flexible Pavement - Predicted Rutting with Improved Mix Design.
Figure E-2	Flexible Pavement - Predicted Rutting.
Table E-3	Flexible Pavement - Predicted Thermal Cracking with Improved Mix Design.
Figure E-3	Flexible Pavement - Predicted Thermal Cracking.

Table E-1: Flexible Pavement - Predicted Roughness (NYSDOT Improved).

Age	HMAC 5" Base 14" (in/mile)	HMAC 6" Base 14" (in/mile)	HMAC 7" Base 14" (in/mile)	HMAC 8" Base 14" (in/mile)	HMAC 9" Base 14" (in/mile)	HMAC 10" Base 14" (in/mile)	HMAC 10" Base 19" (in/mile)	HMAC 10" Base 24" (in/mile)	HMAC 10" Base 29" (in/mile)
5	42.24	46.69	51.76	57.57	62.71	69.89	76.24	82.96	89.79
10	45.31	50.61	56.64	63.54	69.95	78.19	85.74	93.74	101.86
15	47.37	53.23	59.91	67.55	74.31	83.76	92.12	100.97	109.95
20	48.96	55.26	62.44	70.65	77.91	88.07	97.05	106.56	116.21
25	50.28	56.94	64.53	73.21	80.89	91.63	101.12	111.18	121.39
30	51.41	58.38	66.32	75.41	83.45	94.69	104.63	115.15	125.83
35	52.41	59.65	67.91	77.35	85.71	97.39	107.72	118.66	129.76
40	53.31	60.80	69.33	79.09	87.73	99.81	110.49	121.80	133.28
45	54.12	61.84	70.63	80.68	89.58	102.02	113.01	124.66	136.48
50	54.87	62.79	71.82	82.14	91.27	104.05	115.34	127.30	139.43
W_{18}	4.00	8.00	16.00	30.00	50.00	85.00	160.00	290.00	500.00

Notes:

1. Terminal serviceability is 170.00 inches per mile.

Figure E-1: Flexible Pavement (NYSDOT)

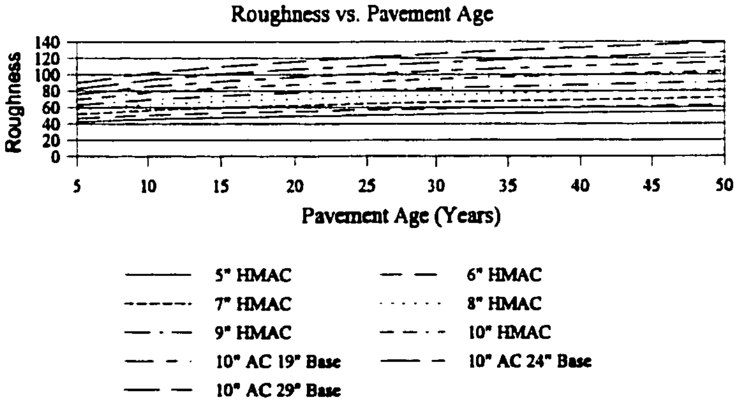


Table E-2: Flexible Pavement - Predicted Rutting (NYSDOT Improved).

Age	HMAC 5" Base 14" (inch)	HMAC 6" Base 14" (inch)	HMAC 7" Base 14" (inch)	HMAC 8" Base 14" (inch)	HMAC 9" Base 14" (inch)	HMAC 10" Base 14" (inch)	HMAC 10" Base 19" (inch)	HMAC 10" Base 24" (inch)	HMAC 10" Base 29" (inch)
5	0.29	0.32	0.35	0.39	0.41	0.45	0.49	0.55	0.59
10	0.32	0.36	0.40	0.44	0.74	0.51	0.56	0.62	0.67
15	0.35	0.39	0.43	0.47	0.51	0.55	0.60	0.67	0.72
20	0.37	0.41	0.45	0.50	0.53	0.57	0.63	0.70	0.76
25	0.38	0.43	0.47	0.52	0.56	0.60	0.66	0.73	0.79
30	0.40	0.44	0.49	0.54	0.57	0.62	0.68	0.76	0.82
35	0.41	0.45	0.50	0.55	0.59	0.64	0.70	0.78	0.84
40	0.42	0.46	0.51	0.56	0.61	0.65	0.72	0.80	0.86
45	0.43	0.47	0.53	0.58	0.62	0.67	0.73	0.82	0.88
50	0.44	0.48	0.54	0.59	0.63	0.68	0.75	0.83	0.90
W_{18}	4.00	8.00	16.00	30.00	50.00	85.00	160.00	290.00	500.00

Notes:

1. Low severity rutting is less than 0.38 inches.
2. High severity rutting is greater than 0.75 inches.

Figure E-2: Flexible Pavement (NYSDOT)

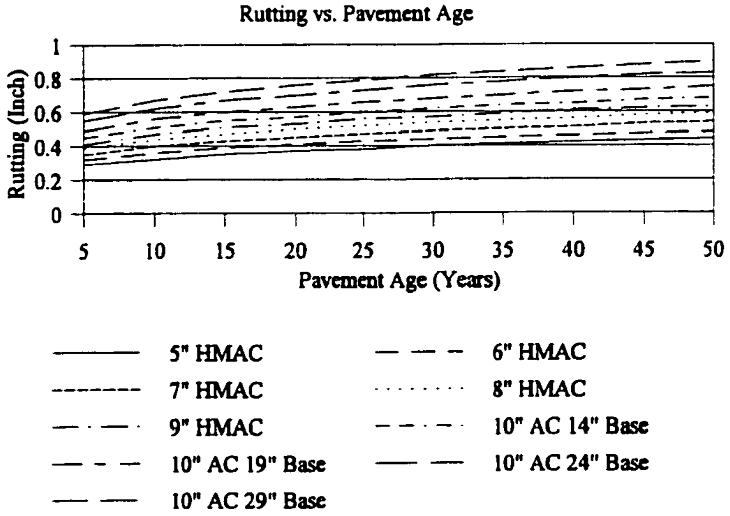


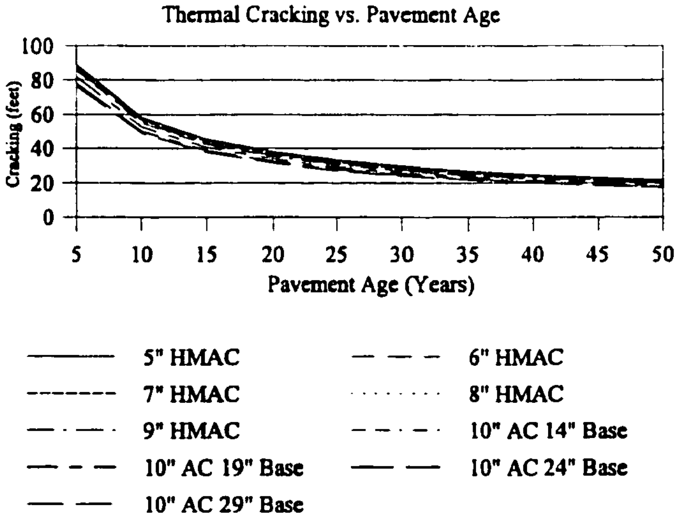
Table E-3: Flexible Pavement - Predicted Thermal Cracking (NYSDOT Improved).

Age	HMAC 5" Base 14" (feet)	HMAC 6" Base 14" (feet)	HMAC 7" Base 14" (feet)	HMAC 8" Base 14" (feet)	HMAC 9" Base 14" (feet)	HMAC 10" Base 14" (feet)	HMAC 10" Base 19" (feet)	HMAC 10" Base 24" (feet)	HMAC 10" Base 29" (feet)
5	89.01	88.44	87.73	87.03	86.33	85.77	81.91	78.23	76.45
10	58.08	57.54	56.89	56.23	55.59	55.08	52.60	50.23	49.09
15	45.24	44.75	44.15	43.56	42.97	42.51	40.60	38.77	37.89
20	37.89	37.44	36.89	36.34	35.80	35.37	33.78	32.26	31.52
25	33.03	32.60	32.08	31.57	31.07	30.67	29.29	27.97	27.33
30	29.52	29.12	28.63	28.15	27.67	27.30	26.07	24.90	24.33
35	26.84	26.47	26.00	25.54	25.09	24.74	23.62	22.56	22.05
40	24.72	24.36	23.92	23.48	23.05	22.71	21.69	20.71	20.24
45	22.99	22.65	22.22	21.80	21.39	21.07	20.12	19.21	18.78
50	21.55	21.21	20.80	20.40	20.01	19.70	18.81	17.96	17.55
W_{18}	4.00	8.00	16.00	30.00	50.00	85.00	160.00	290.00	500.00

Notes:

1. Crack spacing is measured in feet.

Figure E-3: Flexible Pavement (NYSDOT)



APPENDIX F :

Flexible Pavement - Predicted Life Cycle Maintenance Plan with Improved Mix Design.

Contents:

Table F-1 : Flexible Pavement - Life Cycle Maintenance Plan - Case 1.
Table F-2 : Flexible Pavement - Life Cycle Maintenance Plan - Case 2.
Table F-3 : Flexible Pavement - Life Cycle Maintenance Plan - Case 3.
Table F-4 : Flexible Pavement - Life Cycle Maintenance Plan - Case 4.
Table F-5 : Flexible Pavement - Life Cycle Maintenance Plan - Case 5.
Table F-6 : Flexible Pavement - Life Cycle Maintenance Plan - Case 6.
Table F-7 : Flexible Pavement - Life Cycle Maintenance Plan - Case 7.
Table F-8 : Flexible Pavement - Life Cycle Maintenance Plan - Case 8.
Table F-9 : Flexible Pavement - Life Cycle Maintenance Plan - Case 9.

Table F-1: Flexible Pavement: Life Cycle Maintenance Plan - HMAC 5 Inch, Base 14 Inch.

Year	Maintenance Treatment	Predicted Roughness (in/mile)	Predicted Rutting (inch)	Predicted Cracking (feet)	Required Filling (LF/mile)	Required Shimming (ton/mile)	Required Overlay (ton/mile)
0	Initial Construction	---	---	---	---	---	---
5	Crack Filling	42.24	0.29	89.01	712	0	0
10	Filling & Shimming.	45.31	0.32	58.08	1091	63.06	0
15	Crack Filling	47.37	0.35	45.24	1401	0	0
20	Filling & Shimming.	48.96	0.37	37.89	1672	72.92	0
25	Crack Filling	50.28	0.38	33.03	1918	0	0
30	Filling & Shimming.	51.41	0.40	29.52	2146	78.83	0
35	Crack Filling	52.41	0.41	26.84	2361	0	0
40	Filling & Shimming.	53.31	0.42	24.72	2563	82.77	0
45	Crack Filling	54.12	0.43	22.99	2756	0	0
50	End of Service Life	---	---	---	---	---	---

Notes:

1. Single Course Overlay required for high severity rutting (>0.75") else use shimming & patching.
2. 1.5" Single Course Overlay has 15.0 year service life (See Appendix J).

Table F-2: Flexible Pavement: Life Cycle Maintenance Plan - HMAC 6 Inch, Base 14 Inch.

Year	Maintenance Treatment	Predicted Roughness (in/mile)	Predicted Rutting (inch)	Predicted Cracking (feet)	Required Filling (LF/mile)	Required Shimming (ton/mile)	Required Overlay (ton/mile)
0	Initial Construction	---	---	---	---	---	---
5	Crack Filling	46.69	0.32	88.44	716	0	0
10	Filling & Shimming.	50.61	0.36	57.54	1101	70.95	0
15	Crack Filling	53.23	0.39	44.75	1416	0	0
20	Filling & Shimming.	55.26	0.41	37.44	1692	80.80	0
25	Crack Filling	56.94	0.43	32.60	1944	0	0
30	Filling & Shimming.	58.38	0.44	29.12	2176	86.71	0
35	Crack Filling	59.65	0.45	26.47	2394	0	0
40	Filling & Shimming.	60.80	0.46	24.36	2601	90.65	0
45	Crack Filling	61.84	0.47	22.65	2797	0	0
50	End of Service Life	---	---	---	---	---	---

Notes:

1. Single Course Overlay required for high severity rutting (>0.75") else use shimming & patching.
2. 1.5" Single Course Overlay has 15.0 year service life (See Appendix J).

Table F-3: Flexible Pavement: Life Cycle Maintenance Plan - HMAC 7 Inch, Base 14 Inch.

Year	Maintenance Treatment	Predicted Roughness (in/mile)	Predicted Rutting (inch)	Predicted Cracking (feet)	Required Filling (LF/mile)	Required Shimming (ton/mile)	Required Overlay (ton/mile)
0	Initial Construction	---	---	---	---	---	---
5	Crack Filling	51.76	0.35	87.73	722	0	0
10	Filling & Shimming.	56.64	0.40	56.89	1114	78.83	0
15	Crack Filling	59.91	0.43	44.15	1435	0	0
20	Filling & Shimming.	62.44	0.45	36.89	1718	88.68	0
25	Crack Filling	64.53	0.47	32.08	1975	0	0
30	Filling & Shimming.	66.32	0.49	28.63	2213	96.57	0
35	Crack Filling	67.61	0.50	26.00	2437	0	0
40	Filling & Shimming.	69.33	0.51	23.92	649	100.51	0
45	Crack Filling	70.63	0.53	22.22	2851	0	0
50	End of Service Life	---	---	---	---	---	---

Notes:

1. Single Course Overlay required for high severity rutting (>0.75") else use shimming & patching.
2. 1.5" Single Course Overlay has 10.0 year service life (See Appendix J).

Table F-4: Flexible Pavement: Life Cycle Maintenance Plan - HMAC 8 Inch, Base 14 Inch.

Year	Maintenance Treatment	Predicted Roughness (in/mile)	Predicted Rutting (inch)	Predicted Cracking (feet)	Required Filling (LF/mile)	Required Shimming (ton/mile)	Required Overlay (ton/mile)
0	Initial Construction	---	---	---	---	---	---
5	Crack Filling	57.57	0.39	87.03	728	0	0
10	Filling & Shimming.	63.54	0.44	56.23	1127	86.71	0
15	Crack Filling	67.55	0.47	43.56	1455	0	0
20	Filling & Shimming.	70.65	0.50	36.34	1744	98.54	0
25	Crack Filling	73.21	0.52	31.57	2007	0	0
30	Filling & Shimming.	75.41	0.54	28.15	2251	106.42	0
35	Crack Filling	77.35	0.55	25.54	2481	0	0
40	Filling & Shimming.	79.09	0.56	23.48	2698	110.36	0
45	Crack Filling	80.68	0.58	21.80	2906	0	0
50	End of Service Life	---	---	---	---	---	---

Notes:

1. **Single Course Overlay required for high severity rutting (>0.75") else use shimming & patching.**
2. **1.5" Single Course Overlay has 10.0 year service life (See Appendix J).**

Table F-5: Flexible Pavement: Life Cycle Maintenance Plan - HMAC 9 Inch, Base 14 Inch.

Year	Maintenance Treatment	Predicted Roughness (in/mile)	Predicted Rutting (inch)	Predicted Cracking (feet)	Required Filling (LF/mile)	Required Shimming (ton/mile)	Required Overlay (ton/mile)
0	Initial Construction	---	---	---	---	---	---
5	Crack Filling	62.71	0.41	86.33	734	0	0
10	Filling & Shimming.	69.65	0.47	55.59	1140	92.63	0
15	Crack Filling	74.31	0.51	42.97	1475	0	0
20	Filling & Shimming.	77.91	0.53	35.80	1770	104.45	0
25	Crack Filling	80.89	0.56	31.07	2039	0	0
30	Filling & Shimming.	83.45	0.57	27.67	2290	112.33	0
35	Crack Filling	85.71	0.59	25.09	2525	0	0
40	Filling & Shimming.	87.73	0.61	23.05	2749	102.22	0
45	Crack Filling	89.58	0.62	21.39	2962	0	0
50	End of Service Life	---	---	---	---	---	---

Notes:

1. Single Course Overlay required for high severity rutting (>0.75") else use shimming & patching.
2. 1.5" Single Course Overlay has 10.0 year service life (See Appendix J).

Table F-6: Flexible Pavement: Life Cycle Maintenance Plan - HMAC 10 In., Base 14 In..

Year	Maintenance Treatment	Predicted Roughness (in/mile)	Predicted Rutting (inch)	Predicted Cracking (feet)	Required Filling (LF/mile)	Required Shimming (ton/mile)	Required Overlay (ton/mile)
0	Initial Construction	---	---	---	---	---	---
5	Crack Filling	69.89	0.45	85.77	739	0	0
10	Filling & Shimming.	78.19	0.51	55.08	1150	100.51	0
15	Crack Filling	83.76	0.55	42.51	1490	0	0
20	Filling & Shimming.	88.07	0.57	35.37	1791	112.33	0
25	Crack Filling	91.63	0.60	30.67	2066	0	0
30	Filling & Shimming.	94.69	0.62	27.30	2321	122.19	0
35	Crack Filling	97.39	0.64	24.74	2561	0	0
40	Filling & Shimming.	99.81	0.65	22.71	2790	128.10	0
45	Crack Filling	102.02	0.67	21.07	3007	0	0
50	End of Service Life	---	---	---	---	---	---

Notes:

1. Single Course Overlay required for high severity rutting (>0.75") else use shimming & patching.
2. 1.5" Single Course Overlay has 10.0 year service life (See Appendix J).

Table F-7: Flexible Pavement: Life Cycle Maintenance Plan - HMAC 10 In., Base 19 In..

Year	Maintenance Treatment	Predicted Roughness (in/mile)	Predicted Rutting (inch)	Predicted Cracking (feet)	Required Filling (LF/mile)	Required Shimming (ton/mile)	Required Overlay (ton/mile)
0	Initial Construction	—	—	—	—	—	—
5	Crack Filling	76.24	0.49	81.91	774	0	0
10	Filling & Shimming.	85.74	0.56	52.60	1205	110.36	0
15	Crack Filling	92.12	0.60	40.60	1561	0	0
20	Filling & Shimming.	97.05	0.63	33.78	1876	124.16	0
25	Crack Filling	101.12	0.66	29.29	2163	0	0
30	Filling & Shimming.	104.63	0.68	26.07	2430	134.01	0
35	Crack Filling	107.72	0.70	23.62	2682	0	0
40	Filling & Shimming.	110.49	0.72	21.69	2921	141.89	0
45	Crack Filling	113.01	0.73	20.12	3149	0	0
50	End of Service Life	—	—	—	—	—	—

Notes:

1. Single Course Overlay required for high severity rutting (>0.75") else use shimming & patching.
2. 2.0" Single Course Overlay has 10.0 year service life (See Appendix J).

Table F-8: Flexible Pavement: Life Cycle Maintenance Plan - HMAC 10 In., Base 24 In..

Year	Maintenance Treatment	Predicted Roughness (in/mile)	Predicted Rutting (inch)	Predicted Cracking (feet)	Required Filling (LF/mile)	Required Shimming (ton/mile)	Required Overlay (ton/mile)
0	Initial Construction	—	—	—	—	—	—
5	Crack Filling	82.69	0.55	78.23	810	0	0
10	Filling & Shimming.	93.74	0.62	50.23	1261	122.19	0
15	Crack Filling	100.97	0.67	38.77	1634	0	0
20	Filling & Shimming.	106.56	0.70	32.26	1964	137.95	0
25	Crack Filling	111.18	0.73	27.97	2265	0	0
30	Filling & 2" Overlay.	115.15	0.76	24.90	2545	149.78	568.26
35	Crack Filling	118.66	0.78	22.56	2809	0	0
40	Filling & 2" Overlay.	121.80	0.80	20.71	3059	157.66	568.26
45	Crack Filling	124.66	0.82	19.21	3298	0	0
50	End of Service Life	—	—	—	—	—	—

Notes:

1. Single Course Overlay required for high severity rutting (>0.75") else use shimming & patching.
2. 2.0" Single Course Overlay has 10.0 year service life (See Appendix J).

Table F-9: Flexible Pavement: Life Cycle Maintenance Plan - HMAC 10 In., Base 29 In..

Year	Maintenance Treatment	Predicted Roughness (in/mile)	Predicted Rutting (inch)	Predicted Cracking (feet)	Required Filling (LF/mile)	Required Shimming (ton/mile)	Required Overlay (ton/mile)
0	Initial Construction	---	---	---	---	---	---
5	Crack Filling	89.79	0.59	76.45	829	0	0
10	Filling & Shimming.	101.86	0.67	49.09	1291	132.04	0
15	Crack Filling	109.95	0.72	37.89	1672	0	0
20	Fill & 2.5" Overlay.	116.21	0.76	31.52	2010	149.78	568.26
25	Crack Filling	121.39	0.79	27.33	2318	0	0
30	Fill & 2.5" Overlay.	125.38	0.82	24.33	2604	161.60	568.26
35	Crack Filling	126.76	0.84	22.05	2873	0	0
40	Fill & 2.5" Overlay.	133.28	0.86	20.24	3130	169.49	568.26
45	Crack Filling	136.48	0.88	18.78	3374	0	0
50	End of Service Life	---	---	---	---	---	---

Notes:

1. Single Course Overlay required for high severity rutting (>0.75") else use shimming & patching.
2. 2.5" Single Course Overlay has 10.0 year service life (See Appendix J).

APPENDIX G :

Rigid Pavement - Predicted Roughness& Distress Data with Improved Design.

Contents:

Table G-1 Rigid Pavement - Predicted Roughness with Improved Design.
Figure G-1 Rigid Pavement - Predicted Roughness.
Table G-2 Rigid Pavement - Predicted Joint Faulting with Improved Design.
Figure G-2 Rigid Pavement - Predicted Joint Faulting.
Table G-3 Rigid Pavement - Predicted Joint Spalling with Improved Design.
Figure G-3 Rigid Pavement - Predicted Joint Spalling.

Table G-1: Rigid Pavement - Predicted Roughness (Improved NYSDOT Design).

Age	PCC Slab Thickness 8 Inch (in/mile)	PCC Slab Thickness 9 Inch (in/mile)	PCC Slab Thickness 10 Inch (in/mile)	PCC Slab Thickness 11 Inch (in/mile)	PCC Slab Thickness 12 Inch (in/mile)	PCC Slab Thickness 13 Inch (in/mile)
5	101.06	93.93	86.80	79.67	72.54	65.41
10	105.03	97.90	90.77	83.64	76.51	69.38
15	109.01	101.88	94.75	87.62	80.49	73.36
20	112.98	105.85	98.72	91.59	84.46	77.33
25	116.96	109.83	102.70	95.57	88.44	81.31
30	120.93	113.80	106.67	99.54	92.41	85.28
35	124.91	117.78	110.65	103.52	96.39	89.26
40	128.88	121.75	114.62	107.49	100.36	93.23
45	132.86	125.73	118.60	111.47	104.34	97.21
50	136.83	129.70	122.57	115.44	108.31	101.18

Note:

1. Terminal serviceability is 170.00 inch/mile.

Figure G-1: Rigid Pavement (NYSDOT)

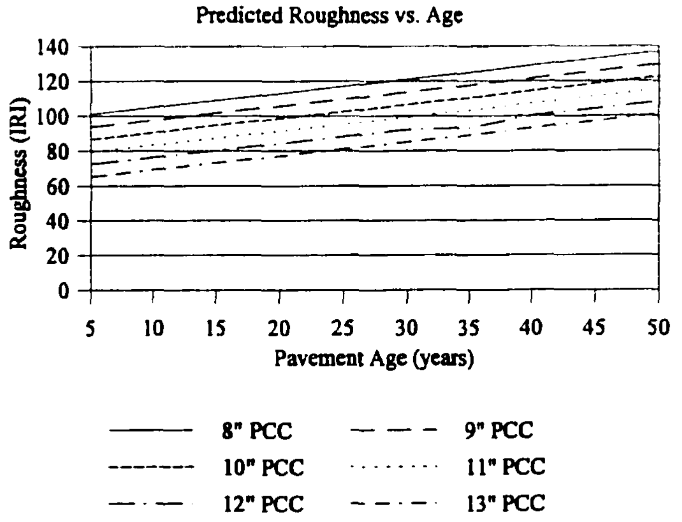


Table G-2: Rigid Pavement - Predicted Joint Faulting (Improved NYSDOT Design).

Age	PCC Slab Thickness 8 Inch (inch)	PCC Slab Thickness 9 Inch (inch)	PCC Slab Thickness 10 Inch (inch)	PCC Slab Thickness 11 Inch (inch)	PCC Slab Thickness 12 Inch (inch)	PCC Slab Thickness 13 Inch (inch)
5	0	0	0	0	0	0
10	0	0	0	0	0	0
15	0	0	0	0	0	0
20	0	0	0	0	0	0
25	0.01	0.01	0.01	0.01	0.01	0.01
30	0.03	0.04	0.04	0.05	0.05	0.06
35	0.06	0.07	0.08	0.09	0.11	0.12
40	0.10	0.11	0.13	0.15	0.17	0.18
45	0.14	0.16	0.19	0.22	0.25	0.27
50	0.19	0.22	0.26	0.29	0.34	0.36

Note:

1. Critical faulting, effecting roughness, is greater than 0.19 inches.

Figure G-2: Rigid Pavement (NYSDOT)

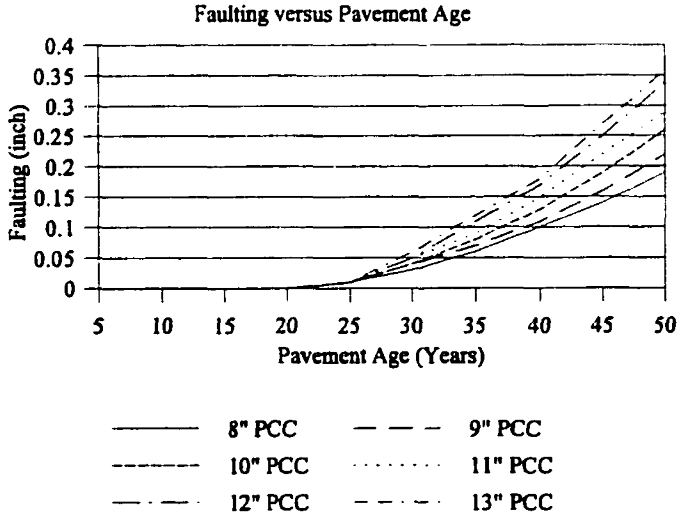


Table G-3: Rigid Pavement - Predicted Joint Spalling (Improved NYSDOT Design).

Age	PCC Slab Thickness 8 Inch (%Joints)	PCC Slab Thickness 9 Inch (% Joints)	PCC Slab Thickness 10 Inch (% Joints)	PCC Slab Thickness 11 Inch (% Joints)	PCC Slab Thickness 12 Inch (% Joints)	PCC Slab Thickness 13 Inch (% Joints)
5	1.58	1.58	1.58	1.58	1.58	1.58
10	2.66	2.66	2.66	2.66	2.66	2.66
15	3.75	3.75	3.75	3.75	3.75	3.75
20	4.84	4.84	4.84	4.84	4.84	4.84
25	5.92	5.92	5.92	5.92	5.92	5.92
30	7.01	7.01	7.01	7.01	7.01	7.01
35	8.10	8.10	8.10	8.10	8.10	8.10
40	9.18	9.18	9.18	9.18	9.18	9.18
45	10.27	10.27	10.27	10.27	10.27	10.27
50	11.36	11.36	11.36	11.36	11.36	11.36

Note:

1. Model predicts medium to high severity spalling only.

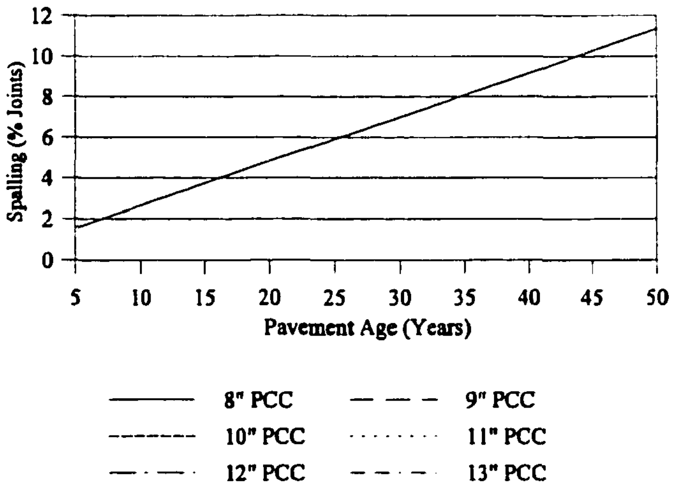


Figure G-3: Rigid Pavement (NYSDOT)

Predicted Spalling vs. Pavement Age

APPENDIX H :

Rigid Pavement - Predicted Life Cycle Maintenance Plan with Improved Design.

Contents:

Table H-1 : Rigid Pavement - Life Cycle Maintenance Plan - PCC Slab Thickness 8 Inches.
Table H-2 : Rigid Pavement - Life Cycle Maintenance Plan - PCC Slab Thickness 9 Inches.
Table H-3 : Rigid Pavement - Life Cycle Maintenance Plan - PCC Slab Thickness 10 Inches.
Table H-4 : Rigid Pavement - Life Cycle Maintenance Plan - PCC Slab Thickness 11 Inches.
Table H-5 : Rigid Pavement - Life Cycle Maintenance Plan - PCC Slab Thickness 12 Inches.
Table H-6 : Rigid Pavement - Life Cycle Maintenance Plan - PCC Slab Thickness 13 Inches.

Table H-1: Rigid Pavement: Life Cycle Maintenance - PCC Slab Thickness 8 Inches.

Year	Maintenance Treatment	Predicted Rough. (in/mile)	Predicted Faulting (inch)	Predicted Spalling (%Joint)	Required Sealing (LF/mile)	Required Grinding (SF/mile)	Required Patching (SF/mile)	Required Overlay (SF/mile)
0	Initial Const.	---	---	---	---	---	---	---
10	Seal Joints & Spalls	105.03	0.00	2.66	14520	0	105.34	0
20	Seal Joints & Spalls	112.98	0.00	4.84	14520	0	191.66	0
30	Seal Joints & Spalls	120.93	0.03	7.01	14520	0	277.60	0
40	Seal Joints & Spalls	128.88	0.10	9.18	14520	0	363.55	0
50	End of Service Life	136.83	0.19	11.36	---	---	---	---

Note:
1. Grinding is required if faulting is greater than 0.19 inches, overlay required if faulting is greater than 0.75 inches.

Table H-2: Rigid Pavement: Life Cycle Maintenance - PCC Slab Thickness 9 Inches.

Year	Maintenance Treatment	Predicted Rough. (in/mile)	Predicted Faulting (inch)	Predicted Spalling (%Joint)	Required Sealing (LF/mile)	Required Grinding (SF/mile)	Required Patching (SF/mile)	Required Overlay (SF/mile)
0	Initial Const.	---	---	---	---	---	---	---
10	Seal Joints & Spalls	97.90	0.00	2.66	14520	0	105.34	0
20	Seal Joints & Spalls	105.85	0.00	4.84	14520	0	191.66	0
30	Seal Joints & Spalls	113.80	0.04	7.01	14520	0	277.60	0
40	Seal Joints & Spalls	121.75	0.11	9.18	14520	0	363.53	0
50	End of Service Life	129.70	0.22	11.36	---	---	---	---

Note:
1. Grinding is required if faulting is greater than 0.19 inches, overlay required if faulting is greater than 0.75 inches.

Table H-3: Rigid Pavement: Life Cycle Maintenance - PCC Slab Thickness 10 Inches.

Year	Maintenance Treatment	Predicted Rough. (in/mile)	Predicted Faulting (inch)	Predicted Spalling (%Joint)	Required Sealing (LF/mile)	Required Grinding (SF/mile)	Required Patching (SF/mile)	Required Overlay (SF/mile)
0	Initial Const.	---	---	---	---	---	---	---
10	Seal Joints & Spalls	90.77	0.00	2.66	14520	0	105.34	0
20	Seal Joints & Spalls	98.72	0.00	4.84	14520	0	191.66	0
30	Seal Joints & Spalls	106.67	0.04	7.01	14520	0	277.60	0
40	Seal Joints & Spalls	114.62	0.13	9.18	14520	0	363.55	0
50	End of Service Life	122.57	0.26	11.36	---	---	---	---

Note:

1. Grinding is required if faulting is greater than 0.19 inches, overlay required if faulting is greater than 0.75 inches.

Table H-4: Rigid Pavement: Life Cycle Maintenance - PCC Slab Thickness 11 Inches.

Year	Maintenance Treatment	Predicted Rough. (in/mile)	Predicted Faulting (inch)	Predicted Spalling (%Joint)	Required Sealing (LF/mile)	Required Grinding (SF/mile)	Required Patching (SF/mile)	Required Overlay (SF/mile)
0	Initial Const.	---	---	---	---	---	---	---
10	Seal Joints & Spalls	83.64	0.00	2.66	14520	0	105.34	0
20	Seal Joints & Spalls	91.59	0.00	4.84	14520	0	191.66	0
30	Seal Joints & Spalls	99.54	0.05	7.01	14520	0	277.60	0
40	Seal Joints & Spalls	107.49	0.15	9.18	14520	0	363.55	0
45	Grind & Reseal.	111.47	0.22	10.27	14520	7920.00	0.00	0
50	End of Service Life	115.44	0.29	11.36	---	---	---	---

Note:

1. Grinding is required if faulting is greater than 0.19 inches, overlay required if faulting is greater than 0.75 inches.

Table H-5: Rigid Pavement: Life Cycle Maintenance - PCC Slab Thickness 12 Inches.

Year	Maintenance Treatment	Predicted Rough. (in/mile)	Predicted Faulting (inch)	Predicted Spalling (%Joint)	Required Sealing (LF/mile)	Required Grinding (SF/mile)	Required Patching (SF/mile)	Required Overlay (SF/mile)
0	Initial Const.	---	---	---	---	---	---	---
10	Seal Joints & Spalls	76.51	0.00	2.66	14520	0	105.34	0
20	Seal Joints & Spalls	84.46	0.00	4.84	14520	0	191.66	0
30	Seal Joints & Spalls	92.41	0.05	7.01	14520	0	277.60	0
40	Seal Joints & Spalls	100.36	0.17	9.18	14520	0	363.55	0
45	Grind & Reseal	104.34	0.25	10.27	14520	7920.00	0..00	0
50	End of Service Life	108.31	0.34	11.36	---	---	---	---

Note:

1. Grinding is required if faulting is greater than 0.19 inches, overlay required if faulting is greater than 0.75 inches.

Table H-6: Rigid Pavement: Life Cycle Maintenance - PCC Slab Thickness 13 Inches.

Year	Maintenance Treatment	Predicted Rough. (in/mile)	Predicted Faulting (inch)	Predicted Spalling (%Joint)	Required Sealing (LF/mile)	Required Grinding (SF/mile)	Required Patching (SF/mile)	Required Overlay (SF/mile)
0	Initial Const.	---	---	---	---	---	---	---
10	Seal Joints & Spalls	69.38	0.00	2.66	14520	0	105.34	0
20	Seal Joints & Spalls	77.33	0.00	4.84	14520	0	191.66	0
30	Seal Joints & Spalls	85.28	0.06	7.01	14520	0	277.60	0
40	Seal, Spalls & Grind	93.23	0.19	9.18	14520	7920.00	363.55	0
45	Grind & Reseal	97.21	0.27	10.27	14520	7920.00	0.00	0
50	End of Service Life	101.18	0.36	11.36	---	---	---	---

APPENDIX I :

Predicted Service Life - One Course HMAC Overlay - Rigid Pavement.

Contents:
Table I-1 : Predicted Service Life - One Course HMAC Overlay - Rigid Pavement.
Computation Sheets - One Course HMAC Overlay - Rigid Pavement.

Table I-1 : Predicted Service Life - One Course HMAC Overlay - Rigid Pavement.

Case No.	PCC Slab Depth (Inch)	Perm. Base Depth (Inch)	Subbase Course Depth (Inch)	SNy	Allowable Load (Million ESAL)	Annual Load (Million ESAL)	Predicted Service Life (Years)
1	8	4	12	6.04	7.20	0.70	10
2	9	4	12	6.55	13.80	1.30	11
3	10	4	12	7.05	24.50	2.50	10
4	11	4	12	7.55	42.60	4.40	10
5	12	4	12	8.06	74.10	7.60	10
6	13	4	12	8.56	123.00	10.00	12

Source: AASHTO [2], Huang [13], NYSDOT [33][34].

Computation Sheet - One Course HMAC Overlay - Rigid Pavement.

AASHTO [2] Design Equation

$h_{OL} = \{SN_y - F_{RL}\,(0.8D_x + Sn_{x\text{-}rp})\} \,/\, a_{OL}$

* $h_{OL} = 2$ inches	Proposed one course overlay thickness.
* $a_{OL} = 0.42$	Layer Coefficient (Source: NYSDOT [33][34])
* F_{RL}	Remaining Life Factor
* D_x	Effective depth of existing concrete pavement.
* $Sn_{x\text{-}rp}$	Effective strength of existing subbase layer.

Effective Strength of Existing Subbase Layer

$SN_{x\text{-}rp} = a_{SB} * d_{SB} * m_{SB}$

* $a_{SB} = 0.12$	Subbase layer coefficient (Source: NYSDOT [33]).
* $d_{SB} = 12.0$	Depth of subbase course (Source: NYSDOT [33]).
* $m_{SB} = 0.90$	Subbase drainage coefficient (Source: NYSDOT [33]).

$SN_{x\text{-}rp} = (0.12)(12)(0.90) = 1.30$

Effective Depth of Existing Concrete Pavement

$D_x = D_o * C_x$

* $D_o = 8$ to 13	Depth of concrete pavement (Varies from 8 to 13 inches) (Source : NYSDOT [33]).
* $C_x = 0.70$	Structural condition factor (Source : AASHTO [2]).

$D_x = 0.70(\,D_o)$

Remaining Life Factor.

$F_{RL} = f\,(R_{LX}, R_{LY})$

$R_{LX} = 10\%$	Source : AASHTO [2].
$R_{LY} = 85\%$	Source : AASHTO [2].
$F_{RL} = 0.90$	Source : AASHTO [2].

Derived Formula:

$SN_Y = h_{OL} * a_{OL} + F_{RL}\,(0.8\,D_x + SN_{x\text{-}rp})$

$SN_Y = 2(0.42) + 0.90\,(0.8(0.7D_o\,) + 1.30)$

$SN_Y = 2.01 + 0.504\,D_o$

APPENDIX J :

Predicted Service Life - One Course HMAC Overlay - Flexible Pavement.

Contents:

Table J-1 : Predicted Service Life - 1.5 Inch HMAC Overlay - Flexible Pavement.
Table J-2 : Predicted Service Life - 2.0 Inch HMAC Overlay - Flexible Pavement.
Table J-3 : Predicted Service Life - 2.5 Inch HMAC Overlay - Flexible Pavement.
Computation Sheet - One Course HMAC Overlay - Flexible Pavement.

Table J-1 : Predicted Service Life - 1.5 Inch HMAC Overlay - Flexible Pavement.

Case No.	HMA Layer Depth (Inch)	Perm. Base Depth (Inch)	Sub. Course Depth (Inch)	Select Fill Depth (Inch)	SNx-eff	SNy	Allowed Load (Million ESAL)	Annual Load (Million ESAL)	Predict. Service Life (Years)
1	5	4	12	0	5.07	3.67	1.48	0.08	19
2	6	4	12	0	5.60	3.99	2.56	0.16	16
3	7	4	12	0	6.12	4.30	4.31	0.32	13
4	8	4	12	0	6.65	4.62	7.06	0.60	12
5	9	4	12	0	7.17	4.93	11.32	1.00	11
6	10	4	12	0	7.70	5.25	17.82	1.70	10
7	10	4	12	6	8.24	5.57	27.88	3.20	9
8	10	4	12	12	8.78	5.90	42.89	5.80	7
9	10	4	12	18	9.32	6.22	64.89	10.00	6

Source : Adapted from AASHTO [2], Huang [13], NYSDOT [33][34].

Table J-2 :Predicted Service Life - 2.0 Inch HMAC Overlay - Flexible Pavement.

Case No.	HMA Layer Depth (Inch)	Perm. Base Depth (Inch)	Sub. Course Depth (Inch)	Select Fill Depth (Inch)	SNx-eff	SNy	Allowed Load (Million ESAL)	Annual Load (Million ESAL)	Predict. Service Life (Years)
1	5	4	12	0	5.07	3.88	2.14	0.08	27
2	6	4	12	0	5.60	4.20	3.63	0.16	23
3	7	4	12	0	6.12	4.51	6.00	0.32	19
4	8	4	12	0	6.65	4.83	9.69	0.60	16
5	9	4	12	0	7.17	5.14	15.35	1.00	15
6	10	4	12	0	7.70	5.46	23.87	1.70	14
7	10	4	12	6	8.24	5.78	36.93	3.20	12
8	10	4	12	12	8.78	6.11	56.20	5.80	10
9	10	4	12	18	9.32	6.43	84.16	10.00	8

Source : Adapted from AASHTO [2], Huang [13], NYSDOT [33][34].

Table J-3 : Predicted Service Life - 2.5 Inch Overlay - Flexible Pavement.

Case No.	HMA Layer Depth (Inch)	Perm. Base Depth (Inch)	Sub. Course Depth (Inch)	Select Fill Depth (Inch)	SNx-eff	SNy	Allowed Load (Million ESAL)	Annual Load (Million ESAL)	Predict. Service Life (Years)
1	5	4	12	0	5.07	4.09	3.06	0.08	38
2	6	4	12	0	5.60	4.41	5.09	0.16	32
3	7	4	12	0	6.12	4.72	8.28	0.32	26
4	8	4	12	0	6.65	5.04	13.19	0.60	22
5	9	4	12	0	7.17	5.35	20.64	1.00	21
6	10	4	12	0	7.70	5.67	31.74	1.70	16
7	10	4	12	6	8.24	5.99	48.57	3.20	15
8	10	4	12	12	8.78	6.32	73.14	5.80	13
9	10	4	12	18	9.32	6.64	108.47	10.00	11

Source : Adapted from AASHTO [2], Huang [13], NYSDOT [33][34].

Computation Sheet - One Course HMAC Overlay - Flexible Pavement.

AASHTO [2] Design Equation.

$H_{OL} = SN_{OL} / a_{OL} = \{SN_Y - F_{RL} (SN_{X\text{-}EFF})\} a_{OL}$

* H_{OL}	Proposed one course overlay thickness.
* a_{OL}	Layer Coefficient (0.42) (Source: NYSDOT [33][34])
* F_{RL}	Remaining Life Factor.
* $SN_{X\text{-}EFF}$	Effective Strength (Structural Number).
* SN_Y	Structural Number of pavement with overlay.

Effective Strength of Existing Pavement Structure ($SN_{X\text{-}EFF}$).

$SN_{X\text{-}EFF} = a_{ac}\, d_{ac}\, m_{ac} + a_{pac}\, d_{pac}\, m_{pac} + a_{sub}\, d_{sub}\, m_{sub} + a_{sf}\, d_{sf}\, m_{sf}$

* d_{ac}	Thickness of HMA layer (inch).
* d_{pac}	Thickness of HMA drainage course layer (4 inches).
* d_{sub}	Thickness of subbase layer (12 inches).
* d_{sf}	Thickness of select fill if required (inch).
* m_{ac}	Drainage Coefficient of HMA layer (1.25) [33].
* m_{pac}	Drainage Coefficient of HMA drainage layer (1.25) [33].
* m_{sub}	Drainage Coefficient of subbase layer (0.90) [33].
* m_{sf}	Drainage Coefficient of fill layer (0.90) [33].
* a_{ac}	Layer Coefficient of HMA (0.42) [33].
* a_{pac}	Layer Coefficient of HMA drainage layer (0.23) [33].
* a_{sub}	Layer Coefficient of subbase (0.12) [33].
* a_{sf}	Layer Coefficient of fill (0.10) [33].

Remaining Life Factor (F_{RL}).

$F_{RL} = f\,(R_{LX}, R_{LY})$.

* $R_{LX} = 20\%$	Source : AASHTO [2].
* $R_{LY} = 70\%$	Source : AASHTO [2].
* $F_{RL} = 0.60$	Source : AASHTO [2].

Derived Formula:

$SN_Y = (H_{OL} * a_{OL}) + (F_{RL} * SN_{X\text{-}EFF})$.

APPENDIX K :

Flexible Pavement - Typical Line Items Associated With Initial Construction Costs.

Contents:

Table K-1 : Flexible Pavement - Initial Construction Cost Computations.
Table K-1 Continued : Flexible Pavement - Initial Cost Construction Computations.
Table K-1 Continued : Flexible Pavement - Initial Cost Construction Computations.

Table K-1: Flexible Pavement - Initial Construction Costs Computations.

Case 1. - 5 Inch HMAC, 0 Inch Select Fill.

NYSDOT Line Item	Line Item Description	Units	Unit Cost ($/unit)	Estimated Quantity (unit/lane mile)	Subtotal Cost ($)
203.02	Excavation (21")	CY	6.60	4107.00	27106.20
203.07	Select Fill Subgrade Course (0")	CY	12.25	0.00	0.00
304.01	Subbase Course (12")	CY	13.39	2347.00	31426.33
403.10	Asphalt - Permeable Base Course (4")	TON	31.09	1325.00	41194.25
403.11	Asphalt - Base Course (2")	TON	31.00	725.00	22475.00
403.13	Asphalt - Binder Course (1.5")	TON	32.63	571.00	18631.73
403.17	Asphalt - Top Course (1.5")	TON	34.81	568.00	19772.08
Total	(Cost per lane mile)	---	---	---	160605.59
Total	(Cost per square foot)	---	---	---	2.53

Source: NYSDOT [36][37].

Case 2. - 6 Inch HMAC, 0 Inch Select Fill.

NYSDOT Line Item	Line Item Description	Units	Unit Cost ($/unit)	Estimated Quantity (unit/lane mile)	Subtotal Cost ($)
203.02	Excavation (22")	CY	6.60	4302.22	28394.67
203.07	Select Fill Subgrade Course (0")	CY	12.25	0.00	0.00
304.01	Subbase Course (12")	CY	13.39	2347.00	31426.33
403.10	Asphalt - Permeable Base Course (4")	TON	31.09	1325.00	41194.25
403.11	Asphalt - Base Course (3")	TON	31.00	1087.42	33709.90
403.13	Asphalt - Binder Course (1.5")	TON	32.63	571.00	18631.73
403.17	Asphalt - Top Course (1.5")	TON	34.81	568.00	19772.08
Total	(Cost per lane mile)	---	---	---	173128.95
Total	(Cost per square foot)	---	---	---	2.73

Source: NYSDOT [36][37].

Table K-1: Flexible Pavement - Initial Construction Costs Computations (Continued).

Case 3. - 7 Inch HMAC, 0 Inch Select Fill.

NYSDOT Line Item	Line Item Description	Units	Unit Cost ($/unit)	Estimated Quantity (unit/lane mile)	Subtotal Cost ($)
203.02	Excavation (23")	CY	6.60	4497.78	29685.33
203.07	Select Fill Subgrade Course (0")	CY	12.25	0.00	0.00
304.01	Subbase Course (12")	CY	13.39	2347.00	31426.33
403.10	Asphalt - Permeable Base Course (4")	TON	31.09	1325.00	41194.25
403.11	Asphalt - Base Course (4")	TON	31.00	1449.89	44946.53
403.13	Asphalt - Binder Course (1.5")	TON	32.63	571.00	18631.73
403.17	Asphalt - Top Course (1.5")	TON	34.81	568.00	19772.08
Total	(Cost per lane mile)	---	---	---	185656.25
Total	(Cost per square foot)	---	---	---	2.93

Source: NYSDOT [36][37].

Case 4. - 8 Inch HMAC, 0 Inch Select Fill.

NYSDOT Line Item	Line Item Description	Units	Unit Cost ($/unit)	Estimated Quantity (unit/lane mile)	Subtotal Cost ($)
203.02	Excavation (24")	CY	6.60	4693.33	30976.00
203.07	Select Fill Subgrade Course (0")	CY	12.25	0.00	0.00
304.01	Subbase Course (12")	CY	13.39	2347.00	31426.33
403.10	Asphalt - Permeable Base Course (4")	TON	31.09	1325.00	41194.25
403.11	Asphalt - Base Course (5")	TON	31.00	1812.36	56183.16
403.13	Asphalt - Binder Course (1.5")	TON	32.63	571.00	18631.73
403.17	Asphalt - Top Course (1.5")	TON	34.81	568.00	19772.08
Total	(Cost per lane mile)	---	---	---	198183.55
Total	(Cost per square foot)	---	---	---	3.13

Source: NYSDOT [36][37].

Table K-1: Flexible Pavement - Initial Construction Costs Computations (Continued).

Case 5. - 9 Inch HMAC, 0 Inch Select Fill.

NYSDOT Line Item	Line Item Description	Units	Unit Cost ($/unit)	Estimated Quantity (unit/lane mile)	Subtotal Cost ($)
203.02	Excavation (25")	CY	6.60	4888.89	32266.67
203.07	Select Fill Subgrade Course (0")	CY	12.25	0.00	0.00
304.01	Subbase Course (12")	CY	13.39	2347.00	31426.33
403.10	Asphalt - Permeable Base Course (4")	TON	31.09	1325.00	41194.25
403.11	Asphalt - Base Course (6")	TON	31.00	2174.83	67419.79
403.13	Asphalt - Binder Course (1.5")	TON	32.63	571.00	18631.73
403.17	Asphalt - Top Course (1.5")	TON	34.81	568.00	19772.08
Total	(Cost per lane mile)	---	---	---	210710.85
Total	(Cost per square foot)	---	---	---	3.33

Source: NYSDOT [36][37].

Case 6. - 10 Inch HMAC, 0 Inch Select Fill.

NYSDOT Line Item	Line Item Description	Units	Unit Cost ($/unit)	Estimated Quantity (unit/lane mile)	Subtotal Cost ($)
203.02	Excavation (26")	CY	6.60	5084.44	33557.33
203.07	Select Fill Subgrade Course (0")	CY	12.25	0.00	0.00
304.01	Subbase Course (12")	CY	13.39	2347.00	31426.33
403.10	Asphalt - Permeable Base Course (4")	TON	31.09	1325.00	41194.25
403.11	Asphalt - Base Course (7")	TON	31.00	2537.30	78656.42
403.13	Asphalt - Binder Course (1.5")	TON	32.63	571.00	18631.73
403.17	Asphalt - Top Course (1.5")	TON	34.81	568.00	19772.08
Total	(Cost per lane mile)	---	---	---	223238.15
Total	(Cost per square foot)	---	---	---	3.52

Source: NYSDOT [36][37].

Table K-1: Flexible Pavement - Initial Construction Costs Computations (Continued).

Case 7. - 10 Inch HMAC, 6 Inch Select Fill.

NYSDOT Line Item	Line Item Description	Units	Unit Cost ($/unit)	Estimated Quantity (unit/lane mile)	Subtotal Cost ($)
203.02	Excavation (32")	CY	6.60	6257.78	41301.33
203.07	Select Fill Subgrade Course (6")	CY	12.25	1173.33	14373.33
304.01	Subbase Course (12")	CY	13.39	2347.00	31426.33
403.10	Asphalt - Permeable Base Course (4")	TON	31.09	1325.00	41194.25
403.11	Asphalt - Base Course (7")	TON	31.00	2537.30	78656.42
403.13	Asphalt - Binder Course (1.5")	TON	32.63	571.00	18631.73
403.17	Asphalt - Top Course (1.5")	TON	34.81	568.00	19772.08
Total	(Cost per lane mile)	---	---	---	245355.48
Total	(Cost per square foot)	---	---	---	3.87

Source: NYSDOT [36][37].

Case 8. - 10 Inch HMAC, 12 Inch Select Fill.

NYSDOT Line Item	Line Item Description	Units	Unit Cost ($/unit)	Estimated Quantity (unit/lane mile)	Subtotal Cost ($)
203.02	Excavation (38")	CY	6.60	7431.11	49045.33
203.07	Select Fill Subgrade Course (12")	CY	12.25	2346.67	28746.67
304.01	Subbase Course (12")	CY	13.39	2347.00	31426.33
403.10	Asphalt - Permeable Base Course (4")	TON	31.09	1325.00	41194.25
403.11	Asphalt - Base Course (7")	TON	31.00	2537.30	78656.42
403.13	Asphalt - Binder Course (1.5")	TON	32.63	571.00	18631.73
403.17	Asphalt - Top Course (1.5")	TON	34.81	568.00	19772.08
Total	(Cost per lane mile)	---	---	---	267472.81
Total	(Cost per square foot)	---	---	---	4.22

Source: NYSDOT [36][37].

Table K-1: Flexible Pavement - Initial Construction Costs Computations (Continued).

Case 9. - 10 Inch HMAC, 18 Inch Select Fill.

NYSDOT Line Item	Line Item Description	Units	Unit Cost ($/unit)	Estimated Quantity (unit/lane mile)	Subtotal Cost ($)
203.02	Excavation (44")	CY	6.60	8604.44	56789.33
203.07	Select Fill Subgrade Course (18")	CY	12.25	3520.00	43120.00
304.01	Subbase Course (12")	CY	13.39	2347.00	31426.33
403.10	Asphalt - Permeable Base Course (4")	TON	31.09	1325.00	41194.25
403.11	Asphalt - Base Course (7")	TON	31.00	2537.30	78656.42
403.13	Asphalt - Binder Course (1.5")	TON	32.63	571.00	18631.73
403.17	Asphalt - Top Course (1.5")	TON	34.81	568.00	19772.08
Total	(Cost per lane mile)	---	---	---	289590.15
Total	(Cost per square foot)	---	---	---	4.57

Source: NYSDOT [36][37].

APPENDIX L :

Flexible Pavement - Typical Line Items Associated With Initial Construction Costs.

Contents:

Table L-1 : Flexible Pavement - Maintenance Cost Computations.

Table L-1: Flexible Pavement - Maintenance Cost Computations.

Crack Filling.

NYSDOT Item Number	Line Item Description	Units	Unit Cost ($/unit)	Estimated Quantity (unit/lane mile)	Subtotal Cost ($)
18403.76	Clean and Seal Cracks	LF	1.63	Varies*	Varies*
Total	(Cost per Lane Mile)	---	---	---	1.63

Notes:
1. Total quantity varies with predicted linear feet of thermal cracking per lane mile.
2. Cost per lane mile = 1.63 * Predicted feet of cracking.

Patching and Shimming.

NYSDOT Item Number	Line Item Description	Units	Unit Cost ($/unit)	Estimated Quantity (unit/lane mile)	Subtotal Cost ($)
04403.93	Shimming & Patching Asphalt Concrete	TON	80.15	Varies*	Varies*
490.30	Cold Milling of Asphalt Concrete	SY	3.37	3520.00	11862.40
633.0202	Clean Pavement Surface	SY	0.07	7040.00	492.80
407.01	Tack Coat	GAL	1.85	352.00	651.20
Total	(Cost per Lane Mile)	---	---	---	13006.40

Notes:
1. Quantity of shimming varies with predicted rut depth.
2. Cost per lane mile = 13006 + (80.15 * Predicted Tons of AC).

Single Course HMAC Overlay (1.5 Inches).

NYSDOT Item Number	Line Item Description	Units	Unit Cost ($/unit)	Estimated Quantity (unit/lane mile)	Subtotal Cost ($)
04403.93	Shimming & Patching Asphalt.	TON	80.15	Varies*	Varies*
490.10	Production Cold Milling of Asphalt.	SY	1.95	7040.00	13728.00
633.0202	Cleaning Pavement Surface.	SY	0.07	7040.00	492.80
407.01	Tack Coat.	GAL	1.85	352.00	651.20
403.17	Asphalt - Top Course	TON	34.81	568.00	19772.08
Total	(Cost per Lane Mile)	---	---	---	34644.08

Notes:
1. Quantity of shimming varies with predicted rut depth.
2. Cost per lane mile = 34644.08 + (80.15 * Predicted Tons of AC).

Table L-1: Flexible Pavement - Maintenance Cost Computations (Continued).

Single Course HMAC Overlay (2.0 Inches).

NYSDOT Item Number	Line Item Description	Units	Unit Cost ($/unit)	Estimated Quantity (unit/lane mile)	Subtotal Cost ($)
04403.93	Shimming & Patching Asphalt.	TON	80.15	Varies*	Varies*
490.10	Production Cold Milling of Asphalt.	SY	1.95	7040.00	13728.00
633.0202	Cleaning Pavement Surface.	SY	0.07	7040.00	492.80
407.01	Tack Coat.	GAL	1.85	352.00	651.20
403.17	Asphalt - Top Course	TON	34.81	757.00	26351.17
Total	(Cost per Lane Mile)	---	---	---	41223.17

Notes:

1. Quantity of shimming varies with predicted rut depth.
2. Cost per lane mile = 41233.17 + (80.15 * Predicted Tons of AC).

Single Course HMAC Overlay (2.5 Inches).

NYSDOT Item Number	Line Item Description	Units	Unit Cost ($/unit)	Estimated Quantity (unit/lane mile)	Subtotal Cost ($)
04403.93	Shimming & Patching Asphalt.	TON	80.15	Varies*	Varies*
490.10	Production Cold Milling of Asphalt.	SY	1.95	7040.00	13728.00
633.0202	Cleaning Pavement Surface.	SY	0.07	7040.00	492.80
407.01	Tack Coat.	GAL	1.85	352.00	651.20
403.17	Asphalt - Top Course	TON	34.81	947.00	32965.07
Total	(Cost per Lane Mile)	---	---	---	47387.07

Notes:

1. Quantity of shimming varies with predicted rut depth.
2. Cost per lane mile = 47837.07 + (80.15 * Predicted Tons of AC).

APPENDIX M :

Rigid Pavement - Typical Line Items Associated With Initial Construction Costs.

Contents:

Table M-1 : Rigid Pavement - Initial Construction Cost Computations.

Table M-1: Initial Construction Cost Computations.

Case 1 - PCC Slab Thickness - 8 Inches.

NYSDOT Item Number	Item Work Description	Units	Unit Cost ($/unit)	Estimated Quantity (unit/lane mile)	Subtotal Cost ($)
203.02	Excavation (24")	CY	6.60	4693.33	30976.00
304.01	Subbase Course (12")	CY	13.39	2347.00	31426.33
403.10	AC - Permeable Base (4")	TON	31.09	1325.00	41194.25
502.06	Concrete Pavement (8")	CY	131.91	1564.44	206365.87
502.20	Transverse Joints	LF	6.57	3960.00	26017.20
502.30	Longitudinal Joints	EA	5.80	2622.00	13119.60
18502.4402	Saw and Seal Joints	LF	5.44	11880.00	64627.20
Total	(Cost per lane mile)	---	---	---	413726.45
Total	(Cost per square foot)	---	---	---	6.53

Source : Adapted from NYSDOT [36][37].

Case 2 - PCC Slab Thickness - 9 Inches.

NYSDOT Item Number	Item Work Description	Units	Unit Cost ($/unit)	Estimated Quantity (unit/lane mile)	Subtotal Cost ($)
203.02	Excavation (25")	CY	6.60	4888.89	32266.67
304.01	Subbase Course (12")	CY	13.39	2347.00	31426.33
403.10	AC - Permeable Base (4")	TON	31.09	1325.00	41194.25
502.06	Concrete Pavement (9")	CY	131.91	1760.00	232161.60
502.20	Transverse Joints	LF	6.57	3960.00	26017.20
502.30	Longitudinal Joints	EA	5.80	2622.00	13119.60
18502.4402	Saw and Seal Joints	LF	5.44	11880.00	64627.20
Total	(Cost per lane mile)	---	---	---	440813.05
Total	(Cost per square foot)	---	---	---	6.96

Source : Adapted from NYSDOT [36][37].

Table M-1: Initial Construction Cost Computations (Continued).

Case 3 - PCC Slab Thickness - 10 Inches.

NYSDOT Item Number	Item Work Description	Units	Unit Cost ($/unit)	Estimated Quantity (unit/lane mile)	Subtotal Cost ($)
203.02	Excavation (26")	CY	6.60	5084.44	33557.30
304.01	Subbase Course (12")	CY	13.39	2347.00	31426.33
403.10	AC - Permeable Base (4")	TON	31.09	1325.00	41194.25
502.06	Concrete Pavement (10")	CY	131.91	1955.56	257957.33
502.20	Transverse Joints	LF	6.57	3960.00	26017.20
502.30	Longitudinal Joints	EA	5.80	2622.00	13119.60
18502.4402	Saw and Seal Joints	LF	5.44	11880.00	64627.20
Total	(Cost per lane mile)	---	---	---	467899.21
Total	(Cost per square foot)	---	---	---	7.38

Source : Adapted from NYSDOT [36][37].

Case 4 - PCC Slab Thickness - 11 Inches.

NYSDOT Item Number	Item Work Description	Units	Unit Cost ($/unit)	Estimated Quantity (unit/lane mile)	Subtotal Cost ($)
203.02	Excavation (27")	CY	6.60	5280.00	34848.00
304.01	Subbase Course (12")	CY	13.39	2347.00	31426.33
403.10	AC - Permeable Base (4")	TON	31.09	1325.00	41194.25
502.06	Concrete Pavement (11)	CY	131.91	2151.11	283753.07
502.20	Transverse Joints	LF	6.57	3960.00	26017.20
502.30	Longitudinal Joints	EA	5.80	2622.00	13119.60
18502.4402	Saw and Seal Joints	LF	5.44	11880.00	64627.20
Total	(Cost per lane mile)	---	---	---	494985.65
Total	(Cost per square foot)	---	---	---	7.81

Source : Adapted from NYSDOT [36][37].

Table M-1: Initial Construction Cost Computations (Continued).

Case 5 - PCC Slab Thickness - 12 Inches.

NYSDOT Item Number	Item Work Description	Units	Unit Cost ($/unit)	Estimated Quantity (unit/lane mile)	Subtotal Cost ($)
203.02	Excavation (28")	CY	6.60	5475.56	36138.70
304.01	Subbase Course (12")	CY	13.39	2347.00	31426.33
403.10	AC - Permeable Base (4")	TON	31.09	1325.00	41194.25
502.06	Concrete Pavement (12")	CY	131.91	2346.67	309548.80
502.20	Transverse Joints	LF	6.57	3960.00	26017.20
502.30	Longitudinal Joints	EA	5.80	2622.00	13119.60
18502.4402	Saw and Seal Joints	LF	5.44	11880.00	64627.20
Total	(Cost per lane mile)	---	---	---	522072.08
Total	(Cost per square foot)	---	---	---	8.24

Source : Adapted from NYSDOT [36][37].

Case 6 - PCC Slab Thickness - 13 Inches.

NYSDOT Item Number	Item Work Description	Units	Unit Cost ($/unit)	Estimated Quantity (unit/lane mile)	Subtotal Cost ($)
203.02	Excavation (29")	CY	6.60	5671.11	37429.33
304.01	Subbase Course (12")	CY	13.39	2347.00	31426.33
403.10	AC - Permeable Base (4")	TON	31.09	1325.00	41194.25
502.06	Concrete Pavement (13")	CY	131.91	2542.22	335344.53
502.20	Transverse Joints	LF	6.57	3960.00	26017.20
502.30	Longitudinal Joints	EA	5.80	2622.00	13119.60
18502.4402	Saw and Seal Joints	LF	5.44	11880.00	64627.20
Total	(Cost per lane mile)	---	---	---	549158.44
Total	(Cost per square foot)	---	---	---	8.67

Source : Adapted from NYSDOT [36][37].

APPENDIX N :

Rigid Pavement - Typical Line Items Associated With Maintenance Costs.

Contents:

Table N-1 : Rigid Pavement - Maintenance Cost Computations.

Table N-1: Maintenance Cost Computations.

Joint & Crack Sealing .

NYSDOT Item Number	Item Work Description	Units	Unit Cost ($/unit)	Estimated Quantity (unit/lane mile)	Subtotal Cost ($)
502.70	Clean and reseal joints.	LF	2.53	Varies	Varies
Total	(Cost per linear foot)	---	---	---	2.53

Cost per lane mile = $2.53 * (Predicted feet of cracking).

Spall Patching.

NYSDOT Item Number	Item Work Description	Units	Unit Cost ($/unit)	Estimated Quantity (unit/lane mile)	Subtotal Cost ($)
502.4467	Repair and fill PCC spall	SF	10.84	Varies	Varies
Total	(Cost per square foot)	---	---	---	10.84

Cost per lane mile = $10.84 * (Predicted Square Feet of Spalling).

Grinding & Shimming.

NYSDOT Item Number	Item Work Description	Units	Unit Cost ($/unit)	Estimated Quantity (unit/lane mile)	Subtotal Cost ($)
490.40	Misc. Milling of PCC	SY	4.10	0.111	0.46
633.0202	Clean Surface	SY	0.07	0.111	0.01
407.01	Tack Coat	GAL	1.85	0.024	0.04
403.15	AC - Shim Course	TON	45.12	0.003	0.14
Total	(Cost per square foot)	---	---	---	0.64

Cost per lane mile = $0.64 * (Predicted Square feet of Grinding & Shimming).

Single Course HMAC Overlay (2.0").

NYSDOT Item Number	Item Work Description	Units	Unit Cost ($/unit)	Estimated Quantity (unit/lane mile)	Subtotal Cost ($)
490.20	Cold Milling of PCC	SY	2.02	7040.00	14220.80
633.0202	Clean Surface	SY	0.07	7040.00	492.80
407.01	Tack Coat	GAL	1.85	352.00	651.20
403.17	AC - Top Course	TON	34.81	757.00	26351.17
Total	(Cost per lane mile)	---	---	---	41715.97

Cost per lane mile = $41715.97

APPENDIX O :

Typical Network Level Construction Costs.

Contents:

Table O-1 : Network Level Pavement Construction Costs (Flexible Pavement).
Table O-2 : Network Level Pavement Construction Costs (Rigid Pavement).

Table O-1 : Network Level Pavement Construction Costs (Flexible Pavement)

Maintenance Type	Reg. 1	Reg. 2	Reg. 3	Reg. 4	Reg. 5	Reg. 6	Reg. 7	Reg. 8	Reg. 9	Reg. 10	Reg. 11	Ave.
Routine Maint.	1.01	0.89	0.92	0.72	0.78	1.26	0.59	0.88	0.80	0.90	1.88	0.97
% of Statewide	104	92	95	74	80	130	61	91	82	93	194	100
Preventive Maint.	5.26	5.26	6.05	6.58	5.96	6.13	5.09	5.96	6.21	8.50	15.00	6.99
% of Statewide	75	75	87	94	85	88	73	85	89	122	215	100
Corrective Maint.	9.97	10.11	11.84	13.68	11.85	11.24	10.29	12.31	12.63	20.35	32.26	14.26
% of Statewide	70	71	83	96	83	79	72	86	89	143	226	100
Rehabilitation	13.9	14.22	16.67	19.21	16.73	15.83	14.52	17.10	17.73	28.34	44.74	19.94
% of Statewide	70	71	84	96	84	79	73	86	89	142	224	100
High Cost Rehab.	26.69	26.94	30.85	34.21	28.35	33.44	28.08	32.00	34.79	50.43	85.18	37.19
% of Statewide	72	72	83	92	76	90	76	86	94	136	224	100
Reconstruction	51.46	51.82	57.16	63.29	57.69	55.59	53.32	57.26	59.42	82.26	118.2	64.22
% of Statewide	80	81	89	97	90	87	83	89	93	128	184	100
Average % of Statewide	79	77	87	92	83	92	73	87	89	27	211	100

Source : NYSDOT [26].

Table O-2 : Network Level Pavement Construction Costs (Rigid Pavement).

Maintenance Type	Reg. 1	Reg. 2	Reg. 3	Reg. 4	Reg. 5	Reg. 6	Reg. 7	Reg. 8	Reg. 9	Reg. 10	Reg. 11	STW Ave.
Routine Maint.	1.62	2.00	2.19	1.54	1.86	3.02	1.08	1.98	2.19	3.38	5.21	2.37
% of Statewide	68	84	92	65	78	127	46	84	92	143	220	100
Preventive Maint.	1.72	2.19	2.33	1.68	2.00	3.16	1.22	2.15	2.35	3.55	5.42	2.53
% of Statewide	68	87	92	66	79	125	48	85	93	140	214	100
Corrective Maint.	3.86	4.21	2.96	2.55	3.02	3.84	2.39	4.43	4.58	5.96	7.98	4.17
% of Statewide	93	101	71	61	72	92	57	106	110	143	191	100
Rehabilitation	15.88	16.87	19.69	21.74	19.59	20.44	17.07	20.59	20.93	32.72	51.59	23.38
% of Statewide	68	72	84	93	84	87	73	88	90	140	221	100
High Cost Rehab.	18.25	19.31	22.55	25.00	22.48	23.34	19.58	23.42	23.86	37.46	59.80	26.73
% of Statewide	68	72	84	94	84	87	73	88	89	140	220	100
Reconstruction	96.66	102.6	91.52	98.29	101.9	104.2	111.1	108.3	112.0	156.4	154.6	112.5
% of Statewide	86	91	81	87	91	93	99	96	100	139	137	100
Average % of Statewide	75	85	84	78	81	102	66	91	96	141	201	100

Source : NYSDOT [26].

APPENDIX P :

Predicted Life Cycle Cost Computations - NYSDOT Flexible Pavement Case Study.

Contents:	**Page:**
Input Screen.	173
Output Screen - AASHTO Flexible Design Analysis.	174
Output Screen - Mechanistic Design Analysis (Alternatives 1 through 3).	175
Output Screen - Mechanistic Design Analysis (Alternatives 4 through 6).	176
Output Screen - Mechanistic Design Analysis (Alternatives 7 through 9).	177
Output Screen - Economic Analysis.	178
Output Screen - Predicted Roughness and Distresses.	179

FLEXIBLE PAVEMENT : LIFE-CYCLE PAVEMENT DESIGN ANALYSIS.

By : Patrick J. Prancl
January 6, 2000.

* Note : Algorithm is valid for SHRP Wet-Freeze Climate Region and has been developed for use by the New York State Department of Transportation.

INPUT SCREEN

Traffic Data:

Data Input	Units	Data Input	Default Value
ADT	veh./day	20000	----
Heavy Vehicles	%	10	----
Load Factor	ESAL/truck	1.85	1.85
Direction Distribution	%	50	50
Lane Distribution	%	85	----
Combined Growth	%	2	----

Environmental Data :

Data Input	Units	Data Input	Default Value
Annual Freeze-Thaw Cycles	# Cycles	80	80
Annual Days > 90 Degrees	Days	9	9
Freeze Index	Deg-day	925	925
Annual Precipitation	Inch	38	38

Pavement Characteristic Data:

Data Input	Units	Data Input	Default Value
Asphalt Viscosity	Poise	1600	1600
HMAC Voids (% Volume)	%	4	4
MHAC Aggregate Passing #4 Seive	%	65	65
Subbase Passing #200 Seive	%	10	10

Geometric Data :

Data Input	Units	Data Input	Default Value
Travel Lane Width	feet	12	12
Inner Shoulder Width	feet	4	4
Outer Shoulder Width	feet	8	12
Travel Lanes Per Direction	#	2	-----
Pavement Length	mile	1	-----
Discount Rate	%	4	4

file: flex.123

OUTPUT - AASHTO FLEXIBLE DESIGN ANALYSIS.

Design Alt.	HMAC Slab Thickness (inch)	Subbase Course Thickness (inch)	Select Fill Thickness (inch)	Total Base Thick* (inch)	Alternative Feasibility
1	5	12	0	14	Overload
2	6	12	0	14	Overload
3	7	12	0	14	Overload
4	8	12	0	14	Overload
5	9	12	0	14	Overload
6	10	12	0	14	Feasible
7	10	12	6	19	Feasible
8	10	12	12	24	Feasible
9	10	12	18	29	Feasible

* Base layer thickness includes 4" permeable AC base, subbase, and select fill; adjusted by layer coefficient.

ALTERNATIVE 1: MECHANISTIC DESIGN ANALYSIS - HMAC THICKNESS OF 5 INCHES (14 INCH BASE)

Year	Cumulative Loading (ESAL*10^6	Predicted IRI (inch/mile)	Predicted Rutting (inch)	Predicted Cracking (Spacing)	Predicted Maintenance Strategy	Required Crack Fill (LF)	Required Shimming (TON)	Required Overlay (SF)	Estimated Agency Cost	LCC Agency Cost	V O.C. Car (million $)	V O.C. Truck (million $)	LCC User Cost
0	0	0	0.00	—	Initial Construction	——	——	——	1288742	1288742	4.16	0.80	0
5	3	46	0.25	59.55	Crack Fill	6384	0	0	13917	11439	4.23	0.83	20603356
10	7	56	0.28	39.38	Shim & Fill	9654	12	0	92098	62218	4.25	0.84	17144740
15	11	63	0.31	30.92	Crack Fill	12296	0	0	26805	14884	4.26	0.84	14141976
20	15	68	0.33	26.04	Shim & Fill	14598	14	0	103087	47048	4.27	0.85	11654998
25	20	73	0.35	22.80	Crack Fill	16677	0	0	36355	13637	4.27	0.85	9601366
30	26	78	0.36	20.45	Shim & Fill	18593	16	0	111949	34516	4.28	0.85	7907638
35	32	82	0.37	18.65	Crack Fill	20384	0	0	44437	11261	4.29	0.86	6511648
40	38	86	0.39	17.22	Shim & Fill	22074	17	0	119667	24925	4.29	0.86	5361511
45	45	90	0.40	16.05	Crack Fill	23681	0	0	51625	8838	4.30	0.86	4414177
50	53	93	0.41	15.08	End Life	——	——	——	0	0	4.30	0.86	3634026
Total	——	——	——	——	——	——	——	——	——	1517509	——	——	100975435

ALTERNATIVE 2: MECHANISTIC DESIGN ANALYSIS - HMAC THICKNESS OF 6 INCHES (14 INCH BASE)

Year	Cumulative Loading (ESAL*10^6	Predicted IRI (inch/mile)	Predicted Rutting (inch)	Predicted Cracking (Spacing)	Predicted Maintenance Strategy	Required Crack Fill (LF)	Required Shimming (TON)	Required Overlay (SF)	Estimated Agency Cost	LCC Agency Cost	V O C. Car (million $)	V O C. Truck (million $)	LCC User Cost
0	0	0	0.00	---	Initial Construction	——	——	——	1391386	1391386	4.16	0.80	0
5	3	49	0.24	61.39	Crack Fill	6192	0	0	13499	11095	4.24	0.83	20615872
10	7	59	0.27	40.39	Shim & Fill	9411	12	0	91526	61832	4.25	0.84	17167417
15	11	66	0.30	31.62	Crack Fill	12023	0	0	26210	14554	4.26	0.85	14163576
20	15	72	0.32	26.58	Shim & Fill	14305	14	0	102398	46733	4.27	0.85	11674597
25	20	78	0.33	23.22	Crack Fill	16369	0	0	35684	13385	4.28	0.85	9618759
30	26	82	0.35	20.80	Shim & Fill	18274	15	0	111199	34285	4.29	0.86	7922878
35	32	87	0.36	18.95	Crack Fill	20057	0	0	43725	11081	4.29	0.86	6524890
40	38	91	0.38	17.49	Shim & Fill	21742	17	0	118883	24762	4.30	0.86	5372949
45	45	95	0.39	16.28	Crack Fill	23345	0	0	50892	8713	4.31	0.87	4424015
50	53	99	0.40	15.28	End Life	——	——	——	0	0	4.31	0.87	3642459
Total	——	——	——	——	——	——	——	——	——	1617824	——	——	101127411

ALTERNATIVE 3: MECHANISTIC DESIGN ANALYSIS - HMAC THICKNESS OF 7 INCHES (14 INCH BASE)

Year	Cumulative Loading (ESAL*10^6	Predicted IRI (inch/mile)	Predicted Rutting (inch)	Predicted Cracking (Spacing)	Predicted Maintenance Strategy	Required Crack Fill (LF)	Required Shimming (TON)	Required Overlay (SF)	Estimated Agency Cost	LCC Agency Cost	V O C. Car (million $)	V O C. Truck (million $)	LCC User Cost
0	0	0	0.00	---	Initial Construction	——	——	——	1494029	1494029	4.16	0.80	0
5	3	52	0.23	63.30	Crack Fill	6006	0	0	13092	10761	4.24	0.84	20627027
10	7	62	0.27	41.43	Shim & Fill	9175	12	0	90976	61460	4.26	0.84	17187629
15	11	70	0.29	32.34	Crack Fill	11756	0	0	25629	14231	4.27	0.85	14182828
20	15	76	0.31	27.12	Shim & Fill	14017	14	0	101730	46428	4.28	0.85	11692066
25	20	81	0.32	23.66	Crack Fill	16066	0	0	35024	13138	4.29	0.86	9634263
30	26	86	0.34	21.17	Shim & Fill	17961	15	0	110470	34060	4.29	0.86	7936461
35	32	91	0.35	19.26	Crack Fill	19736	0	0	43024	10903	4.30	0.86	6536692
40	38	95	0.36	17.75	Shim & Fill	21415	16	0	118121	24603	4.31	0.87	5383145
45	45	100	0.38	16.52	Crack Fill	23014	0	0	50170	8589	4.31	0.87	4432783
50	53	104	0.39	15.49	End Life	——	——	——	0	0	4.32	0.87	3649976
Total	——	——	——	——	——	——	——	——	——	1718202	——	——	101262869

ALTERNATIVE 4: MECHANISTIC DESIGN ANALYSIS - HMAC THICKNESS OF 8 INCHES (14 INCH BASE)

Year	Cumulative Loading ESAL*10^6	Predicted IRI (inch/mile)	Predicted Rutting (inch)	Predicted Cracking (Spacing)	Predicted Maintenance Strategy	Required Crack Fill (LF)	Required Shimming (TON)	Required Overlay (SF)	Estimated Agency Cost	LCC Agency Cost	V.O.C. Car (million $)	V.O.C. Truck (million $)	LCC User Cost
0	0	0	0.00	---	Initial Construction	——	——	——	1592870	1592870	4.16	0.80	0
5	3	54	0.23	65.26	Crack Fill	5825	0	0	12698	10437	4.24	0.84	20637137
10	7	65	0.26	42.50	Shim & Fill	8945	11	0	90443	61100	4.26	0.84	17205946
15	11	73	0.28	33.07	Crack Fill	11496	0	0	25061	13915	4.27	0.85	14200275
20	15	79	0.30	27.68	Shim & Fill	13736	13	0	101081	46132	4.28	0.85	11707897
25	20	85	0.32	24.11	Crack Fill	15769	0	0	34377	12896	4.29	0.86	9648312
30	26	90	0.33	21.54	Shim & Fill	17653	15	0	109760	33841	4.30	0.86	7948771
35	32	95	0.34	19.58	Crack Fill	19420	0	0	42335	10728	4.31	0.87	6547388
40	38	99	0.36	18.02	Shim & Fill	21092	16	0	117377	24448	4.31	0.87	5392384
45	45	104	0.37	16.76	Crack Fill	22687	0	0	49458	8467	4.32	0.87	4440729
50	53	108	0.38	15.70	End Life	——	——	——	0	0	4.33	0.88	3656788
Total	——	——	——	——	——	——	——	——	——	1814836	——	——	101385627

ALTERNATIVE 5: MECHANISTIC DESIGN ANALYSIS - HMAC THICKNESS OF 9 INCHES (14 INCH BASE)

Year	Cumulative Loading ESAL*10^6	Predicted IRI (inch/mile)	Predicted Rutting (inch)	Predicted Cracking (Spacing)	Predicted Maintenance Strategy	Required Crack Fill (LF)	Required Shimming (TON)	Required Overlay (SF)	Estimated Agency Cost	LCC Agency Cost	V.O.C. Car (million $)	V.O.C. Truck (million $)	LCC User Cost
0	0	0	0.00	—	Initial Construction	——	——	——	1695514	1695514	4.16	0.80	0
5	3	56	0.22	67.29	Crack Fill	5650	0	0	12316	10123	4.25	0.84	20646413
10	7	67	0.26	43.60	Shim & Fill	8720	11	0	89928	60752	4.26	0.85	17222753
15	11	75	0.28	33.82	Crack Fill	11241	0	0	24505	13607	4.28	0.85	14216283
20	15	82	0.30	28.24	Shim & Fill	13460	13	0	100449	45844	4.29	0.86	11722423
25	20	88	0.31	24.56	Crack Fill	15478	0	0	33742	12657	4.30	0.86	9661203
30	26	93	0.32	21.91	Shim & Fill	17350	14	0	109068	33628	4.30	0.86	7960066
35	32	98	0.34	19.89	Crack Fill	19108	0	0	41656	10556	4.31	0.87	6557202
40	38	103	0.35	18.30	Shim & Fill	20775	15	0	116649	24297	4.32	0.87	5400861
45	45	108	0.36	17.00	Crack Fill	22365	0	0	48756	8347	4.33	0.88	4448021
50	53	112	0.37	15.91	End Life	——	——	——	0	0	4.33	0.88	3663038
Total	——	——	——	——	——	——	——	——	——	1915324	——	——	101498264

ALTERNATIVE 6: MECHANISTIC DESIGN ANALYSIS - HMAC THICKNESS OF 10 INCHES (14 INCH BASE)

Year	Cumulative Loading ESAL*10^6	Predicted IRI (inch/mile)	Predicted Rutting (inch)	Predicted Cracking (Spacing)	Predicted Maintenance Strategy	Required Crack Fill (LF)	Required Shimming (TON)	Required Overlay (SF)	Estimated Agency Cost	LCC Agency Cost	V.O.C. Car (million $)	V.O.C. Truck (million $)	LCC User Cost
0	0	0	0.00	--	Initial Construction	——	——	——	1794355	1794355	4.16	0.80	0
5	3	58	0.22	69.38	Crack Fill	5480	0	0	11946	9818	4.25	0.84	20655007
10	7	70	0.25	44.72	Shim & Fill	8501	11	0	89428	60414	4.27	0.85	17238323
15	11	78	0.27	34.59	Crack Fill	10992	0	0	23962	13305	4.28	0.85	14231114
20	15	85	0.29	28.82	Shim & Fill	13189	13	0	99833	45563	4.29	0.86	11735879
25	20	91	0.30	25.02	Crack Fill	15192	0	0	33119	12424	4.30	0.86	9673146
30	26	97	0.32	22.29	Shim & Fill	17053	14	0	108390	33419	4.31	0.87	7970530
35	32	102	0.33	20.22	Crack Fill	18802	0	0	40989	10387	4.32	0.87	6566294
40	38	107	0.34	18.58	Shim & Fill	20462	15	0	115936	24148	4.32	0.87	5408715
45	45	111	0.35	17.24	Crack Fill	22048	0	0	48064	8228	4.33	0.88	4454775
50	53	116	0.36	16.13	End Life	——	——	——	0	0	4.34	0.88	3668828
Total	——	——	——	——	——	——	——	——	——	2012062	——	——	101602611

ALTERNATIVE 7: MECHANISTIC DESIGN ANALYSIS - HMAC THICKNESS OF 10 INCHES (19 INCH BASE)

Year	Cumulative Loading (ESAL*10^6	Predicted IRI (inch/mile)	Predicted Rutting (inch)	Predicted Cracking (Spacing)	Predicted Maintenance Strategy	Required Crack Fill (LF)	Required Shimming (TON)	Required Overlay (SF)	Estimated Agency Cost	LCC Agency Cost	V.O.C. Car (million $)	V.O.C. Truck (million $)	LCC User Cost
0	0	0	0.00	---	Initial Construction	-----	-----	-----	1973030	1973030	4.16	0.80	0
5	3	57	0.22	69.38	Crack Fill	5480	0	0	11946	9818	4.25	0.84	20650127
10	7	68	0.25	44.72	Shim & Fill	8501	11	0	89412	60404	4.27	0.85	17229482
15	11	77	0.27	34.59	Crack Fill	10992	0	0	23962	13305	4.28	0.85	14222693
20	15	83	0.29	28.82	Shim & Fill	13189	13	0	99815	45554	4.29	0.86	11728238
25	20	89	0.30	25.02	Crack Fill	15192	0	0	33119	12424	4.30	0.86	9666365
30	26	95	0.31	22.29	Shim & Fill	17053	14	0	108370	33413	4.31	0.87	7964589
35	32	100	0.33	20.22	Crack Fill	18802	0	0	40989	10387	4.31	0.87	6561131
40	38	105	0.34	18.58	Shim & Fill	20462	15	0	115915	24144	4.32	0.87	5404255
45	45	109	0.35	17.24	Crack Fill	22048	0	0	48064	8228	4.33	0.88	4450940
50	53	114	0.36	16.13	End Life	-----	-----	-----	0	0	4.34	0.88	3665540
Total	-----	-----	-----	-----	-----	-----	-----	-----	-----	2190707	-----	-----	101543360

ALTERNATIVE 8: MECHANISTIC DESIGN ANALYSIS - HMAC THICKNESS OF 10 INCHES (24 INCH BASE)

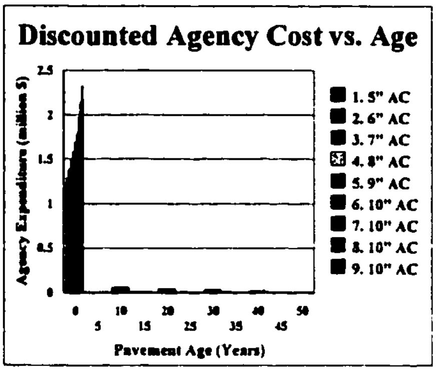
Year	Cumulative Loading (ESAL*10^6	Predicted IRI (inch/mile)	Predicted Rutting (inch)	Predicted Cracking (Spacing)	Predicted Maintenance Strategy	Required Crack Fill (LF)	Required Shimming (TON)	Required Overlay (SF)	Estimated Agency Cost	LCC Agency Cost	V.O.C. Car (million $)	V.O.C. Truck (million $)	LCC User Cost
0	0	0	0.00	---	Initial Construction	-----	-----	-----	2147904	2147904	4.16	0.80	0
5	3	56	0.21	69.38	Crack Fill	5480	0	0	11946	9818	4.25	0.84	20645338
10	7	67	0.24	44.72	Shim & Fill	8501	11	0	89400	60396	4.26	0.85	17220804
15	11	75	0.27	34.59	Crack Fill	10992	0	0	23962	13305	4.28	0.85	14214427
20	15	82	0.28	28.82	Shim & Fill	13189	12	0	99801	45548	4.29	0.86	11720738
25	20	88	0.30	25.02	Crack Fill	15192	0	0	33119	12424	4.30	0.86	9659709
30	26	93	0.31	22.29	Shim & Fill	17053	14	0	108355	33408	4.30	0.86	7958757
35	32	98	0.32	20.22	Crack Fill	18802	0	0	40989	10387	4.31	0.87	6556064
40	38	103	0.33	18.58	Shim & Fill	20462	15	0	115899	24140	4.32	0.87	5399878
45	45	107	0.35	17.24	Crack Fill	22048	0	0	48064	8228	4.33	0.87	4447175
50	53	112	0.36	16.13	End Life	-----	-----	-----	0	0	4.33	0.88	3662313
Total	-----	-----	-----	-----	-----	-----	-----	-----	-----	2365559	-----	-----	101485204

ALTERNATIVE 9: MECHANISTIC DESIGN ANALYSIS - HMAC THICKNESS OF 10 INCHES (29 INCH BASE)

Year	Cumulative Loading (ESAL*10^6	Predicted IRI (inch/mile)	Predicted Rutting (inch)	Predicted Cracking (Spacing)	Predicted Maintenance Strategy	Required Crack Fill (LF)	Required Shimming (TON)	Required Overlay (SF)	Estimated Agency Cost	LCC Agency Cost	V.O.C. Car (million $)	V.O.C. Truck (million $)	LCC User Cost
0	0	0	0.00	---	Initial Construction	-----	-----	-----	2326579	2326579	4.16	0.80	0
5	3	55	0.21	69.38	Crack Fill	5480	0	0	11946	9818	4.25	0.84	20640637
10	7	66	0.24	44.72	Shim & Fill	8501	11	0	89391	60389	4.26	0.85	17212287
15	11	74	0.26	34.59	Crack Fill	10992	0	0	23962	13305	4.27	0.85	14206314
20	15	80	0.28	28.82	Shim & Fill	13189	12	0	99790	45543	4.28	0.86	11713377
25	20	86	0.30	25.02	Crack Fill	15192	0	0	33119	12424	4.29	0.86	9653176
30	26	91	0.31	22.29	Shim & Fill	17053	14	0	108343	33404	4.30	0.86	7953033
35	32	96	0.32	20.22	Crack Fill	18802	0	0	40989	10387	4.31	0.87	6551091
40	38	101	0.33	18.58	Shim & Fill	20462	15	0	115886	24138	4.32	0.87	5395582
45	45	105	0.34	17.24	Crack Fill	22048	0	0	48064	8228	4.32	0.87	4443480
50	53	110	0.35	16.13	End Life	-----	-----	-----	0	0	4.33	0.88	3659146
Total	-----	-----	-----	-----	-----	-----	-----	-----	-----	2544216	-----	-----	101428122

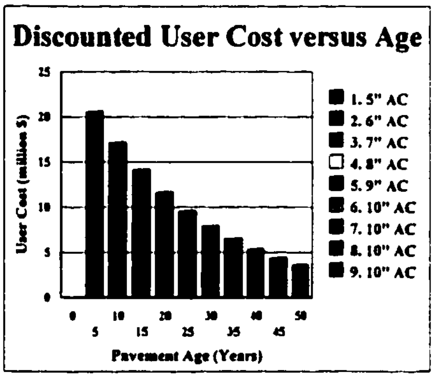
OUTPUT - ECONOMIC ANALYSIS - AGENCY EXPEDITURE

Year	Alt 1 5" HMAC 14" Base (million $)	Alt 2 6" HMAC 14" Base (million $)	Alt 3 7" HMAC 14" Base (million $)	Alt 4 8" HMAC 14" Base (million $)	Alt 5 9" HMAC 14" Base (million $)	Alt 6. 10" HMAC 14" Base (million $)	Alt 7 10" HMAC 19" Base (million $)	Alt 8 10" HMAC 24" Base (million $)	Alt 9 10" HMAC 29" Base (million $)
0	1.29	1.39	1.49	1.59	1.70	1.79	1.97	2.15	2.33
5	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
10	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
15	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
20	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
25	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
30	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
35	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
40	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
45	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	1.52	1.62	1.72	1.81	1.92	2.01	2.19	2.37	2.54



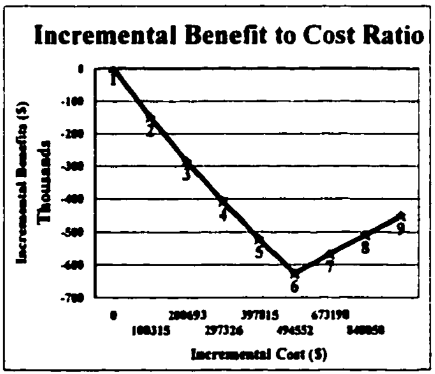
OUTPUT - ECONOMIC ANALYSIS - USER COSTS

Year	Alt 1 5" HMAC 14" Base (million $)	Alt 2 6" HMAC 14" Base (million $)	Alt 3 7" HMAC 14" Base (million $)	Alt 4 8" HMAC 14" Base (million $)	Alt 5 9" HMAC 14" Base (million $)	Alt 6. 10" HMAC 14" Base (million $)	Alt 7 10" HMAC 19" Base (million $)	Alt 8 10" HMAC 24" Base (million $)	Alt 9 10" HMAC 29" Base (million $)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	20.60	20.62	20.63	20.64	20.65	20.66	20.65	20.65	20.64
10	17.14	17.17	17.19	17.21	17.22	17.24	17.23	17.22	17.21
15	14.14	14.16	14.18	14.20	14.22	14.23	14.22	14.21	14.21
20	11.65	11.67	11.69	11.71	11.72	11.74	11.73	11.72	11.71
25	9.60	9.62	9.63	9.65	9.66	9.67	9.67	9.66	9.65
30	7.91	7.92	7.94	7.95	7.96	7.97	7.96	7.96	7.95
35	6.51	6.52	6.54	6.55	6.56	6.57	6.56	6.56	6.55
40	5.36	5.37	5.38	5.39	5.40	5.41	5.40	5.40	5.40
45	4.41	4.42	4.43	4.44	4.45	4.45	4.45	4.45	4.44
50	3.63	3.64	3.65	3.66	3.66	3.67	3.67	3.66	3.66
Total	100.98	101.13	101.26	101.39	101.50	101.60	101.54	101.49	101.43



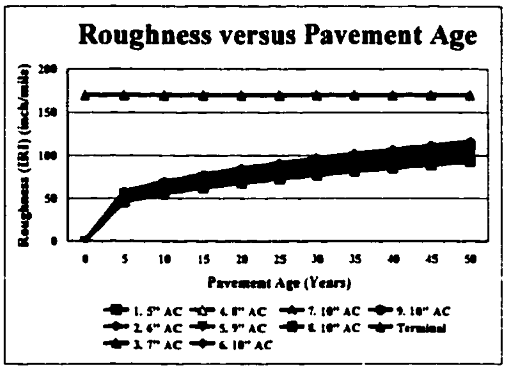
OUTPUT - INCREMENTAL B/C ANALYSIS

Alternative Number	Agency Cost ($)	User Cost ($)	Incremental Cost ($)	Incremental Benefit ($)	Incremental B/C Ratio
1	1517509	100975435	0	0	—
2	1617824	101127411	100315	-151976	-1.51
3	1718202	101262869	100378	-135459	-1.35
4	1814836	101385627	96633	-122758	-1.27
5	1915324	101498264	100488	-112636	-1.12
6	2012062	101602611	96738	-104348	-1.08
7	2190707	101543360	178646	59251	0.33
8	2365559	101485204	174851	58156	0.33
9	2544216	101428122	178657	57082	0.32



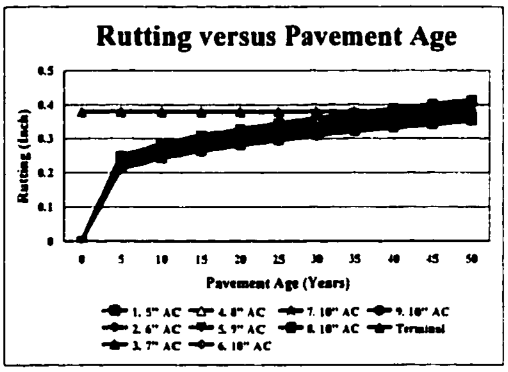
OUTPUT - PREDICTED ROUGHNESS

Year	Alt 1. 5" AC 14" Base inch/mile	Alt 2. 6" AC 14" Base inch/mile	Alt 3. 7" AC 14" Base inch/mile	Alt 4. 8" AC 14" Base inch/mile	Alt 5. 9" AC 14" Base inch/mile	Alt 6. 10" AC 14" Base inch/mile	Alt 7 10" AC 19" Base inch/mile	Alt 8 10" AC 24" Base inch/mile	Alt 9 10" AC 29" Base inch/mile	Terminal Roughness inch/mile
0	0	0	0	0	0	0	0	0	0	170
5	46	49	52	54	56	58	57	56	55	170
10	56	59	62	65	67	70	68	67	66	170
15	63	66	70	73	75	78	77	75	74	170
20	68	72	76	79	82	85	83	82	80	170
25	73	78	81	85	88	91	89	88	86	170
30	78	82	86	90	93	97	95	93	91	170
35	82	87	91	95	98	102	100	98	96	170
40	86	91	95	99	103	107	105	103	101	170
45	90	95	100	104	108	111	109	107	105	170
50	93	99	104	108	112	116	114	112	110	170
Total	—	—	—	—	—	—	—	—	—	—



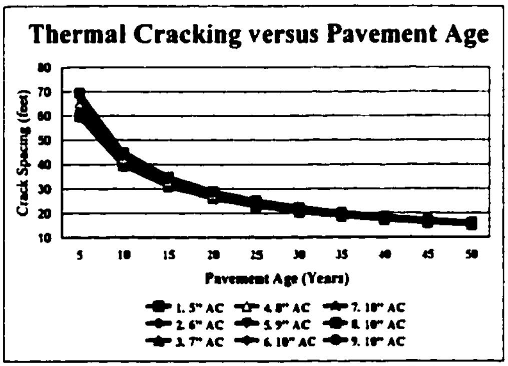
OUTPUT - PREDICTED RUTTING

Year	Alt 1. 5" AC 14" Base (inch)	Alt 2. 6" AC 14" Base (inch)	Alt 3. 7" AC 14" Base (inch)	Alt 4. 8" AC 14" Base (inch)	Alt 5. 9" AC 14" Base (inch)	Alt 6. 10" AC 14" Base (inch)	Alt 7 10" AC 19" Base (inch)	Alt 8 10" AC 24" Base (inch)	Alt 9 10" AC 29" Base (inch)	Terminal Rutting (inch)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38
5	0.25	0.24	0.23	0.23	0.22	0.22	0.22	0.21	0.21	0.38
10	0.28	0.27	0.27	0.26	0.26	0.25	0.25	0.24	0.24	0.38
15	0.31	0.30	0.29	0.28	0.28	0.27	0.27	0.27	0.26	0.38
20	0.33	0.32	0.31	0.30	0.30	0.29	0.29	0.28	0.28	0.38
25	0.35	0.33	0.32	0.32	0.31	0.30	0.30	0.30	0.30	0.38
30	0.36	0.35	0.34	0.33	0.32	0.32	0.31	0.31	0.31	0.38
35	0.37	0.36	0.35	0.34	0.34	0.33	0.33	0.32	0.32	0.38
40	0.39	0.38	0.36	0.36	0.35	0.34	0.34	0.33	0.33	0.38
45	0.40	0.39	0.38	0.37	0.36	0.35	0.35	0.35	0.34	0.38
50	0.41	0.40	0.39	0.38	0.37	0.36	0.36	0.36	0.35	0.38
Total	—	—	—	—	—	—	—	—	—	—



OUTPUT - PREDICTED THERMAL CRACKING

Year	Alt 1. 5" AC 14" Base (feet)	Alt 2. 6" AC 14" Base (feet)	Alt 3. 7" AC 14" Base (feet)	Alt 4. 8" AC 14" Base (feet)	Alt 5. 9" AC 14" Base (feet)	Alt 6. 10" AC 14" Base (feet)	Alt 7 10" AC 19" Base (feet)	Alt 8 10" AC 24" Base (feet)	Alt 9 10" AC 29" Base (feet)
0	—	—	—	—	—	—	—	—	—
5	59.55	61.39	63.30	65.26	67.29	69.38	69.38	69.38	69.38
10	39.38	40.39	41.43	42.50	43.60	44.72	44.72	44.72	44.72
15	30.92	31.62	32.34	33.07	33.82	34.59	34.59	34.59	34.59
20	26.04	26.58	27.12	27.68	28.24	28.82	28.82	28.82	28.82
25	22.80	23.22	23.66	24.11	24.56	25.02	25.02	25.02	25.02
30	20.45	20.80	21.17	21.54	21.91	22.29	22.29	22.29	22.29
35	18.65	18.95	19.26	19.58	19.89	20.22	20.22	20.22	20.22
40	17.22	17.49	17.75	18.02	18.30	18.58	18.58	18.58	18.58
45	16.05	16.28	16.52	16.76	17.00	17.24	17.24	17.24	17.24
50	15.08	15.28	15.49	15.70	15.91	16.13	16.13	16.13	16.13
Total	—	—	—	—	—	—	—	—	—



APPENDIX Q :

Predicted Life Cycle Cost Computations - NYSDOT Rigid Pavement Case Study.

Contents:	Page:
Input Screen.	181
Output Screen - AASHTO Rigid Design Analysis.	182
Output Screen - Mechanistic Design Analysis (Alternatives 1 through 3).	183
Output Screen - Mechanistic Design Analysis (Alternatives 4 through 6).	184
Output Screen - Economic Analysis.	185
Output Screen - Predicted Roughness and Distresses.	186

RIGID PAVEMENT : LIFE-CYCLE PAVEMENT DESIGN ANALYSIS.

By : Patrick J. Prancl
January 6, 2000.

* Note : Algorithm is valid for SHRP Wet-Freeze Climate Region and has been developed for use by the New York State Department of Transportation.

INPUT SCREEN

Traffic Data:

Data Input	Units	Data Input	Default Value
ADT	veh./day	64000	----
Heavy Vehicles	%	12	----
Load Factor	ESAL/truck	1.85	1.85
Direction Distribution	%	50	50
Lane Distribution	%	85	----
Combined Growth	%	2	----

Environmental Data :

Data Input	Units	Data Input	Default Value
Annual Freeze-Thaw Cycles	# Cycles	80	80

Pavement Characteristic Data:

Data Input	Units	Data Input	Default Value
Subgrade Reaction (Kstatic)	p.c.i.	200	200
Transverse Joint Spacing	feet	16	16
Transverse Dowel Diameter	inch	2	2

Geometric Data :

Data Input	Units	Data Input	Default Value
Travel Lane Width	feet	12	12
Inner Shoulder Width	feet	4	4
Outer Shoulder Width	feet	8	12
Travel Lanes Per Direction	#	2	-----
Pavement Length	mile	1	-----
Discount Rate	%	4	4

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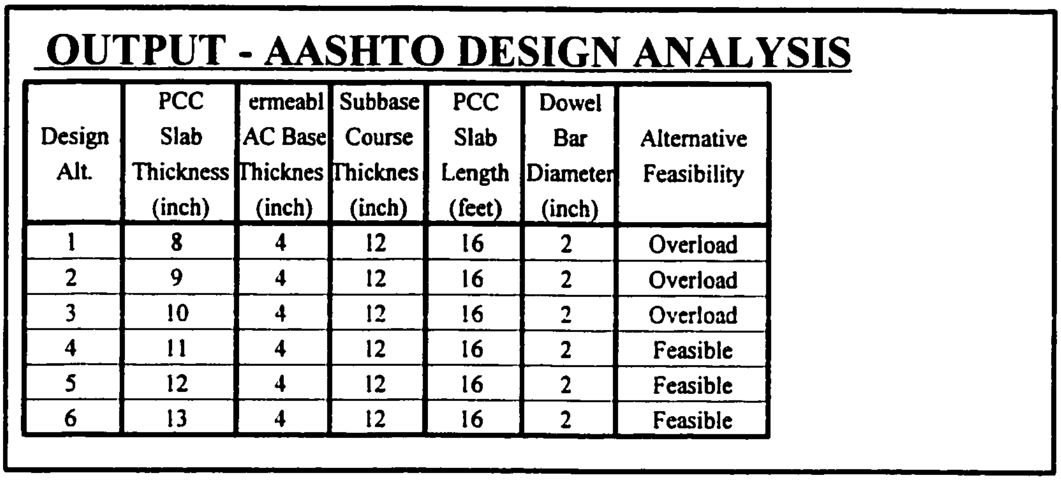


OUTPUT - AASHTO DESIGN ANALYSIS

Design Alt.	PCC Slab Thickness (inch)	ermeabl AC Base Thicknes (inch)	Subbase Course Thicknes (inch)	PCC Slab Length (feet)	Dowel Bar Diameter (inch)	Alternative Feasibility
1	8	4	12	16	2	Overload
2	9	4	12	16	2	Overload
3	10	4	12	16	2	Overload
4	11	4	12	16	2	Feasible
5	12	4	12	16	2	Feasible
6	13	4	12	16	2	Feasible

MECHANISTIC DESIGN ANALYSIS - SLAB THICKNESS OF 8 INCHES

Year	Cumulative Loading (ESAL)	Cumulativ Loading SAL*10^	Predicted IRI (inch/mile	Predicted Faulting (inch)	Predicted Spalling (% Slab)	Predicted Maintenance Strategy	Required Sealing (LF)	Required Patching (SF)	Required Grinding (SF)	Required Overlay (SF)	Estimated Agency Cost	LCC Agency Cost	V O.C. Car (million $)	V O C Truck (million $)	LCC User Cost
0	0	0	97	0.00	0.49	Initial Const.	—	—	—	—	3326400	3326400	12.26	3.03	0
5	11469788	11	101	0.00	1.57	—	0	0	0	0	0	0	12.28	3.04	62885435
10	24133360	24	105	0.00	2.66	Seal & Patch	55440	6740	0	0	282169	190623	12.29	3.05	51778328
15	38114968	38	109	0.00	3.74	—	0	0	0	0	0	0	12.31	3.06	42632876
20	53551792	54	113	0.00	4.83	Seal & Patch	55440	12238	0	0	359025	163854	12.33	3.07	35102649
25	70595293	71	117	0.01	5.91	—	0	0	0	0	0	0	12.35	3.08	28902395
30	89412696	89	121	0.04	7.00	Seal & Patch	55440	17735	0	0	435880	134390	12.36	3.09	23797231
35	110188629	110	125	0.09	8.08	—	0	0	0	0	0	0	12.38	3.10	19593757
40	133126937	133	129	0.14	9.17	Seal & Patch	55440	23233	0	0	512736	106797	12.40	3.11	16132723
45	158452684	158	133	0.21	10.25	Grind & Reseal	55440	0	97679	0	271945	46557	12.41	3.12	13283004
50	186414354	186	137	0.28	11.34	End Life	—	—	—	—	0	0	12.43	3.13	10936633
Total	—	—	—	—	—	—	—	—	—	—	—	3968622	—	—	305045031

MECHANISTIC DESIGN ANALYSIS - SLAB THICKNESS OF 9 INCHES

Year	Cumulative Loading (ESAL)	Cumulativ Loading illion ESA	Predicted IRI (inch/mile	Predicted Faulting (inch)	Predicted Spalling (% Slab)	Predicted Maintenance Strategy	Required Sealing (LF)	Required Patching (SF)	Required Grinding (SF)	Required Overlay (SF)	Estimated Agency Cost	LCC Agency Cost	V O.C. Car (million $)	V O.C. Truck (million $)	LCC User Cost
0	0	0	90	0.00	0.49	Initial Const.	—	—	—	—	3505075	3505075	12.23	3.01	0
5	11469788	11	94	0.00	1.57	—	0	0	0	0	0	0	12.25	3.02	62686660
10	24133360	24	98	0.00	2.66	Seal & Patch	55440	6740	0	0	282169	190623	12.26	3.03	51614949
15	38114968	38	102	0.00	3.74	—	0	0	0	0	0	0	12.28	3.04	42498590
20	53551792	54	106	0.00	4.83	Seal & Patch	55440	12238	0	0	359025	163854	12.30	3.05	34992277
25	70595293	71	110	0.01	5.91	—	0	0	0	0	0	0	12.31	3.06	28811676
30	89412696	89	114	0.04	7.00	Seal & Patch	55440	17735	0	0	435880	134390	12.33	3.07	23722668
35	110188629	110	118	0.09	8.08	—	0	0	0	0	0	0	12.35	3.08	19532471
40	133126937	133	122	0.14	9.17	Seal & Patch	55440	23233	0	0	512736	106797	12.37	3.09	16082350
45	158452684	158	126	0.21	10.25	Grind & Reseal	55440	0	97679	0	271945	46557	12.38	3.10	13241602
50	186414354	186	130	0.28	11.34	End Life	—	—	—	—	0	0	12.40	3.11	10902603
Total	—	—	—	—	—	—	—	—	—	—	—	4147297	—	—	304085845

MECHANISTIC DESIGN ANALYSIS - SLAB THICKNESS OF 10 INCHES

Year	Cumulative Loading (ESAL)	Cumulativ Loading illion ESA	Predicted IRI (inch/mile	Predicted Faulting (inch)	Predicted Spalling (% Slab)	Predicted Maintenance Strategy	Required Sealing (LF)	Required Patching (SF)	Required Grinding (SF)	Required Overlay (SF)	Estimated Agency Cost	LCC Agency Cost	V O.C. Car (million $)	V O.C. Truck (million $)	LCC User Cost
0	0	0	83	0.00	0.49	Initial Const.	—	—	—	—	3710362	3710362	12.20	2.99	0
5	11469788	11	87	0.00	1.57	—	0	0	0	0	0	0	12.22	3.00	62487884
10	24133360	24	91	0.00	2.66	Seal & Patch	55440	6740	0	0	282169	190623	12.23	3.01	51451570
15	38114968	38	95	0.00	3.74	—	0	0	0	0	0	0	12.25	3.02	42364305
20	53551792	54	99	0.00	4.83	Seal & Patch	55440	12238	0	0	359025	163854	12.27	3.03	34881904
25	70595293	71	103	0.01	5.91	—	0	0	0	0	0	0	12.28	3.04	28720958
30	89412696	89	107	0.04	7.00	Seal & Patch	55440	17735	0	0	435880	134390	12.30	3.05	23648104
35	110188629	110	111	0.09	8.08	—	0	0	0	0	0	0	12.32	3.06	19471185
40	133126937	133	115	0.14	9.17	Seal & Patch	55440	23233	0	0	512736	106797	12.34	3.07	16031977
45	158452684	158	119	0.21	10.25	Grind & Reseal	55440	0	97679	0	271945	46557	12.35	3.08	13200199
50	186414354	186	123	0.28	11.34	End Life	—	—	—	—	0	0	12.37	3.09	10868573
Total	—	—	—	—	—	—	—	—	—	—	—	4352583	—	—	303126659

MECHANISTIC DESIGN ANALYSIS - SLAB THICKNESS OF 11 INCHES

Year	Cumulative Loading (ESAL)	Cumulativ Loading illion ESA	Predicted IRI inch/mile	Predicted Faulting (inch)	Predicted Spalling (% Slab)	Predicted Maintenance Strategy	Required Sealing (LF)	Required Patching (SF)	Required Grinding (SF)	Required Overlay (SF)	Estimated Agency Cost	LCC Agency Cost	V.O.C. Car (million $)	V.O.C. Truck (million $)	LCC User Cost
0	0	0	76	0.00	0.49	Initial Const.	—	—	—	—	3915648	3915648	12.17	2.98	0
5	11469788	11	80	0.00	1.57	—	0	0	0	0	0	0	12.18	2.99	62289109
10	24133360	24	84	0.00	2.66	Seal & Patch	55440	6740	0	0	282169	190623	12.20	3.00	51288191
15	38114968	38	88	0.00	3.74	—	0	0	0	0	0	0	12.22	3.01	42230019
20	53551792	54	92	0.00	4.83	Seal & Patch	55440	12238	0	0	359025	163854	12.24	3.02	34771531
25	70595293	71	96	0.01	5.91	—	0	0	0	0	0	0	12.25	3.02	28630240
30	89412696	89	100	0.04	7.00	Seal & Patch	55440	17735	0	0	435880	134390	12.27	3.03	23573540
35	110188629	110	104	0.09	8.08	—	0	0	0	0	0	0	12.29	3.04	19409898
40	133126937	133	107	0.14	9.17	Seal & Patch	55440	23233	0	0	512736	106797	12.30	3.05	15981605
45	158452684	158	111	0.21	10.25	Grind & Reseal	55440	0	97679	0	271945	46557	12.32	3.06	13158796
50	186414354	186	115	0.28	11.34	End Life	—	—	—	—	0	0	12.34	3.07	10834543
Total	—	—	—	—	—	—	—	—	—	—	—	4557870	—	—	302167473

MECHANISTIC DESIGN ANALYSIS - SLAB THICKNESS OF 12 INCHES

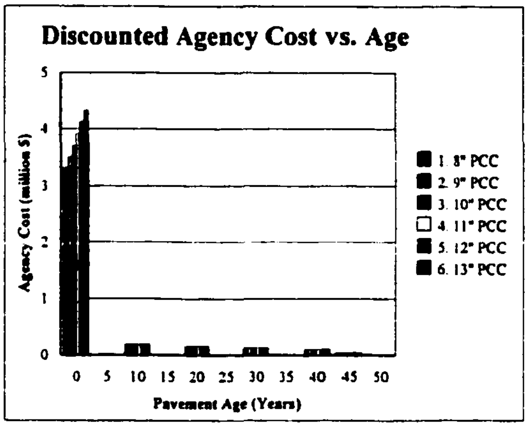
Year	Cumulative Loading (ESAL)	Cumulativ Loading illion ESA	Predicted IRI inch/mile	Predicted Faulting (inch)	Predicted Spalling (% Slab)	Predicted Maintenance Strategy	Required Sealing (LF)	Required Patching (SF)	Required Grinding (SF)	Required Overlay (SF)	Estimated Agency Cost	LCC Agency Cost	V.O.C. Car (million $)	V.O.C. Truck (million $)	LCC User Cost
0	0	0	69	0.00	0.49	Initial Const.	—	—	—	—	4124736	4124736	12.14	2.96	0
5	11469788	11	73	0.00	1.57	—	0	0	0	0	0	0	12.15	2.97	62090334
10	24133360	24	77	0.00	2.66	Seal & Patch	55440	6740	0	0	282169	190623	12.17	2.98	51124813
15	38114968	38	80	0.00	3.74	—	0	0	0	0	0	0	12.19	2.99	42095734
20	53551792	54	84	0.00	4.83	Seal & Patch	55440	12238	0	0	359025	163854	12.21	3.00	34661158
25	70595293	71	88	0.01	5.91	—	0	0	0	0	0	0	12.22	3.01	28539521
30	89412696	89	92	0.04	7.00	Seal & Patch	55440	17735	0	0	435880	134390	12.24	3.02	23498976
35	110188629	110	96	0.09	8.08	—	0	0	0	0	0	0	12.26	3.03	19348612
40	133126937	133	100	0.14	9.17	Seal & Patch	55440	23233	0	0	512736	106797	12.27	3.04	15931232
45	158452684	158	104	0.21	10.25	Grind & Reseal	55440	0	97679	0	271945	46557	12.29	3.05	13117394
50	186414354	186	108	0.28	11.34	End Life	—	—	—	—	0	0	12.31	3.06	10800513
Total	—	—	—	—	—	—	—	—	—	—	—	4766958	—	—	301208287

MECHANISTIC DESIGN ANALYSIS - SLAB THICKNESS OF 13 INCHES

Year	Cumulative Loading (ESAL)	Cumulativ Loading illion ESA	Predicted IRI inch/mile	Predicted Faulting (inch)	Predicted Spalling (% Slab)	Predicted Maintenance Strategy	Required Sealing (LF)	Required Patching (SF)	Required Grinding (SF)	Required Overlay (SF)	Estimated Agency Cost	LCC Agency Cost	V.O.C. Car (million $)	V.O.C. Truck (million $)	LCC User Cost
0	0	0	61	0.00	0.49	Initial Const.	—	—	—	—	4330022	4330022	12.11	2.94	0
5	11469788	11	65	0.00	1.57	—	0	0	0	0	0	0	12.12	2.95	61891559
10	24133360	24	69	0.00	2.66	Seal & Patch	55440	6740	0	0	282169	190623	12.14	2.96	50961434
15	38114968	38	73	0.00	3.74	—	0	0	0	0	0	0	12.16	2.97	41961449
20	53551792	54	77	0.00	4.83	Seal & Patch	55440	12238	0	0	359025	163854	12.17	2.98	34550785
25	70595293	71	81	0.01	5.91	—	0	0	0	0	0	0	12.19	2.99	28448803
30	89412696	89	85	0.04	7.00	Seal & Patch	55440	17735	0	0	435880	134390	12.21	3.00	23424412
35	110188629	110	89	0.09	8.08	—	0	0	0	0	0	0	12.23	3.01	19287326
40	133126937	133	93	0.14	9.17	Seal & Patch	55440	23233	0	0	512736	106797	12.24	3.02	15880859
45	158452684	158	97	0.21	10.25	Grind & Reseal	55440	0	97679	0	271945	46557	12.26	3.03	13075991
50	186414354	186	101	0.28	11.34	End Life	—	—	—	—	0	0	12.28	3.04	10766483
Total	—	—	—	—	—	—	—	—	—	—	—	4972244	—	—	300249100

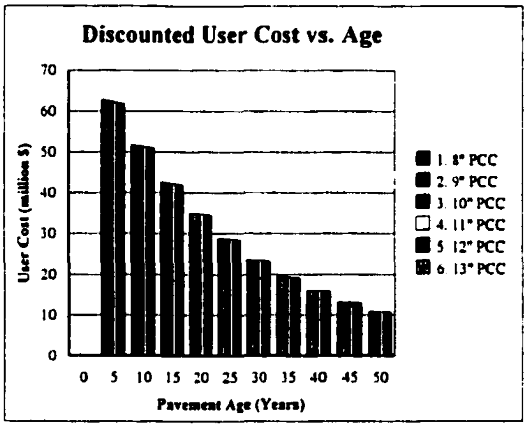
OUTPUT - ECONOMIC ANALYSIS - AGENCY EXPEDITURE

Year	Alt 1. 8" PCC (million $)	Alt 2. 9" PCC (million $)	Alt 3. 10" PCC (million $)	Alt 4. 11" PCC (million $)	Alt 5. 12" PCC (million $)	Alt 6. 13" PCC (million $)
0	3.33	3.51	3.71	3.92	4.12	4.33
5	0.00	0.00	0.00	0.00	0.00	0.00
10	0.19	0.19	0.19	0.19	0.19	0.19
15	0.00	0.00	0.00	0.00	0.00	0.00
20	0.16	0.16	0.16	0.16	0.16	0.16
25	0.00	0.00	0.00	0.00	0.00	0.00
30	0.13	0.13	0.13	0.13	0.13	0.13
35	0.00	0.00	0.00	0.00	0.00	0.00
40	0.11	0.11	0.11	0.11	0.11	0.11
45	0.05	0.05	0.05	0.05	0.05	0.05
50	0.00	0.00	0.00	0.00	0.00	0.00
Total	3.97	4.15	4.35	4.56	4.77	4.97



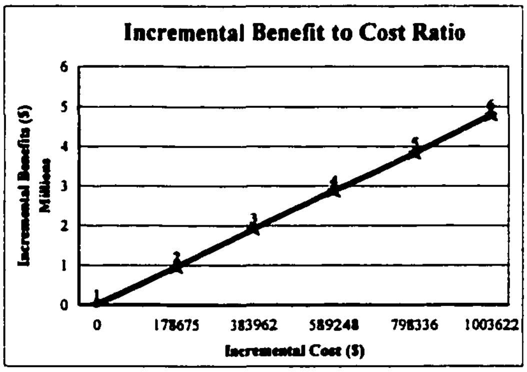
OUTPUT - ECONOMIC ANALYSIS - USER COSTS

Year	Alt 1. 8" PCC (million $)	Alt 2. 9" PCC (million $)	Alt 3. 10" PCC (million $)	Alt 4. 11" PCC (million $)	Alt 5. 12" PCC (million $)	Alt 6. 13" PCC (million $)
0	0.00	0.00	0.00	0.00	0.00	0.00
5	62.89	62.69	62.49	62.29	62.09	61.89
10	51.78	51.61	51.45	51.29	51.12	50.96
15	42.63	42.50	42.36	42.23	42.10	41.96
20	35.10	34.99	34.88	34.77	34.66	34.55
25	28.90	28.81	28.72	28.63	28.54	28.45
30	23.80	23.72	23.65	23.57	23.50	23.42
35	19.59	19.53	19.47	19.41	19.35	19.29
40	16.13	16.08	16.03	15.98	15.93	15.88
45	13.28	13.24	13.20	13.16	13.12	13.08
50	10.94	10.90	10.87	10.83	10.80	10.77
Total	305.05	304.09	303.13	302.17	301.21	300.25



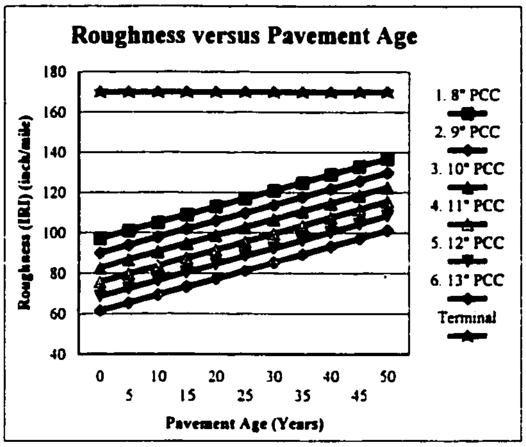
OUTPUT - INCREMENTAL B/C ANALYSIS

Alternative Number	Agency Cost ($)	User Cost ($)	Incremental Cost ($)	Incremental Benefit ($)	Incremental B/C Ratio
1	3968622	305045031	0	0	—
2	4147297	304085845	178675	959186	5.37
3	4352583	303126659	205286	959186	4.67
4	4557870	302167473	205286	959186	4.67
5	4766958	301208287	209088	959186	4.59
6	4972244	300249100	205286	959186	4.67



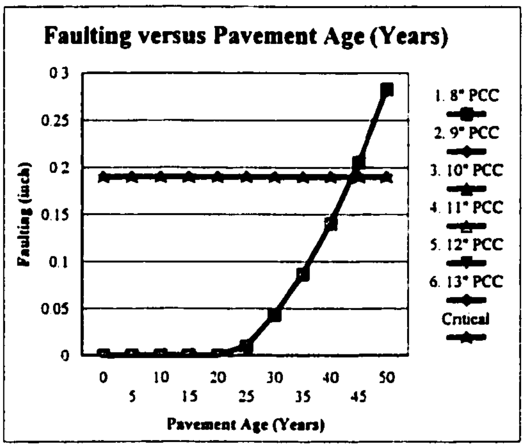
OUTPUT - PREDICTED ROUGHNESS

Year	Alt 1. 8" PCC (inch/mile)	Alt 2. 9" PCC (inch/mile)	Alt 3. 10" PCC (inch/mile)	Alt 4. 11" PCC (inch/mile)	Alt 5. 12" PCC (inch/mile)	Alt 6. 13" PCC (inch/mile)	Terminal Roughness (inch/mile)
0	97.08	89.95	82.82	75.69	68.56	61.43	170.00
5	101.06	93.93	86.80	79.67	72.54	65.41	170.00
10	105.03	97.90	90.77	83.64	76.51	69.38	170.00
15	109.01	101.88	94.75	87.62	80.49	73.36	170.00
20	112.98	105.85	98.72	91.59	84.46	77.33	170.00
25	116.96	109.83	102.70	95.57	88.44	81.31	170.00
30	120.93	113.80	106.67	99.54	92.41	85.28	170.00
35	124.91	117.78	110.65	103.52	96.39	89.26	170.00
40	128.88	121.75	114.62	107.49	100.36	93.23	170.00
45	132.86	125.73	118.60	111.47	104.34	97.21	170.00
50	136.83	129.70	122.57	115.44	108.31	101.18	170.00
Total	—	—	—	—	—	—	—


Roughness versus Pavement Age

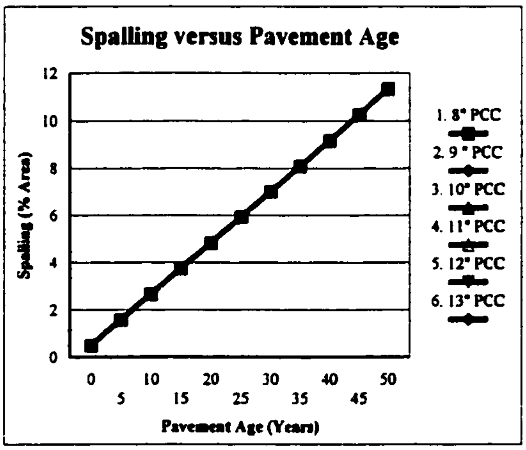
OUTPUT - PREDICTED FAULTING

Year	Alt 1. 8" PCC (inch)	Alt 2. 9" PCC (inch)	Alt 3. 10" PCC (inch)	Alt 4. 11" PCC (inch)	Alt 5. 12" PCC (inch)	Alt 6. 13" PCC (inch)	Critical Faulting (inch)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.19
5	0.00	0.00	0.00	0.00	0.00	0.00	0.19
10	0.00	0.00	0.00	0.00	0.00	0.00	0.19
15	0.00	0.00	0.00	0.00	0.00	0.00	0.19
20	0.00	0.00	0.00	0.00	0.00	0.00	0.19
25	0.01	0.01	0.01	0.01	0.01	0.01	0.19
30	0.04	0.04	0.04	0.04	0.04	0.04	0.19
35	0.09	0.09	0.09	0.09	0.09	0.09	0.19
40	0.14	0.14	0.14	0.14	0.14	0.14	0.19
45	0.21	0.21	0.21	0.21	0.21	0.21	0.19
50	0.28	0.28	0.28	0.28	0.28	0.28	0.19
Total	—	—	—	—	—	—	—


Faulting versus Pavement Age (Years)

OUTPUT - PREDICTED SPALLING

Year	Alt 1. 8" PCC (%)	Alt 2. 9" PCC (%)	Alt 3. 10" PCC (%)	Alt 4. 11" PCC (%)	Alt 5. 12" PCC (%)	Alt 6. 13" PCC (%)
0	0.49	0.49	0.49	0.49	0.49	0.49
5	1.57	1.57	1.57	1.57	1.57	1.57
10	2.66	2.66	2.66	2.66	2.66	2.66
15	3.74	3.74	3.74	3.74	3.74	3.74
20	4.83	4.83	4.83	4.83	4.83	4.83
25	5.91	5.91	5.91	5.91	5.91	5.91
30	7.00	7.00	7.00	7.00	7.00	7.00
35	8.08	8.08	8.08	8.08	8.08	8.08
40	9.17	9.17	9.17	9.17	9.17	9.17
45	10.25	10.25	10.25	10.25	10.25	10.25
50	11.34	11.34	11.34	11.34	11.34	11.34
Total	—	—	—	—	—	—


Spalling versus Pavement Age

APPENDIX R :

Initial Agency Cost Matrices, New York State.

Contents:

Table R-1: NYSDOT Flexible Pavement - Initial Agency Cost Matrix.
Table R-1: NYSDOT Flexible Pavement - Initial Agency Cost Matrix (Continued).
Table R-2: NYSDOT Rigid Pavement - Initial Agency Cost Matrix.
Table R-2: NYSDOT Rigid Pavement - Initial Agency Cost Matrix (Continued).

Table R-1: NYSDOT Flexible Pavement - Inital Agency Cost Matrix

Cost dollars is per square foot

AC Thickness (inch)	Subbase Thickness (inch)	Depth Excavation (inch)	Depth AC Base (inch)	Initial Cost (sf)	POH Cost (34%)	Total I.C. (sf)
3	0	7	0	1.56	0.53	2.09
4	0	8	1	1.77	0.60	2.37
5	0	9	2	1.98	0.67	2.65
6	0	10	3	2.19	0.74	2.93
7	0	11	4	2.40	0.82	3.22
8	0	12	5	2.61	0.89	3.50
9	0	13	6	2.82	0.96	3.78
10	0	14	7	3.03	1.03	4.06
11	0	15	8	3.24	1.10	4.34
15	0	19	12	4.08	1.39	5.47
20	0	24	17	5.13	1.74	6.87
25	0	29	22	6.18	2.10	8.28
3	6	13	0	1.92	0.65	2.57
4	6	14	1	2.13	0.72	2.85
5	6	15	2	2.34	0.80	3.14
6	6	16	3	2.55	0.87	3.42
7	6	17	4	2.76	0.94	3.70
8	6	18	5	2.97	1.01	3.98
9	6	19	6	3.18	1.08	4.26
10	6	20	7	3.39	1.15	4.54
11	6	21	8	3.60	1.22	4.82
15	6	25	12	4.44	1.51	5.95
20	6	30	17	5.49	1.87	7.36
25	6	35	22	6.54	2.22	8.76
3	12	19	0	2.28	0.78	3.06
4	12	20	1	2.49	0.85	3.34
5	12	21	2	2.70	0.92	3.62
6	12	22	3	2.91	0.99	3.90
7	12	23	4	3.12	1.06	4.18
8	12	24	5	3.33	1.13	4.46
9	12	25	6	3.54	1.20	4.74
10	12	26	7	3.75	1.28	5.03
11	12	27	8	3.96	1.35	5.31
15	12	31	12	4.80	1.63	6.43
20	12	36	17	5.85	1.99	7.84
25	12	41	22	6.90	2.35	9.25

Notes:

Assume 1.5" minimum depth of AC top course and 1.5" minimum depth for AC binder.
Depth of AC Permeable drainage course is fixed at 4".
Depth Excavation = AC Thickness + 4" Permeable AC + Subbase Thickness
Cost of Top Course Asphalt = $34.81 per Ton [36][37].
Cost of Binder Course Asphalt = $32.63 per Ton [36][37].
Cost of Base Course Asphalt = $31.00 per Ton [36][37].
Cost of Permeable Asphalt Drainage Course = $31.09 per Ton [36][37].
Cost of Subbase Material = $13.39 per Cubic Yard [36][37].
Cost of Excavation = $6.60 per Cubic Yard [36][37].

Table R-1: NYSDOT Flexible Pavement - Inital Agency Cost Matrix (Continued).

Cost dollars is per square foot

AC Thickness (inch)	Subbase Thickness (inch)	Depth Excavation (inch)	Depth AC Base (inch)	Initial Cost (sf)	POH Cost (34%)	Total I.C. (sf)
3	18	25	0	2.64	0.90	3.54
4	18	26	1	2.85	0.97	3.82
5	18	27	2	3.06	1.04	4.10
6	18	28	3	3.27	1.11	4.38
7	18	29	4	3.48	1.18	4.66
8	18	30	5	3.69	1.25	4.94
9	18	31	6	3.90	1.33	5.23
10	18	32	7	4.11	1.40	5.51
11	18	33	8	4.32	1.47	5.79
15	18	37	12	5.16	1.75	6.91
20	18	42	17	6.21	2.11	8.32
25	18	47	22	7.26	2.47	9.73
3	24	31	0	3.00	1.02	4.02
4	24	32	1	3.21	1.09	4.30
5	24	33	2	3.42	1.16	4.58
6	24	34	3	3.63	1.23	4.86
7	24	35	4	3.84	1.31	5.15
8	24	36	5	4.05	1.38	5.43
9	24	37	6	4.26	1.45	5.71
10	24	38	7	4.47	1.52	5.99
11	24	39	8	4.68	1.59	6.27
15	24	43	12	5.52	1.88	7.40
20	24	48	17	6.57	2.23	8.80
25	24	53	22	7.62	2.59	10.21
3	30	37	0	3.36	1.14	4.50
4	30	38	1	3.57	1.21	4.78
5	30	39	2	3.78	1.29	5.07
6	30	40	3	3.99	1.36	5.35
7	30	41	4	4.20	1.43	5.63
8	30	42	5	4.41	1.50	5.91
9	30	43	6	4.62	1.57	6.19
10	30	44	7	4.83	1.64	6.47
11	30	45	8	5.04	1.71	6.75
15	30	49	12	5.88	2.00	7.88
20	30	54	17	6.93	2.36	9.29
25	30	59	22	7.98	2.71	10.69
3	36	43	0	3.72	1.26	4.98
4	36	44	1	3.93	1.34	5.27
5	36	45	2	4.14	1.41	5.55
6	36	46	3	4.35	1.48	5.83
7	36	47	4	4.56	1.55	6.11
8	36	48	5	4.77	1.62	6.39
9	36	49	6	4.98	1.69	6.67
10	36	50	7	5.19	1.76	6.95
11	36	51	8	5.40	1.84	7.24
15	36	55	12	6.24	2.12	8.36
20	36	60	17	7.29	2.48	9.77
25	36	65	22	8.34	2.84	11.18

Table R-2: NYSDOT Rigid Pavement - Initial Agency Cost Matrix.

Cost is dollars per square foot.

PCC Thickness (inch)	Subbase Thickness (inch)	Depth Excavation (inch)	Joint Spacing (feet)	Initial Cost ($/sf)	POH Cost (34%)	Total I.C. ($/sf)
7	6	17	20	5.39	1.83	7.22
7	6	17	18	5.46	1.86	7.32
7	6	17	16	5.54	1.88	7.42
7	12	23	20	5.75	1.96	7.71
7	12	23	18	5.82	1.98	7.80
7	12	23	16	5.90	2.01	7.91
7	18	29	20	6.11	2.08	8.19
7	18	29	18	6.18	2.10	8.28
7	18	29	16	6.26	2.13	8.39
8	6	18	20	5.81	1.98	7.79
8	6	18	18	5.88	2.00	7.88
8	6	18	16	5.96	2.03	7.99
8	12	24	20	6.17	2.10	8.27
8	12	24	18	6.24	2.12	8.36
8	12	24	16	6.32	2.15	8.47
8	18	30	20	6.53	2.22	8.75
8	18	30	18	6.60	2.24	8.84
8	18	30	16	6.68	2.27	8.95
9	6	19	20	6.23	2.12	8.35
9	6	19	18	6.30	2.14	8.44
9	6	19	16	6.38	2.17	8.55
9	12	25	20	6.59	2.24	8.83
9	12	25	18	6.66	2.26	8.92
9	12	25	16	6.74	2.29	9.03
9	18	31	20	6.95	2.36	9.31
9	18	31	18	7.02	2.39	9.41
9	18	31	16	7.10	2.41	9.51
10	6	20	20	6.65	2.26	8.91
10	6	20	18	6.72	2.28	9.00
10	6	20	16	6.80	2.31	9.11
10	12	26	20	7.01	2.38	9.39
10	12	26	18	7.08	2.41	9.49
10	12	26	16	7.16	2.43	9.59
10	18	32	20	7.37	2.51	9.88
10	18	32	18	7.44	2.53	9.97
10	18	32	16	7.52	2.56	10.08

Notes:

1. Assume 7" minimum depth of PCC slab as per PCA [13].
2. Depth of Permeable AC drainage course is fixed at 4".
3. Depth Excavtion = PCC thickness + subbase thickness + 4".
4. Cost of excavation = $6.60 per cubic yard [36][37].
5. Cost of subbase = $13.39 per cubic yard [36][37].
6. Cost of concrete = $131.91 per cubic yard [36][37].
7. Cost of Asphalt drainage course = $31.09 per ton [36][37].
8. Cost of transverse joints = $6.57 per linear foot [36][37].
9. Cost of longitudinal ties = $5.80 each [36][37].
10. Cost of sawing and sealing = $5.44 per linear foot [36][37].

Table R-2: NYSDOT Rigid Pavement - Initial Agency Cost Matrix (Continued).

Cost is dollars per square foot.

PCC Thickness (inch)	Subbase Thickness (inch)	Depth Excavation (inch)	Joint Spacing (feet)	Initial Cost ($/sf)	POH Cost (34%)	Total I.C. ($/sf)
11	6	21	20	7.07	2.40	9.47
11	6	21	18	7.14	2.43	9.57
11	6	21	16	7.22	2.45	9.67
11	12	27	20	7.43	2.53	9.96
11	12	27	18	7.50	2.55	10.05
11	12	27	16	7.58	2.58	10.16
11	18	33	20	7.79	2.65	10.44
11	18	33	18	7.86	2.67	10.53
11	18	33	16	7.94	2.70	10.64
12	6	22	20	7.49	2.55	10.04
12	6	22	18	7.56	2.57	10.13
12	6	22	16	7.64	2.60	10.24
12	12	28	20	7.85	2.67	10.52
12	12	28	18	7.92	2.69	10.61
12	12	28	16	8.00	2.72	10.72
12	18	34	20	8.21	2.79	11.00
12	18	34	18	8.28	2.82	11.10
12	18	34	16	8.36	2.84	11.20
13	6	23	20	7.91	2.69	10.60
13	6	23	18	7.98	2.71	10.69
13	6	23	16	8.06	2.74	10.80
13	12	29	20	8.27	2.81	11.08
13	12	29	18	8.34	2.84	11.18
13	12	29	16	8.42	2.86	11.28
13	18	35	20	8.63	2.93	11.56
13	18	35	18	8.70	2.96	11.66
13	18	35	16	8.78	2.99	11.77
15	6	25	20	8.75	2.98	11.73
15	6	25	18	8.82	3.00	11.82
15	6	25	16	8.90	3.03	11.93
15	12	31	20	9.11	3.10	12.21
15	12	31	18	9.18	3.12	12.30
15	12	31	16	9.26	3.15	12.41
15	18	37	20	9.47	3.22	12.69
15	18	37	18	9.54	3.24	12.78
15	18	37	16	9.62	3.27	12.89

Notes:

1. Assume 7" minimum depth of PCC slab as per PCA [13].
2. Depth of Permeable AC drainage course is fixed at 4".
3. Depth Excavtion = PCC thickness + subbase thickness + 4".
4. Cost of excavation = $6.60 per cubic yard [36][37].
5. Cost of subbase = $13.39 per cubic yard [36][37].
6. Cost of concrete = $131.91 per cubic yard [36][37].
7. Cost of Asphalt drainage course = $31.09 per ton [36][37].
8. Cost of transverse joints = $6.57 per linear foot [36][37].
9. Cost of longitudinal ties = $5.80 each [36][37].
10. Cost of sawing and sealing = $5.44 per linear foot [36][37].

APPENDIX S :
NYSDOT Flexible Pavement - Economic Optimization Trials.

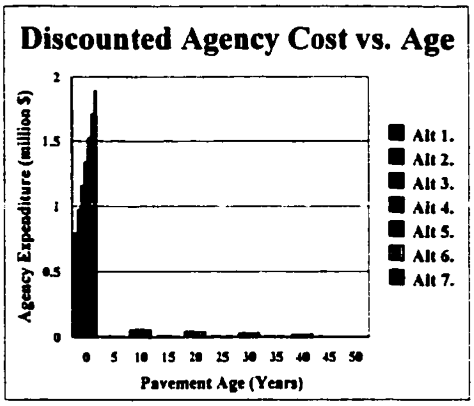
Contents:

Table S-1: NYSDOT Flexible Pavement - Economic Optimization - 3" HMA Trial.
Table S-2: NYSDOT Flexible Pavement - Economic Optimization - 4" HMA Trial.
Table S-3: NYSDOT Flexible Pavement - Economic Optimization - 5" HMA Trial.
Table S-4: NYSDOT Flexible Pavement - Economic Optimization - 6" HMA Trial.
Table S-5: NYSDOT Flexible Pavement - Economic Optimization - 7" HMA Trial.
Table S-6: NYSDOT Flexible Pavement - Economic Optimization - 8" HMA Trial.
Table S-7: NYSDOT Flexible Pavement - Economic Optimization - 9" HMA Trial.
Table S-8: NYSDOT Flexible Pavement - Economic Optimization - 10" HMA Trial.
Table S-9: NYSDOT Flexible Pavement - Economic Optimization - 11" HMA Trial.
Table S-10: NYSDOT Flexible Pavement - Economic Optimization - 15" HMA Trial.
Table S-11: NYSDOT Flexible Pavement - Economic Optimization - 20" HMA Trial.
Table S-12: NYSDOT Flexible Pavement - Economic Optimization - 25" HMA Trial.

Table S-1: NYSDOT Flexible Pavement - Economic Optimization - 3" HMA Trial

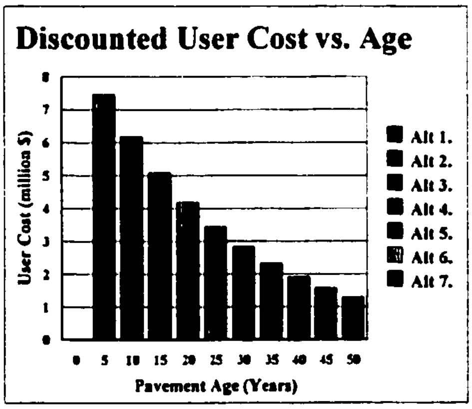
OUTPUT - ECONOMIC ANALYSIS - AGENCY EXPEDITURE (3" HMA)

Year	Alt 1 3" AC 0" Base (million $)	Alt 2 3" AC 6" Base (million $)	Alt 3 3" AC 12" Base (million $)	Alt 4 3" AC 18" Base (million $)	Alt 5 3" AC 24" Base (million $)	Alt 6. 3" AC 30" Base (million $)	Alt 7 3" AC 36" Base (million $)
0	0.79	0.98	1.16	1.35	1.53	1.71	1.89
5	0.01	0.01	0.01	0.01	0.01	0.01	0.01
10	0.06	0.06	0.06	0.06	0.06	0.06	0.06
15	0.01	0.01	0.01	0.01	0.01	0.01	0.01
20	0.05	0.05	0.05	0.04	0.04	0.04	0.04
25	0.01	0.01	0.01	0.01	0.01	0.01	0.01
30	0.03	0.03	0.03	0.03	0.03	0.03	0.03
35	0.01	0.01	0.01	0.01	0.01	0.01	0.01
40	0.02	0.02	0.02	0.02	0.02	0.02	0.02
45	0.01	0.01	0.01	0.01	0.01	0.01	0.01
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	1.02	1.20	1.38	1.56	1.74	1.91	2.10



OUTPUT - ECONOMIC ANALYSIS - USER COSTS (3" HMA)

Year	Alt 1 3" AC 0" Base (million $)	Alt 2 3" AC 6" Base (million $)	Alt 3 3" AC 12" Base (million $)	Alt 4 3" AC 18" Base (million $)	Alt 5 3" AC 24" Base (million $)	Alt 6. 3" AC 30" Base (million $)	Alt 7 3" AC 36" Base (million $)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	7.47	7.47	7.47	7.46	7.46	7.46	7.46
10	6.19	6.19	6.19	6.18	6.18	6.18	6.18
15	5.10	5.10	5.10	5.09	5.09	5.09	5.09
20	4.20	4.20	4.20	4.19	4.19	4.19	4.19
25	3.46	3.46	3.45	3.45	3.45	3.45	3.45
30	2.85	2.84	2.84	2.84	2.84	2.84	2.84
35	2.34	2.34	2.34	2.34	2.34	2.34	2.34
40	1.93	1.93	1.93	1.92	1.92	1.92	1.92
45	1.59	1.59	1.58	1.58	1.58	1.58	1.58
50	1.31	1.30	1.30	1.30	1.30	1.30	1.30
Total	36.42	36.41	36.40	36.38	36.37	36.36	36.34



OUTPUT - INCREMENTAL B/C ANALYSIS (3" HMA).

Alt Number	Agency Cost ($)	User Cost ($)	Incremental Cost ($)	Incremental Benefit ($)	Incremental B/C Ratio
1	1018405	36424388	0	0	—
2	1196358	36410134	177953	14253	0.08
3	1378345	36396196	181987	13938	0.08
4	1556722	36382567	178377	13630	0.08
5	1735276	36369239	178554	13328	0.07
6	1913997	36356206	178721	13033	0.07
7	2096459	36343462	182461	12744	0.07

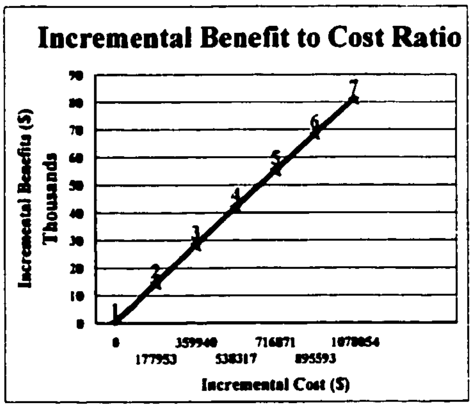
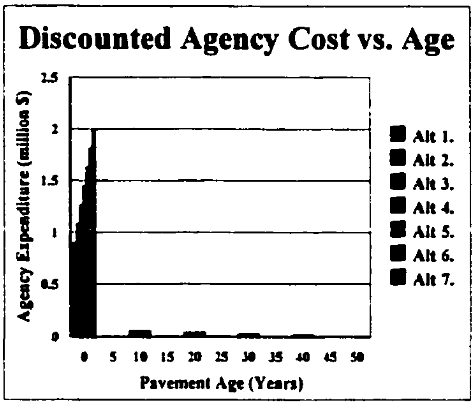


Table S-2: NYSDOT Flexible Pavement - Economic Optimization - 4" HMA Trial.

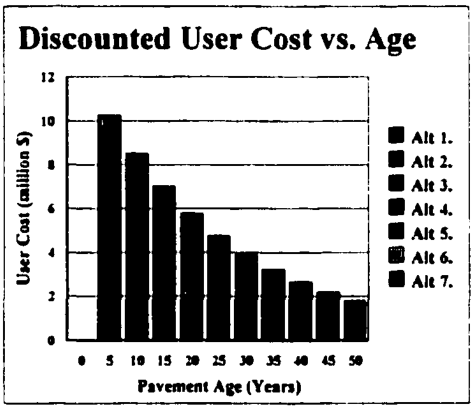
OUTPUT - ECONOMIC ANALYSIS - AGENCY EXPEDITURE (4" HMA)

Year	Alt 1 4" AC 0" Base (million $)	Alt 2 4" AC 6" Base (million $)	Alt 3 4" AC 12" Base (million $)	Alt 4 4" AC 18" Base (million $)	Alt 5 4" AC 24" Base (million $)	Alt 6. 4" AC 30" Base (million $)	Alt 7 4" AC 36" Base (million $)
0	0.90	1.08	1.27	1.45	1.63	1.82	2.00
5	0.01	0.01	0.01	0.01	0.01	0.01	0.01
10	0.06	0.06	0.06	0.06	0.06	0.06	0.06
15	0.01	0.01	0.01	0.01	0.01	0.01	0.01
20	0.05	0.05	0.05	0.04	0.04	0.04	0.04
25	0.01	0.01	0.01	0.01	0.01	0.01	0.01
30	0.03	0.03	0.03	0.03	0.03	0.03	0.03
35	0.01	0.01	0.01	0.01	0.01	0.01	0.01
40	0.02	0.02	0.02	0.02	0.02	0.02	0.02
45	0.01	0.01	0.01	0.01	0.01	0.01	0.01
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	1.13	1.31	1.49	1.67	1.84	2.02	2.21



OUTPUT - ECONOMIC ANALYSIS - USER COSTS (4" HMA)

Year	Alt 1 4" AC 0" Base (million $)	Alt 2 4" AC 6" Base (million $)	Alt 3 4" AC 12" Base (million $)	Alt 4 4" AC 18" Base (million $)	Alt 5 4" AC 24" Base (million $)	Alt 6. 4" AC 30" Base (million $)	Alt 7 4" AC 36" Base (million $)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	10.28	10.28	10.28	10.28	10.27	10.27	10.27
10	8.54	8.53	8.53	8.53	8.52	8.52	8.52
15	7.04	7.03	7.03	7.03	7.02	7.02	7.02
20	5.80	5.79	5.79	5.79	5.78	5.78	5.78
25	4.77	4.77	4.77	4.77	4.76	4.76	4.76
30	3.93	3.93	3.93	3.92	3.92	3.92	3.92
35	3.23	3.23	3.23	3.23	3.23	3.23	3.22
40	2.66	2.66	2.66	2.66	2.66	2.65	2.65
45	2.19	2.19	2.19	2.19	2.19	2.18	2.18
50	1.80	1.80	1.80	1.80	1.80	1.80	1.80
Total	50.25	50.22	50.20	50.18	50.16	50.14	50.12



OUTPUT - INCREMENTAL B/C ANALYSIS (4" HMA).

Alt Number	Agency Cost ($)	User Cost ($)	Incremental Cost ($)	Incremental Benefit ($)	Incremental B/C Ratio
1	1127238	50247565	0	0	—
2	1305092	50224336	177854	23229	0.13
3	1486984	50201621	181892	22715	0.12
4	1665270	50179409	178286	22212	0.12
5	1843737	50157688	178467	21720	0.12
6	2022375	50136448	178638	21240	0.12
7	2208638	50115679	186263	20770	0.11

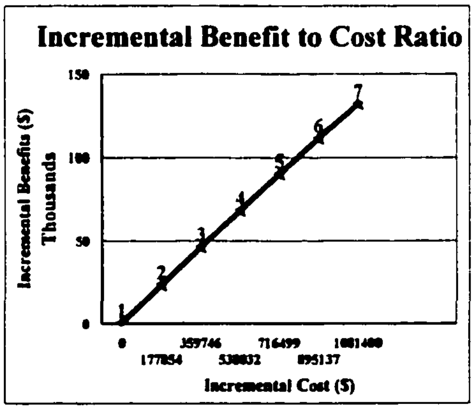
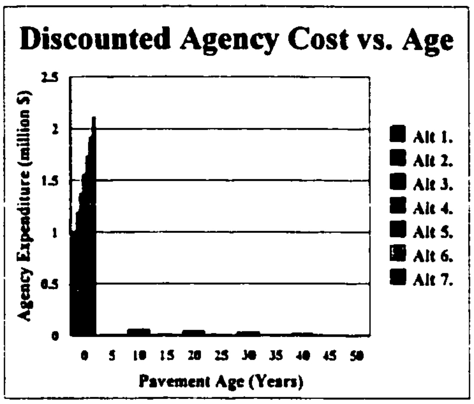


Table S-3: NYSDOT Flexible Pavement - Economic Optimization - 5" HMA Trial

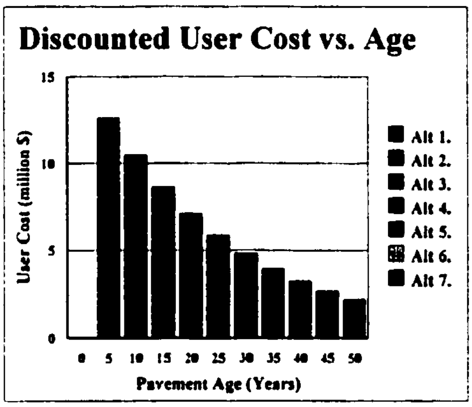
OUTPUT - ECONOMIC ANALYSIS - AGENCY EXPEDITURE (5" HMA)

Year	Alt 1 5" AC 0" Base (million $)	Alt 2 5" AC 6" Base (million $)	Alt 3 5" AC 12" Base (million $)	Alt 4 5" AC 18" Base (million $)	Alt 5 5" AC 24" Base (million $)	Alt 6. 5" AC 30" Base (million $)	Alt 7 5" AC 36" Base (million $)
0	1.01	1.19	1.38	1.56	1.74	1.93	2.11
5	0.01	0.01	0.01	0.01	0.01	0.01	0.01
10	0.06	0.06	0.06	0.06	0.06	0.06	0.06
15	0.01	0.01	0.01	0.01	0.01	0.01	0.01
20	0.05	0.05	0.05	0.05	0.04	0.04	0.04
25	0.01	0.01	0.01	0.01	0.01	0.01	0.01
30	0.03	0.03	0.03	0.03	0.03	0.03	0.03
35	0.01	0.01	0.01	0.01	0.01	0.01	0.01
40	0.02	0.02	0.02	0.02	0.02	0.02	0.02
45	0.01	0.01	0.01	0.01	0.01	0.01	0.01
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	1.24	1.42	1.60	1.77	1.95	2.13	2.32


Discounted Agency Cost vs. Age

OUTPUT - ECONOMIC ANALYSIS - USER COSTS (5" HMA)

Year	Alt 1 5" AC 0" Base (million $)	Alt 2 5" AC 6" Base (million $)	Alt 3 5" AC 12" Base (million $)	Alt 4 5" AC 18" Base (million $)	Alt 5 5" AC 24" Base (million $)	Alt 6. 5" AC 30" Base (million $)	Alt 7 5" AC 36" Base (million $)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	12.63	12.63	12.63	12.62	12.62	12.62	12.62
10	10.50	10.50	10.49	10.49	10.48	10.48	10.47
15	8.66	8.66	8.65	8.65	8.64	8.64	8.63
20	7.14	7.13	7.13	7.12	7.12	7.12	7.11
25	5.88	5.87	5.87	5.87	5.86	5.86	5.86
30	4.84	4.84	4.83	4.83	4.83	4.82	4.82
35	3.98	3.98	3.98	3.98	3.97	3.97	3.97
40	3.28	3.28	3.28	3.27	3.27	3.27	3.27
45	2.70	2.70	2.70	2.69	2.69	2.69	2.69
50	2.22	2.22	2.22	2.22	2.22	2.21	2.21
Total	61.83	61.80	61.77	61.74	61.71	61.68	61.65


Discounted User Cost vs. Age

OUTPUT - INCREMENTAL B/C ANALYSIS (5" HMA).

Alt Number	Agency Cost ($)	User Cost ($)	Incremental Cost ($)	Incremental Benefit ($)	Incremental B/C Ratio
1	1236105	61833531	0	0	---
2	1417659	61801347	181555	32184	0.18
3	1595653	61769875	177993	31471	0.18
4	1773847	61739101	178194	30775	0.17
5	1952225	61709007	178378	30094	0.17
6	2134579	61679579	182354	29428	0.16
7	2317041	61650803	182461	28776	0.16

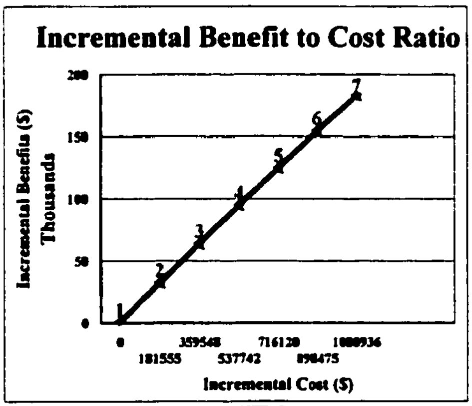
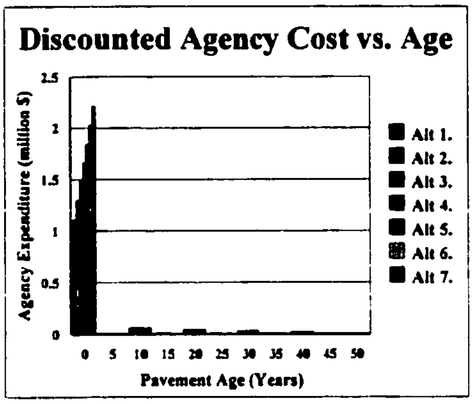

Incremental Benefit to Cost Ratio

Table S-4: NYSDOT Flexible Pavement - Economic Optimization - 6" HMA Trial.

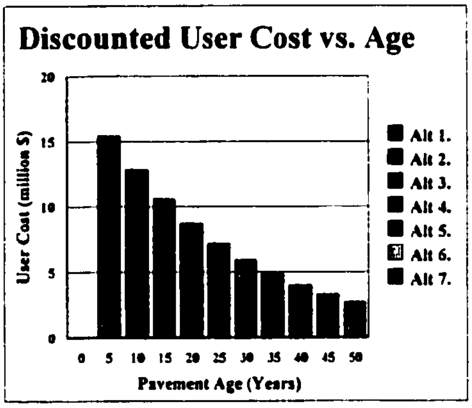
OUTPUT - ECONOMIC ANALYSIS - AGENCY EXPEDITURE (6" HMA)

Year	Alt 1 6" AC 0" Base (million $)	Alt 2 6" AC 6" Base (million $)	Alt 3 6" AC 12" Base (million $)	Alt 4 6" AC 18" Base (million $)	Alt 5 6" AC 24" Base (million $)	Alt 6. 6" AC 30" Base (million $)	Alt 7 6" AC 36" Base (million $)
0	1.11	1.30	1.48	1.67	1.85	2.03	2.22
5	0.01	0.01	0.01	0.01	0.01	0.01	0.01
10	0.06	0.06	0.06	0.06	0.06	0.06	0.06
15	0.02	0.01	0.01	0.01	0.01	0.01	0.01
20	0.05	0.05	0.05	0.05	0.04	0.04	0.04
25	0.01	0.01	0.01	0.01	0.01	0.01	0.01
30	0.03	0.03	0.03	0.03	0.03	0.03	0.03
35	0.01	0.01	0.01	0.01	0.01	0.01	0.01
40	0.03	0.02	0.02	0.02	0.02	0.02	0.02
45	0.01	0.01	0.01	0.01	0.01	0.01	0.01
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	1.35	1.53	1.70	1.88	2.06	2.24	2.43



OUTPUT - ECONOMIC ANALYSIS - USER COSTS (6" HMA)

Year	Alt 1 6" AC 0" Base (million $)	Alt 2 6" AC 6" Base (million $)	Alt 3 6" AC 12" Base (million $)	Alt 4 6" AC 18" Base (million $)	Alt 5 6" AC 24" Base (million $)	Alt 6. 6" AC 30" Base (million $)	Alt 7 6" AC 36" Base (million $)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	15.46	15.45	15.45	15.45	15.44	15.44	15.44
10	12.87	12.86	12.85	12.85	12.84	12.83	12.83
15	10.61	10.61	10.60	10.59	10.59	10.58	10.58
20	8.75	8.74	8.74	8.73	8.73	8.72	8.71
25	7.21	7.20	7.20	7.19	7.19	7.18	7.18
30	5.94	5.93	5.93	5.92	5.92	5.91	5.91
35	4.89	4.88	4.88	4.88	4.87	4.87	4.87
40	4.02	4.02	4.02	4.01	4.01	4.01	4.01
45	3.31	3.31	3.31	3.31	3.30	3.30	3.30
50	2.73	2.73	2.72	2.72	2.72	2.72	2.71
Total	75.78	75.73	75.69	75.65	75.61	75.57	75.53



OUTPUT - INCREMENTAL B/C ANALYSIS (6" HMA).

Alt Number	Agency Cost ($)	User Cost ($)	Incremental Cost ($)	Incremental Benefit ($)	Incremental B/C Ratio
1	1345044	75775854	0	0	—
2	1526495	75732058	181451	43796	0.24
3	1704389	75689231	177894	42827	0.24
4	1882488	75647352	178099	41879	0.24
5	2060776	75606400	178287	40952	0.23
6	2243043	75566354	182267	40046	0.22
7	2425504	75527195	182461	39159	0.21

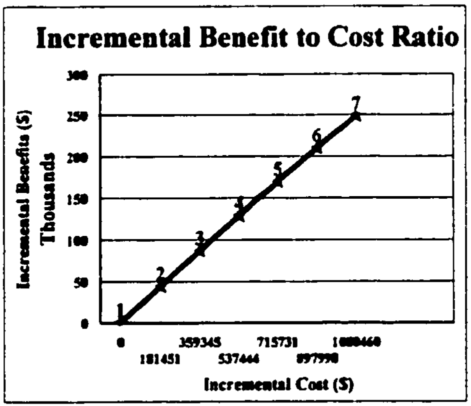
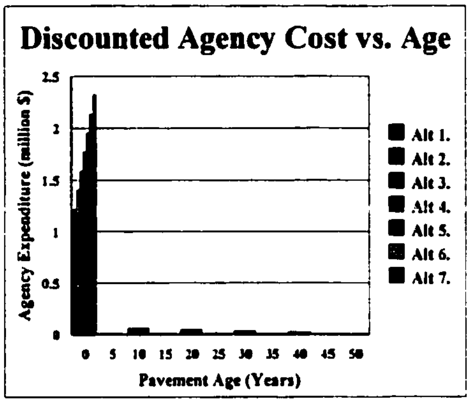


Table S-5: NYSDOT Flexible Pavement - Economic Optimization - 7" HMA Trial.

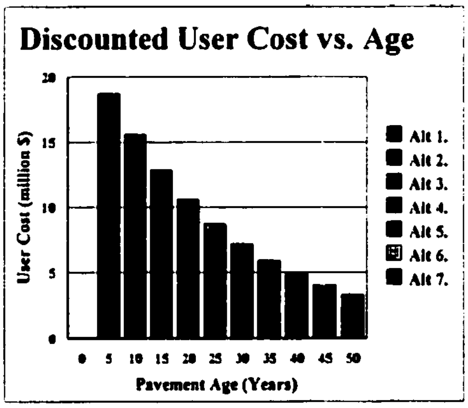
OUTPUT - ECONOMIC ANALYSIS - AGENCY EXPEDITURE (7" HMA)

Year	Alt 1 7" AC 0" Base (million $)	Alt 2 7" AC 6" Base (million $)	Alt 3 7" AC 12" Base (million $)	Alt 4 7" AC 18" Base (million $)	Alt 5 7" AC 24" Base (million $)	Alt 6. 7" AC 30" Base (million $)	Alt 7 7" AC 36" Base (million $)
0	1.22	1.41	1.59	1.77	1.96	2.14	2.32
5	0.01	0.01	0.01	0.01	0.01	0.01	0.01
10	0.06	0.06	0.06	0.06	0.06	0.06	0.06
15	0.02	0.01	0.01	0.01	0.01	0.01	0.01
20	0.05	0.05	0.05	0.05	0.05	0.04	0.04
25	0.01	0.01	0.01	0.01	0.01	0.01	0.01
30	0.04	0.03	0.03	0.03	0.03	0.03	0.03
35	0.01	0.01	0.01	0.01	0.01	0.01	0.01
40	0.03	0.03	0.02	0.02	0.02	0.02	0.02
45	0.01	0.01	0.01	0.01	0.01	0.01	0.01
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	1.46	1.64	1.81	1.99	2.17	2.35	2.53


Discounted Agency Cost vs. Age

OUTPUT - ECONOMIC ANALYSIS - USER COSTS (7" HMA)

Year	Alt 1 7" AC 0" Base (million $)	Alt 2 7" AC 6" Base (million $)	Alt 3 7" AC 12" Base (million $)	Alt 4 7" AC 18" Base (million $)	Alt 5 7" AC 24" Base (million $)	Alt 6 7" AC 30" Base (million $)	Alt 7 7" AC 36" Base (million $)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	18.75	18.75	18.75	18.74	18.74	18.73	18.73
10	15.63	15.62	15.61	15.60	15.60	15.59	15.58
15	12.90	12.89	12.88	12.87	12.87	12.86	12.85
20	10.63	10.63	10.62	10.61	10.60	10.60	10.59
25	8.76	8.76	8.75	8.74	8.74	8.73	8.72
30	7.22	7.21	7.21	7.20	7.20	7.19	7.19
35	5.95	5.94	5.94	5.93	5.93	5.92	5.92
40	4.90	4.89	4.89	4.88	4.88	4.88	4.87
45	4.03	4.03	4.02	4.02	4.02	4.01	4.01
50	3.32	3.32	3.31	3.31	3.31	3.30	3.30
Total	92.09	92.03	91.98	91.92	91.87	91.81	91.76


Discounted User Cost vs. Age

OUTPUT - INCREMENTAL B/C ANALYSIS (7" HMA).

Alt Number	Agency Cost ($)	User Cost ($)	Incremental Cost ($)	Incremental Benefit ($)	Incremental B/C Ratio
1	1457852	92092509	0	0	—
2	1635395	92034045	177543	58464	0.33
3	1813188	91976874	177793	57170	0.32
4	1991189	91920969	178001	55905	0.31
5	2173185	91866302	181996	54668	0.30
6	2351561	91812844	178376	53458	0.30
7	2534022	91760569	182461	52275	0.29

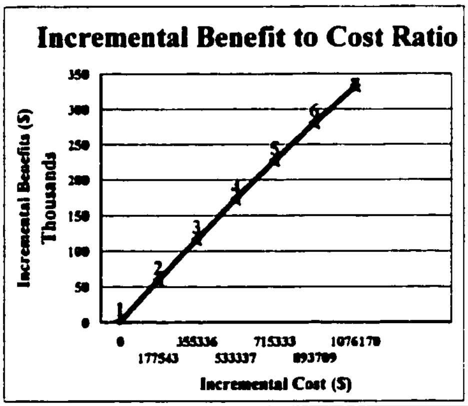
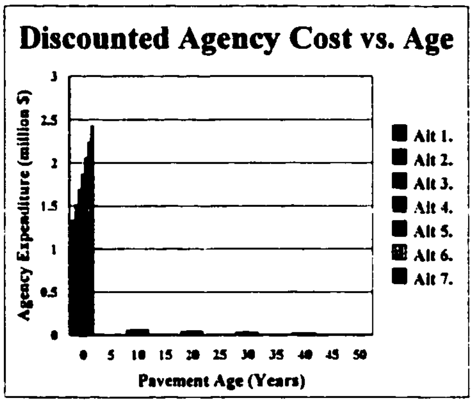

Incremental Benefit to Cost Ratio

Table S-6: NYSDOT Flexible Pavement - Economic Optimization - 8" HMA Trial.

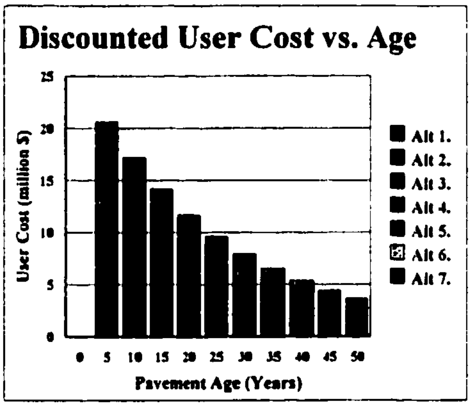
OUTPUT - ECONOMIC ANALYSIS - AGENCY EXPEDITURE (8" HMA).

Year	Alt 1 8" AC 0" Base (million $)	Alt 2 8" AC 6" Base (million $)	Alt 3 8" AC 12" Base (million $)	Alt 4 8" AC 18" Base (million $)	Alt 5 8" AC 24" Base (million $)	Alt 6. 8" AC 30" Base (million $)	Alt 7 8" AC 36" Base (million $)
0	1.33	1.51	1.70	1.88	2.06	2.25	2.43
5	0.01	0.01	0.01	0.01	0.01	0.01	0.01
10	0.06	0.06	0.06	0.06	0.06	0.06	0.06
15	0.02	0.02	0.01	0.01	0.01	0.01	0.01
20	0.05	0.05	0.05	0.05	0.05	0.04	0.04
25	0.01	0.01	0.01	0.01	0.01	0.01	0.01
30	0.04	0.03	0.03	0.03	0.03	0.03	0.03
35	0.01	0.01	0.01	0.01	0.01	0.01	0.01
40	0.03	0.03	0.02	0.02	0.02	0.02	0.02
45	0.01	0.01	0.01	0.01	0.01	0.01	0.01
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	1.57	1.74	1.92	2.10	2.28	2.46	2.64



OUTPUT - ECONOMIC ANALYSIS - USER COSTS (8" HMA).

Year	Alt 1 8" AC 0" Base (million $)	Alt 2 8" AC 6" Base (million $)	Alt 3 8" AC 12" Base (million $)	Alt 4 8" AC 18" Base (million $)	Alt 5 8" AC 24" Base (million $)	Alt 6. 8" AC 30" Base (million $)	Alt 7 8" AC 36" Base (million $)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	20.65	20.64	20.64	20.63	20.62	20.62	20.61
10	17.22	17.21	17.20	17.19	17.18	17.17	17.16
15	14.22	14.21	14.20	14.19	14.18	14.17	14.16
20	11.72	11.71	11.71	11.70	11.69	11.68	11.67
25	9.66	9.65	9.65	9.64	9.63	9.62	9.62
30	7.96	7.95	7.95	7.94	7.93	7.93	7.92
35	6.56	6.55	6.55	6.54	6.53	6.53	6.52
40	5.40	5.40	5.39	5.39	5.38	5.38	5.37
45	4.45	4.44	4.44	4.44	4.43	4.43	4.42
50	3.66	3.66	3.66	3.65	3.65	3.64	3.64
Total	101.50	101.43	101.36	101.30	101.23	101.17	101.11



OUTPUT - INCREMENTAL B/C ANALYSIS (8" HMA)

Alt Number	Agency Cost ($)	User Cost ($)	Incremental Cost ($)	Incremental Benefit ($)	Incremental B/C Ratio
1	1566884	101499250	0	0	—
2	1744319	101430569	177435	68682	0.39
3	1922008	101363407	177689	67162	0.38
4	2099910	101297732	177902	65675	0.37
5	2281811	101233510	181901	64222	0.35
6	2460096	101170710	178285	62800	0.35
7	2642557	101109300	182461	61410	0.34

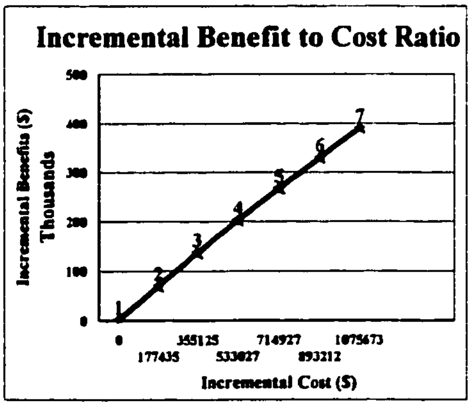
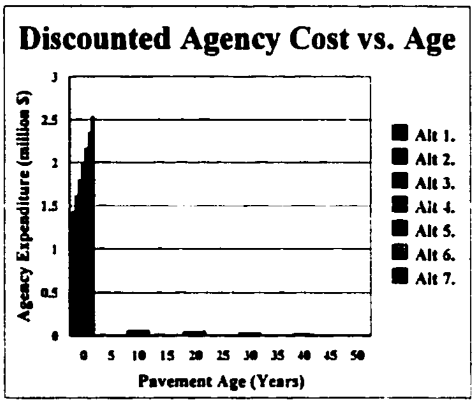


Table S-7: NYSDOT Flexible Pavement - Economic Analysis - 9" HMA Trial

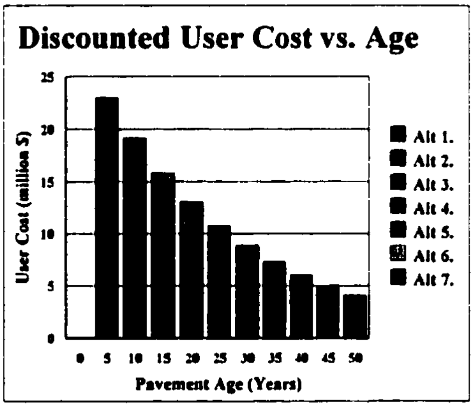
OUTPUT - ECONOMIC ANALYSIS - AGENCY EXPEDITURE (9" HMA).

Year	Alt 1 9" AC 0" Base (million $)	Alt 2 9" AC 6" Base (million $)	Alt 3 9" AC 12" Base (million $)	Alt 4 9" AC 18" Base (million $)	Alt 5 9" AC 24" Base (million $)	Alt 6. 9" AC 30" Base (million $)	Alt 7 9" AC 36" Base (million $)
0	1.44	1.62	1.80	1.99	2.17	2.35	2.54
5	0.01	0.01	0.01	0.01	0.01	0.01	0.01
10	0.06	0.06	0.06	0.06	0.06	0.06	0.06
15	0.02	0.02	0.01	0.01	0.01	0.01	0.01
20	0.05	0.05	0.05	0.05	0.05	0.05	0.05
25	0.02	0.01	0.01	0.01	0.01	0.01	0.01
30	0.04	0.04	0.03	0.03	0.03	0.03	0.03
35	0.01	0.01	0.01	0.01	0.01	0.01	0.01
40	0.03	0.03	0.03	0.02	0.02	0.02	0.02
45	0.01	0.01	0.01	0.01	0.01	0.01	0.01
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	1.68	1.85	2.03	2.21	2.39	2.57	2.75



OUTPUT - ECONOMIC ANALYSIS - USER COSTS (9" HMA).

Year	Alt 1 9" AC 0" Base (million $)	Alt 2 9" AC 6" Base (million $)	Alt 3 9" AC 12" Base (million $)	Alt 4 9" AC 18" Base (million $)	Alt 5 9" AC 24" Base (million $)	Alt 6 9" AC 30" Base (million $)	Alt 7 9" AC 36" Base (million $)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	23.01	23.00	23.00	22.99	22.99	22.98	22.97
10	19.21	19.20	19.19	19.18	19.17	19.16	19.14
15	15.86	15.85	15.84	15.83	15.82	15.81	15.80
20	13.08	13.07	13.06	13.05	13.04	13.03	13.02
25	10.79	10.78	10.77	10.76	10.75	10.74	10.73
30	8.89	8.88	8.87	8.86	8.86	8.85	8.84
35	7.32	7.32	7.31	7.30	7.29	7.29	7.28
40	6.03	6.03	6.02	6.01	6.01	6.00	6.00
45	4.97	4.96	4.96	4.95	4.95	4.94	4.94
50	4.09	4.09	4.08	4.08	4.07	4.07	4.07
Total	113.26	113.18	113.10	113.02	112.95	112.87	112.80



OUTPUT - INCREMENTAL B/C ANALYSIS (9" HMA)

Alt Number	Agency Cost ($)	User Cost ($)	Incremental Cost ($)	Incremental Benefit ($)	Incremental B/C Ratio
1	1675989	113261260	0	0	—
2	1853314	113179728	177325	81533	0.46
3	2030897	113100000	177583	79728	0.45
4	2212499	113022036	181602	77964	0.43
5	2390500	112945798	178002	76238	0.43
6	2568692	112871247	178191	74551	0.42
7	2751153	112798347	182461	72901	0.40

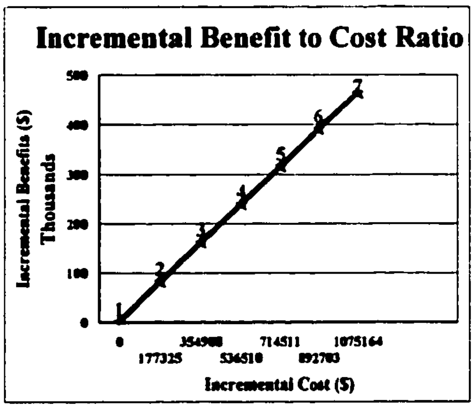
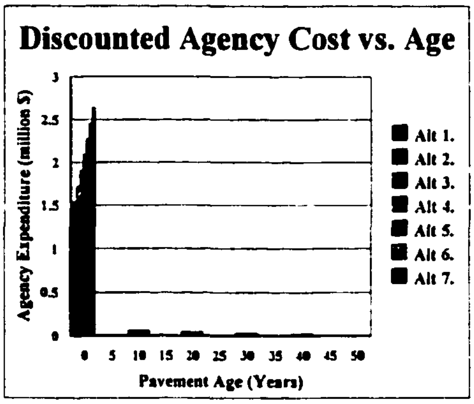


Table S-8: NYSDOT Flexible Pavement - Economic Optimization - 10" HMA Trial.

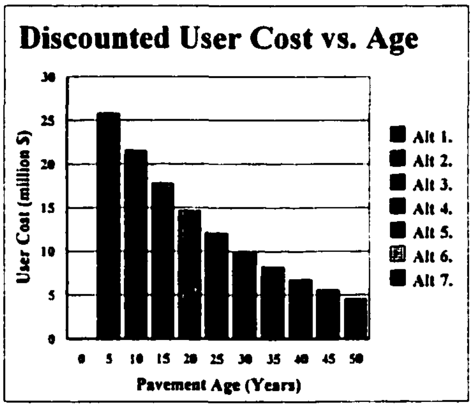
OUTPUT - ECONOMIC ANALYSIS - AGENCY EXPEDITURE (10" HMA).

Year	Alt 1 10" AC 0" Base (million $)	Alt 2 10" AC 6" Base (million $)	Alt 3 10" AC 12" Base (million $)	Alt 4 10" AC 18" Base (million $)	Alt 5 10" AC 24" Base (million $)	Alt 6. 10" AC 30" Base (million $)	Alt 7 10" AC 36" Base (million $)
0	1.54	1.73	1.91	2.09	2.28	2.46	2.64
5	0.01	0.01	0.01	0.01	0.01	0.01	0.01
10	0.06	0.06	0.06	0.06	0.06	0.06	0.06
15	0.02	0.02	0.02	0.01	0.01	0.01	0.01
20	0.05	0.05	0.05	0.05	0.05	0.05	0.05
25	0.02	0.01	0.01	0.01	0.01	0.01	0.01
30	0.04	0.04	0.03	0.03	0.03	0.03	0.03
35	0.01	0.01	0.01	0.01	0.01	0.01	0.01
40	0.03	0.03	0.03	0.02	0.02	0.02	0.02
45	0.01	0.01	0.01	0.01	0.01	0.01	0.01
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	1.79	1.96	2.14	2.32	2.50	2.68	2.86


Discounted Agency Cost vs. Age

OUTPUT - ECONOMIC ANALYSIS - USER COSTS (10" HMA).

Year	Alt 1 10" AC 0" Base (million $)	Alt 2 10" AC 6" Base (million $)	Alt 3 10" AC 12" Base (million $)	Alt 4 10" AC 18" Base (million $)	Alt 5 10" AC 24" Base (million $)	Alt 6. 10" AC 30" Base (million $)	Alt 7 10" AC 36" Base (million $)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	25.85	25.84	25.84	25.83	25.82	25.81	25.81
10	21.61	21.59	21.58	21.56	21.55	21.54	21.52
15	17.84	17.83	17.82	17.80	17.79	17.78	17.77
20	14.72	14.71	14.70	14.68	14.67	14.66	14.65
25	12.14	12.13	12.11	12.10	12.09	12.08	12.07
30	10.00	9.99	9.98	9.97	9.96	9.96	9.95
35	8.24	8.23	8.23	8.22	8.21	8.20	8.19
40	6.79	6.78	6.78	6.77	6.76	6.76	6.75
45	5.59	5.59	5.58	5.58	5.57	5.56	5.56
50	4.61	4.60	4.60	4.59	4.59	4.58	4.58
Total	127.39	127.30	127.20	127.11	127.02	126.93	126.84


Discounted User Cost vs. Age

OUTPUT - INCREMENTAL B/C ANALYSIS (10" HMA)

Alt Number	Agency Cost ($)	User Cost ($)	Incremental Cost ($)	Incremental Benefit ($)	Incremental B/C Ratio
1	1785166	127394295	0	0	—
2	1962377	127296929	177211	97366	0.55
3	2143653	127201718	181276	95211	0.53
4	2321349	127108614	177696	93104	0.52
5	2499251	127017571	177902	91043	0.51
6	2677346	126928543	178096	89028	0.50
7	2859807	126841485	182461	87058	0.48

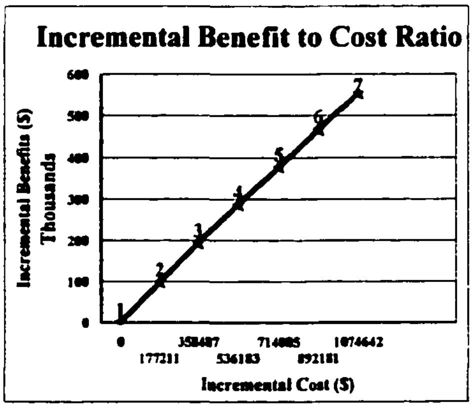
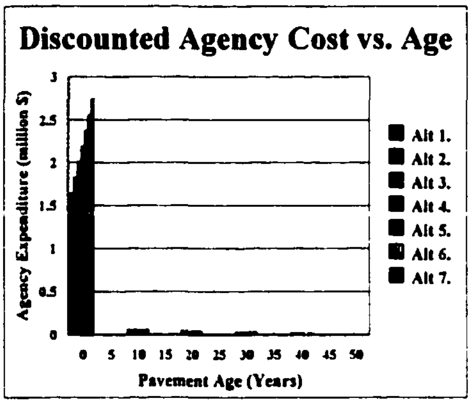

Incremental Benefit to Cost Ratio

Table S-9: NYSDOT Flexible Pavement - Economic Analysis - 11" HMA Trial.

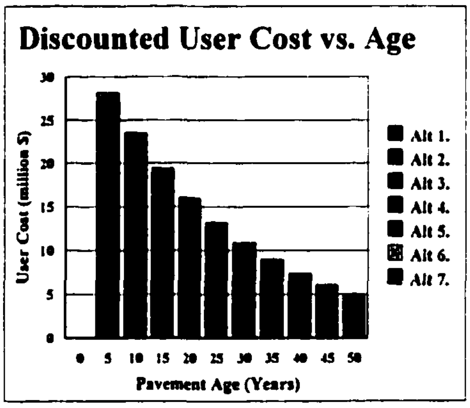
OUTPUT - ECONOMIC ANALYSIS - AGENCY EXPEDITURE (11" HMA).

Year	Alt 1 11" AC 0" Base (million $)	Alt 2 11" AC 6" Base (million $)	Alt 3 11" AC 12" Base (million $)	Alt 4 11" AC 18" Base (million $)	Alt 5 11" AC 24" Base (million $)	Alt 6. 11" AC 30" Base (million $)	Alt 7 11" AC 36" Base (million $)
0	1.65	1.83	2.02	2.20	2.38	2.57	2.75
5	0.01	0.01	0.01	0.01	0.01	0.01	0.01
10	0.06	0.06	0.06	0.06	0.06	0.06	0.06
15	0.02	0.02	0.02	0.01	0.01	0.01	0.01
20	0.05	0.05	0.05	0.05	0.05	0.05	0.05
25	0.02	0.02	0.01	0.01	0.01	0.01	0.01
30	0.04	0.04	0.04	0.03	0.03	0.03	0.03
35	0.01	0.01	0.01	0.01	0.01	0.01	0.01
40	0.03	0.03	0.03	0.03	0.02	0.02	0.02
45	0.01	0.01	0.01	0.01	0.01	0.01	0.01
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	1.89	2.07	2.25	2.43	2.61	2.79	2.97



OUTPUT - ECONOMIC ANALYSIS - USER COSTS (11" HMA).

Year	Alt 1 11" AC 0" Base (million $)	Alt 2 11" AC 6" Base (million $)	Alt 3 11" AC 12" Base (million $)	Alt 4 11" AC 18" Base (million $)	Alt 5 11" AC 24" Base (million $)	Alt 6. 11" AC 30" Base (million $)	Alt 7 11" AC 36" Base (million $)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	28.22	28.21	28.20	28.19	28.19	28.18	28.17
10	23.61	23.59	23.58	23.56	23.54	23.53	23.51
15	19.50	19.49	19.47	19.46	19.44	19.43	19.41
20	16.09	16.08	16.06	16.05	16.04	16.02	16.01
25	13.27	13.26	13.24	13.23	13.22	13.21	13.20
30	10.94	10.93	10.92	10.90	10.89	10.88	10.87
35	9.01	9.00	8.99	8.98	8.98	8.97	8.96
40	7.43	7.42	7.41	7.40	7.39	7.39	7.38
45	6.12	6.11	6.10	6.10	6.09	6.08	6.08
50	5.04	5.03	5.03	5.02	5.02	5.01	5.01
Total	139.23	139.12	139.01	138.90	138.80	138.70	138.60



OUTPUT - INCREMENTAL B/C ANALYSIS (11" HMA)

Alt Number	Agency Cost ($)	User Cost ($)	Incremental Cost ($)	Incremental Benefit ($)	Incremental B/C Ratio
1	1894398	139230139	0	0	—
2	2071493	139118287	177095	111851	0.63
3	2252658	139008912	181165	109376	0.60
4	2430248	138901957	177590	106955	0.60
5	2608047	138797369	177800	104588	0.59
6	2786045	138695096	177998	102273	0.57
7	2972308	138595086	186263	100009	0.54

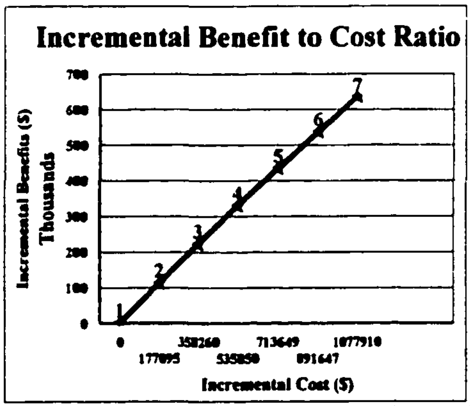
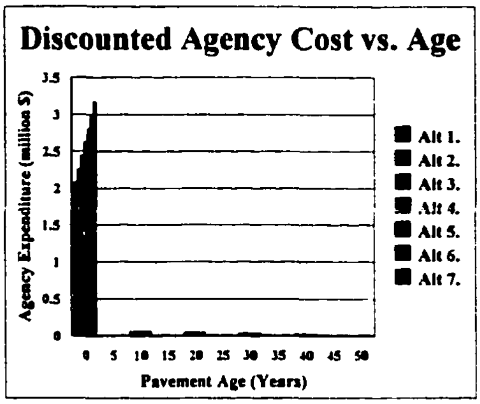


Table S-10: NYSDOT Flexible Pavement - Economic Optimization - 15" HMA Trial.

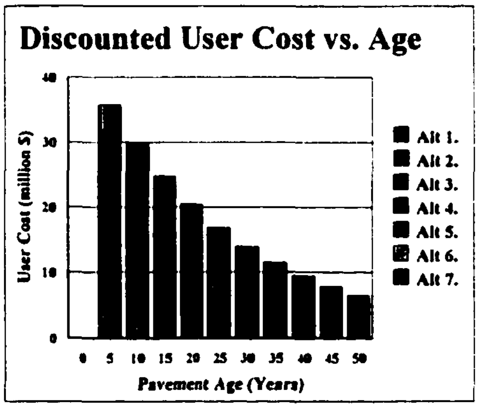
OUTPUT - ECONOMIC ANALYSIS - AGENCY EXPEDITURE (15" HMA).

Year	Alt 1 15" AC 0" Base (million $)	Alt 2 15" AC 6" Base (million $)	Alt 3 15" AC 12" Base (million $)	Alt 4 15" AC 18" Base (million $)	Alt 5 15" AC 24" Base (million $)	Alt 6. 15" AC 30" Base (million $)	Alt 7 15" AC 36" Base (million $)
0	2.08	2.26	2.44	2.63	2.81	3.00	3.18
5	0.01	0.01	0.01	0.01	0.01	0.01	0.01
10	0.06	0.06	0.06	0.06	0.06	0.06	0.06
15	0.02	0.02	0.02	0.02	0.02	0.01	0.01
20	0.05	0.05	0.05	0.05	0.05	0.05	0.05
25	0.02	0.02	0.02	0.02	0.01	0.01	0.01
30	0.04	0.04	0.04	0.04	0.04	0.03	0.03
35	0.01	0.01	0.01	0.01	0.01	0.01	0.01
40	0.03	0.03	0.03	0.03	0.03	0.03	0.03
45	0.01	0.01	0.01	0.01	0.01	0.01	0.01
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	2.34	2.51	2.69	2.87	3.05	3.23	3.41


Discounted Agency Cost vs. Age

OUTPUT - ECONOMIC ANALYSIS - USER COSTS (15" HMA).

Year	Alt 1 15" AC 0" Base (million $)	Alt 2 15" AC 6" Base (million $)	Alt 3 15" AC 12" Base (million $)	Alt 4 15" AC 18" Base (million $)	Alt 5 15" AC 24" Base (million $)	Alt 6. 15" AC 30" Base (million $)	Alt 7 15" AC 16" Base (million $)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	35.84	35.82	35.81	35.80	35.78	35.77	35.76
10	30.07	30.04	30.02	29.99	29.97	29.95	29.93
15	24.86	24.83	24.81	24.79	24.77	24.75	24.72
20	20.52	20.50	20.48	20.46	20.44	20.42	20.40
25	16.93	16.91	16.89	16.88	16.86	16.84	16.82
30	13.96	13.95	13.93	13.91	13.90	13.88	13.87
35	11.51	11.50	11.48	11.47	11.46	11.44	11.43
40	9.49	9.48	9.46	9.45	9.44	9.43	9.42
45	7.82	7.81	7.80	7.79	7.78	7.77	7.76
50	6.45	6.44	6.43	6.42	6.41	6.40	6.39
Total	177.44	177.28	177.11	176.96	176.80	176.65	176.50


Discounted User Cost vs. Age

OUTPUT - INCREMENTAL B/C ANALYSIS (15" HMA)

Alt Number	Agency Cost ($)	User Cost ($)	Incremental Cost ($)	Incremental Benefit ($)	Incremental B/C Ratio
1	2335783	177442529	0	0	—
2	2512388	177276851	176604	165678	0.94
3	2689280	177114840	176892	162011	0.92
4	2866418	176956415	177138	158425	0.89
5	3047586	176801496	181168	154919	0.86
6	3225169	176650006	177583	151490	0.85
7	3407630	176501869	182461	148137	0.81

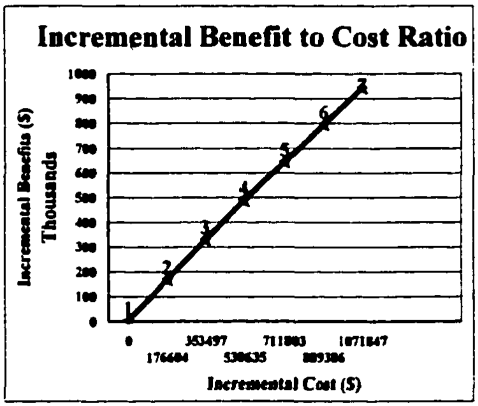
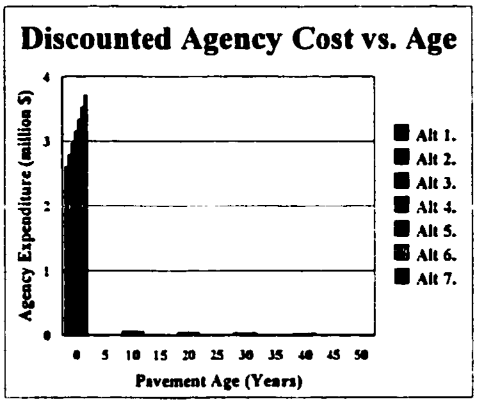

Incremental Benefit to Cost Ratio

Table S-11: NYSDOT Flexible Pavement - Economic Optimization - 20" HMA Trial.

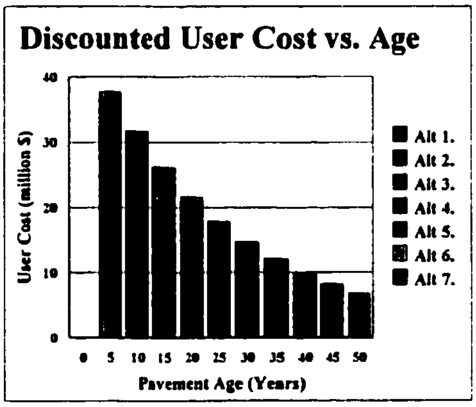
OUTPUT - ECONOMIC ANALYSIS - AGENCY EXPEDITURE (20" HMA).

Year	Alt 1 20" AC 0" Base (million $)	Alt 2 20" AC 6" Base (million $)	Alt 3 20" AC 12" Base (million $)	Alt 4 20" AC 18" Base (million $)	Alt 5 20" AC 24" Base (million $)	Alt 6. 20" AC 30" Base (million $)	Alt 7 20" AC 36" Base (million $)
0	2.61	2.80	2.98	3.16	3.35	3.53	3.71
5	0.01	0.01	0.01	0.01	0.01	0.01	0.01
10	0.07	0.07	0.06	0.06	0.06	0.06	0.06
15	0.02	0.02	0.02	0.02	0.02	0.02	0.02
20	0.05	0.05	0.05	0.05	0.05	0.05	0.05
25	0.02	0.02	0.02	0.02	0.02	0.02	0.02
30	0.04	0.04	0.04	0.04	0.04	0.04	0.04
35	0.02	0.02	0.02	0.01	0.01	0.01	0.01
40	0.03	0.03	0.03	0.03	0.03	0.03	0.03
45	0.01	0.01	0.01	0.01	0.01	0.01	0.01
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	2.88	3.06	3.24	3.42	3.59	3.77	3.96



OUTPUT - ECONOMIC ANALYSIS - USER COSTS (20" HMA).

Year	Alt 1 20" AC 0" Base (million $)	Alt 2 20" AC 6" Base (million $)	Alt 3 20" AC 12" Base (million $)	Alt 4 20" AC 18" Base (million $)	Alt 5 20" AC 24" Base (million $)	Alt 6. 20" AC 30" Base (million $)	Alt 7 20" AC 36" Base (million $)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	37.79	37.78	37.76	37.75	37.73	37.72	37.70
10	31.78	31.75	31.72	31.69	31.66	31.64	31.61
15	26.29	26.26	26.23	26.21	26.18	26.16	26.13
20	21.71	21.69	21.66	21.64	21.62	21.59	21.57
25	17.92	17.90	17.88	17.86	17.83	17.81	17.79
30	14.78	14.76	14.74	14.73	14.71	14.69	14.67
35	12.19	12.18	12.16	12.14	12.13	12.11	12.10
40	10.05	10.04	10.02	10.01	10.00	9.98	9.97
45	8.29	8.28	8.26	8.25	8.24	8.23	8.22
50	6.83	6.82	6.81	6.80	6.79	6.78	6.77
Total	187.64	187.44	187.26	187.07	186.89	186.71	186.54



OUTPUT - INCREMENTAL B/C ANALYSIS (20" HMA)

Alt Number	Agency Cost ($)	User Cost ($)	Incremental Cost ($)	Incremental Benefit ($)	Incremental B/C Ratio
1	2884339	187637846	0	0	—
2	3064066	187444498	179727	193348	1.08
3	3240305	187255429	176239	189069	1.07
4	3416817	187070545	176512	184884	1.05
5	3593583	186889752	176766	180793	1.02
6	3774392	186712961	180809	176791	0.98
7	3956854	186540083	182462	172878	0.95

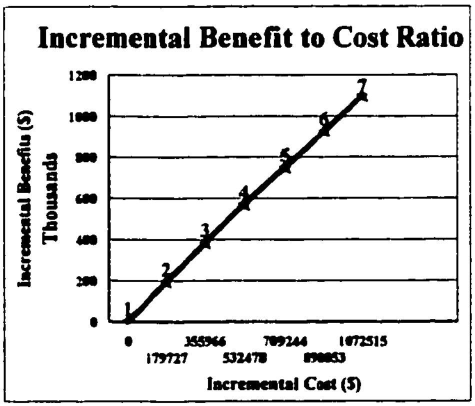
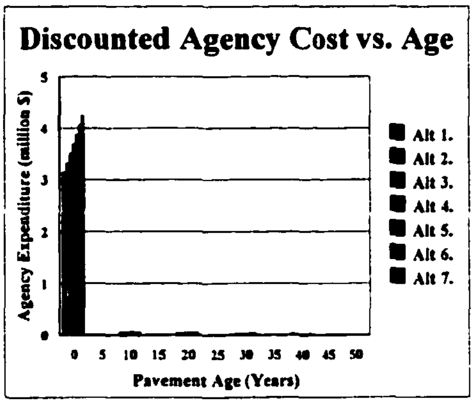


Table S-12: NYSDOT Flexible Pavement - Economic Optimization - 25" HMA Trial.

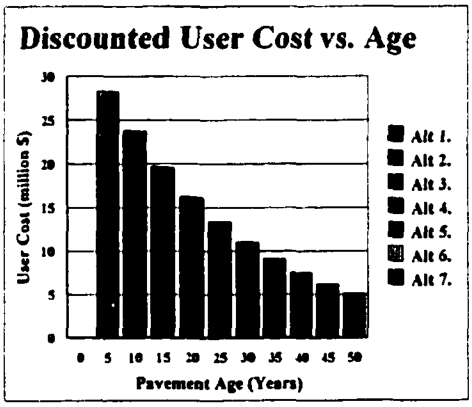
OUTPUT - ECONOMIC ANALYSIS - AGENCY EXPEDITURE (25").

Year	Alt 1 25" AC 0" Base (million $)	Alt 2 25" AC 6" Base (million $)	Alt 3 25" AC 12" Base (million $)	Alt 4 25" AC 18" Base (million $)	Alt 5 25" AC 24" Base (million $)	Alt 6. 25" AC 30" Base (million $)	Alt 7 25" AC 36" Base (million $)
0	3.15	3.33	3.52	3.70	3.88	4.06	4.25
5	0.01	0.01	0.01	0.01	0.01	0.01	0.01
10	0.07	0.07	0.07	0.07	0.06	0.06	0.06
15	0.02	0.02	0.02	0.02	0.02	0.02	0.02
20	0.06	0.05	0.05	0.05	0.05	0.05	0.05
25	0.02	0.02	0.02	0.02	0.02	0.02	0.02
30	0.04	0.04	0.04	0.04	0.04	0.04	0.04
35	0.02	0.02	0.02	0.02	0.02	0.02	0.02
40	0.03	0.03	0.03	0.03	0.03	0.03	0.03
45	0.02	0.01	0.01	0.01	0.01	0.01	0.01
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	3.44	3.61	3.79	3.97	4.15	4.32	4.51


Discounted Agency Cost vs. Age

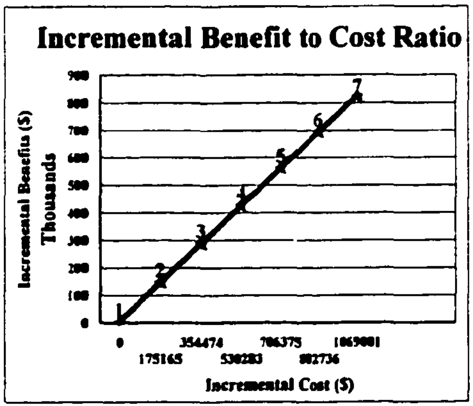
OUTPUT - ECONOMIC ANALYSIS - USER COSTS (25").

Year	Alt 1 25" AC 0" Base (million $)	Alt 2 25" AC 6" Base (million $)	Alt 3 25" AC 12" Base (million $)	Alt 4 25" AC 18" Base (million $)	Alt 5 25" AC 24" Base (million $)	Alt 6 25" AC 30" Base (million $)	Alt 7 25" AC 36" Base (million $)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	28.34	28.33	28.32	28.31	28.30	28.29	28.28
10	23.83	23.81	23.79	23.77	23.75	23.73	23.71
15	19.71	19.69	19.67	19.65	19.63	19.62	19.60
20	16.28	16.26	16.25	16.23	16.21	16.19	16.18
25	13.44	13.42	13.41	13.39	13.37	13.36	13.34
30	11.09	11.07	11.06	11.04	11.03	11.02	11.00
35	9.14	9.13	9.12	9.11	9.09	9.08	9.07
40	7.54	7.53	7.52	7.51	7.50	7.49	7.48
45	6.21	6.21	6.20	6.19	6.18	6.17	6.16
50	5.12	5.12	5.11	5.10	5.09	5.08	5.08
Total	140.72	140.57	140.43	140.29	140.16	140.02	139.89


Discounted User Cost vs. Age

OUTPUT - INCREMENTAL B/C ANALYSIS (25")

Alt Number	Agency Cost ($)	User Cost ($)	Incremental Cost ($)	Incremental Benefit ($)	Incremental B/C Ratio
1	3438631	140716253	0	0	—
2	3613796	140571510	175165	144743	0.83
3	3793105	140429971	179309	141539	0.79
4	3968914	140291564	175809	138407	0.79
5	4145006	140156221	176092	135343	0.77
6	4321367	140023873	176361	132348	0.75
7	4507632	139894455	186265	129419	0.69


Incremental Benefit to Cost Ratio

APPENDIX T :

NYSDOT Flexible Pavement - Performance Optimization Trials.

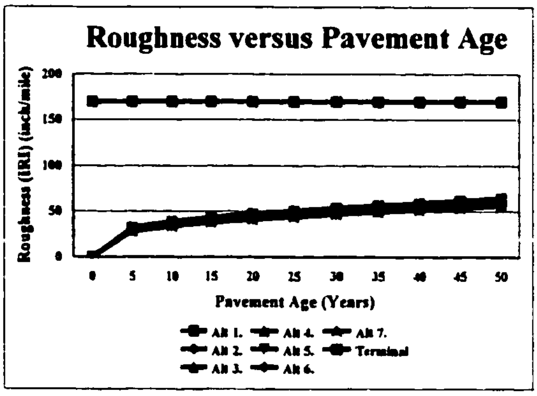
Contents:

Table T-1: NYSDOT Flexible Pavement - Performance Optimization - 3" HMA Trial.
Table T-2: NYSDOT Flexible Pavement - Performance Optimization - 4" HMA Trial.
Table T-3: NYSDOT Flexible Pavement - Performance Optimization - 5" HMA Trial.
Table T-4: NYSDOT Flexible Pavement - Performance Optimization - 6" HMA Trial.
Table T-5: NYSDOT Flexible Pavement - Performance Optimization - 7" HMA Trial.
Table T-6: NYSDOT Flexible Pavement - Performance Optimization - 8" HMA Trial.
Table T-7: NYSDOT Flexible Pavement - Performance Optimization - 9" HMA Trial.
Table T-8: NYSDOT Flexible Pavement - Performance Optimization - 10" HMA Trial.
Table T-9: NYSDOT Flexible Pavement - Performance Optimization - 11" HMA Trial.
Table T-10: NYSDOT Flexible Pavement - Performance Optimization - 15" HMA Trial.
Table T-11: NYSDOT Flexible Pavement - Performance Optimization - 20" HMA Trial.
Table T-12: NYSDOT Flexible Pavement - Performance Optimization - 25" HMA Trial.

Table T-1: NYSDOT Flexible Pavement - Performance Optimization - 3" HMA Trial

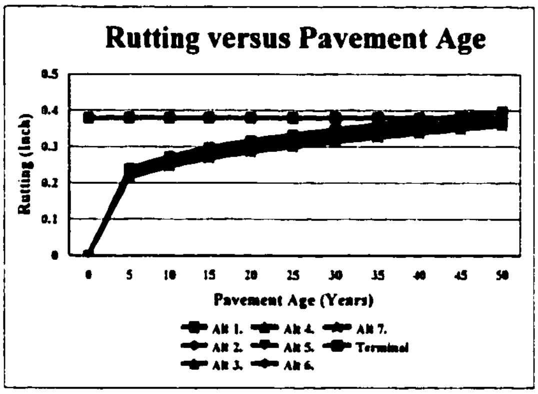
OUTPUT - PREDICTED ROUGHNESS (3" HMA).

Year	Alt 1. 3" AC 0" Base (in/mi)	Alt 2. 3" AC 6" Base (in/mi)	Alt 3. 3" AC 12" Base (in/mi)	Alt 4. 3" AC 18" Base (in/mi)	Alt 5. 3" AC 24" Base (in/mi)	Alt 6. 3" AC 30" Base (in/mi)	Alt 7 3" AC 36" Base (in/mi)	Terminal Roughness (inch/mile)
0	0	0	0	0	0	0	0	170
5	32	31	31	30	29	29	28	170
10	38	38	37	36	35	34	34	170
15	43	42	41	40	39	39	38	170
20	47	46	45	44	43	42	41	170
25	50	49	48	47	46	45	44	170
30	53	52	51	50	49	48	47	170
35	56	55	54	53	51	50	49	170
40	59	58	56	55	54	53	51	170
45	62	60	59	58	56	55	54	170
50	64	63	61	60	59	57	56	170
Total	—	—	—	—	—	—	—	—



OUTPUT - PREDICTED RUTTING (3" HMA).

Year	Alt 1. 3" AC 0" Base (inch)	Alt 2. 3" AC 6" Base (inch)	Alt 3 3" AC 12" Base (inch)	Alt 4. 3" AC 18" Base (inch)	Alt 5. 3" AC 24" Base (inch)	Alt 6. 3" AC 30" Base (inch)	Alt 7 3" AC 36" Base (inch)	Terminal Rutting (inch)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38
5	0.24	0.23	0.22	0.22	0.22	0.22	0.22	0.38
10	0.27	0.26	0.26	0.25	0.25	0.25	0.25	0.38
15	0.30	0.29	0.28	0.28	0.27	0.27	0.27	0.38
20	0.32	0.30	0.30	0.29	0.29	0.29	0.29	0.38
25	0.33	0.32	0.31	0.31	0.31	0.30	0.30	0.38
30	0.35	0.33	0.33	0.32	0.32	0.32	0.31	0.38
35	0.36	0.35	0.34	0.33	0.33	0.33	0.33	0.38
40	0.37	0.36	0.35	0.35	0.34	0.34	0.34	0.38
45	0.39	0.37	0.36	0.36	0.35	0.35	0.35	0.38
50	0.40	0.38	0.37	0.37	0.36	0.36	0.36	0.38
Total	—	—	—	—	—	—	—	—



OUTPUT - PREDICTED CRACKING (3" HMA).

Year	Alt 1. 3" AC 0" Base (feet)	Alt 2. 3" AC 6" Base (feet)	Alt 3 3" AC 12" Base (feet)	Alt 4. 3" AC 18" Base (feet)	Alt 5. 3" AC 24" Base (feet)	Alt 6. 3" AC 30" Base (feet)	Alt 7 3" AC 36" Base (feet)
0	—	—	—	—	—	—	—
5	60.98	63.63	66.39	69.27	72.27	75.41	75.41
10	40.74	42.51	44.36	46.28	48.29	50.38	50.38
15	32.18	33.58	35.04	36.55	38.14	39.80	39.80
20	27.22	28.40	29.64	30.92	32.26	33.66	33.66
25	23.91	24.95	26.03	27.16	28.33	29.56	29.56
30	21.50	22.43	23.41	24.42	25.48	26.59	26.59
35	19.66	20.51	21.40	22.33	23.30	24.31	24.31
40	18.19	18.98	19.80	20.66	21.56	22.49	22.49
45	16.98	17.72	18.49	19.29	20.13	21.00	21.00
50	15.97	16.67	17.39	18.14	18.93	19.75	19.75
Total	—	—	—	—	—	—	—

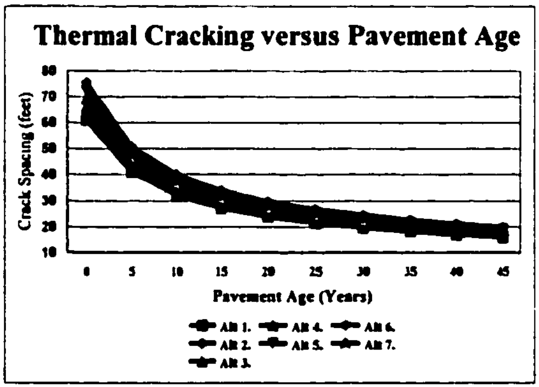
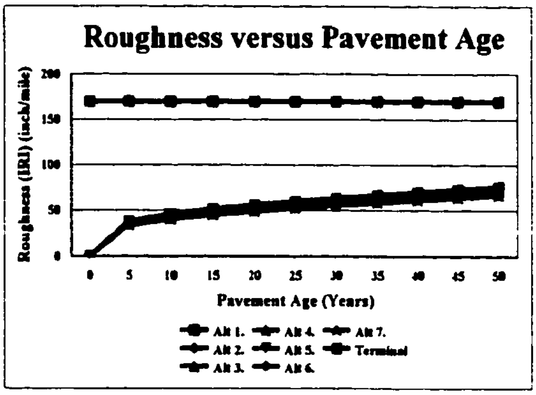


Table T-2: NYSDOT Flexible Pavement - Performance Optimization - 4" HMA Trial.

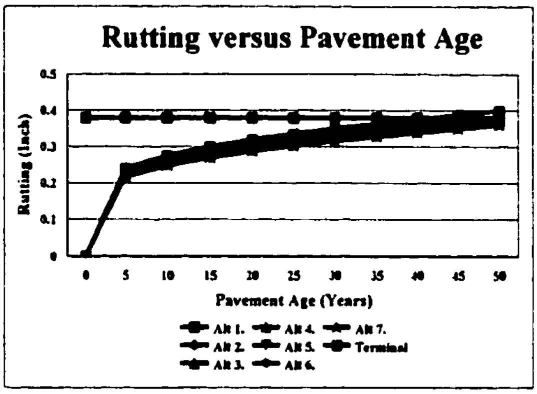
OUTPUT - PREDICTED ROUGHNESS (4" HMA).

Year	Alt 1. 4" AC 0" Base (in/mi)	Alt 2. 4" AC 6" Base (in/mi)	Alt 3. 4" AC 12" Base (in/mi)	Alt 4. 4" AC 18" Base (in/mi)	Alt 5. 4" AC 24" Base (in/mi)	Alt 6. 4" AC 30" Base (in/mi)	Alt 7 4" AC 36" Base (in/mi)	Terminal Roughness (inch/mile)
0	0	0	0	0	0	0	0	170
5	38	37	36	35	35	34	33	170
10	46	45	44	43	42	41	40	170
15	51	50	49	48	47	46	45	170
20	56	54	53	52	51	50	49	170
25	60	58	57	56	54	53	52	170
30	63	62	60	59	58	57	55	170
35	67	65	64	62	61	60	58	170
40	70	68	67	65	64	62	61	170
45	73	71	70	68	67	65	64	170
50	76	74	73	71	69	68	66	170
Total	--	--	--	--	--	--	--	--



OUTPUT - PREDICTED RUTTING (4" HMA).

Year	Alt 1. 4" AC 0" Base (inch)	Alt 2. 4" AC 6" Base (inch)	Alt 3 4" AC 12" Base (inch)	Alt 4. 4" AC 18" Base (inch)	Alt 5. 4" AC 24" Base (inch)	Alt 6. 4" AC 30" Base (inch)	Alt 7 4" AC 36" Base (inch)	Terminal Rutting (inch)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38
5	0.24	0.23	0.23	0.22	0.22	0.22	0.22	0.38
10	0.27	0.26	0.26	0.26	0.25	0.25	0.25	0.38
15	0.30	0.29	0.28	0.28	0.27	0.27	0.27	0.38
20	0.32	0.31	0.30	0.30	0.29	0.29	0.29	0.38
25	0.33	0.32	0.31	0.31	0.31	0.30	0.30	0.38
30	0.35	0.34	0.33	0.32	0.32	0.32	0.32	0.38
35	0.36	0.35	0.34	0.34	0.33	0.33	0.33	0.38
40	0.38	0.36	0.35	0.35	0.35	0.34	0.34	0.38
45	0.39	0.37	0.37	0.36	0.36	0.35	0.35	0.38
50	0.40	0.38	0.38	0.37	0.37	0.36	0.36	0.38
Total	--	--	--	--	--	--	--	--



OUTPUT - PREDICTED CRACKING (4" HMA).

Year	Alt 1. 4" AC 0" Base (feet)	Alt 2. 4" AC 6" Base (feet)	Alt 3. 4" AC 12" Base (feet)	Alt 4. 4" AC 18" Base (feet)	Alt 5. 4" AC 24" Base (feet)	Alt 6. 4" AC 30" Base (feet)	Alt 7 4" AC 36" Base (feet)
0	--	--	--	--	--	--	--
5	60.26	62.87	65.60	68.45	71.42	74.52	74.52
10	40.06	41.79	43.61	45.50	47.47	49.53	49.53
15	31.54	32.91	34.34	35.83	37.38	39.01	39.01
20	26.63	27.78	28.99	30.24	31.56	32.92	32.92
25	23.35	24.36	25.41	26.52	27.67	28.87	28.87
30	20.97	21.88	22.83	23.82	24.85	25.93	25.93
35	19.15	19.98	20.84	21.75	22.69	23.68	23.68
40	17.70	18.47	19.27	20.10	20.98	21.88	21.88
45	16.51	17.23	17.98	18.76	19.57	20.42	20.42
50	15.52	16.19	16.89	17.63	18.39	19.19	19.19
Total	--	--	--	--	--	--	--

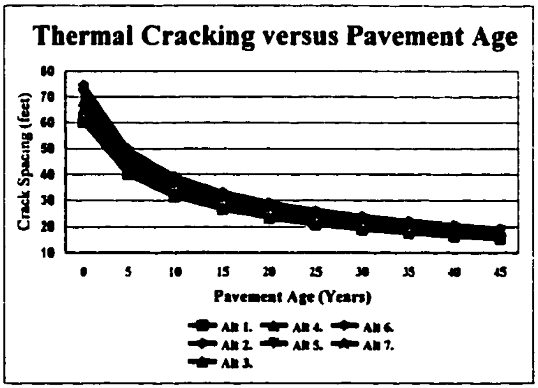
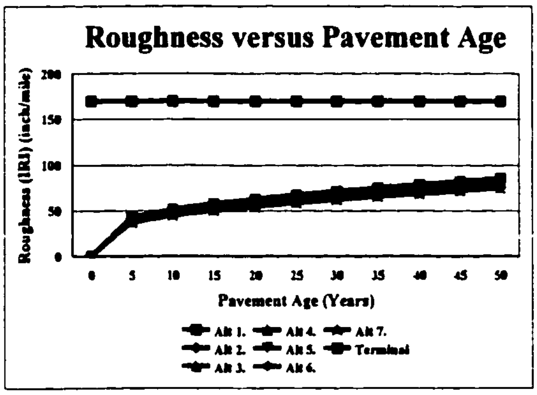


Table T-3: NYSDOT Flexible Pavement - Performance Optimization - 5" HMA Trial

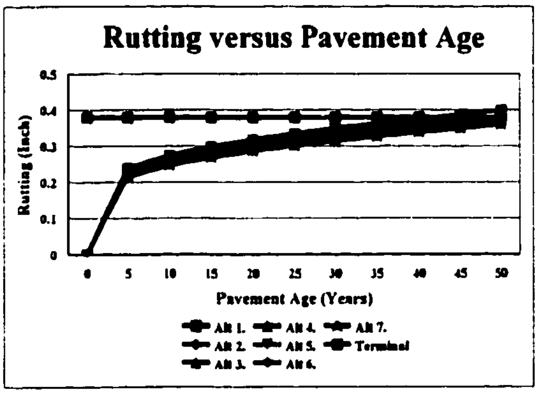
OUTPUT - PREDICTED ROUGHNESS (5" HMA).

Year	Alt 1. 5" AC 0" Base (in/mi)	Alt 2. 5" AC 6" Base (in/mi)	Alt 3 5" AC 12" Base (in/mi)	Alt 4. 5" AC 18" Base (in/mi)	Alt 5. 5" AC 24" Base (in/mi)	Alt 6. 5" AC 30" Base (in/mi)	Alt 7 5" AC 36" Base (in/mi)	Terminal Roughness (inch/mile)
0	0	0	0	0	0	0	0	170
5	43	42	41	40	39	38	37	170
10	51	50	49	48	47	46	45	170
15	58	56	55	54	53	52	50	170
20	63	61	60	59	57	56	55	170
25	67	66	64	63	61	60	59	170
30	71	70	68	67	65	64	62	170
35	75	74	72	70	69	67	66	170
40	79	77	75	74	72	70	69	170
45	82	80	79	77	75	74	72	170
50	86	84	82	80	78	77	75	170
Total	—	—	—	—	—	—	—	—



OUTPUT - PREDICTED RUTTING (5" HMA).

Year	Alt 1. 5" AC 0" Base (inch)	Alt 2. 5" AC 6" Base (inch)	Alt 3. 5" AC 12" Base (inch)	Alt 4. 5" AC 18" Base (inch)	Alt 5. 5" AC 24" Base (inch)	Alt 6. 5" AC 30" Base (inch)	Alt 7 5" AC 36" Base (inch)	Terminal Rutting (inch)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38
5	0.24	0.23	0.23	0.22	0.22	0.22	0.22	0.38
10	0.27	0.26	0.26	0.25	0.25	0.25	0.25	0.38
15	0.30	0.29	0.28	0.28	0.27	0.27	0.27	0.38
20	0.32	0.30	0.30	0.29	0.29	0.29	0.29	0.38
25	0.33	0.32	0.31	0.31	0.31	0.30	0.30	0.38
30	0.35	0.33	0.33	0.32	0.32	0.32	0.32	0.38
35	0.36	0.35	0.34	0.34	0.33	0.33	0.33	0.38
40	0.37	0.36	0.35	0.35	0.34	0.34	0.34	0.38
45	0.39	0.37	0.36	0.36	0.36	0.35	0.35	0.38
50	0.40	0.38	0.38	0.37	0.37	0.36	0.36	0.38
Total	—	—	—	—	—	—	—	—



OUTPUT - PREDICTED CRACKING (5" HMA).

Year	Alt 1. 5" AC 0" Base (feet)	Alt 2. 5" AC 6" Base (feet)	Alt 3. 5" AC 12" Base (feet)	Alt 4. 5" AC 18" Base (feet)	Alt 5. 5" AC 24" Base (feet)	Alt 6. 5" AC 30" Base (feet)	Alt 7 5" AC 36" Base (feet)
0	—	—	—	—	—	—	—
5	59.55	62.13	64.83	67.64	70.57	73.63	73.63
10	39.38	41.09	42.87	44.73	46.67	48.69	48.69
15	30.92	32.26	33.66	35.12	36.64	38.23	38.23
20	26.04	27.17	28.35	29.58	30.86	32.20	32.20
25	22.80	23.78	24.82	25.89	27.02	28.19	28.19
30	20.45	21.33	22.26	23.22	24.23	25.28	25.28
35	18.65	19.46	20.30	21.18	22.10	23.06	23.06
40	17.22	17.97	18.75	19.56	20.41	21.30	21.30
45	16.05	16.75	17.48	18.23	19.03	19.85	19.85
50	15.08	15.73	16.41	17.12	17.87	18.64	18.64
Total	—	—	—	—	—	—	—

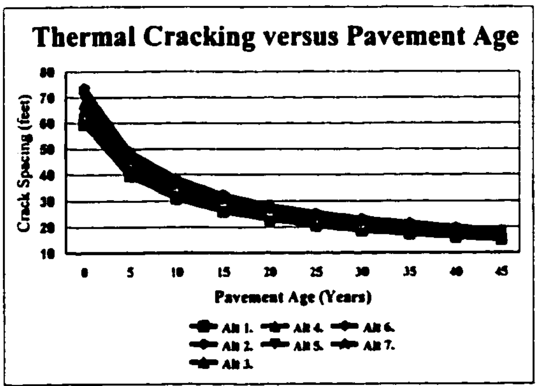
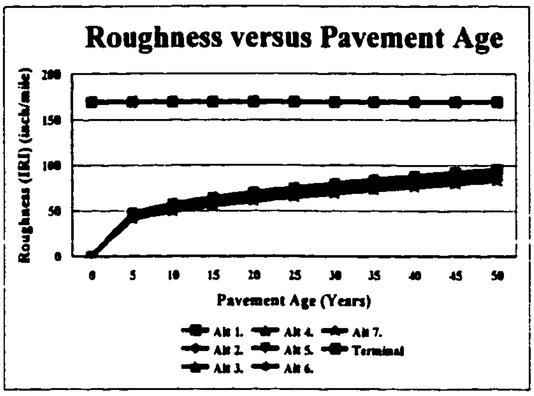


Table T-4: NYSDOT Flexible Pavement - Performance Optimization - 6" HMA Trial.

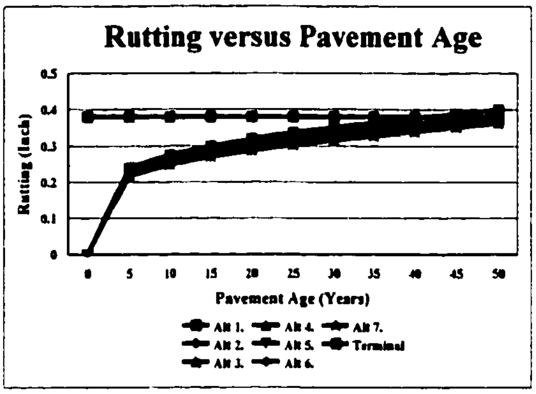
OUTPUT - PREDICTED ROUGHNESS (6" HMA).

Year	Alt 1. 6" AC 0" Base (in/mi)	Alt 2. 6" AC 6" Base (in/mi)	Alt 3. 6" AC 12" Base (in/mi)	Alt 4. 6" AC 18" Base (in/mi)	Alt 5. 6" AC 24" Base (in/mi)	Alt 6. 6" AC 30" Base (in/mi)	Alt 7 6" AC 36" Base (in/mi)	Terminal Roughness (inch/mile)
0	0	0	0	0	0	0	0	170
5	48	46	45	44	43	43	42	170
10	57	56	55	54	52	51	50	170
15	64	63	61	60	59	57	56	170
20	70	68	67	65	64	62	61	170
25	75	73	72	70	68	67	65	170
30	79	78	76	74	73	71	69	170
35	84	82	80	78	77	75	73	170
40	88	86	84	82	80	78	77	170
45	92	90	88	86	84	82	80	170
50	95	93	91	89	87	85	83	170
Total	—	—	—	—	—	—	—	—



OUTPUT - PREDICTED RUTTING (6" HMA).

Year	Alt 1. 6" AC 0" Base (inch)	Alt 2. 6" AC 6" Base (inch)	Alt 3. 6" AC 12" Base (inch)	Alt 4. 6" AC 18" Base (inch)	Alt 5. 6" AC 24" Base (inch)	Alt 6. 6" AC 30" Base (inch)	Alt 7 6" AC 36" Base (inch)	Terminal Rutting (inch)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38
5	0.24	0.23	0.23	0.22	0.22	0.22	0.22	0.38
10	0.28	0.26	0.26	0.26	0.25	0.25	0.25	0.38
15	0.30	0.29	0.28	0.28	0.27	0.27	0.27	0.38
20	0.32	0.31	0.30	0.30	0.29	0.29	0.29	0.38
25	0.33	0.32	0.32	0.31	0.31	0.31	0.30	0.38
30	0.35	0.34	0.33	0.32	0.32	0.32	0.32	0.38
35	0.36	0.35	0.34	0.34	0.33	0.33	0.33	0.38
40	0.38	0.36	0.35	0.35	0.35	0.34	0.34	0.38
45	0.39	0.37	0.37	0.36	0.36	0.35	0.35	0.38
50	0.40	0.38	0.38	0.37	0.37	0.36	0.36	0.38
Total	—	—	—	—	—	—	—	—



OUTPUT - PREDICTED CRACKING (6" HMA).

Year	Alt 1. 6" AC 0" Base (feet)	Alt 2. 6" AC 6" Base (feet)	Alt 3. 6" AC 12" Base (feet)	Alt 4. 6" AC 18" Base (feet)	Alt 5. 6" AC 24" Base (feet)	Alt 6. 6" AC 30" Base (feet)	Alt 7 6" AC 36" Base (feet)
0	—	—	—	—	—	—	—
5	58.84	61.39	64.06	66.84	69.74	72.76	72.76
10	38.71	40.39	42.15	43.97	45.88	47.87	47.87
15	30.30	31.62	32.99	34.42	35.92	37.47	37.47
20	25.47	26.58	27.73	28.93	30.19	31.50	31.50
25	22.26	23.22	24.23	25.28	26.38	27.52	27.52
30	19.94	20.80	21.71	22.65	23.63	24.65	24.65
35	18.17	18.95	19.78	20.63	21.53	22.46	22.46
40	16.76	17.49	18.24	19.03	19.86	20.72	20.72
45	15.61	16.28	16.99	17.73	18.50	19.30	19.30
50	14.65	15.28	15.94	16.63	17.36	18.11	18.11
Total	—	—	—	—	—	—	—

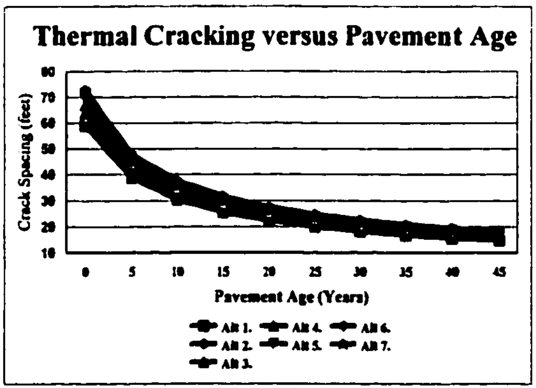
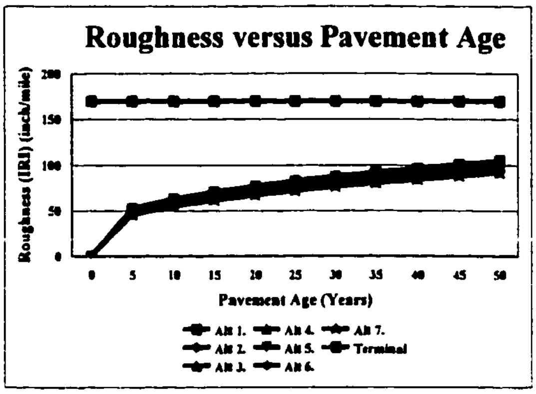


Table T-5: NYSDOT Flexible Pavement - Performance Optimization - 7" HMA Trial.

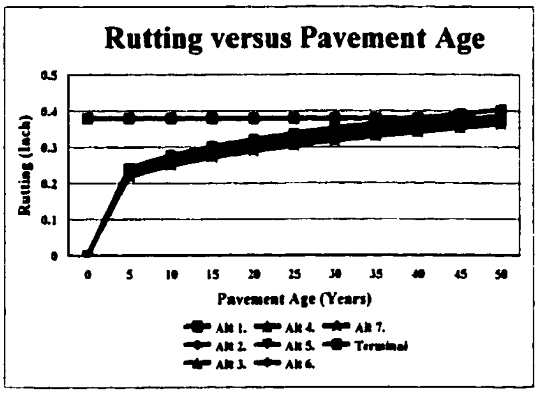
OUTPUT - PREDICTED ROUGHNESS (7" HMA).

Year	Alt 1. 7" AC 0" Base (in/mi)	Alt 2. 7" AC 6" Base (in/mi)	Alt 3. 7" AC 12" Base (in/mi)	Alt 4. 7" AC 18" Base (in/mi)	Alt 5. 7" AC 24" Base (in/mi)	Alt 6. 7" AC 30" Base (in/mi)	Alt 7 7" AC 36" Base (in/mi)	Terminal Roughness (inch/mile)
0	0	0	0	0	0	0	0	170
5	52	51	50	49	48	47	46	170
10	63	62	60	59	58	56	55	170
15	71	69	68	66	65	63	62	170
20	77	75	74	72	70	69	67	170
25	82	91	79	77	75	74	72	170
30	87	86	84	82	80	78	76	170
35	92	90	88	86	84	82	81	170
40	97	94	92	90	88	86	84	170
45	101	99	97	94	92	90	88	170
50	105	103	101	98	96	94	92	170
Total	—	—	—	—	—	—	—	—



OUTPUT - PREDICTED RUTTING (7" HMA).

Year	Alt 1. 7" AC 0" Base (inch)	Alt 2. 7" AC 6" Base (inch)	Alt 3. 7" AC 12" Base (inch)	Alt 4. 7" AC 18" Base (inch)	Alt 5 7" AC 24" Base (inch)	Alt 6. 7" AC 30" Base (inch)	Alt 7 7" AC 36" Base (inch)	Terminal Rutting (inch)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38
5	0.24	0.23	0.23	0.22	0.22	0.22	0.22	0.38
10	0.28	0.27	0.26	0.26	0.25	0.25	0.25	0.38
15	0.30	0.29	0.28	0.28	0.28	0.27	0.27	0.38
20	0.32	0.31	0.30	0.30	0.29	0.29	0.29	0.38
25	0.34	0.32	0.32	0.31	0.31	0.31	0.31	0.38
30	0.35	0.34	0.33	0.33	0.32	0.32	0.32	0.38
35	0.37	0.35	0.34	0.34	0.34	0.33	0.33	0.38
40	0.38	0.36	0.36	0.35	0.35	0.35	0.34	0.38
45	0.39	0.38	0.37	0.36	0.36	0.36	0.35	0.38
50	0.40	0.39	0.38	0.37	0.37	0.37	0.36	0.38
Total	—	—	—	—	—	—	—	—



OUTPUT - PREDICTED CRACKING (7" HMA).

Year	Alt 1. 7" AC 0" Base (feet)	Alt 2. 7" AC 6" Base (feet)	Alt 3. 7" AC 12" Base (feet)	Alt 4. 7" AC 18" Base (feet)	Alt 5. 7" AC 24" Base (feet)	Alt 6. 7" AC 30" Base (feet)	Alt 7 7" AC 36" Base (feet)
0	—	—	—	—	—	—	—
5	58.15	60.67	63.30	66.05	68.91	71.90	71.90
10	38.06	39.71	41.43	43.23	45.11	47.06	47.06
15	29.70	30.99	32.34	33.74	35.20	36.73	36.73
20	24.91	25.99	27.12	28.30	29.52	30.81	30.81
25	21.74	22.68	23.66	24.69	25.76	26.88	26.88
30	19.44	20.29	21.17	22.08	23.04	24.04	24.04
35	17.69	18.46	19.26	20.10	20.97	21.88	21.88
40	16.31	17.01	17.75	18.52	19.33	20.16	20.16
45	15.17	15.83	16.52	17.24	17.98	18.76	18.76
50	14.23	14.84	15.49	16.16	16.86	17.59	17.59
Total	—	—	—	—	—	—	—

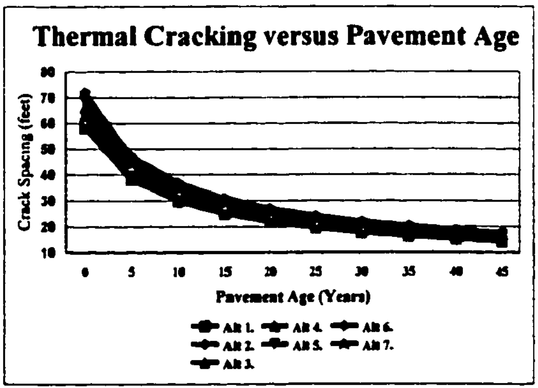
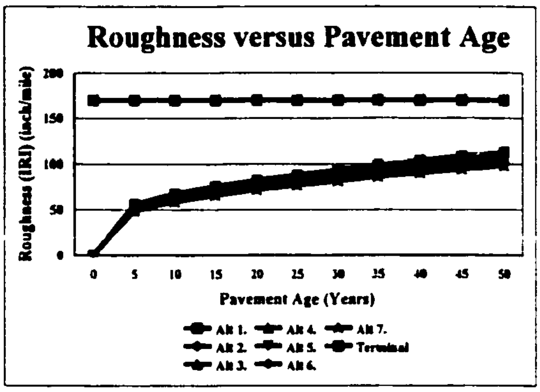


Table T-6: NYSDOT Flexible Pavement - Performance Optimization - 8" HMA Trial.

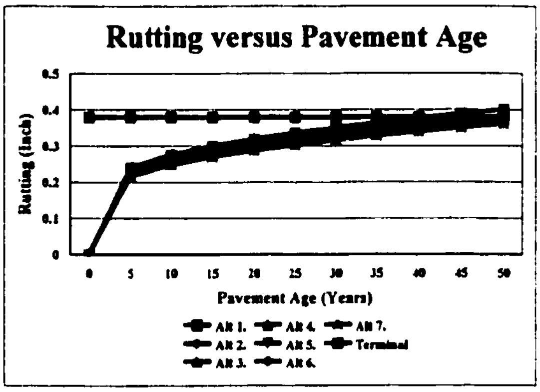
OUTPUT - PREDICTED ROUGHNESS (8" HMA).

Year	Alt 1. 8" AC 0" Base (in/mi)	Alt 2. 8" AC 6" Base (in/mi)	Alt 3. 8" AC 12" Base (in/mi)	Alt 4 8" AC 18" Base (in/mi)	Alt 5. 8" AC 24" Base (in/mi)	Alt 6. 8" AC 30" Base (in/mi)	Alt 7 8" AC 36" Base (in/mi)	Terminal Roughness (inch/mile)
0	0	0	0	0	0	0	0	170
5	56	55	53	52	51	50	49	170
10	67	66	64	63	62	60	59	170
15	75	74	72	71	69	68	66	170
20	82	80	79	77	75	73	72	170
25	88	86	84	82	81	79	77	170
30	93	91	89	87	85	84	82	170
35	98	96	94	92	90	88	86	170
40	103	101	99	97	94	92	90	170
45	108	105	103	101	99	96	94	170
50	112	110	107	105	103	100	98	170
Total	—	—	—	—	—	—	—	—



OUTPUT - PREDICTED RUTTING (8" HMA).

Year	Alt 1. 8" AC 0" Base (inch)	Alt 2. 8" AC 6" Base (inch)	Alt 3. 8" AC 12" Base (inch)	Alt 4. 8" AC 18" Base (inch)	Alt 5 8" AC 24" Base (inch)	Alt 6. 8" AC 30" Base (inch)	Alt 7 8" AC 36" Base (inch)	Terminal Rutting (inch)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38
5	0.24	0.23	0.23	0.22	0.22	0.22	0.22	0.38
10	0.28	0.26	0.26	0.26	0.25	0.25	0.25	0.38
15	0.30	0.29	0.28	0.28	0.27	0.27	0.27	0.38
20	0.32	0.31	0.30	0.30	0.29	0.29	0.29	0.38
25	0.34	0.32	0.32	0.31	0.31	0.31	0.30	0.38
30	0.35	0.34	0.33	0.32	0.32	0.32	0.32	0.38
35	0.36	0.35	0.34	0.34	0.33	0.33	0.33	0.38
40	0.38	0.36	0.35	0.35	0.35	0.34	0.34	0.38
45	0.39	0.37	0.37	0.36	0.36	0.35	0.35	0.38
50	0.40	0.38	0.38	0.37	0.37	0.36	0.36	0.38
Total	—	—	—	—	—	—	—	—



OUTPUT - PREDICTED CRACKING (8" HMA).

Year	Alt 1. 8" AC 0" Base (feet)	Alt 2. 8" AC 6" Base (feet)	Alt 3. 8" AC 12" Base (feet)	Alt 4. 8" AC 18" Base (feet)	Alt 5. 8" AC 24" Base (feet)	Alt 6. 8" AC 30" Base (feet)	Alt 7 8" AC 36" Base (feet)
0	—	—	—	—	—	—	—
5	57.46	59.95	62.55	65.26	68.09	71.05	71.05
10	37.42	39.04	40.73	42.50	44.34	46.27	46.27
15	29.11	30.38	31.69	33.07	34.50	36.00	36.00
20	24.37	25.42	26.53	27.68	28.88	30.13	30.13
25	21.22	22.14	23.11	24.11	25.15	26.24	26.24
30	18.96	19.78	20.64	21.54	22.47	23.44	23.44
35	17.23	17.98	18.76	19.58	20.43	21.31	21.31
40	15.87	16.56	17.27	18.02	18.81	19.62	19.62
45	14.75	15.39	16.06	16.76	17.48	18.24	18.24
50	13.82	14.42	15.05	15.70	16.38	17.09	17.09
Total	—	—	—	—	—	—	—

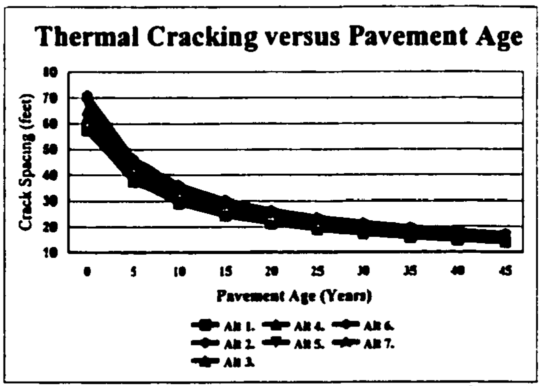
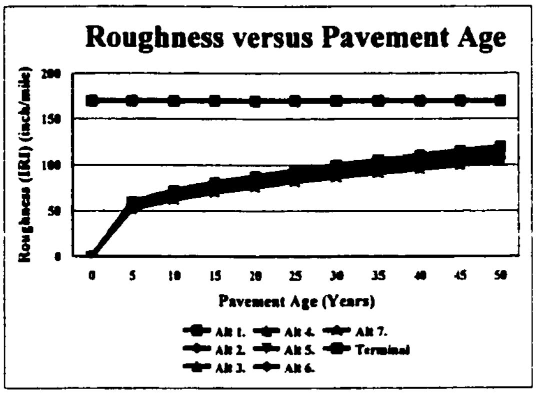


Table T-7: NYSDOT Flexible Pavement - Performance Analysis - 9" HMA Trial.

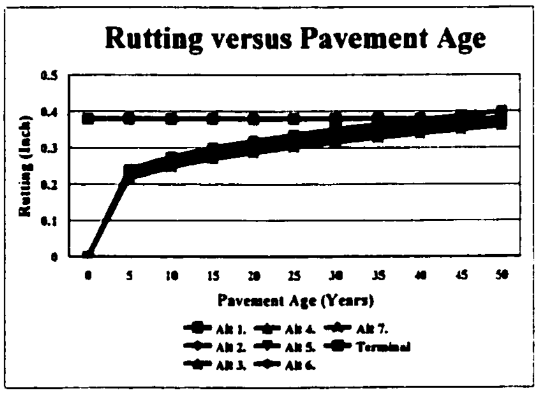
OUTPUT - PREDICTED ROUGHNESS (9" HMA).

Year	Alt 1. 9" AC 0" Base (in/mi)	Alt 2. 9" AC 6" Base (in/mi)	Alt 3. 9" AC 12" Base (in/mi)	Alt 4. 9" AC 18" Base (in/mi)	Alt 5. 9" AC 24" Base (in/mi)	Alt 6. 9" AC 30" Base (in/mi)	Alt 7 9" AC 36" Base (in/mi)	Terminal Roughness (inch/mile)
0	0	0	0	0	0	0	0	170
5	60	58	57	56	55	53	52	170
10	72	70	69	67	66	64	63	170
15	80	79	77	75	74	72	70	170
20	88	86	84	82	80	78	77	170
25	94	92	90	88	86	84	82	170
30	100	97	95	93	91	89	87	170
35	105	103	100	98	96	94	92	170
40	110	108	105	103	101	98	96	170
45	115	112	110	107	105	103	100	170
50	120	117	114	112	109	107	105	170
Total	---	---	---	---	---	---	---	---



OUTPUT - PREDICTED RUTTING (9" HMA).

Year	Alt 1. 9" AC 0" Base (inch)	Alt 2. 9" AC 6" Base (inch)	Alt 3. 9" AC 12" Base (inch)	Alt 4. 9" AC 18" Base (inch)	Alt 5. 9" AC 24" Base (inch)	Alt 6. 9" AC 30" Base (inch)	Alt 7 9" AC 36" Base (inch)	Terminal Rutting (inch)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38
5	0.24	0.23	0.23	0.22	0.22	0.22	0.22	0.38
10	0.27	0.26	0.26	0.26	0.25	0.25	0.25	0.38
15	0.30	0.29	0.28	0.28	0.27	0.27	0.27	0.38
20	0.32	0.31	0.30	0.30	0.29	0.29	0.29	0.38
25	0.33	0.32	0.31	0.31	0.31	0.30	0.30	0.38
30	0.35	0.34	0.33	0.32	0.32	0.32	0.32	0.38
35	0.36	0.35	0.34	0.34	0.33	0.33	0.33	0.38
40	0.38	0.36	0.35	0.35	0.35	0.34	0.34	0.38
45	0.39	0.37	0.37	0.36	0.36	0.35	0.35	0.38
50	0.40	0.38	0.38	0.37	0.37	0.36	0.36	0.38
Total	---	---	---	---	---	---	---	---



OUTPUT - PREDICTED CRACKING (9" HMA).

Year	Alt 1. 9" AC 0" Base (feet)	Alt 2. 9" AC 6" Base (feet)	Alt 3. 9" AC 12" Base (feet)	Alt 4. 9" AC 18" Base (feet)	Alt 5. 9" AC 24" Base (feet)	Alt 6. 9" AC 30" Base (feet)	Alt 7 9" AC 36" Base (feet)
0	---	---	---	---	---	---	---
5	56.78	59.24	61.81	64.49	67.29	70.21	70.21
10	36.78	38.38	40.05	41.78	43.60	45.49	45.49
15	28.54	29.77	31.07	32.41	33.82	35.29	35.29
20	23.83	24.87	25.94	27.07	28.24	29.47	29.47
25	20.72	21.62	22.56	23.54	24.56	25.63	25.63
30	18.49	19.29	20.13	21.00	21.91	22.86	22.86
35	16.79	17.52	18.28	19.07	19.89	20.76	20.76
40	15.44	16.11	16.81	17.54	18.30	19.09	19.09
45	14.34	14.96	15.61	16.29	17.00	17.74	17.74
50	13.43	14.01	14.62	15.25	15.91	16.60	16.60
Total	---	---	---	---	---	---	---

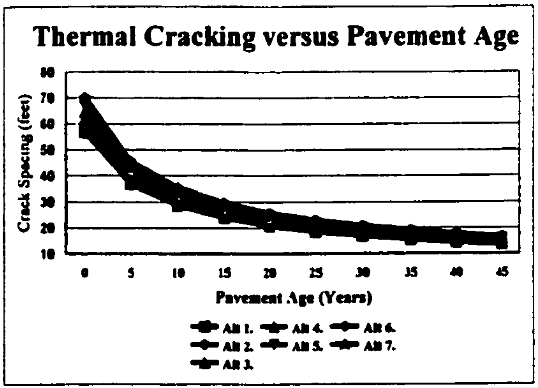
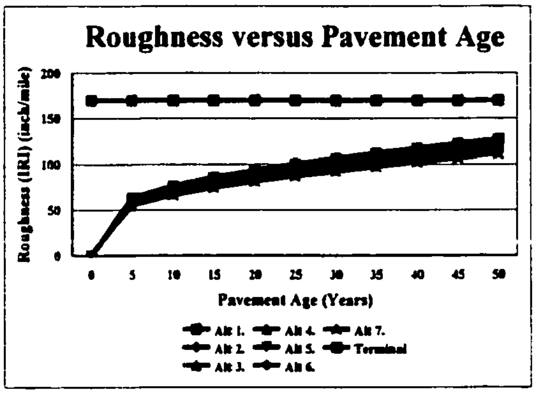


Table T-8: NYSDOT Flexible Pavement - Performance Optimization - 10" HMA Trial.

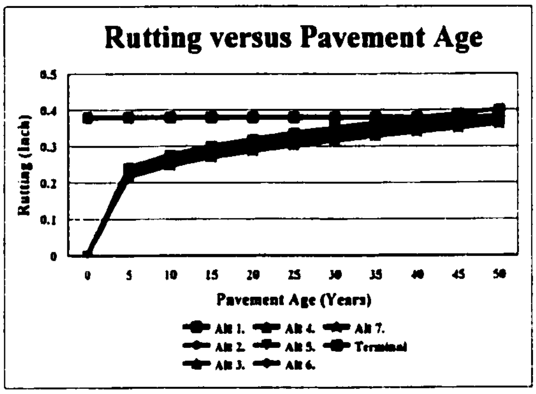
OUTPUT - PREDICTED ROUGHNESS (10" HMA).

Year	Alt 1 10" AC 0" Base (in/mi)	Alt 2. 10" AC 6" Base (in/mi)	Alt 3. 10" AC 12" Base (in/mi)	Alt 4 10" AC 18" Base (in/mi)	Alt 5 10" AC 24" Base (in/mi)	Alt 6. 10" AC 30" Base (in/mi)	Alt 7 10" AC 36" Base (in/mi)	Terminal Roughness (inch/mile)
0	0	0	0	0	0	0	0	170
5	63	62	61	59	58	57	55	170
10	76	75	73	71	70	68	67	170
15	86	84	82	80	78	77	75	170
20	93	91	89	87	85	83	82	170
25	100	98	96	93	91	89	87	170
30	106	104	101	99	97	95	93	170
35	112	109	107	104	102	100	98	170
40	117	114	112	109	107	105	102	170
45	122	120	117	114	112	109	107	170
50	127	125	122	119	116	114	111	170
Total	—	—	—	—	—	—	—	—



OUTPUT - PREDICTED RUTTING (10" HMA).

Year	Alt 1. 10" AC 0" Base (inch)	Alt 2. 10" AC 6" Base (inch)	Alt 3. 10" AC 12" Base (inch)	Alt 4. 10" AC 18" Base (inch)	Alt 5. 10" AC 24" Base (inch)	Alt 6. 10" AC 30" Base (inch)	Alt 7 10" AC 36" Base (inch)	Terminal Rutting (inch)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38
5	0.24	0.23	0.23	0.22	0.22	0.22	0.22	0.38
10	0.28	0.26	0.26	0.26	0.25	0.25	0.25	0.38
15	0.30	0.29	0.28	0.28	0.28	0.27	0.27	0.38
20	0.32	0.31	0.30	0.30	0.29	0.29	0.29	0.38
25	0.34	0.32	0.32	0.31	0.31	0.31	0.30	0.38
30	0.35	0.34	0.33	0.32	0.32	0.32	0.32	0.38
35	0.36	0.35	0.34	0.34	0.33	0.33	0.33	0.38
40	0.38	0.36	0.35	0.35	0.35	0.34	0.34	0.38
45	0.39	0.37	0.37	0.36	0.36	0.35	0.35	0.38
50	0.40	0.38	0.38	0.37	0.37	0.36	0.36	0.38
Total	—	—	—	—	—	—	—	—



OUTPUT - PREDICTED CRACKING (10" HMA).

Year	Alt 1. 10" AC 0" Base (feet)	Alt 2. 10" AC 6" Base (feet)	Alt 3. 10" AC 12" Base (feet)	Alt 4 10" AC 18" Base (feet)	Alt 5 10" AC 24" Base (feet)	Alt 6. 10" AC 30" Base (feet)	Alt 7 10" AC 36" Base (feet)
0	—	—	—	—	—	—	—
5	56.10	58.54	61.08	63.73	66.49	69.38	69.38
10	36.16	37.73	39.37	41.08	42.86	44.72	44.72
15	27.97	29.18	30.45	31.77	33.15	34.59	34.59
20	23.31	24.32	25.38	26.48	27.63	28.82	28.82
25	20.24	21.11	22.03	22.99	23.98	25.02	25.02
30	18.03	18.81	19.63	20.48	21.37	22.29	22.29
35	16.35	17.06	17.80	18.57	19.38	20.22	20.22
40	15.02	15.68	16.36	17.07	17.81	18.58	18.58
45	13.94	14.55	15.18	15.84	16.53	17.24	17.24
50	13.04	13.61	14.20	14.82	15.46	16.13	16.13
Total	—	—	—	—	—	—	—

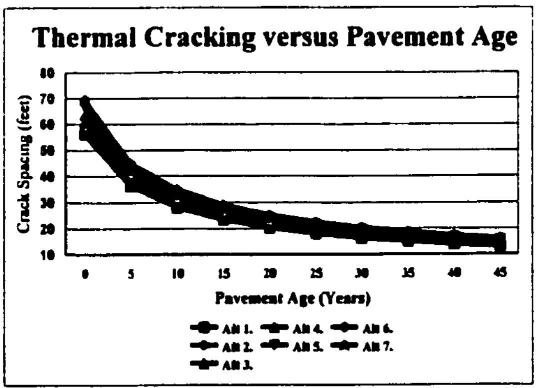
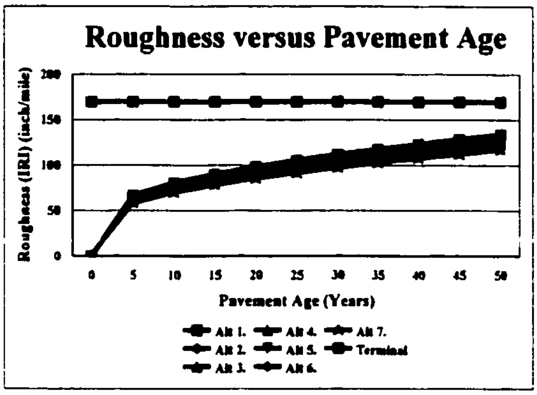


Table T-9: NYSDOT Flexible Pavement - Performance Analysis - 11" HMA Trial

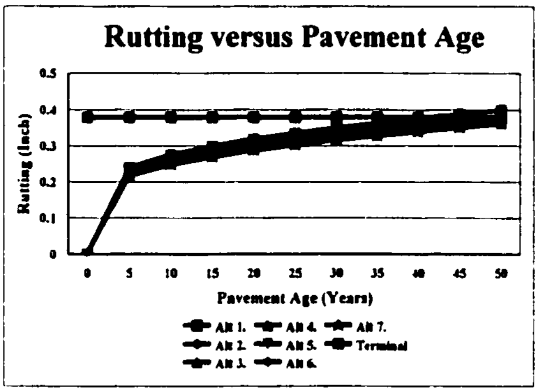
OUTPUT - PREDICTED ROUGHNESS (11" HMA).

Year	Alt 1. 11" AC 0" Base (in/mi)	Alt 2. 11" AC 6" Base (in/mi)	Alt 3. 11" AC 12" Base (in/mi)	Alt 4. 11" AC 18" Base (in/mi)	Alt 5. 11" AC 24" Base (in/mi)	Alt 6. 11" AC 30" Base (in/mi)	Alt 7 11" AC 36" Base (in/mi)	Terminal Roughness (inch/mile)
0	0	0	0	0	0	0	0	170
5	67	65	64	62	61	60	58	170
10	80	79	77	75	74	72	70	170
15	90	88	86	84	82	81	79	170
20	98	96	94	92	90	88	86	170
25	105	103	101	98	96	94	92	170
30	112	109	107	104	102	100	98	170
35	118	115	112	110	107	105	103	170
40	123	121	118	115	113	110	108	170
45	129	126	123	120	118	115	113	170
50	134	131	128	125	123	120	117	170
Total	—	—	—	—	—	—	—	—


Roughness versus Pavement Age

OUTPUT - PREDICTED RUTTING (11" HMA).

Year	Alt 1. 11" AC 0" Base (inch)	Alt 2. 11" AC 6" Base (inch)	Alt 3 11" AC 12" Base (inch)	Alt 4. 11" AC 18" Base (inch)	Alt 5 11" AC 24" Base (inch)	Alt 6. 11" AC 30" Base (inch)	Alt 7 11" AC 36" Base (inch)	Terminal Rutting (inch)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38
5	0.24	0.23	0.23	0.22	0.22	0.22	0.22	0.38
10	0.28	0.26	0.26	0.26	0.25	0.25	0.25	0.38
15	0.30	0.29	0.28	0.28	0.27	0.27	0.27	0.38
20	0.32	0.31	0.30	0.30	0.29	0.29	0.29	0.38
25	0.33	0.32	0.32	0.31	0.31	0.30	0.30	0.38
30	0.35	0.34	0.33	0.32	0.32	0.32	0.32	0.38
35	0.36	0.35	0.34	0.34	0.33	0.33	0.33	0.38
40	0.38	0.36	0.35	0.35	0.35	0.34	0.34	0.38
45	0.39	0.37	0.37	0.36	0.36	0.35	0.35	0.38
50	0.40	0.38	0.38	0.37	0.37	0.36	0.36	0.38
Total	—	—	—	—	—	—	—	—


Rutting versus Pavement Age

OUTPUT - PREDICTED CRACKING (11" HMA).

Year	Alt 1. 11" AC 0" Base (feet)	Alt 2. 11" AC 6" Base (feet)	Alt 3 11" AC 12" Base (feet)	Alt 4. 11" AC 18" Base (feet)	Alt 5 11" AC 24" Base (feet)	Alt 6. 11" AC 30" Base (feet)	Alt 7 11" AC 36" Base (feet)
0	—	—	—	—	—	—	—
5	55.44	57.85	60.36	62.97	65.70	68.56	68.56
10	35.55	37.09	38.70	40.38	42.13	43.96	43.96
15	27.42	28.60	29.85	31.14	32.49	33.90	33.90
20	22.80	23.79	24.82	25.90	27.02	28.19	28.19
25	19.76	20.62	21.51	22.44	23.42	24.43	24.43
30	17.58	18.34	19.14	19.97	20.84	21.74	21.74
35	15.93	16.62	17.34	18.09	18.88	19.69	19.69
40	14.62	15.25	15.92	16.61	17.33	18.08	18.08
45	13.56	14.14	14.76	15.40	16.07	16.76	16.76
50	12.67	13.22	13.79	14.39	15.02	15.67	15.67
Total	—	—	—	—	—	—	—

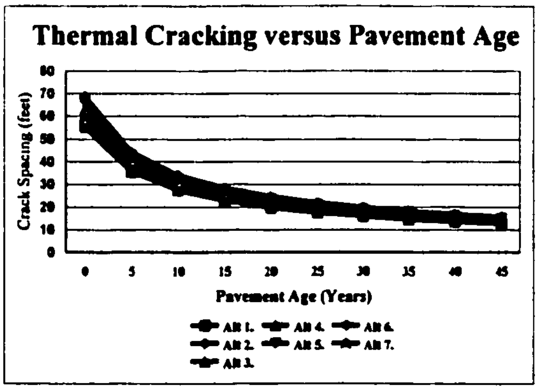
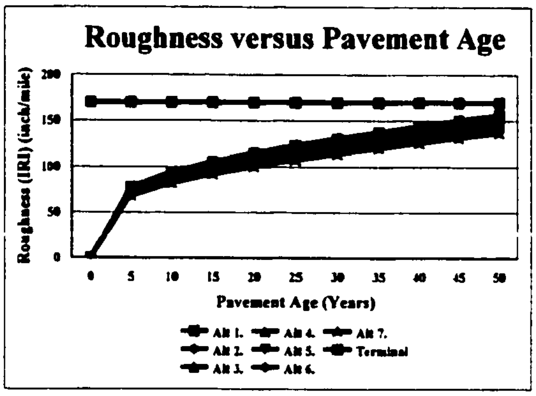

Thermal Cracking versus Pavement Age

Table T-10: NYSDOT Flexible Pavement - Performance Optimization - 15" HMA Trial.

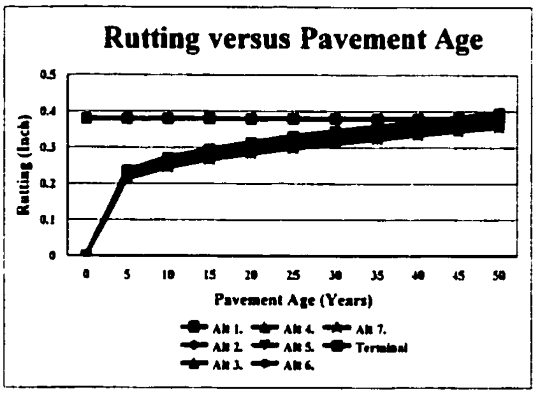
OUTPUT - PREDICTED ROUGHNESS (15" HMA).

Year	Alt 1. 15" AC 0" Base (in/mi)	Alt 2. 15" AC 6" Base (in/mi)	Alt 3. 15" AC 12" Base (in/mi)	Alt 4. 15" AC 18" Base (in/mi)	Alt 5. 15" AC 24" Base (in/mi)	Alt 6. 15" AC 30" Base (in/mi)	Alt 7 15" AC 36" Base (in/mi)	Terminal Roughness (inch/mile)
0	0	0	0	0	0	0	0	170
5	78	76	75	73	71	70	68	170
10	94	92	90	88	86	84	82	170
15	105	103	101	99	96	94	92	170
20	115	112	110	107	105	103	100	170
25	123	120	118	115	112	110	108	170
30	130	128	125	122	119	117	114	170
35	137	134	131	129	126	123	120	170
40	144	141	138	135	132	129	126	170
45	151	147	144	141	138	135	132	170
50	157	153	150	147	143	140	137	170
Total	—	—	—	—	—	—	—	—



OUTPUT - PREDICTED RUTTING (15" HMA).

Year	Alt 1. 15" AC 0" Base (inch)	Alt 2. 15" AC 6" Base (inch)	Alt 3. 15" AC 12" Base (inch)	Alt 4. 15" AC 18" Base (inch)	Alt 5. 15" AC 24" Base (inch)	Alt 6. 15" AC 30" Base (inch)	Alt 7 15" AC 36" Base (inch)	Terminal Rutting (inch)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38
5	0.24	0.23	0.22	0.22	0.22	0.22	0.21	0.38
10	0.27	0.26	0.26	0.25	0.25	0.25	0.25	0.38
15	0.30	0.28	0.28	0.27	0.27	0.27	0.27	0.38
20	0.31	0.30	0.30	0.29	0.29	0.29	0.28	0.38
25	0.33	0.32	0.31	0.31	0.30	0.30	0.30	0.38
30	0.35	0.33	0.32	0.32	0.32	0.31	0.31	0.38
35	0.36	0.34	0.34	0.33	0.33	0.33	0.32	0.38
40	0.37	0.36	0.35	0.34	0.34	0.34	0.34	0.38
45	0.38	0.37	0.36	0.36	0.35	0.35	0.35	0.38
50	0.39	0.38	0.37	0.37	0.36	0.36	0.36	0.38
Total	—	—	—	—	—	—	—	—



OUTPUT - PREDICTED CRACKING (15" HMA).

Year	Alt 1. 15" AC 0" Base (feet)	Alt 2. 15" AC 6" Base (feet)	Alt 3. 15" AC 12" Base (feet)	Alt 4. 15" AC 18" Base (feet)	Alt 5. 15" AC 24" Base (feet)	Alt 6. 15" AC 30" Base (feet)	Alt 7 15" AC 36" Base (feet)
0	—	—	—	—	—	—	—
5	52.86	55.15	57.55	60.04	62.65	65.37	65.37
10	33.21	34.65	36.15	37.72	39.36	41.07	41.07
15	25.30	26.40	27.55	28.74	29.99	31.29	31.29
20	20.86	21.77	22.71	23.70	24.73	25.80	25.80
25	17.96	18.74	19.56	20.41	21.29	22.21	22.21
30	15.90	16.59	17.31	18.06	18.84	19.66	19.66
35	14.34	14.96	15.61	16.28	16.99	17.73	17.73
40	13.11	13.68	14.27	14.89	15.53	16.21	16.21
45	12.11	12.64	13.19	13.76	14.35	14.98	14.98
50	11.29	11.78	12.29	12.82	13.38	13.96	13.96
Total	—	—	—	—	—	—	—

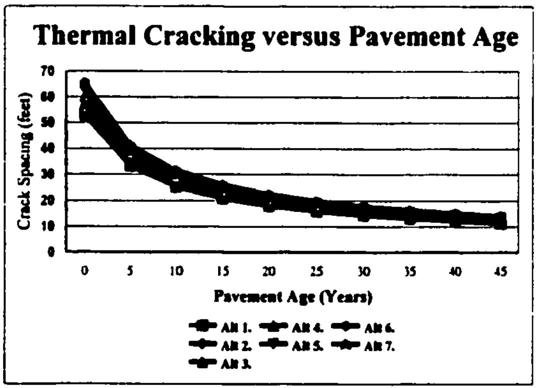
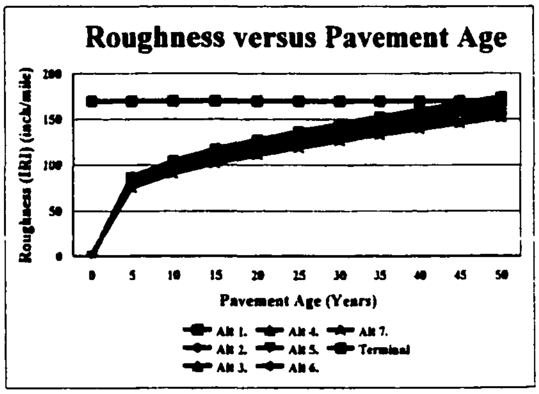


Table T-11: NYSDOT Flexible Pavement - Performance Optimization - 20" HMA Trial.

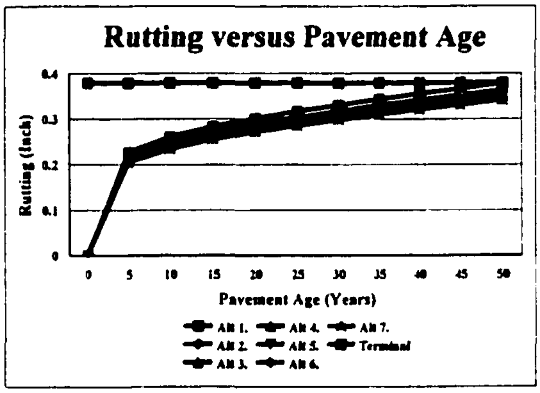
OUTPUT - PREDICTED ROUGHNESS (20" HMA).

Year	Alt 1. 20" AC 0" Base (in/mi)	Alt 2. 20" AC 6" Base (in/mi)	Alt 3. 20" AC 12" Base (in/mi)	Alt 4. 20" AC 18" Base (in/mi)	Alt 5. 20" AC 24" Base (in/mi)	Alt 6. 20" AC 30" Base (in/mi)	Alt 7 20" AC 36" Base (in/mi)	Terminal Roughness (inch/mile)
0	0	0	0	0	0	0	0	170
5	87	85	83	81	79	77	76	170
10	104	102	100	97	95	93	91	170
15	117	114	112	109	107	105	102	170
20	127	124	122	119	116	114	111	170
25	136	133	130	128	125	122	119	170
30	145	141	138	135	132	129	126	170
35	152	149	146	143	139	136	133	170
40	160	156	153	149	146	143	140	170
45	167	163	160	156	153	149	146	170
50	174	170	166	163	159	155	152	170
Total	—	—	—	—	—	—	—	—



OUTPUT - PREDICTED RUTTING (20" HMA).

Year	Alt 1. 20" AC 0" Base (inch)	Alt 2. 20" AC 6" Base (inch)	Alt 3. 20" AC 12" Base (inch)	Alt 4. 20" AC 18" Base (inch)	Alt 5. 20" AC 24" Base (inch)	Alt 6. 20" AC 30" Base (inch)	Alt 7 20" AC 36" Base (inch)	Terminal Rutting (inch)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38
5	0.23	0.22	0.21	0.21	0.21	0.21	0.21	0.38
10	0.26	0.25	0.24	0.24	0.24	0.24	0.24	0.38
15	0.28	0.27	0.27	0.26	0.26	0.26	0.26	0.38
20	0.30	0.29	0.28	0.28	0.28	0.27	0.27	0.38
25	0.32	0.30	0.30	0.29	0.29	0.29	0.29	0.38
30	0.33	0.32	0.31	0.31	0.30	0.30	0.30	0.38
35	0.34	0.33	0.32	0.32	0.32	0.31	0.31	0.38
40	0.36	0.34	0.33	0.33	0.33	0.32	0.32	0.38
45	0.37	0.35	0.35	0.34	0.34	0.33	0.33	0.38
50	0.38	0.36	0.36	0.35	0.35	0.34	0.34	0.38
Total	—	—	—	—	—	—	—	—



OUTPUT - PREDICTED CRACKING (20" HMA).

Year	Alt 1. 20" AC 0" Base (feet)	Alt 2. 20" AC 6" Base (feet)	Alt 3. 20" AC 12" Base (feet)	Alt 4. 20" AC 18" Base (feet)	Alt 5. 20" AC 24" Base (feet)	Alt 6. 20" AC 30" Base (feet)	Alt 7 20" AC 36" Base (feet)
0	—	—	—	—	—	—	—
5	49.81	51.97	54.22	56.57	59.03	61.59	61.59
10	30.50	31.82	33.20	34.64	36.14	37.71	37.71
15	22.89	23.88	24.92	26.00	27.13	28.31	28.31
20	18.67	19.49	20.33	21.21	22.13	23.09	23.09
25	15.95	16.64	17.36	18.11	18.90	19.72	19.72
30	14.02	14.63	15.26	15.92	16.61	17.33	17.33
35	12.57	13.11	13.68	14.28	14.90	15.54	15.54
40	11.44	11.93	12.45	12.99	13.55	14.14	14.14
45	10.52	10.98	11.45	11.95	12.47	13.01	13.01
50	9.77	10.19	10.63	11.09	11.57	12.08	12.08
Total	—	—	—	—	—	—	—

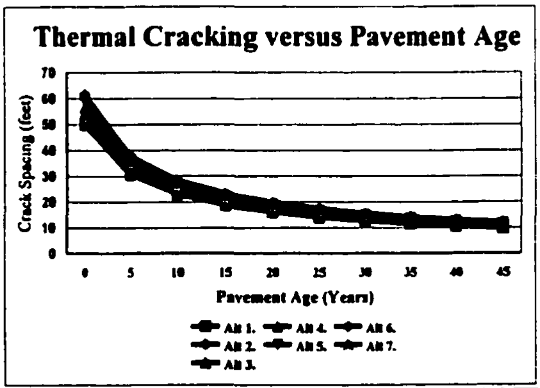
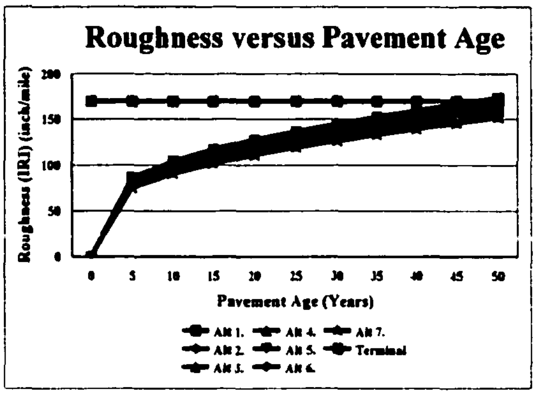


Table T-12: NYSDOT Flexible Pavement - Performance Optimization - 25" HMA Trial.

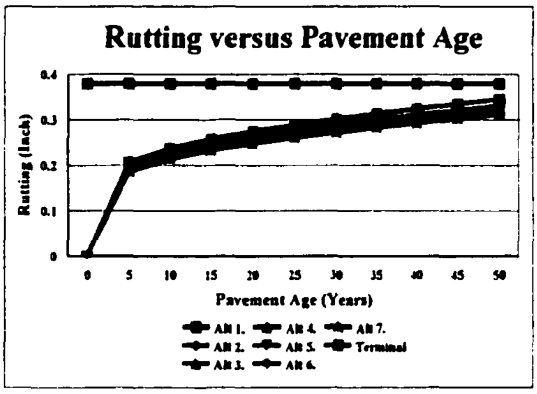
OUTPUT - PREDICTED ROUGHNESS (25" HMA).

Year	Alt 1. 25" AC 0" Base (in/mi)	Alt 2. 25" AC 6" Base (in/mi)	Alt 3. 25" AC 12" Base (in/mi)	Alt 4. 25" AC 18" Base (in/mi)	Alt 5. 25" AC 24" Base (in/mi)	Alt 6. 25" AC 30" Base (in/mi)	Alt 7 25" AC 36" Base (in/mi)	Terminal Roughness (inch/mile)
0	0	0	0	0	0	0	0	170
5	86	85	83	81	79	77	76	170
10	104	102	100	97	95	93	91	170
15	117	114	112	109	107	104	102	170
20	127	124	121	119	116	114	111	170
25	136	133	130	127	124	122	119	170
30	144	141	138	135	132	129	126	170
35	152	149	145	142	139	136	133	170
40	160	156	153	149	146	143	139	170
45	167	163	159	156	152	149	146	170
50	174	170	166	162	159	155	152	170
Total	---	---	---	---	---	---	---	---



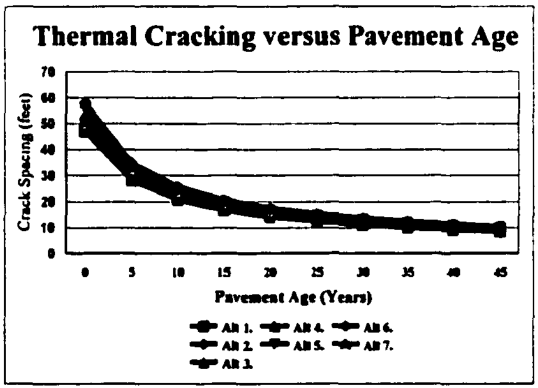
OUTPUT - PREDICTED RUTTING (25" HMA).

Year	Alt 1. 25" AC 0" Base (inch)	Alt 2. 25" AC 6" Base (inch)	Alt 3. 25" AC 12" Base (inch)	Alt 4. 25" AC 18" Base (inch)	Alt 5. 25" AC 24" Base (inch)	Alt 6. 25" AC 30" Base (inch)	Alt 7 25" AC 36" Base (inch)	Terminal Rutting (inch)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38
5	0.21	0.20	0.19	0.19	0.19	0.19	0.19	0.38
10	0.24	0.23	0.22	0.22	0.22	0.22	0.21	0.38
15	0.26	0.25	0.24	0.24	0.24	0.23	0.23	0.38
20	0.27	0.26	0.26	0.25	0.25	0.25	0.25	0.38
25	0.29	0.28	0.27	0.27	0.27	0.26	0.26	0.38
30	0.30	0.29	0.28	0.28	0.28	0.27	0.27	0.38
35	0.31	0.30	0.29	0.29	0.29	0.29	0.28	0.38
40	0.32	0.31	0.31	0.30	0.30	0.30	0.29	0.38
45	0.33	0.32	0.31	0.31	0.31	0.30	0.30	0.38
50	0.34	0.33	0.32	0.32	0.32	0.31	0.31	0.38
Total	---	---	---	---	---	---	---	---



OUTPUT - PREDICTED CRACKING (25" HMA).

Year	Alt 1. 25" AC 0" Base (feet)	Alt 2. 25" AC 6" Base (feet)	Alt 3. 25" AC 12" Base (feet)	Alt 4. 25" AC 18" Base (feet)	Alt 5. 25" AC 24" Base (feet)	Alt 6. 25" AC 30" Base (feet)	Alt 7 25" AC 36" Base (feet)
0	---	---	---	---	---	---	---
5	46.93	48.96	51.09	53.30	55.61	58.03	58.03
10	28.01	29.22	30.49	31.81	33.19	34.63	34.63
15	20.71	21.61	22.54	23.52	24.54	25.61	25.61
20	16.72	17.44	18.20	18.99	19.81	20.67	20.67
25	14.16	14.77	15.41	16.08	16.78	17.51	17.51
30	12.36	12.90	13.46	14.04	14.65	15.28	15.28
35	11.02	11.50	12.00	12.52	13.06	13.63	13.63
40	9.98	10.41	10.86	11.33	11.82	12.34	12.34
45	9.14	9.54	9.95	10.38	10.83	11.30	11.30
50	8.45	8.82	9.20	9.60	10.01	10.45	10.45
Total	---	---	---	---	---	---	---



APPENDIX U :
NYSDOT Rigid Pavement - Economic Optimization Trials.

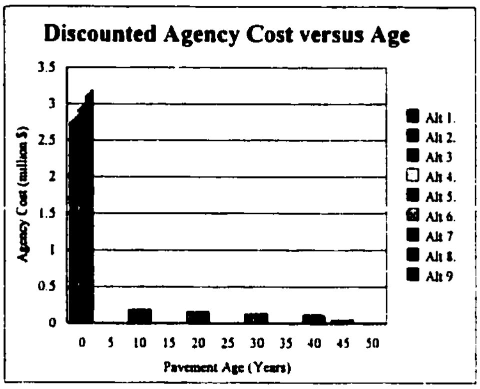
Contents:

Table U-1: NYSDOT Rigid Pavement - Economic Optimization - 7" PCC Trial.
Table U-2: NYSDOT Rigid Pavement - Economic Optimization - 8" PCC Trial.
Table U-3: NYSDOT Rigid Pavement - Economic Optimization - 9" PCC Trial.
Table U-4: NYSDOT Rigid Pavement - Economic Optimization - 10" PCC Trial.
Table U-5: NYSDOT Rigid Pavement - Economic Optimization - 11" PCC Trial.
Table U-6: NYSDOT Rigid Pavement - Economic Optimization - 12" PCC Trial.
Table U-7: NYSDOT Rigid Pavement - Economic Optimization - 13" PCC Trial.
Table U-8: NYSDOT Rigid Pavement - Economic Optimization - 15" PCC Trial.

Table U-1: NYSDOT Rigid Pavement - Economic Optimization - 7" PCC Trial.

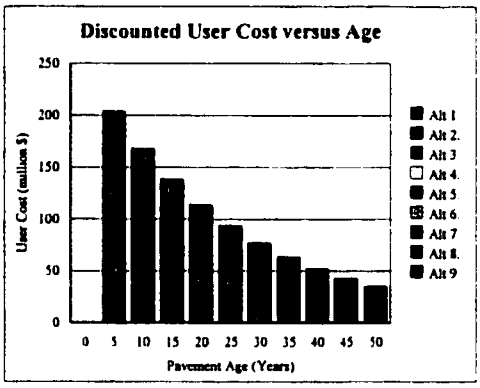
OUTPUT - ECONOMIC ANALYSIS - AGENCY EXPEDITURE (7" PCC)

Year	Alt 1. 7" PCC (million $)	Alt 2. 7" PCC (million $)	Alt 3. 7" PCC (million $)	Alt 4. 7" PCC (million $)	Alt 5. 7" PCC (million $)	Alt 6. 7" PCC (million $)	Alt 7. 7" PCC (million $)	Alt 8. 7" PCC (million $)	Alt 9. 7" PCC (million $)
0	2.74	2.78	2.82	2.93	2.97	3.01	3.11	3.15	3.19
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11
45	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	3.41	3.45	3.48	3.59	3.63	3.67	3.78	3.81	3.84



OUTPUT - ECONOMIC ANALYSIS - USER COSTS (7" PCC).

Year	Alt 1. 7" PCC (million $)	Alt 2. 7" PCC (million $)	Alt 3. 7" PCC (million $)	Alt 4. 7" PCC (million $)	Alt 5. 7" PCC (million $)	Alt 6. 7" PCC (million $)	Alt 7. 7" PCC (million $)	Alt 8. 7" PCC (million $)	Alt 9. 7" PCC (million $)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	204.71	204.33	203.95	204.66	204.29	203.91	204.62	204.25	203.87
10	168.61	168.30	167.99	168.50	168.19	167.88	168.41	168.09	167.78
15	138.88	138.62	138.37	138.73	138.48	138.22	138.60	138.34	138.09
20	114.39	114.18	113.97	114.22	114.01	113.80	114.07	113.85	113.64
25	94.22	94.04	93.87	94.04	93.87	93.69	93.87	93.70	93.53
30	77.60	77.46	77.32	77.42	77.28	77.14	77.26	77.12	76.97
35	63.92	63.80	63.68	63.74	63.63	63.51	63.58	63.47	63.35
40	52.65	52.55	52.45	52.48	52.38	52.29	52.33	52.23	52.14
45	43.36	43.28	43.20	43.21	43.13	43.05	43.07	42.99	42.91
50	35.71	35.65	35.58	35.57	35.51	35.44	35.44	35.38	35.31
Total	994.04	992.22	990.39	992.59	990.76	988.93	991.25	989.42	987.59



OUTPUT - INCREMENTAL B/C ANALYSIS (7" PCC)

Alt No.	Agency Cost ($)	User Cost ($)	Incremental Cost ($)	Incremental Benefit ($)	Incr. B/C Ratio	Incr. B/C Ratio**
1	3407424	994044207	0	0	—	—
2	3445125	992216841	37701	1827366	48.47	48.47
3	3482859	990389475	37734	1827366	48.43	48.43
4	3593343	992588887	110484	-2199412	-19.91	—
5	3627242	990761521	33899	1827366	53.91	—
6	3668778	988934155	41536	1827366	44.00	7.83
7	3775559	991245515	106781	-2311360	-21.65	—
8	3809458	989418148	33899	1827366	53.91	—
9	3835755	987590782	26298	1827366	69.49	8.05

** Considering viable options.

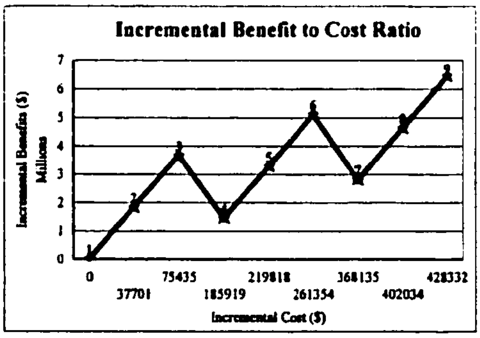
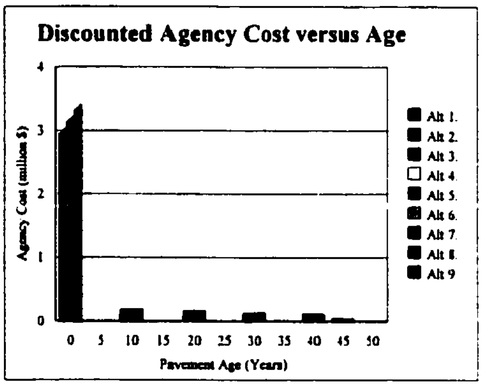


Table U-2: NYSDOT Rigid Pavement - Economic Optimization - 8" PCC Trial.

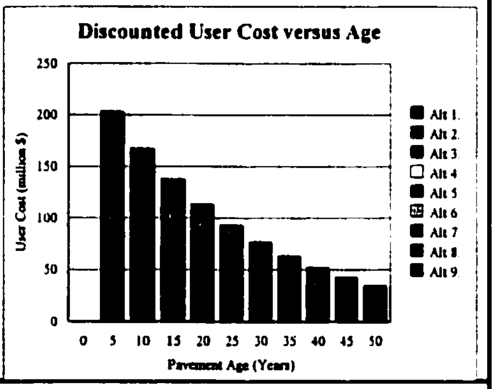
OUTPUT - ECONOMIC ANALYSIS - AGENCY EXPEDITURE (8" PCC)

Year	Alt 1. 8" PCC (million $)	Alt 2. 8" PCC (million $)	Alt 3. 8" PCC (million $)	Alt 4. 8" PCC (million $)	Alt 5. 8" PCC (million $)	Alt 6. 8" PCC (million $)	Alt 7. 8" PCC (million $)	Alt 8. 8" PCC (million $)	Alt 9. 8" PCC (million $)
0	2.96	3.00	3.04	3.14	3.18	3.22	3.33	3.36	3.40
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11
45	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	3.62	3.66	3.70	3.81	3.84	3.88	3.99	4.02	4.05


Discounted Agency Cost versus Age

OUTPUT - ECONOMIC ANALYSIS - USER COSTS (8" PCC).

Year	Alt 1. 8" PCC (million $)	Alt 2. 8" PCC (million $)	Alt 3 8" PCC (million $)	Alt 4. 8" PCC (million $)	Alt 5. 8" PCC (million $)	Alt 6. 8" PCC (million $)	Alt 7. 8" PCC (million $)	Alt 8. 8" PCC (million $)	Alt 9. 8" PCC (million $)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	204.09	203.71	203.33	204.04	203.66	203.28	204.00	203.62	203.24
10	168.10	167.79	167.48	167.99	167.68	167.37	167.89	167.58	167.27
15	138.46	138.20	137.95	138.31	138.06	137.80	138.18	137.92	137.67
20	114.04	113.83	113.62	113.88	113.66	113.45	113.72	113.51	113.30
25	93.93	93.76	93.59	93.76	93.58	93.41	93.59	93.42	93.25
30	77.37	77.23	77.09	77.19	77.05	76.91	77.03	76.88	76.74
35	63.73	63.61	63.49	63.55	63.43	63.32	63.39	63.27	63.16
40	52.49	52.39	52.30	52.32	52.23	52.13	52.17	52.07	51.98
45	43.23	43.15	43.07	43.08	43.00	42.92	42.94	42.86	42.78
50	35.61	35.54	35.48	35.47	35.40	35.34	35.34	35.27	35.21
Total	991.04	989.21	987.39	989.59	987.76	985.93	988.24	986.42	984.59


Discounted User Cost versus Age

OUTPUT - INCREMENTAL B/C ANALYSIS (8" PCC)

Alt No.	Agency Cost ($)	User Cost ($)	ncremental Cost ($)	Incremental Benefit ($)	Incr. B/C Ratio	Incr. B/C Ratio**
1	3624115	991042106	0	0	—	—
2	3658014	989214739	33899	1827366	53.91	53.91
3	3699550	987387373	41536	1827366	44.00	44.00
4	3806232	989586785	106682	-2199412	-20.62	—
5	3840132	987759419	33899	1827366	53.91	—
6	3881667	985932053	41536	1827366	44.00	7.99
7	3988448	988243413	106781	-2311360	-21.65	—
8	4022347	986416047	33899	1827366	53.91	—
9	4048645	984588681	26298	1827366	69.49	8.05

** Considering viable options.

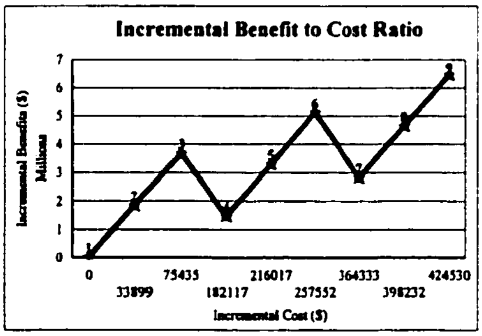
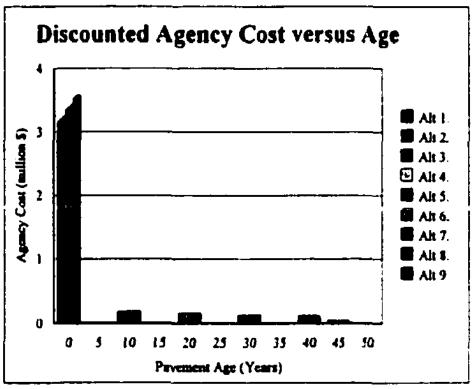

Incremental Benefit to Cost Ratio

Table U-3: NYSDOT Rigid Pavement - Economic Optimization - 9" PCC Trial.

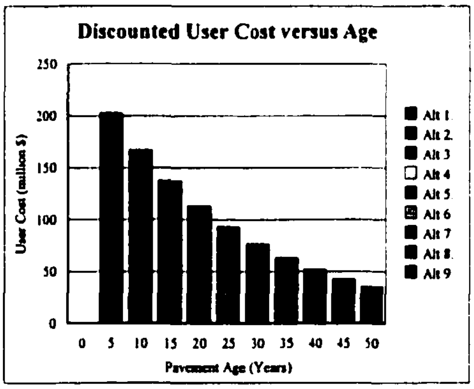
OUTPUT - ECONOMIC ANALYSIS - AGENCY EXPEDITURE (9" PCC)

Year	Alt 1. 9" PCC (million $)	Alt 2. 9" PCC (million $)	Alt 3. 9" PCC (million $)	Alt 4. 9" PCC (million $)	Alt 5. 9" PCC (million $)	Alt 6. 9" PCC (million $)	Alt 7. 9" PCC (million $)	Alt 8. 9" PCC (million $)	Alt 9. 9" PCC (million $)
0	3.17	3.21	3.25	3.36	3.39	3.43	3.54	3.58	3.58
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11
45	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	3.84	3.87	3.91	4.02	4.05	4.09	4.20	4.24	4.23



OUTPUT - ECONOMIC ANALYSIS - USER COSTS (9" PCC).

Year	Alt 1. 9" PCC (million $)	Alt 2. 9" PCC (million $)	Alt 3. 9" PCC (million $)	Alt 4. 9" PCC (million $)	Alt 5. 9" PCC (million $)	Alt 6. 9" PCC (million $)	Alt 7 9" PCC (million $)	Alt 8. 9" PCC (million $)	Alt 9 9" PCC (million $)
0	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0 00
5	203.46	203.08	202.71	203 42	203.04	202.66	203.38	203.00	202.62
10	167.59	167.28	166.97	167.48	167.17	166.86	167.38	167.07	166.76
15	138.04	137.78	137.53	137.89	137.64	137.38	137.76	137.50	137.25
20	113.70	113.49	113.28	113.53	113.32	113.11	113.37	113.16	112.95
25	93.65	93.48	93.30	93.47	93.30	93.13	93.31	93.13	92.96
30	77 14	76.99	76.85	76.96	76.81	76.67	76.79	76.65	76.51
35	63.53	63.42	63.30	63.36	63.24	63.13	63.20	63.08	62.97
40	52.33	52.23	52.14	52.17	52.07	51.97	52.01	51.92	51.82
45	43.10	43.02	42.94	42.95	42.87	42.79	42.81	42.73	42.65
50	35.50	35.44	35.37	35.36	35.29	35.23	35.23	35.16	35.10
Total	988.04	986.21	984.39	986.58	984.76	982.93	985.24	983.41	981.39



OUTPUT - INCREMENTAL B/C ANALYSIS (9" PCC)

Alt No.	Agency Cost ($)	User Cost ($)	Incremental Cost ($)	Incremental Benefit ($)	Incr. B/C Ratio	Incr. B/C Ratio**
1	3837005	988040004	0	0	—	—
2	3870904	986212638	33899	1827366	53.91	53.91
3	3912440	984385272	41536	1827366	44.00	44.00
4	4019122	986584684	106682	-2199412	-20.62	—
5	4053021	984757318	33899	1827366	53 91	—
6	4094557	982929951	41536	1827366	44.00	7.99
7	4201338	985241311	106781	-2311360	-21.65	—
8	4239039	983413945	37701	1827366	48.47	—
9	4227320	981586579	-11718	1827366	-155.94	10.12

** Considering viable options.

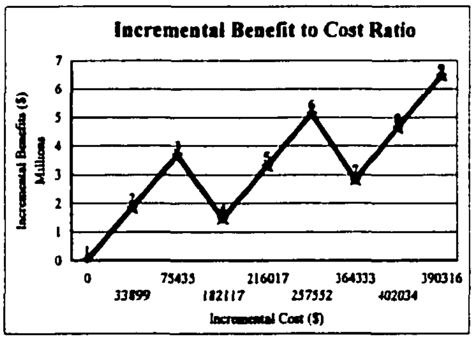
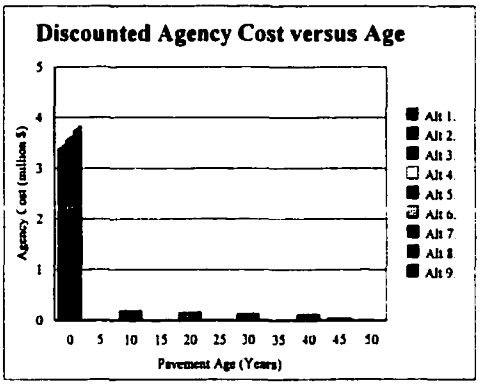


Table U-4: NYSDOT Rigid Pavement - Economic Optimization - 10" PCC Trial.

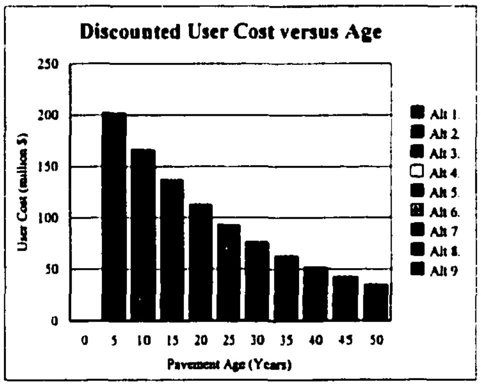
OUTPUT - ECONOMIC ANALYSIS - AGENCY EXPEDITURE (10" PCC)

Year	Alt 1. 10" PCC (million $)	Alt 2. 10" PCC (million $)	Alt 3. 10" PCC (million $)	Alt 4. 10" PCC (million $)	Alt 5. 10" PCC (million $)	Alt 6. 10" PCC (million $)	Alt 7. 10" PCC (million $)	Alt 8. 10" PCC (million $)	Alt 9. 10" PCC (million $)
0	3.39	3.42	3.46	3.57	3.61	3.65	3.76	3.79	3.83
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11
45	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	4.05	4.08	4.13	4.23	4.27	4.31	4.42	4.45	4.48



OUTPUT - ECONOMIC ANALYSIS - USER COSTS (10" PCC).

Year	Alt 1. 10" PCC (million $)	Alt 2. 10" PCC (million $)	Alt 3. 10" PCC (million $)	Alt 4. 10" PCC (million $)	Alt 5. 10" PCC (million $)	Alt 6. 10" PCC (million $)	Alt 7. 10" PCC (million $)	Alt 8. 10" PCC (million $)	Alt 9. 10" PCC (million $)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	202.84	202.46	202.08	202.80	202.42	202.04	202.76	202.38	202.00
10	167.08	166.77	166.45	166.97	166.66	166.35	166.87	166.56	166.25
15	137.62	137.36	137.11	137.47	137.22	136.96	137.34	137.08	136.82
20	113.35	113.14	112.93	113.18	112.97	112.76	113.03	112.82	112.61
25	93.37	93.19	93.02	93.19	93.01	92.84	93.02	92.85	92.68
30	76.90	76.76	76.62	76.72	76.58	76.44	76.56	76.42	76.27
35	63.34	63.23	63.11	63.17	63.05	62.93	63.01	62.89	62.77
40	52.17	52.08	51.98	52.01	51.91	51.82	51.86	51.76	51.66
45	42.97	42.89	42.81	42.82	42.74	42.66	42.68	42.60	42.52
50	35.39	35.33	35.26	35.25	35.19	35.12	35.12	35.06	34.99
Total	985.04	983.21	981.38	983.58	981.76	979.93	982.24	980.41	978.58



OUTPUT - INCREMENTAL B/C ANALYSIS (10" PCC)

Alt No.	Agency Cost ($)	User Cost ($)	ncremental Cost ($)	Incremental Benefit ($)	Incr. B/C Ratio	Incr. B/C Ratio**
1	4049894	985037902	0	0	—	—
2	4083794	983210536	33899	1827366	53.91	53.91
3	4125329	981383170	41536	1827366	44.00	44.00
4	4232011	983582582	106682	-2199412	-20.62	—
5	4269712	981755216	37701	1827366	48.47	—
6	4307446	979927850	37734	1827366	48.43	7.99
7	4418029	982239210	110582	-2311360	-20.90	—
8	4451928	980411844	33899	1827366	53.91	—
9	4478226	978584477	26298	1827366	69.49	7.87

** Considering viable options.

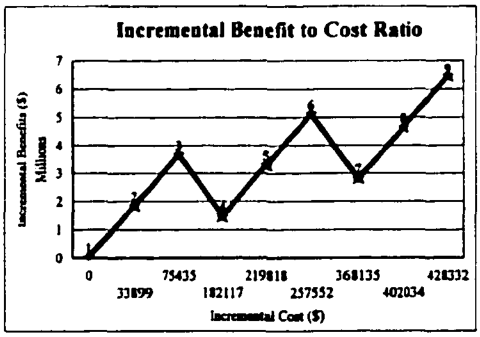
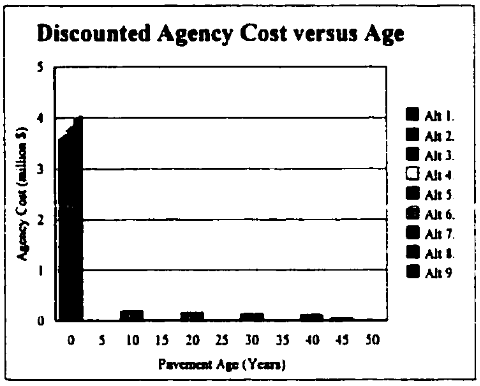


Table U-5: NYSDOT Rigid Pavement - Economic Optimization - 11" PCC Trial.

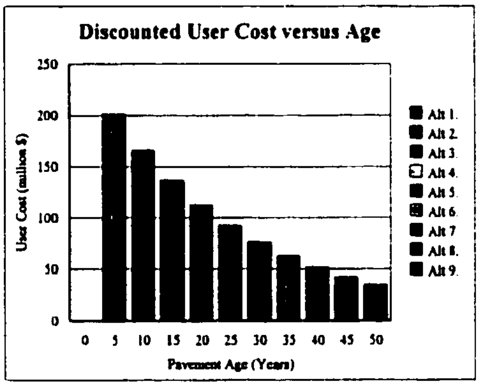
OUTPUT - ECONOMIC ANALYSIS - AGENCY EXPEDITURE (11" PCC)

Year	Alt 1. 11" PCC (million $)	Alt 2. 11" PCC (million $)	Alt 3. 11" PCC (million $)	Alt 4. 11" PCC (million $)	Alt 5. 11" PCC (million $)	Alt 6. 11" PCC (million $)	Alt 7. 11" PCC (million $)	Alt 8. 11" PCC (million $)	Alt 9. 11" PCC (million $)
0	3.60	3.64	3.68	3.79	3.82	3.86	3.97	4.00	4.04
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11
45	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	4.26	4.30	4.34	4.45	4.48	4.52	4.63	4.66	4.69



OUTPUT - ECONOMIC ANALYSIS - USER COSTS (11" PCC).

Year	Alt 1. 11" PCC (million $)	Alt 2. 11" PCC (million $)	Alt 3. 11" PCC (million $)	Alt 4. 11" PCC (million $)	Alt 5. 11" PCC (million $)	Alt 6. 11" PCC (million $)	Alt 7. 11" PCC (million $)	Alt 8. 11" PCC (million $)	Alt 9 11" PCC (million $)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	202.22	201.84	201.46	202.18	201.80	201.42	202.14	201.76	201.38
10	166.57	166.25	165.94	166.46	166.15	165.84	166.36	166.05	165.74
15	137.20	136.94	136.69	137.05	136.80	136.54	136.92	136.66	136.40
20	113.01	112.80	112.59	112.84	112.63	112.42	112.68	112.47	112.26
25	93.08	92.91	92.74	92.90	92.73	92.56	92.74	92.57	92.39
30	76.67	76.53	76.38	76.49	76.35	76.21	76.32	76.18	76.04
35	63.15	63.03	62.92	62.98	62.86	62.74	62.82	62.70	62.58
40	52.01	51.92	51.82	51.85	51.75	51.66	51.70	51.60	51.51
45	42.84	42.76	42.68	42.69	42.61	42.53	42.55	42.47	42.39
50	35.29	35.22	35.16	35.15	35.08	35.02	35.02	34.95	34.89
Total	982.04	980.21	978.38	980.58	978.75	976.93	979.24	977.41	975.58



OUTPUT - INCREMENTAL B/C ANALYSIS (11" PCC)

Alt No.	Agency Cost ($)	User Cost ($)	ncremental Cost ($)	Incremental Benefit ($)	Incr. B/C Ratio	Incr. B/C Ratio**
1	4262784	982035801	0	0	---	---
2	4300485	980208435	37701	1827366	48.47	48.47
3	4338219	978381068	37734	1827366	48.43	48.43
4	4448703	980580481	110484	-2199412	-19.91	---
5	4482602	978753114	33899	1827366	53.91	---
6	4524138	976925748	41536	1827366	44.00	7.83
7	4630919	979237108	106781	-2311360	-21.65	---
8	4664818	977409742	33899	1827366	53.91	---
9	4691115	975582376	26298	1827366	69.49	8.05

** Considering viable options.

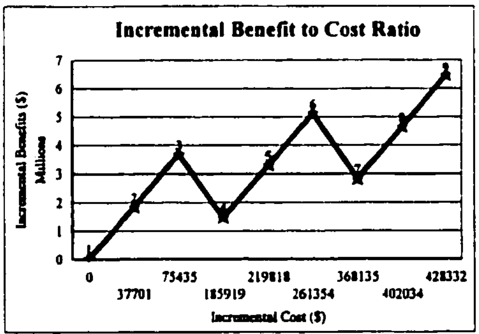
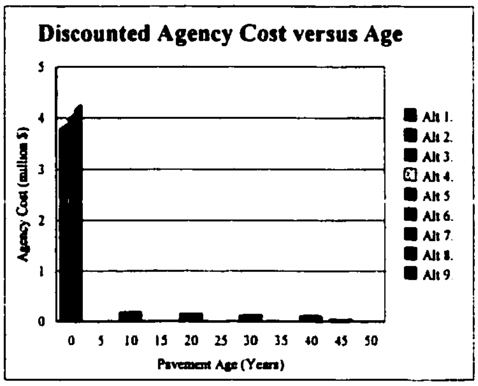


Table U-6: NYSDOT Rigid Pavement - Economic Optimization - 12" PCC Trial.

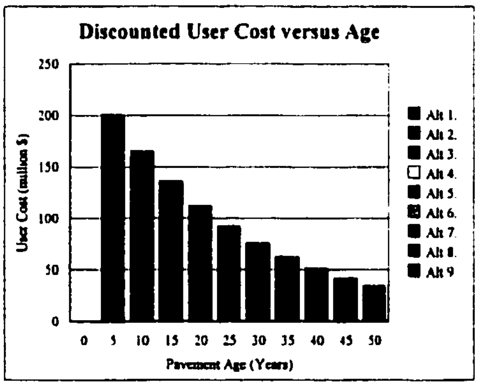
OUTPUT - ECONOMIC ANALYSIS - AGENCY EXPEDITURE (12" PCC)

Year	Alt 1. 12" PCC (million $)	Alt 2. 12" PCC (million $)	Alt 3. 12" PCC (million $)	Alt 4. 12" PCC (million $)	Alt 5. 12" PCC (million $)	Alt 6. 12" PCC (million $)	Alt 7 12" PCC (million $)	Alt 8. 12" PCC (million $)	Alt 9. 12" PCC (million $)
0	3.82	3.85	3.89	4.00	4.03	4.08	4.18	4.22	4.26
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11
45	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	4.48	4.51	4.55	4.66	4.70	4.74	4.84	4.88	4.90


Discounted Agency Cost versus Age

OUTPUT - ECONOMIC ANALYSIS - USER COSTS (12" PCC).

Year	Alt 1. 12" PCC (million $)	Alt 2. 12" PCC (million $)	Alt 3. 12" PCC (million $)	Alt 4. 12" PCC (million $)	Alt 5. 12" PCC (million $)	Alt 6. 12" PCC (million $)	Alt 7. 12" PCC (million $)	Alt 8. 12" PCC (million $)	Alt 9. 12" PCC (million $)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	201.60	201.22	200.84	201.55	201.18	200.80	201.51	201.14	200.76
10	166.05	165.74	165.43	165.95	165.64	165.33	165.85	165.54	165.23
15	136.78	136.52	136.27	136.63	136.38	136.12	136.50	136.24	135.98
20	112.66	112.45	112.24	112.49	112.28	112.07	112.34	112.13	111.92
25	92.80	92.62	92.45	92.62	92.45	92.27	92.46	92.28	92.11
30	76.44	76.29	76.15	76.26	76.11	75.97	76.09	75.95	75.81
35	62.96	62.84	62.72	62.78	62.67	62.55	62.62	62.51	62.39
40	51.86	51.76	51.66	51.69	51.60	51.50	51.54	51.44	51.35
45	42.71	42.63	42.56	42.56	42.48	42.40	42.42	42.34	42.26
50	35.18	35.12	35.05	35.04	34.98	34.91	34.91	34.85	34.78
Total	979.03	977.21	975.38	977.58	975.75	973.92	976.24	974.41	972.58


Discounted User Cost versus Age

OUTPUT - INCREMENTAL B/C ANALYSIS (12" PCC)

Alt No.	Agency Cost ($)	User Cost ($)	ncrementa Cost ($)	Incremental Benefit ($)	Incr. B/C Ratio	Incr. B/C Ratio**
1	4479475	979033699	0	0	—	—
2	4513374	977206333	33899	1827366	53.91	53.91
3	4554910	975378967	41536	1827366	44.00	44.00
4	4661592	977578379	106682	-2199412	-20.62	—
5	4695492	975751013	33899	1827366	53.91	—
6	4737027	973923647	41536	1827366	44.00	7.99
7	4843808	976235007	106781	-2311360	-21.65	—
8	4881509	974407640	37701	1827366	48.47	—
9	4904005	972580274	22496	1827366	81.23	8.05

** Considering viable options.

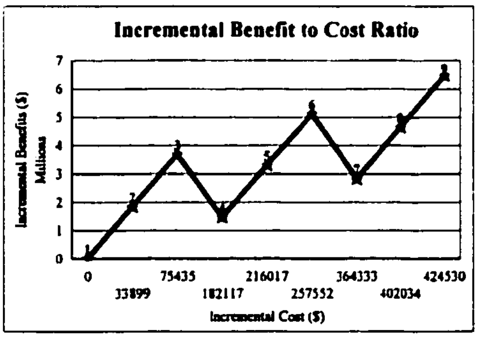
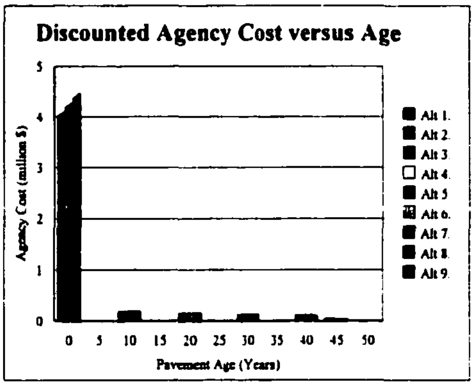

Incremental Benefit to Cost Ratio

Table U-7: NYSDOT Rigid Pavement - Economic Optimization - 13" PCC Trial.

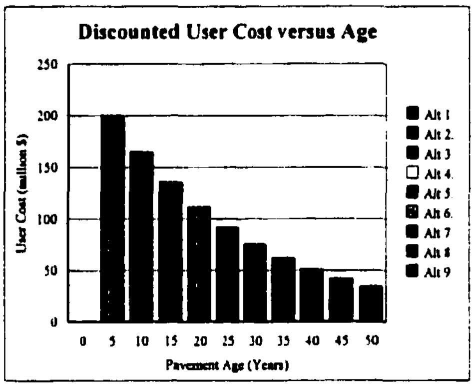
OUTPUT - ECONOMIC ANALYSIS - AGENCY EXPEDITURE (13" PCC)

Year	Alt 1. 13" PCC (million $)	Alt 2. 13" PCC (million $)	Alt 3. 13" PCC (million $)	Alt 4. 13" PCC (million $)	Alt 5. 13" PCC (million $)	Alt 6. 13" PCC (million $)	Alt 7. 13" PCC (million $)	Alt 8. 13" PCC (million $)	Alt 9. 13" PCC (million $)
0	4.03	4.06	4.11	4.21	4.25	4.29	4.39	4.43	4.47
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11
45	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	4.69	4.73	4.77	4.87	4.91	4.95	5.06	5.09	5.12



OUTPUT - ECONOMIC ANALYSIS - USER COSTS (13" PCC).

Year	Alt 1. 13" PCC (million $)	Alt 2. 13" PCC (million $)	Alt 3. 13" PCC (million $)	Alt 4. 13" PCC (million $)	Alt 5. 13" PCC (million $)	Alt 6. 13" PCC (million $)	Alt 7. 13" PCC (million $)	Alt 8. 13" PCC (million $)	Alt 9. 13" PCC (million $)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	200.97	200.60	200.22	200.93	200.55	200.17	200.89	200.51	200.13
10	165.54	165.23	164.92	165.44	165.12	164.81	165.34	165.03	164.72
15	136.36	136.10	135.85	136.21	135.96	135.70	136.08	135.82	135.56
20	112.32	112.11	111.90	112.15	111.94	111.73	111.99	111.78	111.57
25	92.51	92.34	92.17	92.34	92.16	91.99	92.17	92.00	91.83
30	76.20	76.06	75.92	76.02	75.88	75.74	75.86	75.72	75.57
35	62.77	62.65	62.53	62.59	62.48	62.36	62.43	62.32	62.20
40	51.70	51.60	51.51	51.53	51.44	51.34	51.38	51.29	51.19
45	42.58	42.50	42.43	42.43	42.35	42.27	42.29	42.21	42.13
50	35.07	35.01	34.94	34.93	34.87	34.80	34.80	34.74	34.67
Total	976.03	974.20	972.38	974.58	972.75	970.92	973.23	971.41	969.58



OUTPUT - INCREMENTAL B/C ANALYSIS (13" PCC)

Alt No.	Agency Cost ($)	User Cost ($)	Incremental Cost ($)	Incremental Benefit ($)	Incr. B/C Ratio	Incr. B/C Ratio**
1	4692365	976031598	0	0	---	---
2	4726264	974204231	33899	1827366	53.91	53.91
3	4767800	972376865	41536	1827366	44.00	44.00
4	4874482	974576277	106682	-2199412	-20.62	---
5	4912183	972748911	37701	1827366	48.47	---
6	4949917	970921545	37734	1827366	48.43	7.99
7	5056698	973232905	106781	-2311360	-21.65	---
8	5094399	971405539	37701	1827366	48.47	---
9	5120696	969578173	26298	1827366	69.49	7.87

** Considering viable options.

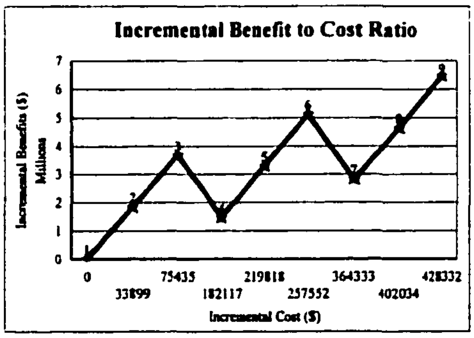
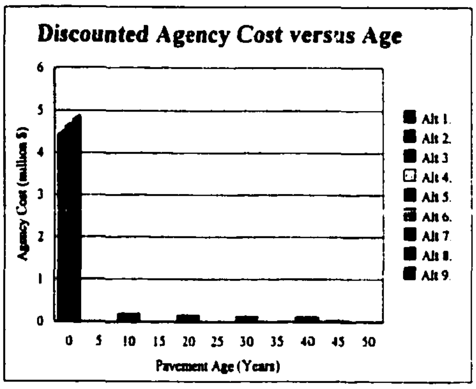


Table U-8: NYSDOT Rigid Pavement - Economic Optimization - 15" PCC Trial.

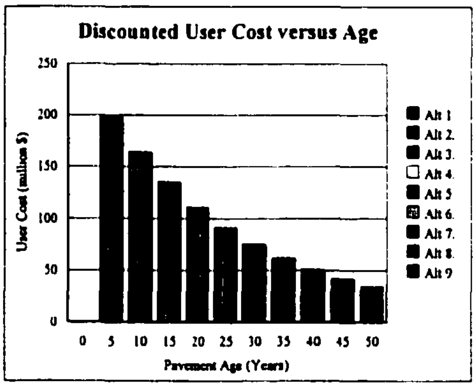
OUTPUT - ECONOMIC ANALYSIS - AGENCY EXPEDITURE (15" PCC)

Year	Alt 1. 15" PCC (million $)	Alt 2. 15" PCC (million $)	Alt 3. 15" PCC (million $)	Alt 4. 15" PCC (million $)	Alt 5. 15" PCC (million $)	Alt 6. 15" PCC (million $)	Alt 7. 15" PCC (million $)	Alt 8. 15" PCC (million $)	Alt 9 15" PCC (million $)
0	4.46	4.49	4.54	4.64	4.68	4.72	4.82	4.86	4.90
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11
45	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	5.12	5.16	5.20	5.30	5.34	5.38	5.49	5.52	5.55



OUTPUT - ECONOMIC ANALYSIS - USER COSTS (15" PCC).

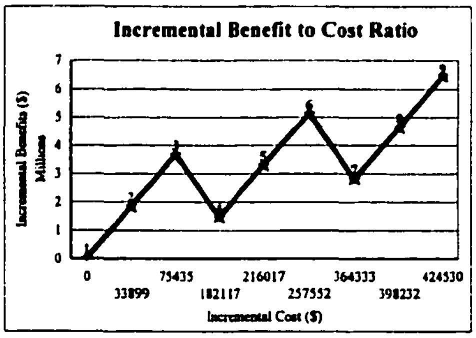
Year	Alt 1. 15" PCC (million $)	Alt 2. 15" PCC (million $)	Alt 3. 15" PCC (million $)	Alt 4. 15" PCC (million $)	Alt 5 15" PCC (million $)	Alt 6. 15" PCC (million $)	Alt 7 15" PCC (million $)	Alt 8. 15" PCC (million $)	Alt 9. 15" PCC (million $)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	199.73	199.35	198.97	199.69	199.31	198.93	199.65	199.27	198.89
10	164.52	164.21	163.90	164.41	164.10	163.79	164.31	164.00	163.69
15	135.52	135.26	135.01	135.37	135.11	134.86	135.24	134.98	134.72
20	111.63	111.42	111.21	111.46	111.25	111.04	111.30	111.09	110.88
25	91.95	91.77	91.60	91.77	91.60	91.42	91.60	91.43	91.26
30	75.74	75.59	75.45	75.56	75.41	75.27	75.39	75.25	75.11
35	62.38	62.27	62.15	62.21	62.09	61.98	62.05	61.93	61.82
40	51.38	51.29	51.19	51.22	51.12	51.03	51.07	50.97	50.88
45	42.32	42.25	42.17	42.17	42.09	42.01	42.03	41.95	41.87
50	34.86	34.80	34.73	34.72	34.66	34.59	34.59	34.53	34.46
Total	970.03	968.20	966.37	968.57	966.74	964.92	967.23	965.40	963.57



OUTPUT - INCREMENTAL B/C ANALYSIS (15" PCC)

Alt No.	Agency Cost ($)	User Cost ($)	ncrementa Cost ($)	Incremental Benefit ($)	Incr. B/C Ratio	Incr. B/C Ratio**
1	5121945	970027394	0	0	---	--
2	5155845	968200028	33899	1827366	53.91	53.91
3	5197380	966372662	41536	1827366	44.00	44.00
4	5304063	968572074	106682	-2199412	-20.62	—
5	5337962	966744708	33899	1827366	53.91	—
6	5379498	964917342	41536	1827366	44.00	7.99
7	5486279	967228702	106781	-2311360	-21.65	---
8	5520178	965401336	33899	1827366	53.91	—
9	5546475	963573969	26298	1827366	69.49	8.05

** Considering viable options.



APPENDIX V :
NYSDOT Rigid Pavement - Performance Optimization Trials.

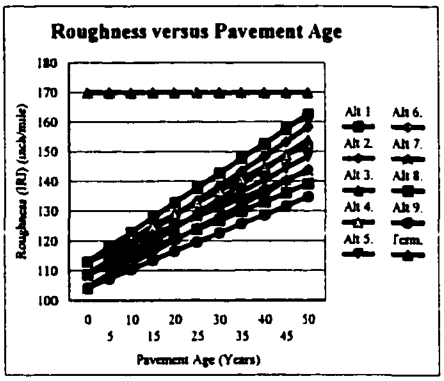
Contents:

Table V-1: NYSDOT Rigid Pavement - Performance Optimization - 7" PCC Trial.
Table V-2: NYSDOT Rigid Pavement - Performance Optimization - 8" PCC Trial.
Table V-3: NYSDOT Rigid Pavement - Performance Optimization - 9" PCC Trial.
Table V-4: NYSDOT Rigid Pavement - Performance Optimization - 10" PCC Trial.
Table V-5: NYSDOT Rigid Pavement - Performance Optimization - 11" PCC Trial.
Table V-6: NYSDOT Rigid Pavement - Performance Optimization - 12" PCC Trial.
Table V-7: NYSDOT Rigid Pavement - Performance Optimization - 13" PCC Trial.
Table V-8: NYSDOT Rigid Pavement - Performance Optimization - 15" PCC Trial.

Table V-1: NYSDOT Rigid Pavement - Performance Optimization - 7" PCC Trial

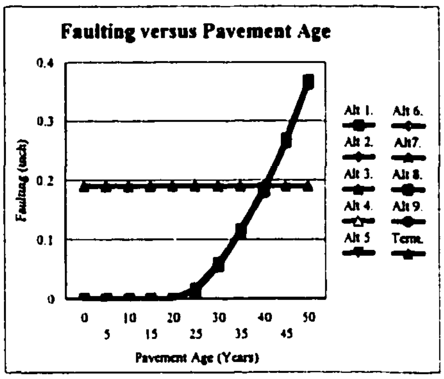
OUTPUT - PREDICTED ROUGHNESS (7" PCC)

Year	Alt 1. 7" PCC (in/mi)	Alt 2. 7" PCC (in/mi)	Alt 3. 7" PCC (in/mi)	Alt 4. 7" PCC (in/mi)	Alt 5. 7" PCC (in/mi)	Alt 6. 7" PCC (in/mi)	Alt 7. 7" PCC (in/mi)	Alt 8. 7" PCC (in/mi)	Alt 9. 7" PCC (in/mi)	Terminal Roughness (inch/mile)
0	112.89	108.55	104.21	112.89	108.55	104.21	112.89	108.55	104.21	170.00
5	117.86	113.52	109.18	116.87	112.53	108.19	115.95	111.61	107.27	170.00
10	122.83	118.49	114.15	120.84	116.50	112.16	119.01	114.67	110.33	170.00
15	127.80	123.46	119.12	124.82	120.48	116.14	122.06	117.72	113.38	170.00
20	132.77	128.43	124.09	128.79	124.45	120.11	125.12	120.78	116.44	170.00
25	137.73	133.39	129.05	132.77	128.43	124.09	128.18	123.84	119.50	170.00
30	142.70	138.36	134.02	136.74	132.40	128.06	131.24	126.90	122.56	170.00
35	147.67	143.33	138.99	140.72	136.38	132.04	134.29	129.95	125.61	170.00
40	152.64	148.30	143.96	144.69	140.35	136.01	137.35	133.01	128.67	170.00
45	157.61	153.27	148.93	148.67	144.33	139.99	140.41	136.07	131.73	170.00
50	162.58	158.24	153.90	152.64	148.30	143.96	143.47	139.13	134.79	170.00
Total	---	---	---	---	---	---				---



OUTPUT - PREDICTED FAULTING (7" PCC)

Year	Alt 1. 7" PCC (inch)	Alt 2. 7" PCC (inch)	Alt 3 7" PCC (inch)	Alt 4. 7" PCC (inch)	Alt 5. 7" PCC (inch)	Alt 6. 7" PCC (inch)	Alt 7. 7" PCC (inch)	Alt 8. 7" PCC (inch)	Alt 9 7" PCC (inch)	Critical Faulting (inch)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
25	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.19
30	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.19
35	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.19
40	0.19	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.19
45	0.27	0.27	0.27	0.27	0.27	0.26	0.27	0.26	0.26	0.19
50	0.37	0.37	0.37	0.37	0.37	0.36	0.37	0.36	0.36	0.19
Total	---	---	---	---	---	---				---



OUTPUT - PREDICTED SPALLING (7" PCC)

Year	Alt 1 7" PCC (%)	Alt 2. 7" PCC (%)	Alt 3. 7" PCC (%)	Alt 4. 7" PCC (%)	Alt 5 7" PCC (%)	Alt 6. 7" PCC (%)	Alt 7 7" PCC (%)	Alt 8. 7" PCC (%)	Alt 9 7" PCC (%)
0	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
5	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57
10	2.66	2.66	2.66	2.66	2.66	2.66	2.66	2.66	2.66
15	3.74	3.74	3.74	3.74	3.74	3.74	3.74	3.74	3.74
20	4.83	4.83	4.83	4.83	4.83	4.83	4.83	4.83	4.83
25	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91
30	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
35	8.08	8.08	8.08	8.08	8.08	8.08	8.08	8.08	8.08
40	9.17	9.17	9.17	9.17	9.17	9.17	9.17	9.17	9.17
45	10.25	10.25	10.25	10.25	10.25	10.25	10.25	10.25	10.25
50	11.34	11.34	11.34	11.34	11.34	11.34	11.34	11.34	11.34
Total	---	---	---	---	---	---	---	---	---

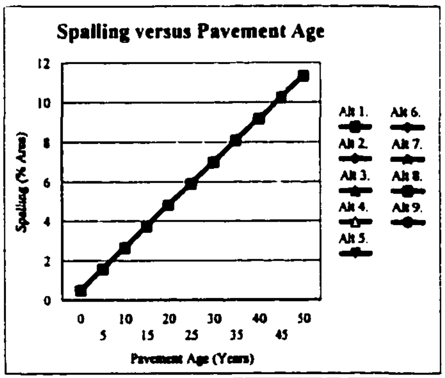
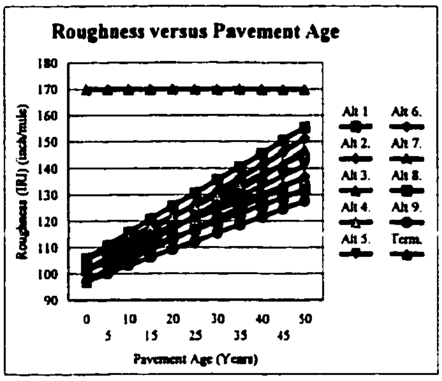


Table V-2: NYSDOT Rigid Pavement - Performance Optimization - 8" PCC Trial

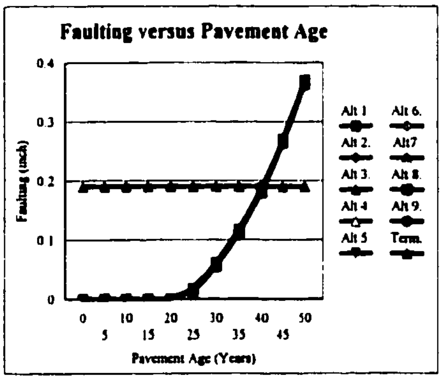
OUTPUT - PREDICTED ROUGHNESS (8" PCC)

Year	Alt 1. 8" PCC (in/mi)	Alt 2. 8" PCC (in/mi)	Alt 3. 8" PCC (in/mi)	Alt 4. 8" PCC (in/mi)	Alt 5. 8" PCC (in/mi)	Alt 6. 8" PCC (in/mi)	Alt 7. 8" PCC (in/mi)	Alt 8. 8" PCC (in/mi)	Alt 9 8" PCC (in/mi)	Terminal Roughness (inch/mile)
0	105.76	101.42	97.08	105.76	101.42	97.08	105.76	101.42	97.08	170.00
5	110.73	106.39	102.05	109.74	105.40	101.06	108.82	104.48	100.14	170.00
10	115.70	111.36	107.02	113.71	109.37	105.03	111.88	107.54	103.20	170.00
15	120.67	116.33	111.99	117.69	113.35	109.01	114.93	110.59	106.25	170.00
20	125.64	121.30	116.96	121.66	117.32	112.98	117.99	113.65	109.31	170.00
25	130.60	126.26	121.92	125.64	121.30	116.96	121.05	116.71	112.37	170.00
30	135.57	131.23	126.89	129.61	125.27	120.93	124.11	119.77	115.43	170.00
35	140.54	136.20	131.86	133.59	129.25	124.91	127.16	122.82	118.48	170.00
40	145.51	141.17	136.83	137.56	133.22	128.88	130.22	125.88	121.54	170.00
45	150.48	146.14	141.80	141.54	137.20	132.86	133.28	128.94	124.60	170.00
50	155.45	151.11	146.77	145.51	141.17	136.83	136.34	132.00	127.66	170.00
Total	—	—	—	—	—	—				—



OUTPUT - PREDICTED FAULTING (8" PCC)

Year	Alt 1. 8" PCC (inch)	Alt 2. 8" PCC (inch)	Alt 3. 8" PCC (inch)	Alt 4. 8" PCC (inch)	Alt 5. 8" PCC (inch)	Alt 6. 8" PCC (inch)	Alt 7 8" PCC (inch)	Alt 8. 8" PCC (inch)	Alt 9 8" PCC (inch)	Critical Faulting (inch)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
25	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.19
30	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.19
35	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.19
40	0.19	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.19
45	0.27	0.27	0.27	0.27	0.27	0.26	0.27	0.26	0.26	0.19
50	0.37	0.37	0.37	0.37	0.37	0.36	0.37	0.36	0.36	0.19
Total	—	—	—	—	—	—				—



OUTPUT - PREDICTED SPALLING (8" PCC)

Year	Alt 1. 8" PCC (%)	Alt 2. 8" PCC (%)	Alt 3 8" PCC (%)	Alt 4 8" PCC (%)	Alt 5 8" PCC (%)	Alt 6. 8" PCC (%)	Alt 7 8" PCC (%)	Alt 8.. 8" PCC (%)	Alt 9. 8" PCC (%)
0	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
5	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57
10	2.66	2.66	2.66	2.66	2.66	2.66	2.66	2.66	2.66
15	3.74	3.74	3.74	3.74	3.74	3.74	3.74	3.74	3.74
20	4.83	4.83	4.83	4.83	4.83	4.83	4.83	4.83	4.83
25	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91
30	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
35	8.08	8.08	8.08	8.08	8.08	8.08	8.08	8.08	8.08
40	9.17	9.17	9.17	9.17	9.17	9.17	9.17	9.17	9.17
45	10.25	10.25	10.25	10.25	10.25	10.25	10.25	10.25	10.25
50	11.34	11.34	11.34	11.34	11.34	11.34	11.34	11.34	11.34
Total	—	—	—	—	—	—	—	—	—

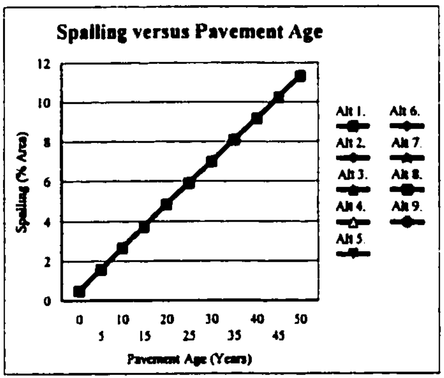
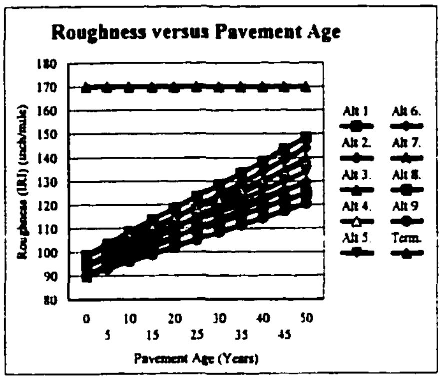


Table V-3: NYSDOT Rigid Pavement - Performance Optimization - 9" PCC Trial.

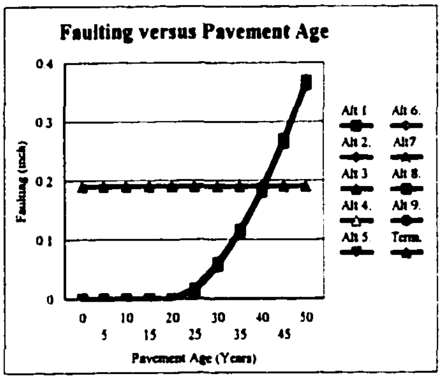
OUTPUT - PREDICTED ROUGHNESS (9" PCC)

Year	Alt 1. 9" PCC (in/mi)	Alt 2. 9" PCC (in/mi)	Alt 3. 9" PCC (in/mi)	Alt 4. 9" PCC (in/mi)	Alt 5. 9" PCC (in/mi)	Alt 6. 9" PCC (in/mi)	Alt 7. 9" PCC (in/mi)	Alt 8. 9" PCC (in/mi)	Alt 9. 9" PCC (in/mi)	Terminal Roughness (inch/mile)
0	98.63	94.29	89.95	98.63	94.29	89.95	98.63	94.29	89.95	170.00
5	103.60	99.26	94.92	102.61	98.27	93.93	101.69	97.35	93.01	170.00
10	108.57	104.23	99.89	106.58	102.24	97.90	104.75	100.41	96.07	170.00
15	113.54	109.20	104.86	110.56	106.22	101.88	107.80	103.46	99.12	170.00
20	118.51	114.17	109.83	114.53	110.19	105.85	110.86	106.52	102.18	170.00
25	123.47	119.13	114.79	118.51	114.17	109.83	113.92	109.58	105.24	170.00
30	128.44	124.10	119.76	122.48	118.14	113.80	116.98	112.64	108.30	170.00
35	133.41	129.07	124.73	126.46	122.12	117.78	120.03	115.69	111.35	170.00
40	138.38	134.04	129.70	130.43	126.09	121.75	123.09	118.75	114.41	170.00
45	143.35	139.01	134.67	134.41	130.07	125.73	126.15	121.81	117.47	170.00
50	148.32	143.98	139.64	138.38	134.04	129.70	129.21	124.87	120.53	170.00
Total	---	---	---	---	---	---				---



OUTPUT - PREDICTED FAULTING (9" PCC)

Year	Alt 1 9" PCC (inch)	Alt 2. 9" PCC (inch)	Alt 3 9" PCC (inch)	Alt 4. 9" PCC (inch)	Alt 5. 9" PCC (inch)	Alt 6 9" PCC (inch)	Alt 7 9" PCC (inch)	Alt 8. 9" PCC (inch)	Alt 9 9" PCC (inch)	Critical Faulting (inch)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
25	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.19
30	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.19
35	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.19
40	0.19	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.19
45	0.27	0.27	0.27	0.27	0.27	0.26	0.27	0.26	0.26	0.19
50	0.37	0.37	0.37	0.37	0.37	0.36	0.37	0.36	0.36	0.19
Total	---	---	---	---	---	---				---



OUTPUT - PREDICTED SPALLING (9" PCC)

Year	Alt 1 9" PCC (%)	Alt 2. 9" PCC (%)	Alt 3. 9" PCC (%)	Alt 4. 9" PCC (%)	Alt 5 9" PCC (%)	Alt 6. 9" PCC (%)	Alt 7 9" PCC (%)	Alt 8 9" PCC (%)	Alt 9 9" PCC (%)
0	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
5	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57
10	2.66	2.66	2.66	2.66	2.66	2.66	2.66	2.66	2.66
15	3.74	3.74	3.74	3.74	3.74	3.74	3.74	3.74	3.74
20	4.83	4.83	4.83	4.83	4.83	4.83	4.83	4.83	4.83
25	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91
30	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
35	8.08	8.08	8.08	8.08	8.08	8.08	8.08	8.08	8.08
40	9.17	9.17	9.17	9.17	9.17	9.17	9.17	9.17	9.17
45	10.25	10.25	10.25	10.25	10.25	10.25	10.25	10.25	10.25
50	11.34	11.34	11.34	11.34	11.34	11.34	11.34	11.34	11.34
Total	---	---	---	---	---	---	---	---	---

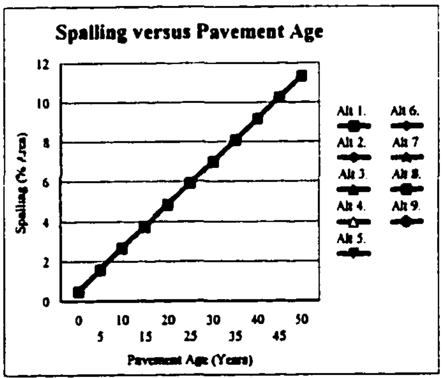
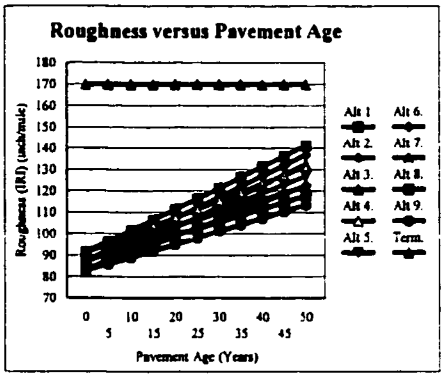


Table V-4: NYSDOT Rigid Pavement - Performance Optimization - 10" PCC Trial.

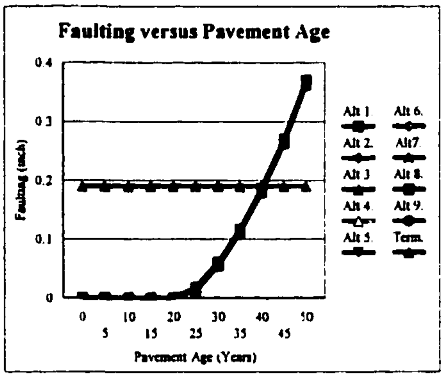
OUTPUT - PREDICTED ROUGHNESS (10" PCC)

Year	Alt 1. 10" PCC (in/mi)	Alt 2. 10" PCC (in/mi)	Alt 3. 10" PCC (in/mi)	Alt 4. 10" PCC (in/mi)	Alt 5. 10" PCC (in/mi)	Alt 6. 10" PCC (in/mi)	Alt 7. 10" PCC (in/mi)	Alt 8. 10" PCC (in/mi)	Alt 9. 10" PCC (in/mi)	Terminal Roughness (inch/mile)
0	91.50	87.16	82.82	91.50	87.16	82.82	91.50	87.16	82.82	170.00
5	96.47	92.13	87.79	95.48	91.14	86.80	94.56	90.22	85.88	170.00
10	101.44	97.10	92.76	99.45	95.11	90.77	97.62	93.28	88.94	170.00
15	106.41	102.07	97.73	103.43	99.09	94.75	100.67	96.33	91.99	170.00
20	111.38	107.04	102.70	107.40	103.06	98.72	103.73	99.39	95.05	170.00
25	116.34	112.00	107.66	111.38	107.04	102.70	106.79	102.45	98.11	170.00
30	121.31	116.97	112.63	115.35	111.01	106.67	109.85	105.51	101.17	170.00
35	126.28	121.94	117.60	119.33	114.99	110.65	112.90	108.56	104.22	170.00
40	131.25	126.91	122.57	123.30	118.96	114.62	115.96	111.62	107.28	170.00
45	136.22	131.88	127.54	127.28	122.94	118.60	119.02	114.68	110.34	170.00
50	141.19	136.85	132.51	131.25	126.91	122.57	122.08	117.74	113.40	170.00
Total	---	---	---	---	---	---				---



OUTPUT - PREDICTED FAULTING (10" PCC)

Year	Alt 1. 10" PCC (inch)	Alt 2. 10" PCC (inch)	Alt 3. 10" PCC (inch)	Alt 4. 10" PCC (inch)	Alt 5. 10" PCC (inch)	Alt 6. 10" PCC (inch)	Alt 7 10" PCC (inch)	Alt 8. 10" PCC (inch)	Alt 9. 10" PCC (inch)	Critical Faulting (inch)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
25	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.19
30	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.19
35	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.19
40	0.19	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.19
45	0.27	0.27	0.27	0.27	0.27	0.26	0.27	0.26	0.26	0.19
50	0.37	0.37	0.37	0.37	0.37	0.36	0.37	0.36	0.36	0.19
Total	---	---	---	---	---	---				---



OUTPUT - PREDICTED SPALLING (10" PCC)

Year	Alt 1. 10" PCC (%)	Alt 2. 10" PCC (%)	Alt 3. 10" PCC (%)	Alt 4. 10" PCC (%)	Alt 5. 10" PCC (%)	Alt 6. 10" PCC (%)	Alt 7 10" PCC (%)	Alt 8. 10" PCC (%)	Alt 9 10" PCC (%)
0	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
5	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57
10	2.66	2.66	2.66	2.66	2.66	2.66	2.66	2.66	2.66
15	3.74	3.74	3.74	3.74	3.74	3.74	3.74	3.74	3.74
20	4.83	4.83	4.83	4.83	4.83	4.83	4.83	4.83	4.83
25	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91
30	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
35	8.08	8.08	8.08	8.08	8.08	8.08	8.08	8.08	8.08
40	9.17	9.17	9.17	9.17	9.17	9.17	9.17	9.17	9.17
45	10.25	10.25	10.25	10.25	10.25	10.25	10.25	10.25	10.25
50	11.34	11.34	11.34	11.34	11.34	11.34	11.34	11.34	11.34
Total	---	---	---	---	---	---	---	---	---

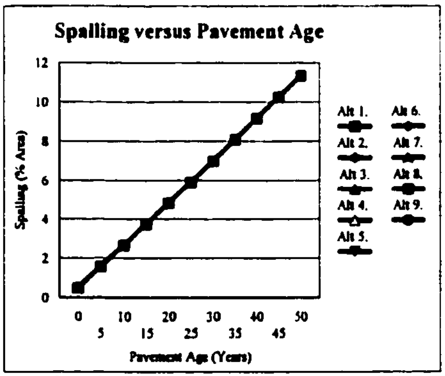
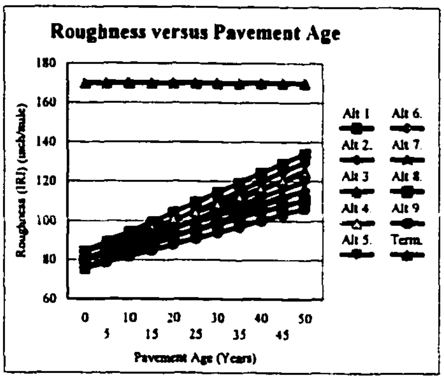


Table V-5: NYSDOT Rigid Pavement - Performance Optimization - 11" PCC Trial

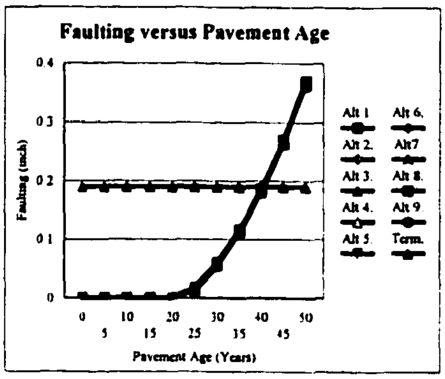
OUTPUT - PREDICTED ROUGHNESS (11" PCC)

Year	Alt 1. 11" PCC (in/mi)	Alt 2. 11" PCC (in/mi)	Alt 3. 11" PCC (in/mi)	Alt 4. 11" PCC (in/mi)	Alt 5. 11" PCC (in/mi)	Alt 6. 11" PCC (in/mi)	Alt 7 11" PCC (in/mi)	Alt 8 11" PCC (in/mi)	Alt 9 11" PCC (in/mi)	Terminal Roughness (inch/mile)
0	84.37	80.03	75.69	84.37	80.03	75.69	84.37	80.03	75.69	170.00
5	89.34	85.00	80.66	88.35	84.01	79.67	87.43	83.09	78.75	170.00
10	94.31	89.97	85.63	92.32	87.98	83.64	90.49	86.15	81.81	170.00
15	99.28	94.94	90.60	96.30	91.96	87.62	93.54	89.20	84.86	170.00
20	104.25	99.91	95.57	100.27	95.93	91.59	96.60	92.26	87.92	170.00
25	109.21	104.87	100.53	104.25	99.91	95.57	99.66	95.32	90.98	170.00
30	114.18	109.84	105.50	108.22	103.88	99.54	102.72	98.38	94.04	170.00
35	119.15	114.81	110.47	112.20	107.86	103.52	105.77	101.43	97.09	170.00
40	124.12	119.78	115.44	116.17	111.83	107.49	108.83	104.49	100.15	170.00
45	129.09	124.75	120.41	120.15	115.81	111.47	111.89	107.55	103.21	170.00
50	134.06	129.72	125.38	124.12	119.78	115.44	114.95	110.61	106.27	170.00
Total	---	---	---	---	---	---				---


Roughness versus Pavement Age

OUTPUT - PREDICTED FAULTING (11" PCC)

Year	Alt 1 11" PCC (inch)	Alt 2. 11" PCC (inch)	Alt 3. 11" PCC (inch)	Alt 4. 11" PCC (inch)	Alt 5. 11" PCC (inch)	Alt 6. 11" PCC (inch)	Alt 7 11" PCC (inch)	Alt 8. 11" PCC (inch)	Alt 9 11" PCC (inch)	Critical Faulting (inch)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
25	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.19
30	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.19
35	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.19
40	0.19	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.19
45	0.27	0.27	0.27	0.27	0.27	0.26	0.27	0.26	0.26	0.19
50	0.37	0.37	0.37	0.37	0.37	0.36	0.37	0.36	0.36	0.19
Total	---	---	---	---	---	---				---


Faulting versus Pavement Age

OUTPUT - PREDICTED SPALLING (11" PCC)

Year	Alt 1. 11" PCC (%)	Alt 2. 11" PCC (%)	Alt 3 11" PCC (%)	Alt 4. 11" PCC (%)	Alt 5 11" PCC (%)	Alt 6 11" PCC (%)	Alt 7 11" PCC (%)	Alt 8. 11" PCC (%)	Alt 9 11" PCC (%)
0	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
5	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57
10	2.66	2.66	2.66	2.66	2.66	2.66	2.66	2.66	2.66
15	3.74	3.74	3.74	3.74	3.74	3.74	3.74	3.74	3.74
20	4.83	4.83	4.83	4.83	4.83	4.83	4.83	4.83	4.83
25	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91
30	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
35	8.08	8.08	8.08	8.08	8.08	8.08	8.08	8.08	8.08
40	9.17	9.17	9.17	9.17	9.17	9.17	9.17	9.17	9.17
45	10.25	10.25	10.25	10.25	10.25	10.25	10.25	10.25	10.25
50	11.34	11.34	11.34	11.34	11.34	11.34	11.34	11.34	11.34
Total	---	---	---	---	---	---	---	---	---

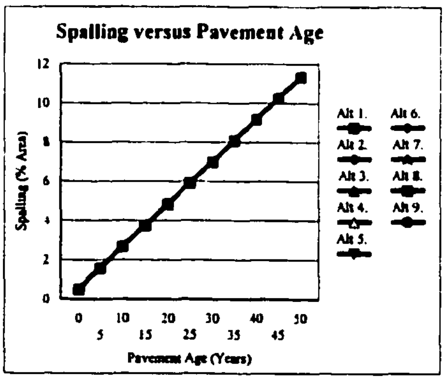
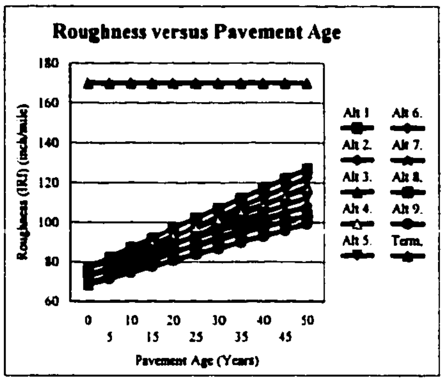

Spalling versus Pavement Age

Table V-6: NYSDOT Rigid Pavement - Performance Optimization - 12" PCC Trial.

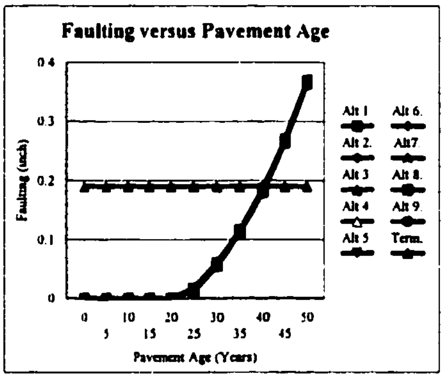
OUTPUT - PREDICTED ROUGHNESS (12" PCC)

Year	Alt 1. 12" PCC (in/mi)	Alt 2. 12" PCC (in/mi)	Alt 3 12" PCC (in/mi)	Alt 4. 12" PCC (in/mi)	Alt 5. 12" PCC (in/mi)	Alt 6. 12" PCC (in/mi)	Alt 7 12" PCC (in/mi)	Alt 8. 12" PCC (in/mi)	Alt 9 12" PCC (in/mi)	Terminal Roughness (inch/mile)
0	77.24	72.90	68.56	77.24	72.90	68.56	77.24	72.90	68.56	170.00
5	82.21	77.87	73.53	81.22	76.88	72.54	80.30	75.96	71.62	170.00
10	87.18	82.84	78.50	85.19	80.85	76.51	83.36	79.02	74.68	170.00
15	92.15	87.81	83.47	89.17	84.83	80.49	86.41	82.07	77.73	170.00
20	97.12	92.78	88.44	93.14	88.80	84.46	89.47	85.13	80.79	170.00
25	102.08	97.74	93.40	97.12	92.78	88.44	92.53	88.19	83.85	170.00
30	107.05	102.71	98.37	101.09	96.75	92.41	95.59	91.25	86.91	170.00
35	112.02	107.68	103.34	105.07	100.73	96.39	98.64	94.30	89.96	170.00
40	116.99	112.65	108.31	109.04	104.70	100.36	101.70	97.36	93.02	170.00
45	121.96	117.62	113.28	113.02	108.68	104.34	104.76	100.42	96.08	170.00
50	126.93	122.59	118.25	116.99	112.65	108.31	107.82	103.48	99.14	170.00
Total	—	—	—	—	—	—				—



OUTPUT - PREDICTED FAULTING (12" PCC)

Year	Alt 1. 12" PCC (inch)	Alt 2. 12" PCC (inch)	Alt 3. 12" PCC (inch)	Alt 4 12" PCC (inch)	Alt 5 12" PCC (inch)	Alt 6. 12" PCC (inch)	Alt 7 12" PCC (inch)	Alt 8. 12" PCC (inch)	Alt 9 12" PCC (inch)	Critical Faulting (inch)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
25	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.19
30	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.19
35	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.19
40	0.19	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.19
45	0.27	0.27	0.27	0.27	0.27	0.26	0.27	0.26	0.26	0.19
50	0.37	0.37	0.37	0.37	0.37	0.36	0.37	0.36	0.36	0.19
Total	—	—	—	—	—	—				—



OUTPUT - PREDICTED SPALLING (12" PCC)

Year	Alt 1 12" PCC (%)	Alt 2. 12" PCC (%)	Alt 3. 12" PCC (%)	Alt 4. 12" PCC (%)	Alt 5. 12" PCC (%)	Alt 6. 12" PCC (%)	Alt 7 12" PCC (%)	Alt 8. 12" PCC (%)	Alt 9 12" PCC (%)
0	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
5	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57
10	2.66	2.66	2.66	2.66	2.66	2.66	2.66	2.66	2.66
15	3.74	3.74	3.74	3.74	3.74	3.74	3.74	3.74	3.74
20	4.83	4.83	4.83	4.83	4.83	4.83	4.83	4.83	4.83
25	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91
30	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
35	8.08	8.08	8.08	8.08	8.08	8.08	8.08	8.08	8.08
40	9.17	9.17	9.17	9.17	9.17	9.17	9.17	9.17	9.17
45	10.25	10.25	10.25	10.25	10.25	10.25	10.25	10.25	10.25
50	11.34	11.34	11.34	11.34	11.34	11.34	11.34	11.34	11.34
Total	—	—	—	—	—	—	—	—	—

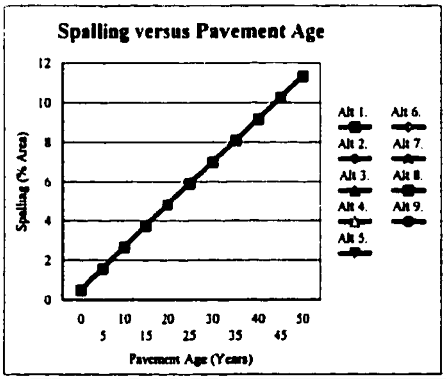
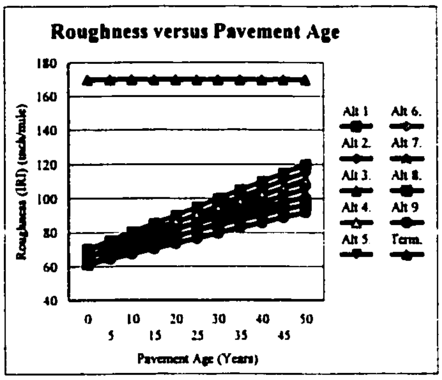


Table V-7: NYSDOT Rigid Pavement - Performance Optimization - 13" PCC Trial

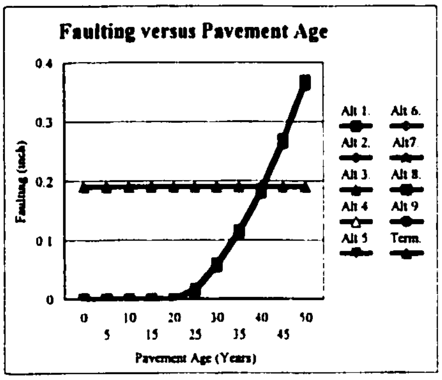
OUTPUT - PREDICTED ROUGHNESS (13" PCC)

Year	Alt 1. 13" PCC (in/mi)	Alt 2. 13" PCC (in/mi)	Alt 3. 13" PCC (in/mi)	Alt 4. 13" PCC (in/mi)	Alt 5. 13" PCC (in/mi)	Alt 6. 13" PCC (in/mi)	Alt 7 13" PCC (in/mi)	Alt 8. 13" PCC (in/mi)	Alt 9. 13" PCC (in/mi)	Terminal Roughness (inch/mile)
0	70.11	65.77	61.43	70.11	65 77	61 43	70 11	65 77	61.43	170.00
5	75.08	70.74	66 40	74.09	69.75	65 41	73.17	68.83	64 49	170 00
10	80.05	75.71	71.37	78.06	73.72	69 38	76.23	71.89	67.55	170.00
15	85.02	80 68	76.34	82.04	77.70	73.36	79 28	74.94	70.60	170 00
20	89 99	85.65	81.31	86.01	81 67	77 33	82.34	78.00	73.66	170.00
25	94.95	90 61	86.27	89.99	85.65	81.31	85 40	81.06	76.72	170.00
30	99.92	95.58	91.24	93.96	89 62	85 28	88.46	84.12	79.78	170.00
35	104.89	100.55	96.21	97 94	93 60	89.26	91.51	87 17	82.83	170.00
40	109.86	105.52	101.18	101.91	97 57	93.23	94.57	90.23	85.89	170 00
45	114.83	110.49	106.15	105.89	101 55	97 21	97 63	93 29	88.95	170.00
50	119.80	115.46	111.12	109.86	105.52	101.18	100.69	96.35	92.01	170.00
Total	—	—	—	—	—	—				—


Roughness versus Pavement Age

OUTPUT - PREDICTED FAULTING (13" PCC)

Year	Alt 1. 13" PCC (inch)	Alt 2. 13" PCC (inch)	Alt 3 13" PCC (inch)	Alt 4. 13" PCC (inch)	Alt 5. 13" PCC (inch)	Alt 6. 13" PCC (inch)	Alt 7 13" PCC (inch)	Alt 8. 13" PCC (inch)	Alt 9 13" PCC (inch)	Critical Faulting (inch)
0	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 19
5	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0.19
10	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0.19
15	0 00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0.19
20	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0.19
25	0 02	0.02	0 01	0 02	0 01	0 01	0 01	0 01	0 01	0 19
30	0 06	0 06	0 06	0 06	0 06	0 06	0 06	0 06	0 05	0.19
35	0.12	0.12	0 11	0 11	0 11	0 11	0 11	0 11	0 11	0 19
40	0 19	0.18	0 18	0 18	0 18	0 18	0 18	0 18	0 18	0 19
45	0 27	0.27	0 27	0 27	0 27	0 26	0.27	0 26	0 26	0 19
50	0.37	0.37	0.37	0 37	0.37	0 36	0.37	0 36	0.36	0 19
Total	—	—	—	—	—	—				—


Faulting versus Pavement Age

OUTPUT - PREDICTED SPALLING (13" PCC)

Year	Alt 1. 13" PCC (%)	Alt 2. 13" PCC (%)	Alt 3. 13" PCC (%)	Alt 4. 13" PCC (%)	Alt 5. 13" PCC (%)	Alt 6. 13" PCC (%)	Alt 7 13" PCC (%)	Alt 8. 13" PCC (%)	Alt 9 13" PCC (%)
0	0.49	0.49	0.49	0.49	0.49	0 49	0.49	0 49	0.49
5	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57
10	2.66	2.66	2.66	2.66	2.66	2 66	2.66	2.66	2.66
15	3.74	3.74	3.74	3.74	3 74	3.74	3 74	3.74	3.74
20	4.83	4 83	4 83	4.83	4 83	4 83	4 83	4.83	4.83
25	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91
30	7 00	7 00	7 00	7.00	7.00	7 00	7 00	7.00	7.00
35	8.08	8.08	8.08	8.08	8.08	8.08	8.08	8.08	8.08
40	9.17	9.17	9.17	9.17	9 17	9.17	9 17	9.17	9.17
45	10.25	10.25	10.25	10.25	10.25	10.25	10.25	10.25	10 25
50	11.34	11.34	11.34	11.34	11.34	11.34	11.34	11.34	11.34
Total	—	—	—	—	—	—	—	—	—

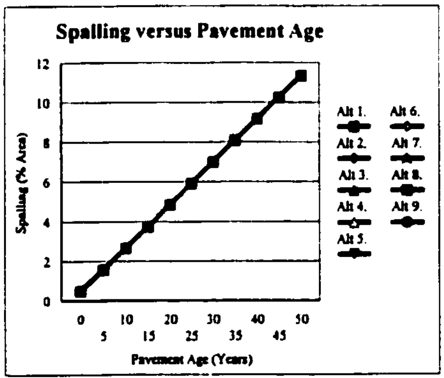
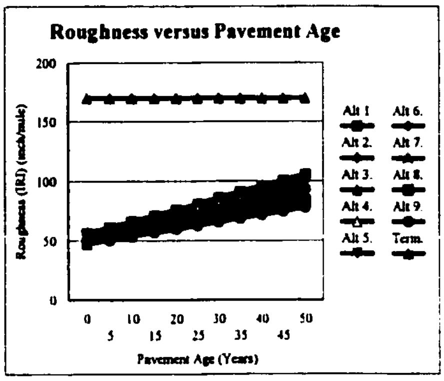

Spalling versus Pavement Age

Table V-8: NYSDOT Rigid Pavement - Performance Optimization - 15" PCC Trial

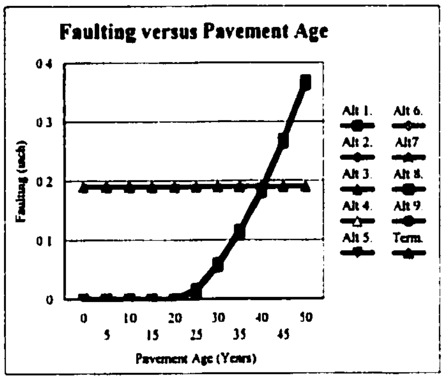
OUTPUT - PREDICTED ROUGHNESS (15" PCC)

Year	Alt 1. 15" PCC (in/mi)	Alt 2. 15" PCC (in/mi)	Alt 3. 15" PCC (in/mi)	Alt 4. 15" PCC (in/mi)	Alt 5. 15" PCC (in/mi)	Alt 6. 15" PCC (in/mi)	Alt 7. 15" PCC (in/mi)	Alt 8. 15" PCC (in/mi)	Alt 9. 15" PCC (in/mi)	Terminal Roughness (inch/mile)
0	55.85	51.51	47.17	55.85	51.51	47.17	55.85	51.51	47.17	170.00
5	60.82	56.48	52.14	59.83	55.49	51.15	58.91	54.57	50.23	170.00
10	65.79	61.45	57.11	63.80	59.46	55.12	61.97	57.63	53.29	170.00
15	70.76	66.42	62.08	67.78	63.44	59.10	65.02	60.68	56.34	170.00
20	75.73	71.39	67.05	71.75	67.41	63.07	68.08	63.74	59.40	170.00
25	80.69	76.35	72.01	75.73	71.39	67.05	71.14	66.80	62.46	170.00
30	85.66	81.32	76.98	79.70	75.36	71.02	74.20	69.86	65.52	170.00
35	90.63	86.29	81.95	83.68	79.34	75.00	77.25	72.91	68.57	170.00
40	95.60	91.26	86.92	87.65	83.31	78.97	80.31	75.97	71.63	170.00
45	100.57	96.23	91.89	91.63	87.29	82.95	83.37	79.03	74.69	170.00
50	105.54	101.20	96.86	95.60	91.26	86.92	86.43	82.09	77.75	170.00
Total	---	---	---	---	---	---				---



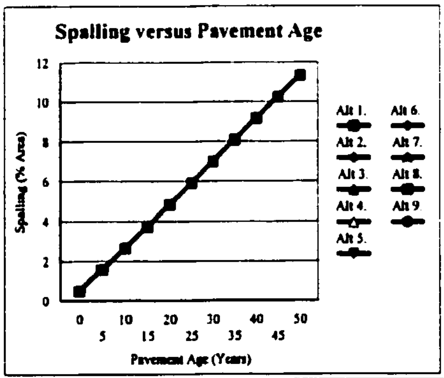
OUTPUT - PREDICTED FAULTING (15" PCC)

Year	Alt 1. 15" PCC (inch)	Alt 2. 15" PCC (inch)	Alt 3 15" PCC (inch)	Alt 4. 15" PCC (inch)	Alt 5. 15" PCC (inch)	Alt 6. 15" PCC (inch)	Alt 7 15" PCC (inch)	Alt 8 15" PCC (inch)	Alt 9 15" PCC (inch)	Critical Faulting (inch)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
25	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.19
30	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.19
35	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.19
40	0.19	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.19
45	0.27	0.27	0.27	0.27	0.27	0.26	0.27	0.26	0.26	0.19
50	0.37	0.37	0.37	0.37	0.37	0.36	0.37	0.36	0.36	0.19
Total	---	---	---	---	---	---				---



OUTPUT - PREDICTED SPALLING (15" PCC)

Year	Alt 1. 15" PCC (%)	Alt 2. 15" PCC (%)	Alt 3. 15" PCC (%)	Alt 4. 15" PCC (%)	Alt 5. 15" PCC (%)	Alt 6 15" PCC (%)	Alt 7 15" PCC (%)	Alt 8. 15" PCC (%)	Alt 9 15" PCC (%)
0	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
5	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57
10	2.66	2.66	2.66	2.66	2.66	2.66	2.66	2.66	2.66
15	3.74	3.74	3.74	3.74	3.74	3.74	3.74	3.74	3.74
20	4.83	4.83	4.83	4.83	4.83	4.83	4.83	4.83	4.83
25	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91
30	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
35	8.08	8.08	8.08	8.08	8.08	8.08	8.08	8.08	8.08
40	9.17	9.17	9.17	9.17	9.17	9.17	9.17	9.17	9.17
45	10.25	10.25	10.25	10.25	10.25	10.25	10.25	10.25	10.25
50	11.34	11.34	11.34	11.34	11.34	11.34	11.34	11.34	11.34
Total	---	---	---	---	---	---	---	---	---



APPENDIX W:

Climate Information: New York State.

Contents:

Table W-1: Annual Weather Parameters: New York State.
Table W-2: Climate Information: New York, New York.
Table W-3: Climate Information: Islip, New York.
Table W-4: Climate Information: Binghamton, New York.
Table W-5: Climate Information: Buffalo, New York.
Table W-6: Climate Information: Rochester, New York.
Table W-7: Climate Information: Syracuse, New York.
Table W-8: Climate Information: Albany, New York.
Table W-9: Climate Information: Plattsburg, New York.
Table W-10: Climate Information: Potsdam, New York.

Table W-1: Annual Weather Parameters: New York State.

Code	Location	Average Annual Precipitation (Inches)	Average Annual Days Exceeding 90 Degrees	Average Annual Days Below 32 Degrees	Average Air Freeze Index (Deg-day)	Average Annual Air F-T Cycles
A	New York, NY	43.1	15	73	675	73
B	Central Islip, NY	46.0	6	98	680	76
C	Binghamton, NY	36.9	3	145	800	61
D	Buffalo, NY	38.1	4	131	880	65
E	Rochester, NY	31.8	11	135	925	65
F	Syracuse, NY	38.5	9	136	930	68
G	Albany, NY	35.8	11	147	1010	61
H	Plattsburg, NY	34.1	6	157	1200	55
I	Potsdam, NY	40.8	3	152	1180	52
---	Mean	38.34	7.55	130.44	920.00	64
---	Median	38.50	9.00	115	938.00	64

Source : Adapted from Williams [53], Lindberg [17], and Huang [13].

Table W-2: Climate Information: New York, New York.

Month	Average Precipitation (Inches)	Average Snow (Inches)	Average Relative Humidity	Wind Speed (mph)
January	3.2	7	57	16.1
February	3.0	8	55	17.3
March	3.8	4	52	17.3
April	3.8	1	51	16.1
May	3.8	0	53	11.5
June	3.3	0	54	11.5
July	4.0	0	54	11.5
August	4.2	0	56	11.5
September	3.3	0	56	10.4
October	3.2	0	56	12.7
November	3.8	1	57	15.0
December	3.6	4	59	16.1

Source: Adapted from Williams [53].

Table W-3: Climate Information: Central Islip, New York.

Month	Average Precipitation (Inches)	Average Snow (Inches)	Average Relative Humidity	Wind Speed (mph)
January	3.69	6.6	61	9.4
February	3.48	4.1	60	9.9
March	4.10	3.9	55	10.6
April	4.23	0.3	55	9.8
May	3.94	0.0	57	8.8
June	3.82	0.0	57	8.5
July	3.46	0.0	61	7.5
August	4.04	0.0	61	7.3
September	3.48	0.0	61	7.8
October	3.55	0.0	59	8.6
November	4.23	1.0	61	9.7
December	4.05	3.7	59	9.6

Source: Adapted from Williams [53].

Table W-4: Climate Information: Binghamton, New York.

Month	Average Precipitation (Inches)	Average Snow (Inches)	Average Relative Humidity	Wind Speed (mph)
January	2.4	19	69	13.8
February	2.4	16	65	13.8
March	2.8	13	60	13.8
April	3.2	5	54	12.7
May	3.4	0	55	11.5
June	3.6	0	57	9.2
July	3.6	0	57	8.1
August	3.4	0	59	8.1
September	3.2	0	62	9.2
October	2.9	0	60	9.2
November	3.1	8	69	10.4
December	2.9	18	72	13.8

Source: Adapted from Williams [53].

Table W-5: Climate Information: Buffalo, New York.

Month	Average Precipitation (Inches)	Average Snow (Inches)	Average Relative Humidity	Wind Speed (mph)
January	2.9	24	73	18.4
February	2.5	18	70	17.3
March	2.9	11	65	16.1
April	3.0	3	57	15.0
May	3.1	0	55	13.8
June	3.1	0	55	13.8
July	2.9	0	53	12.7
August	3.9	0	56	12.7
September	3.3	0	59	12.7
October	3.0	0	60	9.3
November	3.9	11	70	15.0
December	3.5	22	74	15.0

Source: Adapted from Williams [53].

Table W-6: Climate Information: Rochester, New York.

Month	Average Precipitation (Inches)	Average Snow (Inches)	Average Relative Humidity	Wind Speed (mph)
January	2.2	24	71	16.1
February	2.3	23	69	15.0
March	2.5	14	63	15.0
April	2.6	4	56	13.8
May	2.7	0	53	12.7
June	2.8	0	53	11.5
July	2.6	0	52	8.1
August	3.3	0	55	8.1
September	2.8	0	59	8.1
October	2.5	0	61	11.5
November	2.8	7	69	13.8
December	2.6	20	74	13.8

Source: Adapted from Williams [53].

Table W-7: Climate Information: Syracuse, New York.

Month	Average Precipitation (Inches)	Average Snow (Inches)	Average Relative Humidity	Wind Speed (mph)
January	2.5	28	69	15.0
February	2.5	25	67	13.8
March	3.0	16	60	13.8
April	3.2	4	53	13.8
May	3.2	0	53	11.5
June	3.5	0	54	11.5
July	3.6	0	53	9.2
August	3.5	0	56	9.2
September	3.5	0	60	9.2
October	3.2	1	60	10.4
November	3.5	9	68	12.7
December	3.1	25	72	13.8

Source: Adapted from Williams [53].

Table W-8: Climate Information: Albany, New York.

Month	Average Precipitation (Inches)	Average Snow (Inches)	Average Relative Humidity	Wind Speed (mph)
January	2.4	16	64	15.0
February	2.3	14	60	15.0
March	2.8	11	54	15.0
April	2.9	3	49	15.0
May	3.6	0	51	9.2
June	3.4	0	53	9.2
July	3.1	0	53	8.1
August	3.3	0	55	8.1
September	3.1	0	57	8.1
October	2.9	0	56	9.2
November	3.1	4	64	13.8
December	2.9	14	67	13.8

Source: Adapted from Williams [53].

Table W-9: Climate Information: Plattsburg, New York.

Month	Average Precipitation (Inches)	Average Snow (Inches)	Average Relative Humidity	Wind Speed (mph)
January	1.8	19	65	12.7
February	1.8	16	61	11.5
March	2.2	13	58	11.5
April	2.7	4	52	11.5
May	3.0	0	51	11.5
June	3.5	0	54	10.4
July	3.5	0	53	10.4
August	4.0	0	56	10.4
September	3.2	0	61	11.5
October	2.9	0	61	11.5
November	3.1	7	68	11.5
December	2.4	19	69	12.7

Source: Adapted from Williams [53].

Table W-10: Climate Information: Potsdam, New York.

Month	Average Precipitation (Inches)	Average Snow (Inches)	Average Relative Humidity	Wind Speed (mph)
January	3.8	22	69	12.7
February	3.0	18	65	11.5
March	3.5	13	61	11.5
April	2.6	7	55	11.5
May	3.1	0	53	11.4
June	3.4	0	57	10.3
July	3.7	0	56	10.3
August	3.5	0	59	10.3
September	3.7	0	63	9.7
October	3.4	2	64	11.3
November	3.5	12	71	11.3
December	3.6	21	72	12.7

Source: Adapted from Williams [53].

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