A SENSITIVITY ANALYSIS OF FLEXIBLE PAVEMENT SYSTEM FPS2

by

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PREFACE

This report presents a sensitivity analysis performed to establish the reasonableness of solutions and relative importance of some of the variables in the flexible pavement design system FPS2. The variables are analyzed with respect to their effects on the structural design and overall output function of the working system. The report will help the designers who are using the flexible pavement system to use the computer program more efficiently and to understand the effects of different variables.

The analysis presented in this report is the first attempt to determine the sensitivity of various variables involved in the flexible pavement system. The analysis is therefore designed to be simple and the level of effort is kept to the minimum. The present analysis is conducted on program FPS2, which is an earlier version of the system and is based on deflection criteria of design. Various sensitivity analyses conducted on subsequent versions of the flexible pavement system will be reported in a series of reports of which this is the first report.

This is the seventh in a series of reports that describe the work done in the project entitled "A System Analysis of Pavement Design and Research Implementation." The project is a long-range comprehensive research program to develop a system analysis of pavement design and management. The project is conducted in cooperation with the Federal Highway Administration Department of Transportation.

Special thanks are given to Mr. F. H. Scrivner and Mr. James L. Brown for participating in the various phases of this study. The cooperation of the staff of the Center for Highway Research is appreciated for typing the drafts of the report. The assistance of Mr. Arthur Frakes in preparing the manuscript is appreciated. Thanks are also due to Nancy Braun, David Posey, and Curtis Varnel for their assistance in the work.

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LIST OF REPORTS

Report No. 123-1, "A Systems Approach Applied to Pavement Design and Research," by W. Ronald Hudson, B. Frank McCullough, F. H. Scrivner, and James L. Brown, describes a long-range comprehensive research program to develop a pavement systems analysis and presents a working systems model for the design of flexible pavements.

Report No. 123-2, "A Recommended Texas Highway Department Pavement Design System Users Manual," by James L. Brown, Larry J. Buttler, and Hugo E. Orellana, is a manual of instructions to Texas Highway Department personnel for obtaining and processing data for flexible pavement design system.

Report No. 123-3, "Characterization of the Swelling Clay Parameter Used in the Pavement Design System," by Arthur W. Witt, III, and B. Frank McCullough, describes the results of a study of the swelling clay parameter used in pavement design system.

Report No. 123-4, "Developing a Pavement Feedback Data System," by R. C. G. Haas, describes the initial planning and development of a pavement feedback data system.

Report No. 123-5, "A Systems Analysis of Rigid Pavement Design," by Ramesh K. Kher, W. R. Hudson, and B. F. McCullough, describes the development of a working systems model for the design of rigid pavements.

Report No. 123-6, "Calculation of the Elastic Moduli of a Two Layer Pavement System from Measured Surface Deflections," by F. H. Scrivner, C. H. Michalak, and W. M. Moore, describes a computer program which will serve as a subsystem of a future Flexible Pavement System founded on linear elastic theory.

Report No. 123-7, "Annual Report on Important 1970-71 Pavement Research Needs," by B. Frank McCullough, James L. Brown, W. Ronald Hudson, and F. H. Scrivner, describes a list of priority research items based on findings from use of the pavement design system.

Report No. 123-8, "A Sensitivity Analysis of Flexible Pavement System FPS2," by Ramesh K. Kher, B. Frank McCullough, and W. Ronald Hudson, describes the overall importance of this system, the relative importance of the variables of the system and recommendations for efficient use of the computer program.

ABSTRACT

Flexible Pavement System FPS2 is a design concept formulated into a computer program which analyzes flexible pavements utilizing an overall systems approach to the problem. The program uses 45 different types of inputs in the broad categories of design constraints, design variables, and cost variables. The design alternatives are analyzed by using economic concepts.

This report describes a sensitivity analysis performed to establish the relative importance and cost sensitivities of the different variables on the system, study changes in the structural designs generated due to changes in the variable values, and completely debug the program to find anomalies and the problem areas.

An experiment was designed to obtain the required information. Three basic solutions were obtained at three basic levels of the variables; low, average, and high. The sensitivity of each variable was studied at each of these three basic levels by changing the value of the particular variable to the other two levels. A total of over 400 problems were solved for this analysis.

Each problem thus solved was analyzed carefully for the overall cost of the optimal design and its different cost constituents, design thickness obtained, and number of feasible designs generated. Based on the design and cost sensitivities, the variables producing similar effects were grouped together. The variables were rated in the order of their importance with respect to the overall cost of the optimal design. Recommendations are made in two general areas, (1) that of using the computer program and (2) that of achieving better sensitivity analysis information for a similar experiment if performed in the future.

It is concluded that FPS2 gives generally reasonable solutions, the variables are sensitive to various degrees with respect to costs and structural

designs, and the traffic and material properties are the most important parameters of the system.

KEY WORDS: sensitivity analysis, analysis, flexible pavements, pavement design, systems analysis, computer program.

SUMMARY

A sensitivity analysis has been performed on Flexible Pavement System FPS2, which is a computer program to analyze and rationally design flexible pavements using about 45 different input variables. The study was performed to debug the program, rate the variables in the order of their importance, and analyze the effects of each variable with respect to structural designs obtained and various costs computed. About 400 different problems were solved using this working system and the data obtained were analyzed quantitatively as well as qualitatively. The variables were grouped with respect to their effects, and the rating was performed based on the overall cost of optimal designs, and the different qualitative effects of variables are described.

The study is a part of an overall systematic pavement design and research program. The modified version of computer program FPS2 is at present being implemented within the Texas Highway Department. The sensitivity analysis reported in this study has given the authors of the user's manual (Ref 3) more information about the effects of the variables, which is useful in determining the relative amount of time and effort the user should spend for estimating the numerical values for the various variables which are inputs to this system.

IMPLEMENTATION STATEMENT

The findings of the sensitivity analysis described in this report aid in the application and implementation of the working system FPS2, developed in the form of a computer program to design flexible pavements. A modified version of this design procedure is in various stages of implementation within the Texas Highway Department. The sensitivity analysis has given considerable feedback for use in improving the program. The findings reported here have immediate application to improve understanding of the variables of the system, to rate the importance of each variable, and to aid in solving the real problems more efficiently. The implementation of this research study has helped users to decide the level of effort which is needed for a fair numerical estimate of various inputs to the system and thus save time and man-hours of work. This research effort has been incorporated into the user's manual.

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CHAPTER 1. INTRODUCTION

Flexible Pavement System FPS2 (Refs 1, 2, 3) is a design concept utilizing a computer program to analyze and rationally design flexible pavements. An attempt has been made to provide maximum flexibility and choice in the design including the utilization of stage construction and economic decision criteria.

The program user must specify a number of constraints in each problem. These constraints include the minimum and maximum thicknesses of materials in various layers, minimum times to and between various overlays and seal coats, and the maximum funds available for initial construction. A problem is solved by the simultaneous solution of three basic equations, a deflection equation, a traffic equation, and a performance equation.

The design process involves the solution of these equations utilizing as variables traffic, environment, subgrade properties, material stiffnesses, and serviceability indices. The designs are optimized with respect to total cost, including initial construction, overlays, traffic delay during overlays, maintenance, seal coats, and salvage returns. The arrays of designs are then scanned and several near optimal designs selected. The system involves about 45 variables in categories such as restraints, design variables, and cost variables.

Purpose of This Study

The Flexible Pavement System as described above is based on concepts of design and economic analysis (Ref 4) which, although known for a long time, are seldom effectively combined in a pavement design procedure. To warrant confidence in such a system as well as to evaluate the reasonableness of its solutions, it is necessary to check the system by analyzing a number of problems. To accomplish this, a sensitivity analysis has been undertaken with the following objectives:

(1) to better understand this design procedure and its various parts, such as structural design concepts and economic criteria by studying the changes in structural designs and costs due to the changes in the numerical values of the variables;

(2) to establish the relative importance and cost sensitivities of different variables in the system;

(3) to assist the designer in decisions concerning the relative amount of time and effort he should spend for estimating the numerical values of the various inputs to the system;

(4) to completely debug the computer program by solving a large number of different kinds of problems;

(5) to find the anomalies and problem areas in the program; and

(6) to study the amount of computation time which may be needed for the solutions, especially in the cases of combinations of input variables for which the computation times are excessive.

CHAPTER 2. THE COMPUTER PROGRAM

It is not necessary for the designer to have a complete knowledge of the optimization or the computational techniques used in the working system FPS2, but a basic picture of the whole process is necessary in order to use the computer program efficiently. With that point in view the solution process of FPS2 is described in this chapter with the help of an example.

For an input where, for example, three materials are specified to be used, FPS2 provides these materials in various realistic combinations. There are four such realistic combinations here: asphaltic concrete only, asphaltic concrete over the base course, asphaltic concrete over the subbase course, and asphaltic concrete over the base and the subbase courses. Each of these combinations has the subgrade as the last layer beneath it.

Within each combination described above, all possible combinations of layer thicknesses are computed by incrementing the minimum allowable thicknesses by steps of one-half inch up to the maximum allowable thicknesses. All the designs thus produced compose the "original array" of designs. In the process of analysis these designs are tested against the three major restrictions designated by the designer:

(1) maximum funds available for initial construction,

(2) maximum allowable total thickness of initial construction, and

(3) minimum allowable time to the first overlay.

Designs of the original array for which the initial construction costs exceed the initial funds available or for which the initial total thicknesses exceed the maximum allowed value are rejected in the beginning. The program also uses a mathematical elimination based on strength and cost requirements. The designs not satisfying this criterion are also rejected (this elimination does not exist in the later versions of FPS computer programs). Lives for the remaining initial designs are then calculated and the third restriction is applied. The designs having initial lives less than the minimum specified time to the first overlay are rejected. Designs left after these considerations compose the "modified array" of designs.

For each design of this array an optimal overlay strategy is computed. As shown in Fig 1, there can be numerous overlay policies for each design. Sometimes the overlay computations are so lengthy that they consume a large amount of computation time. Figure 1 also shows that there may be fewer overlay strategies for a thicker initial construction as compared to a thinner initial construction. One simple example of the step-by-step formulation of overlay policies for an initial design is shown in Fig 2.

FPS2 considers the overlay thicknesses in increments of one-half inch between 0.5 and 8.0 inches. An overlay strategy is subjected to the following restrictions:

(1) The overlay must increase the pavement life by at least the "minimum time between overlays" specified by the designer.

(2) The overlay policy is stopped when the pavement life is greater than or equal to the "length of analysis period" specified by the designer.

All such initial designs meeting the three designer constraints, satisfying the criteria of strength and cost, and having at least one overlay policy are called "feasible designs."

The rest of the procedure deals with cost calculations. For each feasible design, the overall cost is computed based on the following six items:

(1) initial construction cost,

(2) overlay construction cost,

(3) traffic delay cost during overlay construction,

(4) maintenance cost,

(5) seal coat cost, and

(6) salvage return.

Within each material combination the whole array of feasible designs is scanned and the design with the least cost is printed. Also, all the feasible designs from all the combinations are evaluated and a specified number of near optimal designs in the increasing order of total overall cost are printed in the summary table.

The major phases of the solution process are summarized in a simple flow diagram (Fig 3).

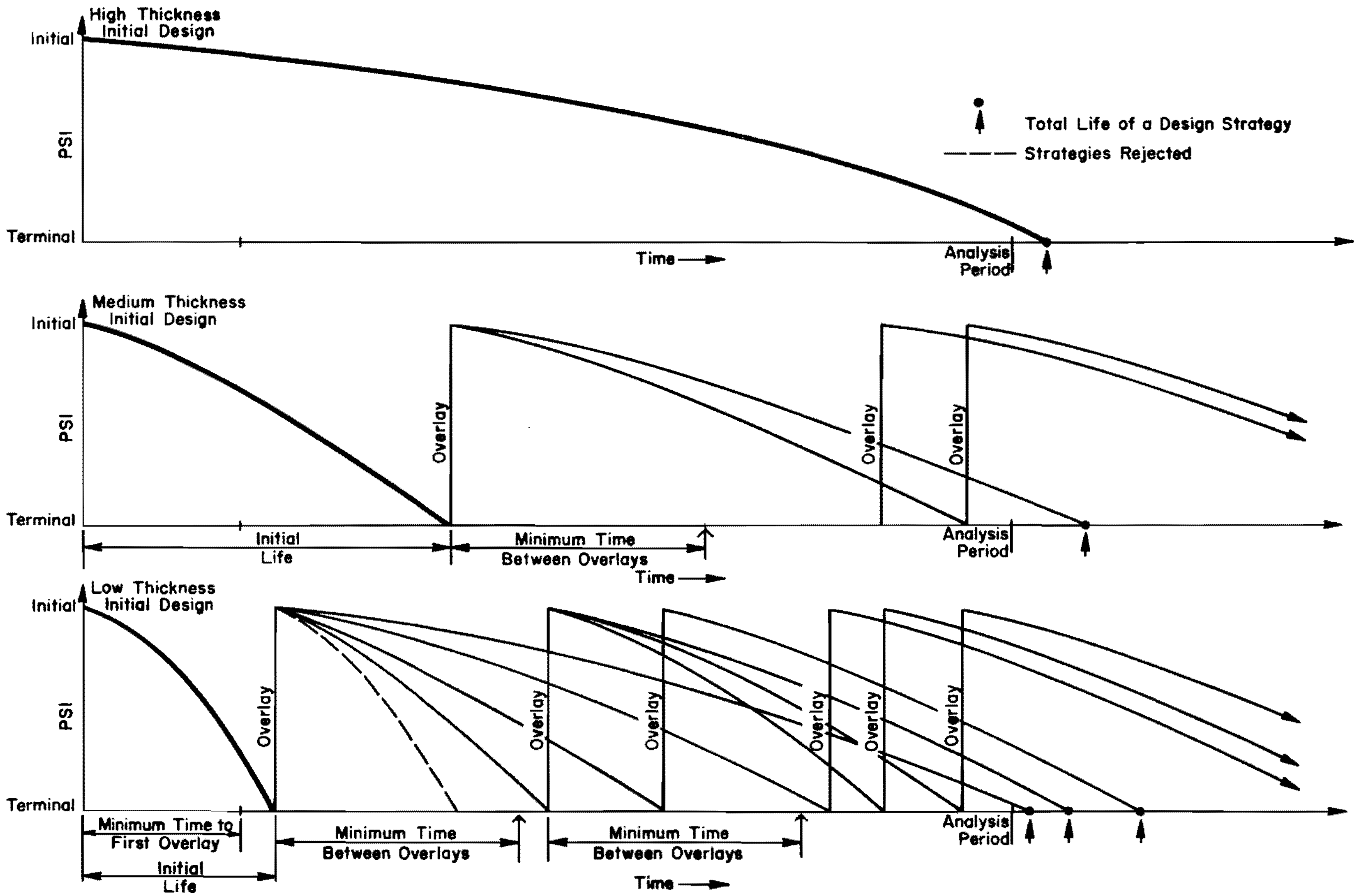

Fig 1. Illustrative overlay strategies for different thickness initial designs.

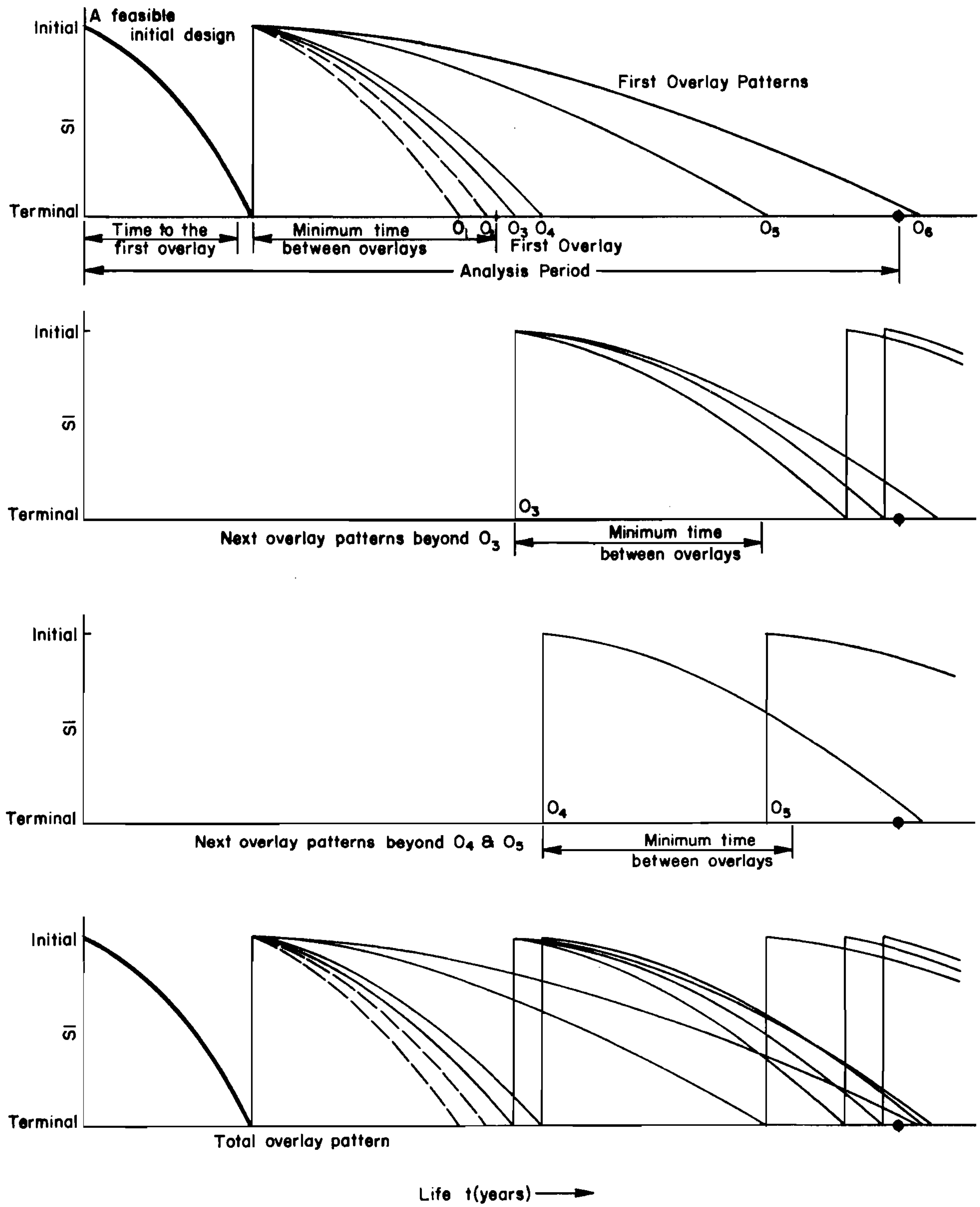

Fig 2. Illustration of overlay patterns for an initial design.

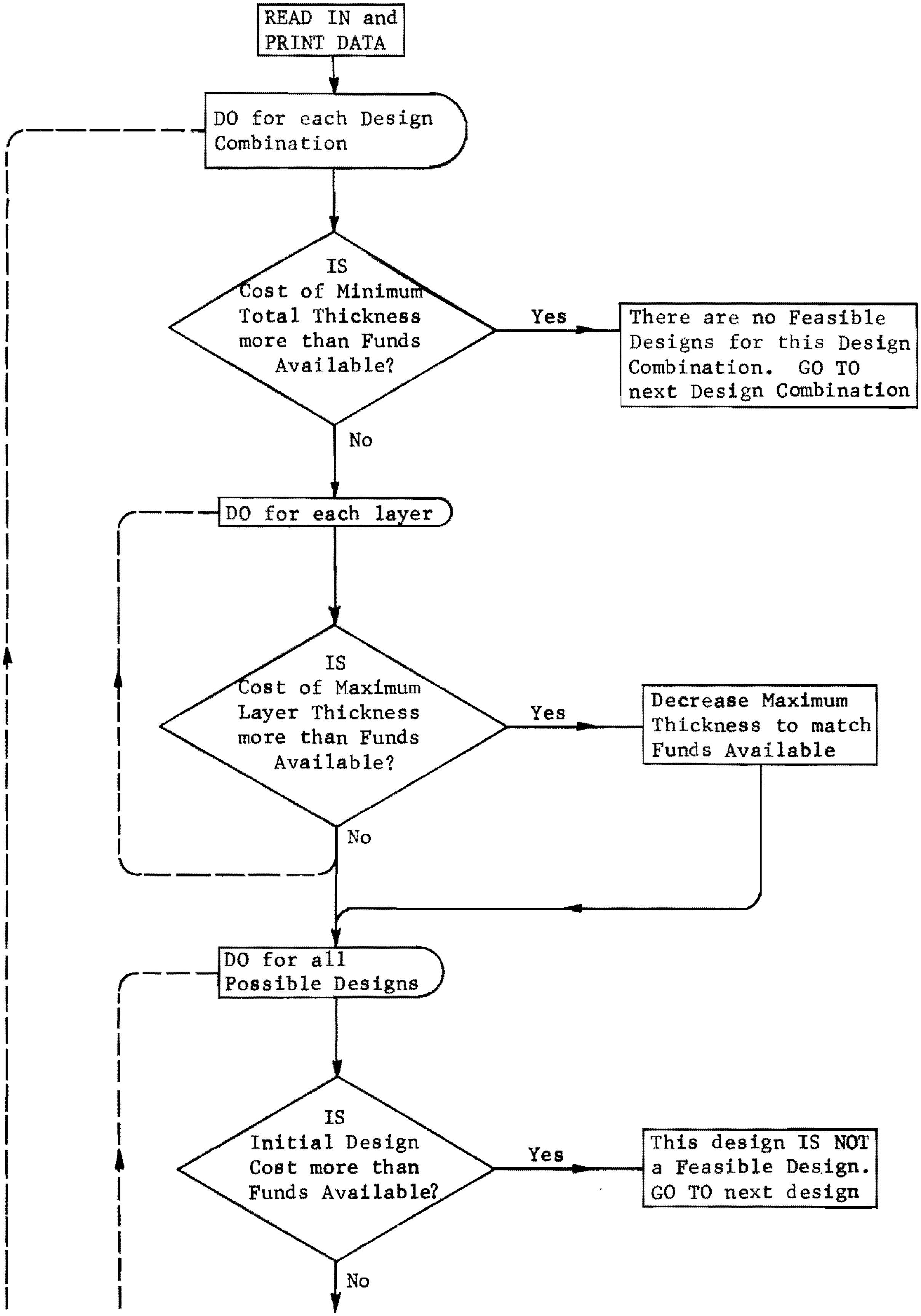

Fig 3. Summary flow diagram for FPS2.

(Continued)

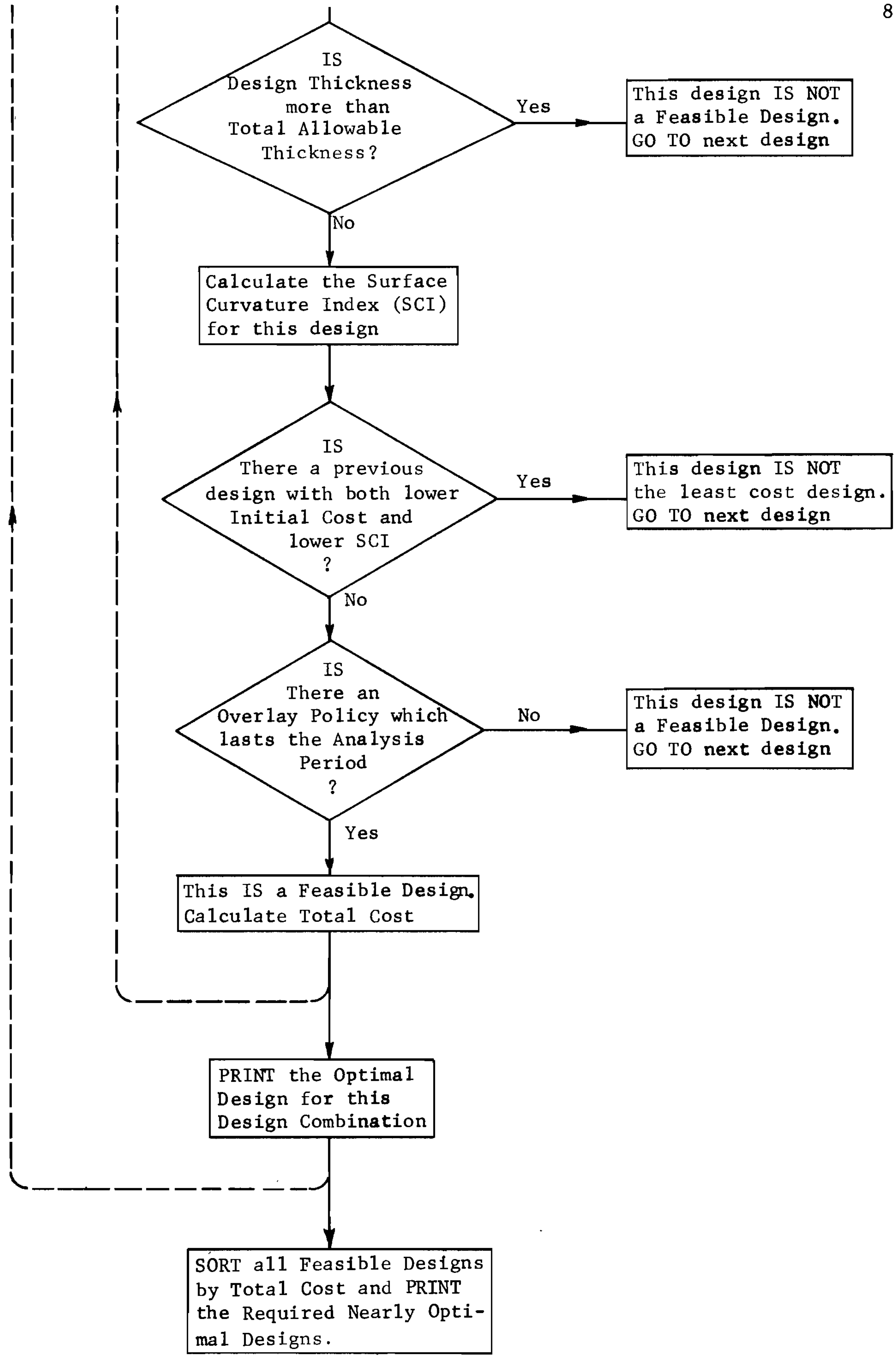

Fig 3. (Continued).

CHAPTER 3. DESIGN AND ANALYSIS OF THE EXPERIMENT

A complete sensitivity study of a system like FPS2 would require an analysis of program output at various levels of the possible ranges of all the variables involved. Such an analysis would require a very large experiment to cover the effects of individual variations of the variables as well as the variations in groups. For a study of all possible interactions of variables, an experiment would have to solve the problems given by a full factorial of several levels of the 45 variables involved in the system. It is obvious that such a large-scale experiment is not practical from a data analysis point of view.

Therefore, what was desired was an initial experiment which can be done with a reasonable amount of time and effort and will give maximum information for effective use of the program and attaining the confidence required for solving actual field problems.

With this in mind, an experiment was selected which would isolate the linear and nonlinear effects of individual variables and would avoid interaction effects, by varying one variable and holding the rest of them constant at a certain level. On the basis of engineering judgment, each variable was given low, average, and high levels. Average levels are those which will generally be met in practice under average design conditions. A low level is that extreme but practical value numerically greater or less than the average value which will give a lower overall optimal design cost than that given by using the average level. Similarly, a high level is that extreme but practical numerical value which will give an overall optimal design cost higher than the cost obtained with the variable at its average level.

First, three basic problems were solved by using the low, average, and high values of all the variables. That is, in an average basic solution, all the input was at average levels of the variables, and similarly, for low and high basic solutions, all the inputs were respectively at low and high levels of the variables. Then the variations were studied. For each of the three basic solutions, two problems were studied for every variable. The problems involved holding all the variables at that particular basic level except the one under study, which was given its values at the other two levels. For example, at the average level, two problems were solved for each variable, one in which the variable was held at its low value and the second where the variable was held at its high value; for each of these problems, all the other variables were held at their average levels. A similar procedure was adopted for the high basic level, in which each variable was varied individually to its average and low values, and for the low basic level, where each variable was studied at its average and high values. The procedure required some 400 separate solutions, which could be accomplished within a reasonable work effort to cover the desired information.

Description of Experiment

Table A1 in the appendix shows the numerical values adopted for the three levels of all the variables. The average basic level was successfully studied at these levels but some revisions had to be made to the initial experiment to conduct the analysis at the low and high levels. The main reasons for these revisions were

(1) to successfully obtain the solution output since for some variables outputs could not be obtained at their initially decided values due to diagonastic errors or nonfeasibility of solutions;

(2) to obtain the solution output within reasonable computation time; and

(3) to obtain the best usable information from the solution output and to avoid unnecessary work since at low and high-level studies it was anticipated, in cases of certain variables, that it would be better due to the above reasons to delete or expand their variations or to keep them constant at their average levels.

Table A2 in the appendix lists all the subsequent changes which were made to the numerical values of the variables at low and high basic studies and also lists the reasons for the specific changes. The values shown in Table A2 in the categories of low-level solutions and high-level solutions therefore replace the corresponding values in Table A1 for the low and high-level basic studies, respectively.

Certain dependency of the variable values was taken into account in this study. ADT at the end of the analysis period and total accumulated 18-kip axles during the analysis period were both considered as dependent upon the

ADT at the beginning of the analysis period. The values used for these dependent variables are shown in Table A3 in the appendix.

Solution Output Data

Table A4 in the appendix gives the optimal costs obtained for the problems solved at the average level. The table gives the low, average, and high values of a variable and the optimal cost obtained for each problem solved. Tables A5 and A6 in the appendix give similar output data for the problems solved at low and high basic levels, respectively. These tables list the variable values at three levels (the revised values, obtained by combining Tables A1 and A2, and the corresponding optimal costs for each problem solved at these two basic levels).

Table A7 in the appendix shows what parts of the total cost are changed with a change in the value of a variable. The table presents the data on the cost breakdown of the optimal designs for each problem solved at the average basic level. To simplify the table only those cost constituents for each problem are listed which are different than the corresponding value in the average solution. Astericks are used to denote that the value is not different from the corresponding value in that basic solution. In addition, the table also lists the design number of the optimal design for each problem solved (Design No. 1 is asphalt concrete only, Design No. 2 is asphalt concrete over the base course, Design No. 3 is asphalt concrete over the subbase course, and Design No. 4 is asphalt concrete over the base and subbase courses).

Table A8 in the appendix lists certain additional information about the optimal designs obtained for the average level basic study. It gives the thicknesses of the materials selected for the optimal design out of each combination, number of feasible designs generated for each combination, total number of feasible designs considered, and the number of the optimal design.

CHAPTER 4. GROUPING OF VARIABLES

The discussion of the solution procedure in Chapter 2 and the experiment described in Chapter 3 indicate that there are three broad categories of variables in the system: design constraints, design variables, and cost variables.

Design Constraints

These parameters are the designer's decisions based primarily upon judgment and sometimes upon the physical limitations necessitated by the special conditions of design and construction. They are as follows:

(1) minimum thicknesses allowed for individual layers,
(2) maximum thicknesses allowed for individual layers,
(3) maximum funds available for initial construction,
(4) maximum total thickness allowed for initial construction,
(5) minimum time allowed to the first overlay,
(6) minimum time allowed between two consecutive overlays,
(7) minimum time allowed to the first seal coat,
(8) minimum time allowed between two consecutive seal coats,
(9) length of the analysis period, and
(10) number of different materials available.

These variables are responsible for generating the original array of designs and then selecting the feasible designs out of it. Therefore, these parameters control the overall solution time for a problem.

An optimal design should be independent of these variables; but, when these variables become restraints over the solution, the optimal design is then dependent upon them. The optimal design in such a case is not the optimum of the whole original array because a part of the original array is cut off by the constraints. On the other hand, opening these constraints beyond certain values may result in bringing a large number of designs under consideration and thereby increase the computation time. Therefore, unless there is some unavoidable restriction over a design constraint input, the value for each of these parameters should be chosen such that

(1) it does not pose a restriction on the optimal design, and

(2) it does not give rise to an excessive number of possible designs.

For example, in order to help avoid certain undesirable very small top thickness designs, it may be desirable that the minimum thickness allowed for the top layer not be very small when there is only one material layer (base course or a subbase course) below it. At the same time, a very high minimum thickness value may be undesirable when the top layer is to be placed over a base plus a subbase layer. In the latter case, this high value may force the program to use a larger total overall thickness than necessary.

Design Variables

These variables affect the serviceability-age history of a design. Since these variables may change the number of feasible designs and their serviceability histories, a solution with a change in any of these variables may pick up an entirely different design as an optimal design for a combination and/or for the total feasible array. These variables are listed below:

(1) district temperature constant,

(2) initial serviceability index,

(3) minimum allowable serviceability index,

(4) no-traffic lower bound on the serviceability index,

(5) swelling clay parameter,

(6) total accumulated equivalent 18-kip single-axle applications over the analysis period,

(7) one-direction average daily traffic at the beginning of the analysis period,

(8) one-direction average daily traffic at the end of the analysis period, and

(9) strength coefficients of individual layers.

Cost Variables

All the remaining variables in the system are called cost variables. They do not affect the formulation of the feasible designs and overlay policies; however, the cost of materials may sometimes cause the designs to be eliminated by the mathematical restrictions of cost and strength described in Chapter 2. This is because there is a proportionate increase or decrease in a particular cost constituent for all the designs.

With few exceptions, these variables generally affect only one cost constituent of a design. The following effects of variables on cost constituents are observed:

(1) Interest rate affects the overlay cost, user cost, maintenance cost, seal coat cost, and salvage value.

(2) In-place cost of materials affects initial construction cost, cost of asphalt concrete (first material) affects overlay cost.

(3) The salvage percentage at the end of the analysis period affects the salvage value only.

(4) Routine maintenance cost and incremental increase in routine maintenance cost affect only the maintenance cost constituent of the overall cost.

(5) Cost per lane-mile of a seal coat affects only the seal coat cost.

(6) The following remaining cost variables affect the traffic delay cost only:

  (a) asphalt concrete production rate,

  (b) asphalt concrete compacted density,

  (c) distance in the overlay direction over which the traffic is slowed,

  (d) distance in the nonoverlay direction over which traffic is slowed,

  (e) detoured distance around the overlay zone,

  (f) percent of average daily traffic passing through the overlay zone during each hour of overlay construction,

  (g) number of hours per day that the overlay takes place,

  (h) percent of vehicles stopped in the overlay zone (overlay direction) due to movement of personnel and equipment,

  (i) percent of vehicles stopped in the overlay zone (nonoverlay direction) due to movement of personnel and equipment,

  (j) average delay per vehicle stopped in the overlay zone (overlay direction),

  (k) average delay per vehicle stopped in the overlay zone (nonoverlay direction),

  (l) number of open lanes in the restricted zone (overlay direction),

  (m) number of open lanes in the restricted zone (nonoverlay direction),

  (n) type of road under consideration,

(o) model number describing the traffic situation,

(p) average approach speed,

(q) average through-speed in the overlay direction, and

(r) average through-speed in the nonoverlay direction.

CHAPTER 5. EFFECTS OF VARIABLES ON DESIGN AND COST

A major objective of a sensitivity analysis is to analyze and determine the changes in structural designs and their costs with certain changes in the numerical values of the variables. This chapter describes the analysis of all the problems solved as described in the chapter on design of the experiment. The data analyses are based on the study of the following aspects of the solutions obtained:

(1) initial thickness,
(2) life of initial construction,
(3) overlay strategies adopted,
(4) selection of optimum design,
(5) number of feasible designs, and
(6) optimal cost.

The analyses of design constraints, design variables, and cost variables are presented below separately because a number of effects are observed to be common within these variable groups.

Design Constraints

These variables generally control the computational time for the solution. In certain cases where the values for these constraints are such that the number of feasible designs and/or the overlay strategies considered are excessive, computational time becomes exceptionally high. The sensitivity of the working system with respect to these variables is described below.

Minimum and Maximum Thicknesses of Materials. These variables determine the range of thickness to be considered for each material. Thicknesses of individual layers are progressively increased by one-half-inch intervals in the solution procedure. The minimum and maximum values should be carefully selected so as to prevent excessively large ranges of thicknesses from giving rise to an excessive amount of computation.

These parameters can sometimes restrain the solution and result in an uneconomical optimal design. For example, in any combination of layers, the solution may be forced to pick the design which includes all the minimum thicknesses, even though their sum may be more than the total thickness required for the most economical design. Such a design will have a higher cost and will not be optimal for the problem if the minimum thicknesses have been arbitrarily assigned. However, it will be an optimal design if these thicknesses are input limitations. Similarly, a restraint on maximum layer thickness might cause the solution to pick a design at that thickness level and, because of the need for a more complex overlay pattern than would be required if a greater maximum thickness were allowed, the design might not be the most economical one.

Maximum Initial Funds Available and Maximum Initial Thickness. Overall structural design and cost of the optimal design remain constant unless these variables become restrictions over the problem. Decreasing any of these variables decreases the amount of calculations. Therefore, if these variables are merely being used to control the number of feasible designs, the designer should be careful so as not to decrease them to such values that they become restrictions.

Minimum Time to First Overlay. Minimum time to the first overlay is an important variable in this design procedure:

(1) It gives the designer a varied choice in the selection of overlay patterns. Sensitivity analysis has demonstrated the great importance of overlay construction from the standpoint of economy. Different patterns of overlay schedules can be obtained by varying this constraint.

(2) By using this variable as a restriction, the designer can cut computation time and the number of feasible designs which will be obtained for a particular problem. This variable is not as effective, relatively, in reducing the number of feasible designs as the variables mentioned above, but it can be very helpful in reducing computation time by reducing the overlay policies for each feasible design. This variable should be very carefully used for any of these purposes because a slight change in it can turn it into a restraint. As the minimum allowable time to the first overlay is increased, the thickness requirements of initial designs go on increasing and, therefore, the number of feasible designs continues decreasing.

The variable can easily be used, by making its numerical input value equal to or greater than the analysis period, to give only initial designs which last the entire analysis period without overlaying. However, it should be noted that in this case the variable will probably be acting as a restraint and may thereby force the cost of the optimal design up. This does not in any way discourage the program user from trying to study or use such designs.

The sensitivity analysis has shown that a relatively low value of time to the first overlay gives desirable and economical results in cases such as high swelling clay deterioration and/or high equivalent 18-kip axles and/or when low strength materials are used. For these conditions, it has sometimes been found that the optimal design has a computed initial life as short as one year.

Minimum Time Between Overlays. Time between overlays is also a restraint and can reduce the number of acceptable overlay policies. It does not generally reduce the number of feasible designs. One apparent effect of increasing this variable is the increase in the initial construction thicknesses, and sometimes a different optimal design results.

Length of the Analysis Period. This variable was held constant at 20 years except for the average level study, where its variation was also studied. The effects of an increased analysis period are a higher number of overlays and an increase in computation time. Designs will obviously cost more, but per-year cost might be reduced.

Design Variables

These variables affect the performance characteristics of designs and include traffic variables, environment, subgrade and material properties, and serviceability limits. These variables are fixed parameters for a particular design problem and generally cannot be varied by the designer. The variables, initial serviceability index and strength coefficients of materials, do depend to some extent on the designer's discretion, since they can be improved by better construction techniques and treatment of available materials, but it should be noted that the cost of construction and materials will also increase with an increase in value of either of these variables.

District Temperature Constant. This variable represents the increased susceptibility of asphaltic concrete to cracking in cold weather. The lower the value of this variable, the higher the strength requirements of the system will be. When all other variables are held constant, a lower value of the district temperature constant gives fewer feasible designs. This is because the initial lives of the designs are decreased at lower values of the district temperature constant and, in turn, cause some of the designs to be eliminated by the minimum time to the first overlay restriction.

Initial and Final Serviceability Indices. These are the imposed limits on serviceability and depend on the type of facility to be constructed. The difference between the two gives the range of serviceability; higher values for these variables represent a better facility.

In the working system, the serviceability-loss curve due to traffic is always modified by the serviceability-loss function due to the swelling clay. For the sensitivity analysis, some problems were studied with a swelling clay parameter of zero in order to observe the nature of the serviceability-loss curve due to traffic only. The results showed the following:

(1) For a particular range of serviceability, the pavement life depends on the position of this range along the serviceability-index scale. A higher-placed range (i.e., a higher initial serviceability index) would require less pavement thickness. In other words, the same design with the same range of the serviceability index will have a longer life at higher initial serviceability index.

(2) The larger this range, the lower the structural requirements of the system will be. In other words, larger serviceability ranges will show longer lives. As a result, the designs with larger ranges of serviceability will be cheaper than those with smaller ranges.

No-Traffic Lower Bound on the Serviceability Index. This variable, along with a swelling clay parameter, as discussed in the next section, is used to define the swelling characteristics of the subgrade on which the pavement is being constructed. The no-traffic lower-bound serviceability index is the ultimate level of serviceability a pavement will attain in infinite time with no traffic. The swelling clay parameter determines the rate at which this ultimate value will be reached.

If all other design variables remain constant, a smaller lower-bound serviceability index results in higher structural requirements of initial construction, produces a smaller number of feasible designs, and produces an optimal design with higher overall cost.

Swelling Clay Parameter. The swelling clay parameter is a very important design variable of the system. For a set of design variables, including a particular value of no-traffic lower-bound serviceability index, there is an upper limit for the numerical value of the swelling clay parameter beyond which no design is feasible. A higher swelling clay parameter will require greater thicknesses for initial construction, have fewer feasible designs, and have higher overall cost for the optimal design.

The rate of serviceability loss due to swelling clay is more in the initial years of the life of a pavement. In the later period, this rate gets smaller with time. It is, therefore, recommended that a smaller value for the minimum time to the first overlay be used when the swelling clay parameter is relatively high. This will require a relatively smaller thickness of initial construction and, because the swelling clay shows most of its deteriorating effect in initial years, the overlay provided thereafter will very economically meet the traffic requirements. A higher value of the time to the first overlay requiring a higher thickness of initial construction in the case of a higher swelling clay parameter is an economic waste, because the pavement deteriorates at the same rate irrespective of the thickness provided. As a result, the thicker pavement requires approximately the same overlay construction as a smaller initial construction thickness.

Equivalent 18-Kip Axle Applications. Equivalent 18-kip axle applications are distributed over the analysis period according to the traffic equation programmed in the system. A higher value of accumulated 18-kip axle applications requires a higher initial thickness and results in a lesser number of feasible designs. The optimal cost increases with an increase in 18-kip axle applications.

Initial and Final ADT. Initial and final ADT variables are included in the traffic equation and therefore affect the life of any design. These variables are also used for calculation of traffic delay cost during an overlay construction. Rate of ADT increase is an important variable and the thickness requirements of the system increase with an increase in its value.

Traffic delay cost increases with an increase in the ADT, and beyond a certain value of ADT, the cost increases very rapidly. It has been observed that beyond a traffic volume of about 1350 to 1500 vehicles per hour in one lane during an overlay construction, the cost of traffic delay is exceptionally high.

Strength Coefficients of Individual Layers and the Subgrade. These are the most important variables of design because of their major functions of representing the materials in the solution process. Variations in the strength coefficients of layers of subgrade affect the shape of the serviceability-age histories of designs and, therefore, vary the number of feasible designs being considered. In addition, these variables in combination with material costs are used to make certain mathematical decisions as to the feasibility of rejecting the initial designs. Every new design considered in the process of solution is tested against the previous design considered. If the previous design is stronger yet lower in cost, the design under consideration is rejected.

An increase in strength coefficient of a material changes the serviceability curve such that the initial lives of the designs containing that material increase. The variations in the number of feasible designs due to the mathematical criteria of strength and cost cannot be predicted even qualitatively. They depend upon the other inputs of a specific problem. However, the solutions in sensitivity analysis always showed an increase in the number of feasible designs with an increase in strength coefficients of the materials.

The strength coefficient of the subgrade is a very important factor in the system, because it enters the structural design calculations of each design in every combination of material layers. Decreasing the strength coefficient of the subgrade always requires a greater initial thickness, gives fewer feasible designs, and results in a higher optimal design cost.

The decreases in the strength coefficients of the materials in the layers also require greater thicknesses for initial construction and therefore greater overall design costs. A decrease in the strength coefficient of a particular material will cause all the designs for the combination which includes that material to be of higher cost and may affect the selection of the optimal design.

Cost Variables

These variables, as discussed earlier, do not affect the structural design requirements in the solution since they have no effect on the strength or performance characteristics of a particular design; hence, they do not affect the feasibility or the number of designs. These variables enter the solution process after the initial designs and their overlay strategies have been computed. They generally increase or decrease one and sometimes more than one component of the total cost and thereby affect the selection of the optimal design. The general effects observed with the variations of these cost variables are given below.

Interest Rate. The interest rate, as built into this system, gives the present value of money which will be spent on future overlays, maintenance, and seal coats. Traffic delay cost and salvage value are likewise discounted to their present values.

A change in interest rate changes all the cost components except initial construction cost. Because interest rate is involved in the calculation of all future expenditures, the solution of a problem with a variation in this value may give an altogether new optimal design. The higher the interest rate, the lower the present value of the costs of the designs will be.

An effect observed from the sensitivity analysis and one which may look obvious is the rearrangement of the order of designs in the optimization due to a change in interest rate. Though the number of feasible designs remains constant, the order in which the designs rank in the final solution is changed. Generally, with a higher interest rate, designs with expenditures further in the future are shifted towards the optimal design.

In-Place Costs of Materials. The in-place costs of materials determine the cost of initial construction, cost of overlay construction, and salvage returns. A change in the cost of any material may force the solution to choose a different optimal design in that combination. Generally, the solution chooses thinner designs in initial construction when the costs of materials are raised. The cost of the optimal design is higher at higher values of these variables. These variables interact with material strengths since cost usually rises with strength. Therefore, where an increase in the cost of a material will be accompanied by an increase in its strength and other properties, the cost of optimal design may or may not increase.

The in-place costs of materials also affect the number of feasible designs resulting from a solution. This is due to the built-in design elimination criterion based on cost and strength described in Chapter 2.

Other Cost Variables. All cost variables other than those discussed above affect only one cost component of the overall cost. They do not affect in any way the structural design calculations or the number of feasible designs. The effect of a change in the value of any of these variables is on the total costs of all the designs. In most cases, a change in any of these variables causes proportionate changes in the total costs of all the feasible designs. This may or may not result in the same optimal structural design being picked up. However, in sensitivity analysis for a large number of problems, the same design was picked as optimal when a cost variable was changed.

Sensitivity analysis did not show any effect on the optimal cost of the number of hours per day that the overlay takes place because the traffic delay cost, as programmed in the system, is a function of overall total number of hours that the overlay construction takes place, rather than the number of hours of work per day. However, in practice, hours of work per day always interacts with the asphalt concrete production rate and the percent ADT passing per hour during overlay. Thus, in a real design problem, a change in work hours per day will affect the optimal cost through affecting these dependent variables.

The effects of design and cost variables on total cost are presented in Chapter 6. The information as to which cost component of the total cost is affected by a change in the value of any of these variables can be observed from Table A7 in the appendix.

This chapter fulfills one of the objectives of the sensitivity analysis: to describe the qualitative effects of the variables on the optimal costs obtained. These qualitative trends are observed from a sensitivity analysis which was purposely designed to give the partial linear and nonlinear effects of the variables and avoid any of their interactions. It should be noted that the interaction effects of the variables are important and may be considerable in certain cases. Linear trends different from those given in this chapter may be observed when interactions of variables (nonlinear trends) are taken into account. At several points in this chapter, the importance of the dependency of variables on each other is very obvious and should be analyzed in any kind of sensitivity analysis. However, the linear effects of the variables as described in this chapter should be good indicators of the general effects of the variables.

CHAPTER 6. RATING OF VARIABLES

One of the objectives of sensitivity analysis is to determine the cost sensitivity of different variables to help establish the relative importance of the variables and thus give the designer guidance as to the amount of time to spend quantifying or estimating the numerical values of these variables. In addition, this relative rating will indicate possible areas of priority for future research needs.

Rating variables on the basis of data developed during this study is complex and is affected by several factors involved in the data generation, including the basic levels, the numerical values used for the variables, and the variation levels. Moreover, different results may be obtained with a different method of rating.

Several methods for rating the variables were investigated. Based on the nature of the data to be analyzed, the method best suited for such an analysis was a study of the average values of the slopes of the curves plotted for the optimal cost versus the variable levels. Figure 4 is an example of several such curves plotted for the average-level basic study. Average slopes were computed for these curves and for those for the high and low-level basic studies. The results for the average-level basic study are presented in Table 1, which shows the average slope computed for each variable.

The variables in the tabulation made for each level of the basic study were rated by dividing the average slopes into groups. Based on these groupings and other qualitative judgments, Table 2 was prepared to indicate by groups (I through V) the relative levels of the cost sensitivities of various variables. The numerical values of the slopes used to develop this table were those obtained for the average-level basic study. The tabulations for the low and high-level basic studies were similar but the data on slopes for these levels were not as comprehensive and accurate as the data for the average basic level; several subsequent revisions were made in the variables at these basic levels and, moreover, the numerical values of the variables at these basic levels were rather extreme.

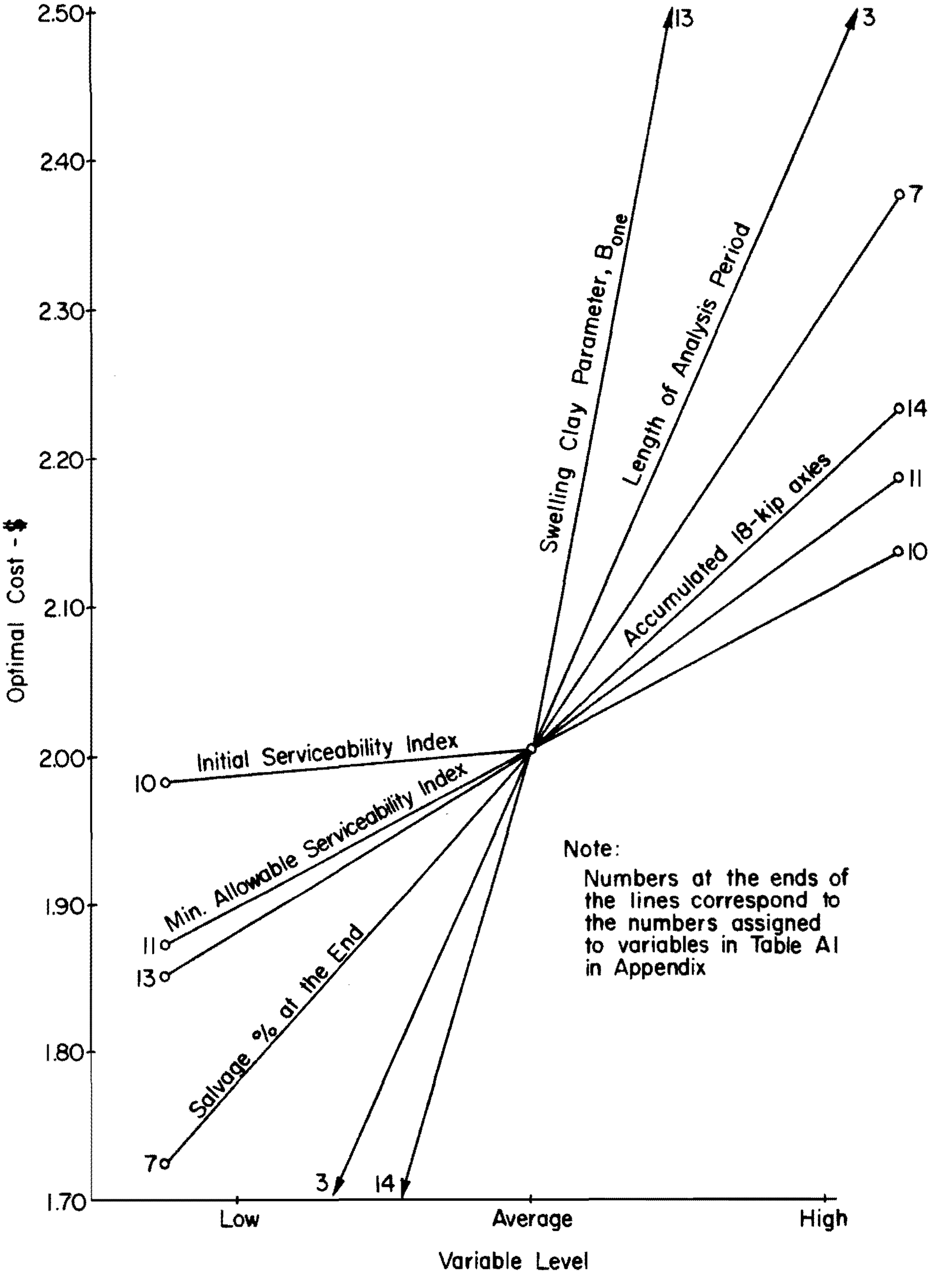

Fig 4. Curves of optimal cost vs variable values for the average level basic study.

(Continued)

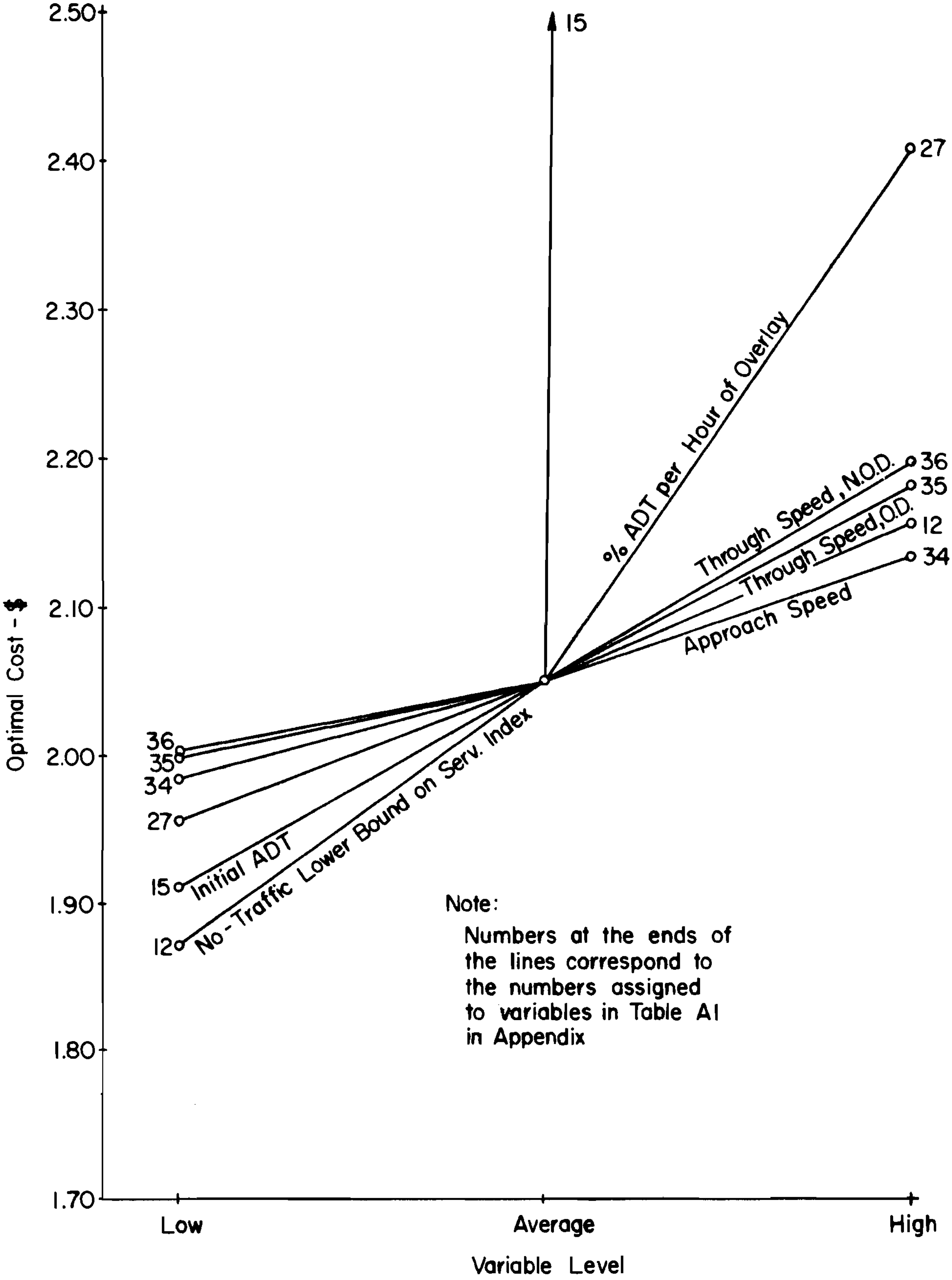

Fig 4. (Continued).

(Continued)

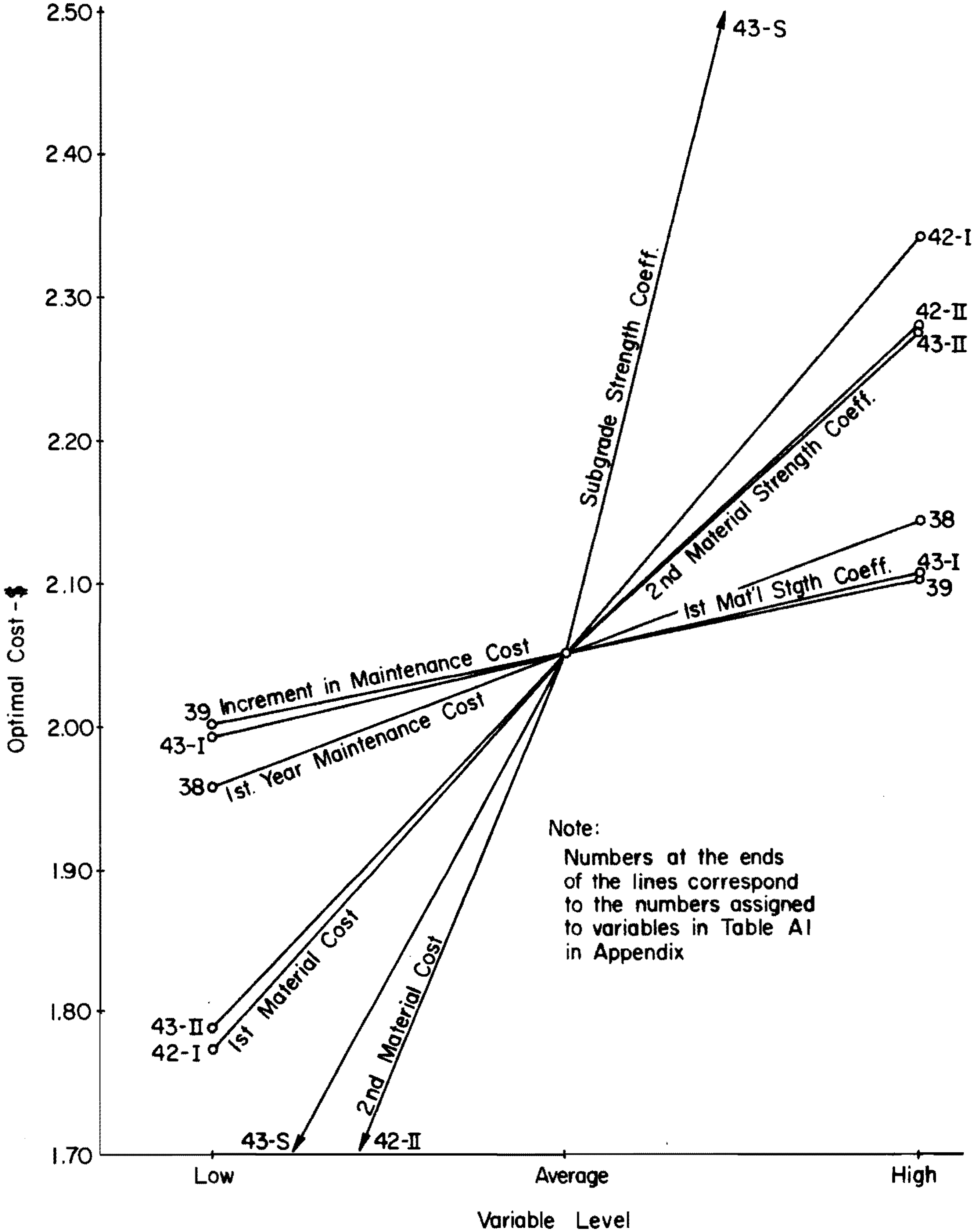

Fig 4. (Continued).

TABLE 1. VALUES OF AVERAGE SLOPES (For Average-Level Basic Study)

Variable		
No.	Name	Average Slope
15	Initial ADT	13.031
13	Swelling clay parameter	1.466
43S	Subgrade strength coefficient	1.447
3	Length of analysis period	1.119
14	Accumulated 18-kip axles	1.064
42II	2nd material in-place cost	0.826
7	Salvage percent at the end	0.654
42I	1st material in-place cost	0.569
17	Minimum time to the first overlay	0.551
43II	2nd material strength coefficient	0.490
27	Percent ADT per hour of overlay	0.452
11	Minimum serviceability index	0.316
43III	3rd material strength coefficient	0.314
42III	3rd material in-place cost	0.287
12	No-traffic lowest serviceability index	0.285
9	District temperature constant	0.283
35	Through-speed, O.D.	0.194
19	Time to the first seal coat	0.193
38	First year maintenance cost	0.186
44I	1st material minimum thickness	0.182
36	Through-speed, N.O.D.	0.179
10	Initial serviceability index	0.152
34	Approach speed	0.149
16	Final ADT	0.121
43I	1st material strength coefficient	0.113
5	AC production rate	0.106
39	Increment increase in maintenance cost	0.100
4	Interest rate	0.079
32	Delay per vehicle stopped, O.D.	0.058
33	Delay per vehicle stopped, N.O.D.	0.058
18	Minimum time between overlays	0.050
31	Percent vehicles stopped, N.O.D.	0.044
30	Percent vehicles stopped, O.D.	0.042
20	Time between seal coats	0.040
45II	2nd material maximum thickness	0.039
2	Maximum dollars available for initial construction	0.039
40	Cost of one seal coat	0.035
24	Distance traffic slowed, O.D.	0.033
6	AC compacted density	0.031
44II	2nd material minimum thickness	0.023
44III	3rd material minimum thickness	0.021
25	Distance traffic slowed, N.O.D.	0.011
28	Number of hours of work per day	0.000
8	Maximum total thickness for initial construction	0.000
45I	1st material maximum thickness	0.000
45III	3rd material maximum thickness	0.000

TABLE 2. RATING OF VARIABLES WITH RESPECT TO OPTIMAL COSTS

	Variable		Group				
	No.	Name	I	II	III	IV	V
DESIGN CONSTRAINTS	2	Maximum dollars available for initial construction					*
	8	Maximum total thickness for initial construction					*
	17	Minimum time to the first overlay		*			
	18	Minimum time between overlays					*
	44I	1st material minimum thickness				*	
	44II	2nd material minimum thickness					*
	44III	3rd material minimum thickness					*
	45I	1st material maximum thickness					*
	45II	2nd material maximum thickness					*
	45III	3rd material maximum thickness					*
DESIGN VARIABLES	3	Length of analysis period	*				
	9	District temperature constant			*		
	10	Initial serviceability index				*	
	11	Minimum serviceability index			*		
	12	No-traffic lower-bound on serviceability index			*		
	13	Swelling clay parameter	*				
	14	Accumulated 18-kip axles	*				
	15	Initial ADT	*				
	16	Final ADT				*	
	43I	1st material strength coefficient				*	
	43II	2nd material strength coefficient		*			
	43III	3rd material strength coefficient			*		
	43S	Subgrade strength coefficient	*				

(Continued)

TABLE 2. (Continued)

	Variable		Group				
	No.	Name	I	II	III	IV	V
COST VARIABLES	4	Interest rate					*
	5	AC production rate				*	
	6	AC compacted density					*
	7	Salvage percent at the end		*			
	19	Time to 1st seal coat				*	
	20	Time between seal coats					*
	24	Distance traffic slowed, O.D.					*
	25	Distance traffic slowed, N.O.D.					*
	27	Percent ADT per hour of overlay		*			
	28	Number of hours of work per day					*
	30	Percent vehicles stopped, O.D.					*
	31	Percent vehicles stopped, N.O.D.					*
	32	Delay per vehicle stopped, O.D.					*
	33	Delay per vehicle stopped, N.O.D.					*
	34	Approach speed				*	
	35	Through speed, O.D.				*	
	36	Through speed, N.O.D.				*	
	38	1st year maintenance cost				*	
	39	Increment increase maintenance cost					*
	40	Cost of seal coat					*
	42I	1st material cost		*			
	42II	2nd material cost		*			
	42III	3rd material cost			*		

It should be noted that the rating of variables presented in this chapter is based on only the partial linear trends. The exact ratings can be obtained only if a study of the variable interactions is also carried out.

CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The sensitivity analysis of the flexible pavement system was made to establish the overall importance of this system, to determine the relative importance of the variables of the system, and to find anomalies and problem areas which the user may face when the system is used.

This analysis led to the following conclusions.

(1) Design constraints do not affect the structural design unless they restrict the solution.

(2) Design constraints generate the number of feasible designs to be considered and are therefore important variables.

(3) Each design constraint can control the number of possible designs, the number of feasible designs, and the optimal cost.

(4) Design variables, also, affect the number of feasible designs in a problem but relatively less than design constraints do.

(5) Design variables are used in the analysis of the structural strength requirements of the system and affect the performance-time characteristics of the designs.

(6) The swelling clay parameter, strength coefficient of subgrade, strength coefficient of materials, district temperature constant, and equivalent total 18-kip axles are important design variables to structural design and number of feasible designs.

(7) Cost variables are important from the cost analysis point of view. They do not enter into the structural design computations of the solution.

(8) The cost of materials and the interest rate are the most important cost variables.

(9) The most important variables from the optimal cost point of view, taken from groups I and II of Table 2, are

(a) initial ADT,

(b) subgrade strength coefficient,

(c) material strength coefficients and their costs,

(d) analysis period,

(e) initial and final serviceability indices, and

(f) swelling clay parameter B_{one} .

Recommendations

Based on the sensitivity analysis, recommendations have been made concerning

(1) revisions to the computer program,

(2) how to efficiently use the computer program, and

(3) how to perform a future sensitivity analysis.

Recommendations for Revisions to the Computer Program. The problems which appeared from time to time during the sensitivity analysis suggested the following revisions and additions to the program:

(1) Using counters, determine the number of possible designs which are not feasible because of

  (a) insufficient funds,

  (b) insufficient specified initial thickness, and

  (c) insufficient time to first overlay.

  The number of rejected designs in each category, along with the total number of possible and feasible designs, will indicate the proportion of possible designs that has been optimized. Then more designs can be studied if it appears that a more economical design is still possible.

(2) Introduce more information messages into the program. Most problems faced in the use of the program are confusing because of the lack of such messages. The designer needs to know the reasons for excessive computation time if it occurs. Information messages for wrong or excessive values of inputs should be added also.

(3) Consider removing the restriction that allows optimizing of only one overlay strategy for an initial design. A second best design strategy for an initial design which is rejected at present may be more economical than the best design strategy for another initial design. Each overlay strategy for an initial design should be considered as a feasible design strategy.

(4) Explore possibilities for reducing computer time. Examples of such possibilities are

  (a) collecting "do loops" which have the same indices,

  (b) replacing successive sums by a single equation,

  (c) converting the program to binary, and

  (d) using a more efficient optimization technique.

Recommendations for More Efficient Use of the Computer Program. For certain combinations of design constraints and design variables, the solution of a problem may take an exceptionally long time. The flexible pavement system computer program FPS2 considers all the possible initial designs and all the overlay patterns for each of those, and when this structural design process is combined with all the cost calculations and the optimization, a highly time-consuming operation sometimes results. This problem appeared during the sensitivity analysis reported herein when low and high basic level solutions were being established; and therefore, the values of a number of variables had to be changed. Several problems could not be solved within even 200 octals of central processor time on the CDC 6600 computer.

In general, computation time for problem solving can be reduced by the following means:

(1) using the minimum range of thickness for each material; however, it is important to include all thicknesses which might be used in any layer combination involving that material. If minimum and maximum thicknesses of materials are selected carefully so that their differences are reduced to the minimum required to cover the designs in all the layer combinations, most of the problems can be solved within reasonable computer times.

(2) reducing as much as possible the number of feasible designs being considered, by using as restraints the variables maximum total thickness of initial construction, minimum time to the first overlay, and maximum number of dollars available. However, care must be taken to avoid eliminating a major part of the possible designs, which may result in losing the optimal design, by forcing this reduction.

(3) reducing or avoiding completely designs with certain combinations of materials by careful use of minimum and maximum thicknesses of materials and/or maximum total thickness of initial construction. If this is attempted, designs avoided for one run should be studied in a second run in which designs obtained in the first trial are reduced or avoided. It is economical to try to understand the probable behavior of the inputs of a problem rather than to allow more time for the computations to get a solution.

General recommendations which consider factors that are important from the standpoint of efficiently using the computer program are:

(1) Use the design constraints carefully, so that they do not become restrictions unless that is desired.

(2) By thorough study of the behavior of design variables and design constraints and continued use of the system, find ways to identify problems which will consume large amounts of computational time and for which solutions may not be reached even within reasonably large computational times. Problems with low levels of the values of design variables will consider a larger number of feasible initial designs than problems with high levels, but the latter may have a

larger number of overlay policies for each feasible initial design. In any of these cases, a problem may use excessive computation time.

(3) Devote more time to the estimation of the numerical values of variables, swelling clay parameter, district temperature constant, initial serviceability index, strength coefficients of subgrade and other materials, maintenance costs, interest rate, and total percentage of ADT which could be handled during an overlay. Total percentage of ADT during an overlay can be decreased by adjusting the time of overlay construction to fall between the periods of peak traffic. A wrong estimation of any of these variables can cause the selection of an optimal design which will prove to be not the most economical under actual conditions.

Recommendations for Performing a Sensitivity Analysis in the Future. The experience gained, the problems faced, and the quantity of information obtained while performing the sensitivity analysis discussed here suggest the following improvements for any future sensitivity analysis to be performed in this series:

(1) Avoid the sensitivity study of design constraints; their sensitivity is different for different sets of design variables and cannot be generalized on the same basis as for design or cost variables.

(2) Study the sensitivity of design variables from a design rather than a cost point of view. Plan the experiment so as to get more information on changes in structural design, rather than optimal cost. A change in a variable can cause large changes in structural design with small changes in optimal cost.

(3) Use five basic levels for the whole groups of design variables; this will give better information with respect to cost and design trends than three, as used in this analysis. In a particular basic level, the variables can be studied at any two desirable levels. In all basic levels, the cost variables can be kept at average levels.

(4) Obtain three basic level solutions for cost variables but do the study of variation for only the average level.

(5) Use the effort saved by following steps 1 and 4 above to undertake special studies which will provide better quality information. Some of these studies are of

   (a) sets of initial and final serviceability indices and the ranges of serviceability (range is initial SI minus final SI);

   (b) sets of swelling clay parameters and the no-traffic lower-bound serviceability indices;

   (c) sets of equivalent 18-kip axles, initial ADT, and final ADT;

   (d) sets of strength coefficients of materials;

   (e) comparative effects of various traffic models; and

   (f) effects of cost strength ratios of the materials.

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APPENDIX

TABLES DESCRIBING THE EXPERIMENT AND ITS OUTPUT

TABLE A1. NUMERICAL VALUES ASSIGNED TO THE VARIABLES AT LOW, AVERAGE, AND HIGH LEVELS

Var. No.	Variable Name	Low	Average	High
1.	Number of different materials available, NM[*]	3	3	3
2.	Maximum number of dollars available for initial construction, CMAX	6.00	4.00	1.40
3.	Length of the analysis period (years), CL	10.00	20.00	35.00
4.	Interest rate or time value of money (percent), RATE	10.00	5.00	0.10
5.	Asphaltic concrete production rate (tons per hour), ACPR	100.00	75.00	50.00
6.	Asphaltic concrete compacted density (tons per compacted cubic yard), ACCD	1.60	1.80	2.00
7.	Salvage percent of structural value at the end of the analysis period, PSVGE	100.00	50.00	0.00
8.	Maximum total thickness of initial construction (inches), TCKMAX	40.00	25.00	14.00
9.	District temperature constant, ALPHA	40.00	25.00	9.00
10.	Initial serviceability index, P1	4.60	4.20	3.80
11.	Minimum allowable serviceability index, P2	1.50	2.50	3.00
12.	No-traffic lower bound on the serviceability index, P2P	3.00	1.50	0.00
13.	Swelling clay parameter, B_{one}	0.00	0.10	0.24
14.	One-direction accumulated 18-kip axles after CL years, XNC	6×10^4	4×10^6	10×10^6
15.	One-direction ADT at the beginning of analysis period, RO	100	10,000	25,000
16.	One-direction ADT at the end of analysis period, RC	10,000	20,000	30,000
17.	Minimum time to the first overlay (years), MTTO	1.00	5.00	11.00

* Symbols as used in the computer program and given in Guide for Data Input in Refs 1, 2, and 3.

(Continued)

TABLE A1. (Continued)

Var. No.	Variable Name	Low	Average	High
18.	Minimum time between overlays, (years), MTBO*	1.00	6.00	10.00
19.	Minimum time to the first seal coat (years), TTSC	10.00	5.00	2.00
20.	Minimum time between seal coat (years), TBSC	10.00	5.00	2.00
21.	Number of open lanes in the overlay direction in the restricted zone, NLRO	1	1	1
22.	Number of open lanes in the non-overlay direction in the restricted zone, NLRN	2	2	2
23.	Number of lanes in each direction, XNLANE	2	2	2
24.	C.L. distance in the overlay direction over which traffic is slowed (miles), XLSO	0.25	0.50	1.00
25.	C.L. distance in the non-overlay direction over which traffic is slowed (miles), XLSN	0.25	0.50	1.00
26.	Detoured distance around the overlay zone (miles), XLSD (input zero unless MODEL 5 is used)	0.00	0.00	0.00
27.	Average percent of ADT passing through the overlay zone during each hour of overlay, PROP	2.00	6.00	10.00
28.	Average number of hours/day that overlay takes place, HPD	4.00	8.00	12.00
29.	Type of road under consideration, ITYPE (input 1 for rural or 2 for urban road)	1	1	1
30.	Percent of vehicles stopped in overlay zone (overlay direction) due to movements of equipment and personnel, PPO2	0.00	5.00	10.00
31.	Percent of vehicles stopped in overlay zone (nonoverlay direction) due to movements of equipment and personnel, PPN2	0.00	5.00	10.00
32.	Average delay/vehicle stopped in overlay zone (overlay direction) due to equipment and personnel (hours), DDO2	0.00	0.10	0.30

* Symbols as used in the computer program and given in Guide for Data Input in Refs 1, 2, and 3.

(Continued)

TABLE A1. (Continued)

Var. No.	Variable Name	Low	Average	High
33.	Average delay/vehicle stopped in overlay zone (nonoverlay direction) due to equipment and personnel (hours), DDN2*	0.00	0.10	0.30
34.	Average approach speed (miles per hour), AAS	40.00	50.00	60.00
35.	Average through speed in overlay direction (miles per hour), ASO	50.00	30.00	10.00
36.	Average through speed in non-overlay direction (miles per hour), ASN	50.00	40.00	10.00
37.	Model number describing the traffic situation, MODEL	3	3	3
38.	Cost per lane mile for routine maintenance during the first year after initial or overlay construction (dollars), CM1	0.00	50.00	100.00
39.	Annual increment in cost per lane mile for routine maintenance (dollars per year), CM2	10.00	20.00	30.00
40.	Cost per lane mile of a seal coat (dollars), SC	687.00	857.00	1108.00
41.	Width of each lane (feet), XLW	12.00	12.00	12.00
42.	In-place cost (dollars per compacted cubic yard) of			
	First material	6.00	10.00	15.00
	Second material	2.00	5.00	8.00
	Third material	0.50	2.00	3.00
43.	Strength coefficient of			
	First material	1.00	0.75	0.50
	Second material	1.00	0.70	0.40
	Third material	0.50	0.40	0.30
	Subgrade	0.35	0.25	0.15

* Symbols as used in the computer program and given in Guide for Data Input in Refs 1, 2, and 3.

(Continued)

TABLE A1. (Continued)

Var. No.	Variable Name	Low	Average	High
44.	Minimum allowable thickness in initial construction (inches) of			
	First material	0.50	1.00	1.50
	Second material	4.00	6.00	8.00
	Third material	4.00	6.00	8.00
45.	Maximum allowable thickness in initial construction (inches) of			
	First material	12.00	6.00	4.00
	Second material	32.00	16.00	8.00
	Third material	32.00	16.00	8.00

TABLE A2. SUBSEQUENT REVISIONS TO THE NUMERICAL VALUES (SHOWN IN TABLE 1A) OF SOME VARIABLES AT LOW AND HIGH LEVELS

Var. No.	Variable Name	At Low Level Solutions			At High Level Solutions		
		Low	Avg.	High	Low	Avg.	High
2	Initial funds available	5.00	4.00	1.40	#1	#1	5.00
3	Analysis period	20.00	#3	#3	#3	#3	20.00
8	Total thickness allowable	11.00	#2	#2	#3	#3	40.00
12	No-traffic lowest SI	3.00	1.50	0.00	#1	#1	1.50
13	Swelling clay parameter				#1	#1	0.10
14	Total equiv. 18-kip axles				6×10^4	4×10^6	6×10^6
15	Initial ADT	100	10,000	22,500	100	#1	10,000
16	Final ADT	200	20,000	30,000	#1	#1	20,000
17	Time to first overlay				#1	#1	3.00
18	Time between overlays				#1	#1	5.00
24	Dist. traff. slowed O.D.	0.30	0.50	1.00	0.30	0.50	1.00
25	Dist. traff. slowed N.O.D.	0.30	0.50	1.00	0.30	0.50	1.00
27	% ADT per hour	4.00	6.00	8.00	2.00	6.00	7.00
28	Hours per day of work	5.00	8.00	10.00	4.00	8.00	11.00

* This problem is solved to study the qualitative trend of the output and is not a part of the experiment.
# Variation at this level was not studied due to one or more than one reason outlined in the text, page 10. Numbers show the exact reason(s) corresponding to the numbers shown in the text.

(Continued)

TABLE A2. (Continued)

Var. No.	Variable Name	At Low Level Solutions Low	Avg.	High	At High Level Solutions Low	Avg.	High
42	In-place cost, 3rd material					2.00	3.00
43	Str. coeff., 1st material				#1,2	0.60*	0.65
43	Str. coeff., 2nd material				#1,2	0.55*	0.60
43	Str. coeff., 3rd material				#1,2	0.25*	0.30
43	Str. Coeff., subgrade mat.				#1,2	0.23*	0.25
44	Min. thickness, 1st material				3.00	#2,3	4.00
44	Min. thickness, 2nd material	4.00	6.00	#1	#2,3	#2,3	8.00
44	Min. thickness, 3rd material	4.00	6.00	#1	#2,3	#2,3	8.00
45	Max. thickness, 1st material	6.00	4.00*	3.00*	#3	#3	12.00
45	Max. thickness, 2nd material	10.00	8.00*	6.00*	#3	#3	16.00
45	Max. thickness, 3rd material	10.00	8.00*	6.00*	#3	16.00*	12.00

* This problem is solved to study the qualitative trend of the output and is not a part of the experiment.
# Variation at this level was not studied due to one or more than one reason outlined in the text, page 10. Numbers show the exact reason(s) corresponding to the numbers shown in the text.

TABLE A3. ADDITIONAL INFORMATION ON THE DESIGNED EXPERIMENT

Variable Values Dependent on Length of Analysis Period
(For solutions at average level)

	Low	Average	High
While studying length of analysis period	10	20	35
Values adopted for			
(a) ADT at the end*	15,000	20,000	27,500
(b) Accumulated 18-kip axles**	2,000,000	4,000,000	7,000,000

* 5% growth assumed from the initial value of 10,000.
** 4,000,000 multiplied by 10/20 for low and 35/20 for high values.

Variable Values Dependent on Initial ADT
(For solutions on all levels)

	Low Level			Average Level			High Level		
	Low	Avg	High	Low	Avg	High	Low	Avg	High
While studying ADT at the beginning	100	10,000	22,500	100	10,000	25,000	100	NS	10,000
Values adopted for ADT at the end*	200	20,000	45,000	200	20,000	50,000	200	NS	20,000

* 5 percent growth considered; NS = not studied.

TABLE A4. SENSITIVITY ANALYSIS OPTIMAL COST OUTPUT DATA FOR AVERAGE LEVEL SOLUTIONS

Optimal cost for the basic average-level design = $2.051

Average cost is considered as 100 percent

		Values and Optimal Costs						
		Low Level			Avg.	High Level		
Var. No.	Variable Name	Var. Value	% of Avg. Value	Opt. Cost	Var. Value	Var. Value	% of Avg. Value	Opt. Cost
1.	Number of different materials available.	-	-	-	3	-	-	-
2.	Maximum number of dollars available for initial construction	6.0	150%	2.051	4.00	1.40	35%	2.090
3.	Length of the analysis period	10	50%	1.449	20	35	175%	2.568
4.	Interest rate or time value of money	10%	200%	1.934	5%	0.1%	2%	2.013
5.	Asphaltic concrete production rate	100	133%	2.016	75	50	66.7%	2.122
6.	Asphaltic concrete compacted density	1.6	88.9%	2.036	1.8	2.0	111.1%	2.067
7.	Salvage percent of structural value at the end of analysis period	100%	200%	1.724	50%	0%	0%	2.378
8.	Maximum total thickness of initial construction	40	160%	2.051	25	14	56%	2.051
9.	District temperature constant	40	160%	1.975	25	9	36%	2.258
10.	Initial serviceability index	4.6	109.5%	1.984	4.2	3.8	90.5%	2.136
11.	Minimum allowable serviceability index	1.5	60%	1.872	2.5	3.0	120%	2.188

Dashes indicate that the variable is held constant for all levels.

(Continued)

TABLE A4. (Continued)

Optimal cost for the basic average-level design = $2.051

Var. No.	Variable Name	Low Level: Var. Value	Low Level: % of Avg. Value	Low Level: Opt. Cost	Avg.: Var. Value	High Level: Var. Value	High Level: % of Avg. Value	High Level: Opt. Cost
12.	No-traffic lower bound on the serviceability index	3.0	200%	1.871	1.5	0.0	0%	2.156
13.	Swelling clay parameter	0.00	0%	1.852	0.10	0.24	240%	3.318
14.	One-direction accumulated equivalent 18-kip axles during the analysis period	60,000	1.5%	1.169	4×10^6	10×10^6	250%	2.233
15.	One-direction ADT at beginning of analysis period	100	1%	1.911	10,000	25,000	250%	14.942
16.	One-direction ADT at end of analysis period	10,000	50%	2.002	20,000	30,000	150%	2.123
17.	Minimum time to the first overlay	1	20%	2.090	5	11	220%	2.641
18.	Minimum time between overlays	1	166.7%	2.051	6	10	166.7%	2.101
19.	Minimum time to the first seal coat	10.0	200%	1.941	5.0	2.0	40%	2.134
20.	Minimum time between seal coats	10.0	200%	2.050	5.0	2.0	40%	2.090
21.	Number of open lanes in the overlay direction in the restricted zone	-	-	-	1	-	-	-
22.	Number of open lanes in the non-overlay direction in the restricted zone	-	-	-	2	-	-	-
23.	Number of lanes in each direction	-	-	-	2.0	-	-	-
24.	Centerline distance in the overlay direction over which traffic is slowed	0.25	50%	2.040	0.5	1.0	200%	2.073

Dashes indicate that the variable is held constant for all levels.

(Continued)

TABLE A4. (Continued)

Optimal cost for the basic average-level design = $2.051

		Values and Optimal Costs						
		Low Level			Avg.	High Level		
Var. No.	Variable Name	Var. Value	% of Avg. Value	Opt. Cost	Var. Value	Var. Value	% of Avg. Value	Opt. Cost
25.	Centerline distance in the non-overlay direction in the restricted zone	0.25	50%	2.048	0.5	1.0	200%	2.059
26.	Detoured distance around the overlay zone	-	-	-	0.00	-	-	-
27.	Average percent of ADT passing through the overlay zone during each hour of overlay	2.0%	33.3%	1.957	6.0%	10.0%	166.7%	2.409
28.	Average number of hours/day that overlay takes place	4.0	50.0%	2.051	8.0	12.0	150%	2.051
29.	Type of road under consideration	-	-	-	1	-	-	-
30.	Percent of vehicles stopped in overlay zone (overlay direction) due to equipment and personnel	0.0%	0%	2.030	5.0%	10.0%	200%	2.072
31.	Percent of vehicles stopped in overlay zone (non-overlay direction) due to equipment and personnel	0.0%	0%	2.029	5.0%	10.0%	200%	2.073
32.	Avg. delay/vehicle stopped in overlay zone (overlay direction) due to equipment and personnel	0.0	0%	2.032	0.1	0.3	300%	2.090
33.	Avg. delay/vehicle stopped in overlay zone (non-overlay direction) due to equipment and personnel	0.0	0%	2.032	0.1	0.3	300%	2.090
34.	Average approach speed	40	80%	1.985	50	60	120%	2.134
35.	Average thru speed in overlay direction	50	166.7%	1.988	30	10	33.3%	2.182
36.	Average thru speed in nonoverlay direction	50	125%	2.020	40	10	25%	2.199
37.	Model number describing the traffic situation	-	-	-	III	-	-	-

Dashes indicate that the variable is held constant for all levels.

(Continued)

TABLE A4. (Continued)

Optimal cost for the basic average-level design = $2.051

		Values and Optimal Costs						
		Low Level			Avg.	High Level		
Var. No.	Variable Name	Var. Value	% of Avg. Value	Opt. Cost	Var. Value	Var. Value	% of Avg. Value	Opt. Cost
38.	Cost per lane mile for maintenance for first year after initial or overlay construction	0.0	0%	1.958	50.0	100.0	200%	2.144
39.	Annual increment in cost per lane mile for routine maintenance	10.0	50%	2.001	20.0	30.0	150%	2.101
40.	Cost per lane mile of a seal coat	687	80.2%	2.037	857	1108	129.5%	2.072
41.	Width of each lane	-	-	-	12	-	-	-
42.	In-place cost per compacted cubic yard							
	First material	6.0	60%	1.773	10.0	15.0	150%	2.342
	Second material	2.0	40%	1.453	5.0	8.0	160%	2.279
	Third material	0.5	25%	1.764	2.0	3.0	150%	2.051
43.	Strength coefficient of the materials							
	First material	1.0	133.3%	1.994	0.75	0.5	66.7%	2.107
	Second material	1.0	142.9%	1.789	0.70	0.4	57.1%	2.279
	Third material	0.5	125%	1.737	0.4	0.3	75%	2.051
	Subgrade	0.35	140%	1.598	0.25	0.15	60%	3.045

Dashes indicate that the variable is held constant for all levels.

(Continued)

TABLE A4. (Continued)

Optimal cost for the basic average-level design = $2.051

Var. No.	Variable Name	Low Level Var. Value	Low Level % of Avg. Value	Low Level Opt. Cost	Avg. Var. Value	High Level Var. Value	High Level % of Avg. Value	High Level Opt. Cost
44.	Minimum allowable thickness in initial construction							
	First material	0.5	50%	1.949	1.0	1.5	150%	2.131
	Second material	4.0	66.7%	2.026	6.0	8.0	133%	2.049
	Third material	4.0	66.7%	2.030	6.0	8.0	133%	2.051
45.	Maximum allowable thickness in initial construction							
	First material	12.0	200%	2.051	6.0	4.0	66.7%	2.051
	Second material	32.0	200%	2.051	16.0	8.0	50%	2.090
	Third material	32.0	200%	2.051	16.0	8.0	50%	2.051

TABLE A5. SENSITIVITY ANALYSIS OPTIMAL COST OUTPUT DATA FOR LOW LEVEL SOLUTIONS

Optimal cost for the basic low-level design = $0.195

		Values and Optimal Costs				
		Low Level	Average Level		High Level	
Var. No.	Variable Name	Var. Value	Var. Value	Opt. Cost	Var. Value	Opt. Cost
1.	Number of different materials available	3	-	-	-	-
2.	Maximum number of dollars available for initial construction	5.00	4.00	0.195	1.40	0.195
3.	Length of the analysis period	20.00	#	#	#	#
4.	Interest rate or time value of money	10.00	5.00	0.259	0.10	0.358
5.	Asphaltic concrete production rate	100.0	75.0	0.195	50.0	0.195
6.	Asphaltic concrete compacted density	1.60	1.80	0.195	2.00	0.195
7.	Salvage percent of structural value at the end of the analysis period	100.0	50.0	0.201	0.0	0.208
8.	Maximum total thickness of initial construction	11.0	#	#	#	#

Dashes indicate that the variable is held constant for all levels.

* This problem is solved to study the qualitative trend of the output and is not a part of the experiment.

Variation at this level was not studied (refer to Table 2A).

(Continued)

TABLE A5. (Continued)

Optimal cost for the basic low-level design = $0.195

		Values and Optimal Costs				
		Low Level	Average Level		High Level	
Var. No.	Variable Name	Var. Value	Var. Value	Opt. Cost	Var. Value	Opt. Cost
9.	District temperature constant	40.00	25.0	0.195	9.0	0.195
10.	Initial serviceability index	4.6	4.2	0.195	3.8	0.195
11.	Minimum allowable serviceability index	1.5	2.5	0.195	3.0	0.195
12.	No-traffic lower bound on the serviceability index	3.00	1.50	0.195	0.0	0.195
13.	Swelling clay parameter	0.00	0.10	0.195	0.24	0.195
14.	One-direction accumulated equivalent 18-kip axles during the analysis period	6×10^4	4×10^6	0.221	10×10^6	0.267
15.	One-direction ADT at beginning of analysis period	100	10×10^3	0.195	22,500	0.195
16.	One-direction ADT at end of analysis period	200	20,000	0.195	30,000	0.195
17.	Minimum time to the first overlay	1.0	5.0	0.195	11.0	0.195

Dashes indicate that the variable is held constant for all levels.

* This problem is solved to study the qualitative trend of the output and is not a part of the experiment.

Variation at this level was not studied (refer to Table 2A).

(Continued)

TABLE A5. (Continued)

Optimal cost for the basic low-level design = $0.195

		Values and Optimal Costs				
		Low Level	Average Level		High Level	
Var. No.	Variable Name	Var. Value	Var. Value	Opt. Cost	Var. Value	Opt. Cost
18.	Minimum time between overlays	1.0	6.0	0.195	10.0	0.195
19.	Minimum time to the first seal coat	10.0	5.0	0.241	2.0	0.269
20.	Minimum time between seal coats	10.0	5.0	0.219	2.0	0.291
21.	Number of open lanes in the overlay direction in the restricted zone	1	-	-	-	-
22.	Number of open lanes in the non-overlay direction in the restricted zone	2	-	-	-	-
23.	Number of lanes in each direction	2	-	-	-	-
24.	Centerline distance in the overlay direction over which traffic is slowed	0.30	0.50	0.195	01.0	0.195
25.	Centerline distance in the non-overlay direction over which traffic is slowed	0.30	0.50	0.195	01.0	0.195

Dashes indicate that the variable is held constant for all levels.

* This problem is solved to study the qualitative trend of the output and is not a part of the experiment.

Variation at this level was not studied (refer to Table 2A).

(Continued)

TABLE A5. (Continued)

Optimal cost for the basic low-level design = $0.195

		Values and Optimal Costs				
		Low Level	Average Level		High Level	
Var. No.	Variable Name	Var. Value	Var. Value	Opt. Cost	Var. Value	Opt. Cost
26.	Detoured distance around the overlay zone	0.0	-	-	-	-
27.	Average percent of ADT passing through the overlay zone during each hour of overlay	4.0	6.0	0.195	8.0	0.195
28.	Average number of hours/day that overlay takes place	5.0	8.0	0.195	10.0	0.195
29.	Type of road consideration	1	-	-	-	-
30.	Percent of vehicles stopped in overlay zone (overlay direction) due to equipment and personnel	0.0	5.0	0.195	10.0	0.195
31.	Percent of vehicles stopped in overlay zone (non-overlay direction) due to equipment and personnel	0.0	5.0	0.195	10.0	0.195

Dashes indicate that the variable is held constant for all levels.

* This problem is solved to study the qualitative trend of the output and is not a part of the experiment.

Variation at this level was not studied (refer to Table 2A).

(Continued)

TABLE A5. (Continued)

Optimal cost for the basic low-level design = $0.195

Var. No.	Variable Name	Low Level Var. Value	Average Level Var. Value	Average Level Opt. Cost	High Level Var. Value	High Level Opt. Cost
32.	Average delay/vehicle stopped in overlay zone (overlay direction) due to equipment and personnel	0.0	0.1	0.195	0.3	0.195
33.	Average delay/vehicle stopped in overlay zone (non-overlay direction) due to equipment and personnel	0.00	0.1	0.195	0.3	0.195
34.	Average approach speed	40.0	50.0	0.195	60.0	0.195
35.	Average through speed in overlay direction	50.0	30.0	0.195	10.0	0.195
36.	Average through speed in non-overlay direction	50.0	40.0	0.195	10.0	0.195
37.	Model number describing the traffic situation	3	-	-	-	-

Dashes indicate that the variable is held constant for all levels.

* This problem is solved to study the qualitative trend of the output and is not a part of the experiment.

Variation at this level was not studied (refer to Table 2A).

(Continued)

TABLE A5. (Continued)

Optimal cost for the basic low-level design = $0.195

		Values and Optimal Costs				
		Low Level	Average Level		High Level	
Var. No.	Variable Name	Var. Value	Var. Value	Opt. Cost	Var. Value	Opt. Cost
38.	Cost per lane mile for maintenance during first year after initial or overlay construction	0.00	50.00	0.262	100.00	0.328
39.	Annual increment in cost per lane mile for routine maintenance	10.00	20.00	0.282	30.00	0.368
40.	Cost per lane mile of a seal coat	687.00	857.00	0.204	1108.00	0.218
41.	Width of each lane	12	-	-	-	-
42.	In-place cost per compacted cubic yard					
	First material	6.00	10.00	0.242	15.00	0.302
	Second material	2.00	5.00	0.195	8.00	0.195
	Third material	0.50	2.00	0.195	3.00	0.195

Dashes indicate that the variable is held constant for all levels.

* This problem is solved to study the qualitative trend of the output and is not a part of the experiment.

Variation at this level was not studied (refer to Table 2A).

(Continued)

TABLE A5. (Continued)

Optimal cost for the basic low-level design = $0.195

		Values and Optimal Costs				
		Low Level	Average Level		High Level	
Var. No.	Variable Name	Var. Value	Var. Value	Opt. Cost	Var. Value	Opt. Cost
43.	Strength coefficient of the materials					
	First material	1.00	00.75	0.195	0.50	0.195
	Second material	1.00	0.70	0.195	0.40	0.195
	Third material	0.50	0.40	0.195	0.30	0.195
	Subgrade	0.35	0.25	0.195	0.15	0.304
44.	Minimum allowable thickness in initial construction					
	First material	0.50	1.00	0.266	1.50	0.337
	Second material	4.00	6.00	0.195	8.00	#
	Third material	4.00	6.00	0.195	8.00	#

Dashes indicate that the variable is held constant for all levels.

* This problem is solved to study the qualitative trend of the output and is not a part of the experiment.

Variation at this level was not studied (refer to Table 2A).

(Continued)

TABLE A5. (Continued)

Optimal cost for the basic low-level design = $0.195

Var. No.	Variable Name	Low Level: Var. Value	Average Level: Var. Value	Average Level: Opt. Cost	High Level: Var. Value	High Level: Opt. Cost
45.	Maximum allowable thickness in initial construction					
	First material	6.00	4.00*	0.195	3.00*	0.195
	Second material	10.00	8.00*	0.195	6.00*	0.195
	Third material	10.00	8.00*	0.195	6.00*	0.195

Dashes indicate that the variable is held constant for all levels.

* This problem is solved to study the qualitative trend of the output and is not a part of the experiment.

Variation at this level was not studied (refer to Table 2A).

TABLE A6. SENSITIVITY ANALYSIS OPTIMAL COST OUTPUT DATA FOR HIGH LEVEL SOLUTIONS

Optimal cost for the basic high-level design = $13.289

Var. No.	Variable Name	Values and Optimal Costs				
		Low Level		Average Level		High Level
		Var. Value	Opt. Cost	Var. Value	Opt. Cost	Var. Value
1.	Number of different materials available	-	-	-	-	3
2.	Maximum number of dollars available for initial construction	#	#	#	#	5.0
3.	Length of the analysis period	#	#	#	#	20.0
4.	Interest rate or time value of money	10.0	8.601	5.0	10.310	0.1
5.	Asphaltic concrete production rate	100.0	10.760	75.0	11.603	50.0
6.	Asphaltic concrete compacted density	1.6	12.278	1.8	12.783	2.0
7.	Salvage percent of structural value at the end of the analysis period	100.0	7.789	50.0	10.539	0.0
8.	Maximum total thickness of initial construction	#	#	#	#	40.0

Dashes indicate that the variable is held constant for all levels.

* This problem is solved to study the qualitative trend of the output and is not a part of the experiment.

Variation at this level was not studied (refer to Table 2A).

(Continued)

TABLE A6. (Continued)

Optimal cost for the basic high-level design = $13.289

Var. No.	Variable Name	Low Level Var. Value	Low Level Opt. Cost	Average Level Var. Value	Average Level Opt. Cost	High Level Var. Value
9.	District temperature constant	40.0	10.244	25.0	10.694	9.0
10.	Initial serviceability index	4.6	10.159	4.2	10.692	3.8
11.	Minimum allowable serviceability index	1.5	8.515	2.5	10.793	3.0
12.	No-traffic lower bound on the serviceability index	#	#	#	#	1.50
13.	Swelling clay parameter	#	#	#	#	0.1
14.	One-direction accumulated equivalent 18-kip axles during the analysis period	6×10^4	8.819	4×10^6	12.820	6×10^6
15.	One-direction ADT at beginning of analysis period	100	8.282	#	#	10,000
16.	One-direction ADT at end of analysis period	#	#	#	#	20,000

Dashes indicate that the variable is held constant for all levels.

* This problem is solved to study the qualitative trend of the output and is not a part of the experiment.

Variation at this level was not studied (refer to Table 2A).

(Continued)

TABLE A6. (Continued)

Optimal cost for the basic high-level design = $13.289

		Values and Optimal Costs				
		Low Level		Average Level		High Level
Var. No.	Variable Name	Var. Value	Opt. Cost	Var. Value	Opt. Cost	Var. Value
17.	Minimum time to the first overlay	#	#	#	#	3.0
18.	Minimum time between overlays	#	#	#	#	5.0
19.	Minimum time to the first seal coat	10.0	12.354	5.0	12.509	2.0
20.	Minimum time between seal coats	10.0	12.978	5.0	12.978	2.0
21.	Number of open lanes in the overlay direction in the restricted zone	-	-	-	-	1
22.	Number of open lanes in the non-overlay direction in the restricted zone	-	-	-	-	2
23.	Number of lanes in each direction	-	-	-	-	2.0
24.	Centerline distance in the overlay direction over which traffic is slowed	0.3	12.206	0.5	12.567	1.0

Dashes indicate that the variable is held constant for all levels.

* This problem is solved to study the qualitative trend of the output and is not a part of the experiment.

Variation at this level was not studied (refer to Table 2A).

(Continued)

TABLE A6. (Continued)

Optimal cost for the basic high-level design = $13.289

Var. No.	Variable Name	Values and Optimal Costs				
		Low Level		Average Level		High Level
		Var. Value	Opt. Cost	Var. Value	Opt. Cost	Var. Value
25.	Centerline distance in the non-overlay direction over which traffic is slowed	0.3	12.206	0.5	12.567	1.0
26.	Detoured distance around the overlay zone	-	-	-	-	0.0
27.	Average percent of ADT passing through the overlay zone during each hour of overlay	2.0	9.677	6.0	12.567	7.0
28.	Average number of hours/day that overlay takes place	4.0	13.289	8.0	13.289	11.0
29.	Type of road consideration	-	-	-	-	1
30.	Percent of vehicles stopped in overlay zone (overlay direction) due to equipment and personnel	0.0	12.750	5.0	13.019	10.0

Dashes indicate that the variable is held constant for all levels.

* This problem is solved to study the qualitative trend of the output and is not a part of the experiment.

Variation at this level was not studied (refer to Table 2A).

(Continued)

TABLE A6. (Continued)

Optimal cost for the basic high-level design = $13.289

Var. No.	Variable Name	Low Level: Var. Value	Low Level: Opt. Cost	Average Level: Var. Value	Average Level: Opt. Cost	High Level: Var. Value
31.	Percent of vehicles stopped in overlay zone (non-overlay direction) due to equipment and personnel	0.0	12.750	5.0	13.019	10.0
32.	Average delay/vehicle stopped in overlay zone (overlay direction) due to equipment and personnel	0.0	12.754	0.1	12.932	0.3
33.	Average delay/vehicle stopped in overlay zone (non-overlay direction) due to equipment and personnel	0.0	12.754	0.1	12.932	0.3
34.	Average approach speed	40.0	12.410	50.0	12.819	60.0
35.	Average through speed in overlay direction	50.0	11.528	30.0	11.933	10.0
36.	Average through speed in non-overlay direction	50.0	11.528	40.0	11.705	10.0

Dashes indicate that the variable is held constant for all levels.

* This problem is solved to study the qualitative trend of the output and is not a part of the experiment.

Variation at this level was not studied (refer to Table 2A).

(Continued)

TABLE A6. (Continued)

Optimal cost for the basic high-level design = $13.289

Var. No.	Variable Name	Low Level: Var. Value	Low Level: Opt. Cost	Average Level: Var. Value	Average Level: Opt. Cost	High Level: Var. Value
37.	Model number describing the traffic situation	-	-	-	-	3
38.	Cost per lane mile for routine maintenance during first year after initial or overlay construction	0.0	13.008	50.0	13.149	100.0
39.	Annual increment in cost per lane mile for routine maintenance	10.0	13.174	20.0	13.232	30.0
40.	Cost per lane mile of a seal coat	687.0	12.934	857.0	13.077	1108.0
41.	Width of each lane	-	-	-	-	12.0
42.	In-place cost per compacted cubic yard					
	First material	6.0	9.507	10.0	11.961	15.0
	Second material	2.0	9.890	5.0	11.966	8.0
	Third material	#	#	2.0	13.170	3.0

Dashes indicate that the variable is held constant for all levels.

* This problem is solved to study the qualitative trend of the output and is not a part of the experiment.

\# Variation at this level was not studied (refer to Table 2A).

(Continued)

TABLE A6. (Continued)

Optimal cost for the basic high-level design = $13.289

Var. No.	Variable Name	Low Level Var. Value	Low Level Opt. Cost	Average Level Var. Value	Average Level Opt. Cost	High Level Var. Value
43.	Strength coefficient of the material					
	First material	#	#	0.60*	14.717	0.65
	Second material	#	#	0.55*	15.878	0.60
	Third material	#	#	0.25*	13.289	0.30
	Subgrade	#	#	0.23*	15.994	0.25
44.	Minimum allowable thickness in initial construction					
	First material	3.0*	13.069	#	#	4.0
	Second material	#	#	#	#	8.0
	Third material	#	#	#	#	

Dashes indicate that the variable is held constant for all levels.

* This problem is solved to study the qualitative trend of the output and is not a part of the experiment.

Variation at this level was not studied (refer to Table 2A).

(Continued)

TABLE A6. (Continued)

Optimal cost for the basic high-level design = $13.289

		Values and Optimal Costs				
		Low Level		Average Level		High Level
Var. No.	Variable Name	Var. Value	Opt. Cost	Var. Value	Opt. Cost	Var. Value
45.	Maximum allowable thickness in initial construction					
	First material	#	#	#	#	12.0
	Second material	#	#	#	#	16.0
	Third material	#	#	16.0*	13.289	12.0

Dashes indicate that the variable is held constant for all levels.

* This problem is solved to study the qualitative trend of the output and is not a part of the experiment.

Variation at this level was not studied (refer Table 2A).

TABLE A7. DATA ON COST BREAKDOWN OF OPTIMAL DESIGNS FOR PROBLEMS SOLVED AT AVERAGE LEVEL

Variable					Optimal Design No.	Various Construction Costs for Most Optimal Design, $						
No.	Name	Average Value	Value for Problem	Solution Level		Initial	Overlay	Traffic Delay	Seal Coats	Main-tenance	Salvage	Total
00	Basic solution			avg	2	1.451	.521	.141	.071	.193	-.327	2.051
01	No. of materials	3	-	-	-	-	-	-	-	-	-	-
			-	-	-	-	-	-	-	-	-	-
02	Dollars available	4.00	6.0	low	*	*	*	*	*	*	*	*
			1.4	high	*	1.381	.558	.147	.128	.190	-.314	2.090
03	Analysis period	20.00	10.0	low	4	1.444	.311	.075	.000	.105	-.486	1.449
			35.0	high	*	1.381	.694	.211	.172	.287	-.176	2.568
04	Interest rate, %	5.00	10.0	low	*	*	.345	.091	.043	.133	-.129	1.934
			0.1	high	4	1.804	.413	.111	.241	.396	-.953	2.013
05	AC production rate	75.00	100.0	low	*	*	*	.106	*	*	*	2.016
			50.0	high	*	*	*	.212	*	*	*	2.122
06	AC compacted density	1.80	1.6	low	*	*	*	.126	*	*	*	2.036
			2.0	high	*	*	*	.157	*	*	*	2.067
07	Salvage value, %	50.00	100.0	low	*	*	*	*	*	*	-.654	1.724
			0.0	high	*	*	*	*	*	*	.000	2.378
08	Maximum total thickness	25.00	40.0	low	*	*	*	*	*	*	*	*
			14.0	high	*	*	*	*	*	*	*	*
09	District temp. constant	25.00	40.0	low	*	1.241	.558	.146	.128	.190	-.288	1.975
			9.0	high	4	1.634	.532	.140	.122	.190	-.361	2.258

Dashes indicate that the variable was held constant for all levels.

An asterisk indicates that the value did not change from the corresponding value computed for the basic solution.

(Continued)

TABLE A7. (Continued)

Variable					Optimal Design No.	Various Construction Costs for Most Optimal Design						
No.	Name	Average Value	Value for Problem	Solution Level		Initial	Overlay	Traffic Delay	Seal Coats	Main-tenance	Salvage	Total
00	Basic solution			avg	2	1.451	.521	.141	.071	.193	-.327	2.051
10	Initial serviceability index	4.20	4.6	low	*	1.311	*	.140	.119	*	-.301	1.984
			3.8	high	4	1.554	*	*	*	*	-.345	2.136
11	Final serviceability index	2.50	1.5	low	4	1.444	.256	.070	.154	.245	-.298	1.872
			3.0	high	4	1.504	.558	.145	.128	.190	-.338	2.188
12	No-traffic lower bound on serviceability	1.50	3.0	low	4	1.444	.256	.070	.154	.245	-.298	1.871
			0.0	high	4	1.464	.558	.145	.128	.190	-.330	2.156
13	Swelling clay parameter	0.10	0.0	low	4	1.524	.000	.000	.229	.387	-.288	1.852
			0.24	high	4	3.134	.326	.076	.133	.265	-.618	3.318
14	Total 18-kip axles	4×10^6	60,000	low	1	.278	.497	.138	.163	.198	-1.05	1.169
			10×10^6	high	4	1.604	.532	.140	.122	.190	-.356	2.233
15	Initial ADT	10,000	100	low	*	*	*	.001	*	*	*	1.911
			25,000	high	4	1.624	.282	12.914	.211	.244	-.332	14.942
16	Final ADT	20,000	10,000	low	4	1.444	*	.097	*	*	-.325	2.002
			30,000	high	4	1.624	.282	.095	.211	.244	-.332	2.123
17	Min. time to first overlay	5.00	1.0	low	*	1.381	.558	.147	.128	.190	-.314	2.090
			11.0	high	4	2.314	.244	.070	.226	.250	-.463	2.641
18	Min. time between overlays	6.00	1.0	low	*	*	*	*	*	*	*	*
			10.0	high	4	1.624	.282	.073	.211	.244	-.332	2.101
19	Min. time to first seal coat	5.00	10.0	low	4	1.624	.282	.073	.051	.244	-.332	1.941
			2.0	high	4	1.624	.282	.073	.244	.244	-.332	2.134
20	Min. time between seal coats	5.00	10.0	low	4	1.624	.282	.073	.160	.244	-.332	2.050
			2.0	high	*	1.381	.558	.147	.128	.190	-.314	2.090

Dashes indicate that the variable was held constant for all levels.

An asterisk indicates that the value did not change from the corresponding value computed for the basic solution.

(Continued)

TABLE A7. (Continued)

Variable					Optimal Design No.	Various Construction Costs for Most Optimal Design						
No.	Name	Average Value	Value for Problem	Solution Level		Initial	Overlay	Traffic Delay	Seal Coats	Main-tenance	Salvage	Total
00	Basic solution			avg	2	1.451	.521	.141	.071	.193	-.327	2.051
	Open lanes in		1	-	-	-	-	-	-	-	-	-
21	O.D. in R. zone	1	1	-	-	-	-	-	-	-	-	-
	Open lanes in		2	-	-	-	-	-	-	-	-	-
22	N.O.D. in R. zone	2	2	-	-	-	-	-	-	-	-	-
	Lanes in each		2	-	-	-	-	-	-	-	-	-
23	direction	2	2	-	-	-	-	-	-	-	-	-
	Distance traffic		0.25	low	*	*	*	.130	*	*	*	2.040
24	slowed in O.D.	0.50	1.00	high	*	*	*	.164	*	*	*	2.073
	Distance traffic		0.25	low	*	*	*	.138	*	*	*	2.048
25	slowed in N.O.D.	0.51	1.00	high	*	*	*	.149	*	*	*	2.059
	Detoured		0.0	-	-	-	-	-	-	-	-	-
26	distance	0.00	0.0	-	-	-	-	-	-	-	-	-
	Percent of ADT		2.0	low	*	*	*	.047	*	*	*	1.957
27	each hour	6.00	10.0	high	4	1.494	.592	.246	.216	.247	-.387	2.409
			4.0	low	*	*	*	*	*	*	*	*
28	Work hours/day	8.00	12.0	high	*	*	*	*	*	*	*	*
			-	-	-	-	-	-	-	-	-	-
29	Type of road	Rural	-	-	-	-	-	-	-	-	-	-
	Percent vehicles		0.0	low	*	*	*	.120	*	*	*	2.030
30	stopped in O.D.	5.00	10.0	high	*	*	*	.162	*	*	*	2.072
	Percent vehicles		0.0	low	*	*	*	.119	*	*	*	2.029
31	stopped in N.O.D.	5.00	10.0	high	*	*	*	.163	*	*	*	2.073

Dashes indicate that the variable was held constant for all levels.

An asterisk indicates that the value did not change from the corresponding value computed for the basic solution.

(Continued)

TABLE A7. (Continued)

Variable					Optimal Design No.	Various Construction Costs for Most Optimal Design						
No.	Name	Average Value	Value for Problem	Solution Level		Initial	Overlay	Traffic Delay	Seal Coats	Main-tenance	Salvage	Total
00	Basic solution			avg	2	1.451	.521	.141	.071	.193	-.327	2.051
	Delay/vehicle		0.0	low	*	*	*	.122	*	*	*	2.032
32	in O.D.	0.10	0.3	high	*	*	*	.180	*	*	*	2.090
	Delay/vehicle		0.0	low	*	*	*	.122	*	*	*	2.032
33	in N.O.D.	0.10	0.3	high	*	*	*	.180	*	*	*	2.090
	Approach		40.0	low	*	*	*	.075	*	*	*	1.985
34	speed	50.00	60.0	high	*	*	*	.224	*	*	*	2.134
	Thru speed		50.0	low	*	*	*	.078	*	*	*	1.988
35	in O.D.	30.00	10.0	high	4	1.624	.282	.154	.211	.244	-.332	2.182
	Thru speed		50.0	low	*	*	*	.111	*	*	*	2.020
36	in N.O.D.	40.00	10.0	high	4	1.624	.282	.171	.211	.244	-.332	2.199
			-	-	-	-	-	-	-	-	-	-
37	Model number	III	-	-	-	-	-	-	-	-	-	-
	Routine		0.0	low	*	*	*	*	*	.100	-.327	1.958
38	maintenance	50.00	100.0	high	*	*	*	*	*	.286	-.327	2.144
	Increment in		10.0	low	*	*	*	*	*	.143	*	2.001
39	routine maint.	20.00	30.0	high	*	*	*	*	*	.244	*	2.101
	Cost of a		687.0	low	*	*	*	*	.057	*	*	2.037
40	seal coat	857.00	1108.0	high	*	*	*	*	.092	*	*	2.072
	Width of		-	-	-	-	-	-	-	-	-	-
41	each lane	12.00	-	-	-	-	-	-	-	-	-	-
42	In place cost		6.00	low	*	1.340	.313	*	*	*	-.285	1.773
42I	First material	10.00	15.00	high	4	1.763	.423	.073	.211	.244	-.372	2.342

Dashes indicate that the variable was held constant for all levels.

An asterisk indicates that the value did not change from the corresponding value computed for the basic solution.

(Continued)

TABLE A7. (Continued)

	Variable				Optimal Design No.	Various Construction Costs for Most Optimal Design						
No.	Name	Average Value	Value for Problem	Solution Level		Initial	Overlay	Traffic Delay	Seal Coats	Main-tenance	Salvage	Total
00	Basic solution			avg	2	1.451	.521	.141	.071	.193	-.327	2.051
			2.00	low		.911	.269	.072	.157	.243	-.199	1.453
42II	Second material	5.00	8.00	high	3	1.661	.532	.140	.122	.190	-.366	2.279
			0.50	low	4	1.294	.269	.072	.157	.243	-.271	1.764
42III	Third material	2.00	3.00	high	*	*	*	*	*	*	*	*
43	Strength Coeff.		1.00	low	*	1.381	*	*	*	*	-.314	1.994
43I	First material	0.75	0.50	high	4	1.444	.532	.143	.122	.190	-.325	2.107
			1.00	low	*	1.241	.282	.073	.211	.244	-.262	1.789
43II	Second material	0.70	.40	high	3	1.661	.532	.140	.122	.190	-.366	2.279
			.50	low	3	.991	.532	.142	.122	.190	-.241	1.737
43III	Third material	0.40	.30	high	*	*	*	*	*	*	*	*
			.35	low	3	.801	.543	.143	.124	.190	-.204	1.598
43S	Subgrade	0.25	.15	high	4	2.604	.532	*	.122	.190	-.544	3.045
44	Min. allowable thickness											
			0.50	low	4	1.326	*	*	*	*	-.304	1.949
44I	First material	1.00	1.50	high	*	1.450	.547	.144	.125	.192	*	2.131
			4.00	low	4	1.347	.532	*	.122	.190	-.306	2.026
44II	Second material	6.00	8.00	high	*	1.449	*	*	*	*	*	2.049
			4.00	low	4	1.353	.532	*	.122	.190	-.309	2.030
44III	Third material	6.00	8.00	high	*	*	*	*	*	*	*	*

Dashes indicate that the variable was held constant for all levels.

An asterisk indicates that the value did not change from the corresponding value computed for the basic solution.

(Continued)

TABLE A7. (Continued)

		Variable			Optimal	Various Construction Costs for Most Optimal Design						
No.	Name	Average Value	Value for Problem	Solution Level	Design No.	Initial	Overlay	Traffic Delay	Seal Coats	Main-tenance	Salvage	Total
00	Basic solution			avg	2	1.451	.521	.141	.071	.193	-.327	2.051
45	Max. allowable thickness											
			12.00	low	*	*	*	*	*	*	*	*
45I	First material	6.00	4.00	high	*	*	*	*	*	*	*	*
			32.00	low	*	*	*	*	*	*	*	*
45II	Second material	16.00	8.00	high	*	1.381	.558	.147	.128	.190	-.314	2.090
			32.00	low	*	*	*	*	*	*	*	*
45III	Third material	16.00	8.00	high	*	*	*	*	*	*	*	*

Dashes indicate that the variable was held constant for all levels.

An asterisk indicates that the value did not change from the corresponding value computed for the basic solution.

TABLE A8. DESIGN THICKNESS AND FEASIBLE DESIGN ANALYSIS FOR AVERAGE LEVEL SOLUTIONS

Variable					Design Number 1, 1st Material		Design Number 2, 1st+2nd Materials		Design Number 3, 1st+3rd Materials		Design Number 4, 1st+2nd+3rd Materials		Optimal Design	
No.	Name	Average Value	Sol. Level	Value for Prob.	Thickness	Feasible Designs	Thicknesses	Feasible Designs	Thicknesses	Feasible Designs	Thicknesses	Feasible Designs	Design No.	Total Feasible Designs
0	Basic solution				NFD	NFD	1.0+ 8.5	33	3.0+15.0	28	1.0+ 6.5+ 8.0	124	2	185
2	Available initial funds	4.00	Low	6.0	1.0	3	*	*	*	29	*	*	*	189
			High	1.4	*	*	1.0+ 8.0	1	NFD	NFD	NFD	NFD	*	1
3	Analysis period	20.00	Low	10.0	*	*	*	32	*	26	1.0+ 6.0+ 6.0	*	4	182
			High	35.0	*	*	1.0+ 8.0	34	2.5+16.0	30	1.0+ 6.0+ 8.0	*	*	188
4	Interest rate	5.00	Low	10.0	*	*	*	*	*	*	1.0+ 6.0+ 6.0	*	*	*
			High	0.1	*	*	1.0+11.5	*	3.0+14.50	*	1.0+ 8.0+ 7.5	*	4	*
5	Concrete prod. rate	75.00	Low	100.0	*	*	*	*	*	*	*	*	*	*
			High	50.0	*	*	*	*	*	*	*	*	*	*
6	Conc. comp. density	1.80	Low	1.60	*	*	*	*	*	*	*	*	*	*
			High	2.00	*	*	*	*	*	*	*	*	*	*
7	Salvage value	50.00	Low	100.0	*	*	*	*	*	*	*	*	*	*
			High	0.0	*	*	*	*	*	*	*	*	*	*
8	Max. allowable thickness	25.00	Low	40.0	*	*	*	*	*	*	*	162	*	223
			High	14.0	*	*	*	19	5.0+ 8.5	7	1.0+ 6.0+ 6.5	8	*	34
9	District temp. constant	25.00	Low	40.0	*	*	1.0+ 7.0	35	2.0+15.0	33	1.0+ 6.0+ 7.0	*	*	192
			High	9.0	*	*	1.0+10.5	29	5.0+14.5	13	1.0+ 7.0+ 7.0	116	4	158
10	Initial SI	4.20	Low	4.6	*	*	1.0+ 7.5	35	2.0+15.0	32	1.0+ 6.0+ 8.5	*	*	191
			High	3.8	*	*	1.0+ 9.0	31	4.0+14.0	21	1.0+ 6.0+ 8.0	*	4	176
11	Minimum SI	2.50	Low	1.5	*	*	*	36	1.0+16.0	36	1.0+ 6.0+ 6.0	*	4	196
			High	3.0	*	*	1.0+ 9.5	30	4.0+16.0	17	1.0+ 6.5+ 6.0	121	4	168
12	No-traffic lowest SI	1.50	Low	3.0	*	*	1.0+ 9.0	35	1.5+16.0	33	1.0+ 6.0+ 6.0	*	4	192
			High	0.0	*	*	1.0+ 9.0	31	4.0+15.0	19	1.0+ 6.0+ 6.5	123	4	173
13	Swelling clay parameter BONE		Low	0.0	*	*	1.0+ 7.5	36	1.0+15.0	38	1.0+ 6.0+ 7.5	*	4	198
				.14	*	*	1.0+ 9.5	31	*	22	1.0+ 6.0+ 7.0	*	4	177
				.16	*	*	1.0+ 9.5	30	4.5+14.0	17	1.0+ 6.0+ 7.5	122	4	169
				.18	*	*	1.0+10.0	29	4.5+16.0	13	1.0+ 6.0+ 8.5	116	4	158
				.20	*	*	1.0+11.0	27	5.5+15.5	5	1.0+ 7.0+ 8.5	106	4	138

NFD means no feasible design was possible.

Table does not contain those variables which were held constant at all levels.

An asterisk indicates that the value did not change from the corresponding value computed for the basic solution.

(Continued)

TABLE A8. (Continued)

Variable					Design Number 1, 1st Material		Design Number 2, 1st+2nd Materials		Design Number 3, 1st+3rd Materials		Design Number 4, 1st+2nd+3rd Materials		Optimal Design	
No.	Name	Average Value	Sol. Level	Value for Prob.	Thickness	Feasible Designs	Thicknesses	Feasible Designs	Thicknesses	Feasible Designs	Thicknesses	Feasible Designs	Design No.	Total Feasible Designs
0	Basic solution				NFD	NFD	1.0+ 8.5	33	3.0+15.0	28	1.0+ 6.5+ 8.0	124	2	185
13	Swelling clay			.21	*	*	1.0+11.5	26	6.0+16.0	1	1.0+ 8.5+ 6.5	99	4	126
	parameter BONE			.22	*	*	1.0+12.5	24	NFD	NFD	1.0+ 9.5+ 6.5	89	4	113
				.23	*	*	1.0+16.0	20	NFD	NFD	1.0+11.5+ 9.0	73	4	93
			High	.24	*	*	4.5+16.0	6	NFD	NFD	2.0+16.0+ 6.5	13	4	19
		0.10		.25	*	*	NFD	NFD	NFD	NFD	NFD	NFD	NFD	NFD
14	Accumulated		Low	60,000	1.0	11	1.0+ 6.0	37	1.0+ 6.0	54	1.0+ 6.0+ 6.0	*	1	226
	18-kip axles	$4x10^6$	High	$10x10^6$	*	*	1.0+10.0	29	4.5+16.0	15	1.0+ 7.0+ 6.5	118	4	162
			Low	100	*	*	*	*	*	*	1.0+ 6.0+ 6.5	*	*	*
15	Initial ADT	10,000	High	25,000	*	*	1.0+10.5	*	5.0+15.0	*	*	*	4	*
			Low	10,000	*	*	1.0+ 9.0	32	3.0+16.0	24	1.0+ 6.0+ 6.0	*	4	180
16	Final ADT	20,000	High	30,000	*	*	1.0+10.5	34	2.5+16.0	30	*	*	4	188
17	Time to first		Low	1 yr	6.0	5	1.0+ 8.0	37	3.5+15.0	53	*	*	*	219
	overlay	5.00		7 yrs	*	*	1.0+10.5	30	4.5+14.0	16	*	120	4	166
				9 yrs	*	*	1.0+11.5	26	6.0+16.0	1	1.0+ 8.0+ 7.5	100	4	127
			High	11 yrs	*	*	1.0+15.50	18	NFD	NFD	1.0+11.5+ 8.0	63	4	81
				12 yrs	*	*	NFD	NFD	NFD	NFD	NFD	NFD	NFD	NFD
18	Time between		Low	1 yr	*	*	*	*	*	*	*	*	*	*
	overlays	6.00	High	10 yrs	*	*	1.0+10.5	*	*	*	*	*	4	*
19	Time to first		Low	10 yrs	*	*	1.0+ 8.0	*	*	*	*	*	4	*
	seal coat	5.00	High	2 yrs	*	*	1.0+ 8.0	*	*	*	*	*	4	*
20	Time between		Low	10 yrs	*	*	*	*	*	*	*	*	4	*
	seal coats	5.00	High	2 yrs	*	*	1.0+ 8.0	*	*	*	1.0+ 6.0+ 6.5	*	*	*
24	Distance traffic		Low	0.25	*	*	*	*	*	*	*	*	*	*
	slowed in (OD)	0.50	High	1.00	*	*	*	*	*	*	*	*	*	*
25	Distance traffic		Low	0.25	*	*	*	*	*	*	*	*	*	*
	slowed in (NOD)	0.50	High	1.00	*	*	*	*	*	*	*	*	*	*
27	Percent ADT		Low	2.0	*	*	*	*	*	*	1.0+ 6.0+ 6.5	*	*	*
	per hour	6.00	High	10.0	*	*	1.0+ 9.0	*	4.0+16.0	*	1.0+ 6.0+ 7.0	*	4	*
28	Work hours		Low	4.0	*	*	*	*	*	*	*	*	*	*
	per day	8.00	High	12.0	*	*	*	*	*	*	*	*	*	*

NFD means no feasible design was possible.

Table does not contain those variables which were held constant at all levels.

An asterisk indicates that the value did not change from the corresponding value computed for the basic solution.

(Continued)

TABLE A8. (Continued)

Variable					Design Number 1, 1st Material		Design Number 2, 1st+2nd Materials		Design Number 3, 1st+3rd Materials		Design Number 4, 1st+2nd+3rd Materials		Optimal Design	
No.	Name	Average Value	Sol. Level	Value for Prob.	Thickness	Feasible Designs	Thicknesses	Feasible Designs	Thicknesses	Feasible Designs	Thicknesses	Feasible Designs	Design No.	Total Feasible Designs
0	Basic solution				NFD	NFD	1.0+ 8.5	33	3.0+15.0	28	1.0+ 6.5+ 8.0	124	2	185
30	Percent vehicles		Low	0.0	*	*	*	*	*	*	*	*	*	*
	stopped (OD)	5.00	High	10.0	*	*	*	*	*	*	*	*	*	*
31	Percent vehicles		Low	0.0	*	*	*	*	*	*	*	*	*	*
	stopped (NOD)	5.00	High	10.0	*	*	*	*	*	*	*	*	*	*
32	Delay per		Low	0.0	*	*	*	*	*	*	*	*	*	*
	vehicle (OD)	0.10	High	0.3	*	*	*	*	*	*	*	*	*	*
33	Delay per		Low	0.0	*	*	*	*	*	*	*	*	*	*
	vehicle (NOD)	0.10	High	0.3	*	*	*	*	*	*	*	*	*	*
			Low	40.0	*	*	*	*	*	*	1.0+ 6.0+ 6.5	*	*	*
34	Approach speed	50.00	High	60.0	*	*	*	*	*	*	*	*	*	*
			Low	50.0	*	*	*	*	*	*	1.0+ 6.0+ 6.5	*	*	*
35	Speed in OD	30.00	High	10.0	*	*	*	*	*	*	*	*	*	*
			Low	50.0	*	*	*	*	*	*	*	*	*	*
36	Speed in NOD	40.00	High	10.0	*	*	*	*	*	*	*	*	4	*
38	Maintenance		Low	0.0	*	*	*	*	*	*	*	*	*	*
	first year	50.00	High	100.0	*	*	*	*	*	*	*	*	*	*
39	Increment in		Low	10.0	*	*	*	*	*	*	*	*	*	*
	maintenance	20.00	High	30.0	*	*	*	*	*	*	*	*	*	*
			Low	687.0	*	*	*	*	*	*	*	*	*	*
40	Seal coat cost	857.00	High	1108.0	*	*	*	*	*	*	*	*	*	*
42	In-place cost		Low	6.00	*	*	*	122	4.5+10.0	21	1.0+ 6.0+ 6.5	128	*	271
	1st material	10.00	High	15.00	*	*	*	24	*	26	*	118	4	168
	In-place cost		Low	2.00	*	*	1.0+11.5	30	*	*	1.0+ 9.0+ 6.0	35	*	93
	2nd material	5.00	High	8.00	*	*	*	69	*	*	1.0+ 6.0+ 9.5	75	3	172
	In-place cost		Low	0.50	*	*	*	*	2.5+15.5	27	1.0+ 6.0+13.5	75	4	135
	3rd material	2.00	High	3.00	*	*	*	*	3.5+12.5	49	1.0+ 7.5+ 6.0	59	*	141
43	Strength coeff.		Low	1.00	*	*	1.0+ 8.0	37	3.0+12.0	41	1.0+ 6.0+ 8.0	160	*	238
	1st material	0.75	High	0.50	*	*	*	18	5.0+16.0	11	1.0+ 6.0+ 6.0	106	4	135
	Strength coeff.		Low	1.00	*	*	1.0+ 7.0	24	*	*	1.0+ 6.0+ 6.5	65	*	117
	2nd material	0.70	High	.40	*	*	6.0+ 6.0	20	*	*	2.0+ 6.0+13.0	48	3	96

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As asterisk indicates that the value did not change from the corresponding value computed for the basic solution.

(Continued)

TABLE A8. (Continued)

Variable					Design Number 1, 1st Material		Design Number 2, 1st+2nd Materials		Design Number 3, 1st+3rd Materials		Design Number 4, 1st+2nd+3rd Materials		Optimal Design	
No.	Name	Average Value	Sol. Level	Value for Prob.	Thickness	Feasible Designs	Thicknesses	Feasible Designs	Thicknesses	Feasible Designs	Thicknesses	Feasible Designs	Design No.	Total Feasible Designs
0	Basic solution				NFD	NFD	1.0+ 8.5	33	3.0+15.0	28	1.0+ 6.5+ 8.0	124	2	185
43	Strength coeff.		Low	.50	*	*	*	*	1.0+13.0	31	1.0+ 6.0+ 6.5	92	3	156
	3rd material	0.40	High	.30	*	*	*	*	6.0+16.0	1	1.0+ 7.0+ 6.0	81	*	115
	Strength coeff.		Low	.35	3.0	7	1.0+ 6.0	40	1.0+ 9.5	63	1.0+ 6.0+ 6.0	91	3	201
	Subgrade	0.25	High	.15	*	*	3.5+16.0	10	NFD	NFD	1.0+12.0+12.0	26	4	36
44	Minimum thickness		Low	0.50	*	*	0.5+ 9.0	34	*	27	0.5+ 6.0+ 6.5	128	4	189
	1st material	1.00	High	1.50	*	*	1.5+ 7.5	*	*	*	1.5+ 6.0+ 8.0	116	*	177
	Minimum thickness		Low	4.00	*	*	*	35	*	*	1.0+ 4.5+ 8.0	136	4	199
	2nd material	6.00	High	8.00	*	*	*	35	*	*	1.0+ 8.0+ 6.0	103	*	166
	Minimum thickness		Low	4.00	*	*	*	*	*	34	1.0+ 6.0+ 4.5	141	4	208
	3rd material	6.00	High	8.00	*	*	*	*	*	34	*	100	*	167
45	Maximum thickness		Low	12.00	8.5	8	*	*	*	69	*	126	*	236
	1st material	6.00	High	4.00	*	*	*	25	*	12	*	120	*	157
	Maximum thickness		Low	32.00	*	*	*	37	*	*	*	122	*	187
	2nd material	16.00	High	8.00	*	*	*	17	*	*	*	79	*	124
	Maximum thickness		Low	32.00	*	*	*	*	1.5+22.0	46	*	123	*	202
	3rd material	16.00	High	8.00	*	*	*	*	5.0+ 8.0	5	*	96	*	134

NFD means no feasible design was possible.

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An asterisk indicates that the value did not change from the corresponding value computed for the basic solution.

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