Attachment 4

SCHOOL OF CIVIL ENGINEERING

INDIANA DEPARTMENT OF HIGHWAYS

JOINT HIGHWAY RESEARCH PROJECT

EXECUTIVE SUMMARY

Interim Report

FHWA/IN/JHRP-84/18 —2

THE USE OF FUZZY SETS MATHEMATICS IN PAVEMENT EVALUATION AND MANAGEMENT

M. Gunaratne
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J.L. Chameau

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JOINT HIGHWAY RESEARCH PROJECT

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NOTE: The first three pages of the full report (letter of transmittal and the two title pages are also included as part of the Executive Summary.

EXECUTIVE SUMMARY

Interim Report

"The Use of Fuzzy Sets Mathematics in Pavement Evaluation and Management"

To: Harold L. Michael, Director
Joint Highway Research Project

August 23, 1984
Revised June 1985
Project: C-36-63J

From: A.G. Altschaeffl, P.E.
Research Engineer

File: 9-7-10

Please find attached an Interim Report entitled, "The Use of Fuzzy Sets Mathematics in Pavement Evaluation and Management." It was authored by Mr. M. Gunaratne, A.G. Altschaeffl, and J.L. Chameau of our staff. This is the first report on the HPR project entitled, "The Use of Fuzzy Sets Mathematics to Assist Pavement Evaluation and management."

This study proposes a methodology for ranking pavement sections according to maintenance urgency. Fuzzy sets mathematics is used to account for the human and system uncertainty inherently present throughout this process. Fuzzy sets are used to represent the subjectivity in pavement serviceability ratings and distress surveys, and the variability in Roadmeter, Skidtester and Dynaflect readings.

The attributes relevant to each category of maintenance are identified and an expert knowledge base containing priority values for known attribute value combinations is formed in collaboration with decision makers. A multi-attribute decision-making process is created to produce a crisp ranking of pavement sections according to maintenance urgency.

This report is presented for review and approval as evidence of partial fulfillment of the objectives of this project.

Respectfully submitted,

A.G. Altschaeffl / J.L. Chameau

A.G. Altschaeffl, P.E.
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EXECUTIVE SUMMARY

Interim Report

"The Use of Fuzzy Sets Mathematics in Pavement Evaluation and Management"

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Project No. C-36-63J

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16. Abstract

A methodology has been created for ranking pavement sections according to maintenance urgency using fuzzy sets mathematics to account for human and system uncertainty in the pavement management system. Fuzzy sets are used to represent the subjectivity in pavement serviceability ratings and distress surveys, and the variability in Roadmeter, Skid-tester and Dynaflect readings.

Techniques are presented for correlation of fuzzy numbers to create the Pavement Serviceability Index. Initial grouping of pavement sections compares the PSI with an Acceptable Serviceability Level and an Unacceptable Serviceability Level, both of which are subjective opinions obtained from experts.

The final ranking is formulated using fuzzy multi-attribute decision-making concepts using an expert knowledge base. This information is obtained from decision makers for known attribute value combinations using suitable questionnaires. The result is a unique ranking of pavement sections according to maintenance urgency.

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EXECUTIVE SUMMARY

Introduction

This report presents the concepts and mathematical foundations for the use of new schemes with which to base decisions for pavement maintenance priorities. We believe that more information about the quality of pavement and the severity of the distress exhibited by the pavement is contained within these new schemes than in the conventional. This can allow the inclusion of more relevant information in the decision-making process than is now possible. This executive summary attempts to lay bare this process and show how the new schemes perform their function.

The many highway pavement sections in Indiana are in many different states of soundness or disrepair. Maintenance budgets, however, are limited. Thus, decisions must be made on which sections most deserve repair during a given year. In addition, criteria must be available for making these decisions. In Indiana, as well as in many other states, the objective of the maintenance program is to maximize pavement "rideability". The system essentially involves two steps: initial screening and decision making.

The initial screening is performed to identify sections requiring maintenance. This operation requires input from highway users and engineers on performance characteristics of pavement sections, and on the levels of those characteristics that suggest unsatisfactory performance. The screening process results in the characterization of pavement sections into several maintenance categories.

The decision-making operation follows the initial screening to provide a rank-ordering of pavement sections within each maintenance category. The decision process requires the delineation of variables, criteria and attributes which are appropriate for each maintenance category. This information can only be provided by experienced engineers and decision-makers. Expert information is also needed to assess the interactions existing among the selected criteria and attributes. Once this expert knowledge base is established, it can be used by engineers to rank pavement sections for as long a time as the data are deemed relevant. Only performance and traffic data (i.e., values of attributes) are required, then, for the pavement sections to be examined.

In this report, techniques are proposed to acquire the knowledge base required by a pavement management system. Mathematical procedures are also developed to organize this information in a computerized decision-making model which makes allowance for the interactions among the different attributes.

This report has three goals:

1. To describe the mathematical techniques used in both the initial screening and the decision process;

2. To develop the framework (set of questionnaires) which can be used to acquire the expert knowledge base;

3. To provide simple numerical examples of application of the mathematical techniques (these examples are simple enough so that the reader can check them by hand calculations; they are provided to show that the mathematical intricacies are only basic algebraic operations). Note that all the mathematical techniques have been computerized for future use.

This report should be read in conjunction with the companion report by Andonyadis et al. (1985). The companion report describes how the mathematical techniques can be used in the pavement management system. It has four goals:

1. To provide simple physical interpretations of the mathematical techniques;

2. To use the answers to questionnaires presented in this report to acquire a typical knowledge base;

3. To show in selected examples how the knowledge base can be used to screen and prioritize pavement sections;

4. To make recommendations for future implementation of the proposed management system.

In this context, the following sections of this summary highlight the important steps of the methodology proposed in this report.

The reader who is not interested in the theoretical concepts behind these steps can concentrate on the companion report (Andonyadis et al., 1985) to see their use, making reference to this report as needed.

Initial Screening and User Input

Road users formally play a major role in evaluating the quality called rideability through the concept of the Pavement Serviceability Rating (PSR). The PSR reflects raters' opinions of the rideability of a selected number of pavement sections. Each rater is asked to state his view on the rideability of each section on a scale of 0 to 5 (poor to excellent); the PSR of the section is defined as the mean value of all raters' opinions. This subjective rating is the datum from which the maintenance program is developed, because everything that follows will tie back to it.

To reduce the need for many rating panels, a mechanical device, the PCA Roadmeter, that measures "roughness" is used on each rated section. A statistical correlation is then prepared between Roadmeter Reading and PSR and the rideability value that is predicted from the equation is called the Pavement Serviceability Index (PSI). Hence, all pavement sections can be screened efficiently by use of the Roadmeter. Then, the PSI of each section is compared to an Acceptable Serviceability Index (ASI) to determine the next course of action. In Indiana, the PSI is defined on a scale of 0 to 5, and 2.5 is used as ASI. Those sections having PSI below 2.5 are considered excessively rough. This is the first decision point to sort out sections to be considered for maintenance in the existing framework.

Two observations deserve to be made at this point. First, the opinion of the rater contains uncertainty and imprecision, if only because judgment has vagueness attached to it in the quantitative sense. Secondly, different raters have different degrees of perceptiveness of what the roughness implies, e.g., someone who knows how pavements perform can infer that the roughness is caused by a defect that generally enlarges quickly and, thus, this is a hazard that requires quick attention. The entire gamut of road user deserves involvement in ratings, but advantage should be taken of the extra perceptiveness that some raters exhibit.

These thoughts can be included in the new scheme. The rater is not asked for a single value of rideability but for weights on a scale of 0 to 1 that he wants to attach to each possible rating value that is available to him. This represents his belief in each value and provides a central tendency to his opinion as well as a range to encompass the uncertainty in his judgment. Each rater can provide such a belief function, called the "membership function," for each section.

With expert information provided from the judgment of highway pavement managers, a perceptiveness weighting can be attached to each rater's opinions. The mathematical bases for assembling all those various "opinions" are presented in this report. The result is a single, all-inclusive membership function for each pavement section. This will contain the spread caused by uncertainty as well as the effects of perceptiveness. Although the amount of information appears to look more complicated than that of existing techniques, so much more is contained in it, no one's opinion is discarded, and it can be computerized easily. If the ultimate judgment on rideability is that of the users, then, indeed, the "fuzzy sets" approach contains a full and thorough assembly of these judgments.

Let us turn, then, to the mechanical measurement of roughness. There is imprecision in the readings. This imprecision comes from both the random uncertainty in the measurement as well as from the human involvement in the procedures. This report addresses the correlation between Roadmeter Reading (RR) and the new "fuzzy PSR" in two ways: (1) as if RR were a crisp, deterministic, reproduceable number; and (2) as if RR were also a vague number described by a membership function to account for its irreproduceability and imprecision. Expert knowledge, through responses to questionnaires distributed to elicit the judgment of these experts, was used in the "fuzzification" of RR. The report provides a program to assemble RR data and to relate these data to the PSR data described earlier. This program allows the creation of the "fuzzy" PSI to describe each pavement section. At this point, then, each section is described as to roughness and rideability and these are related to the basic rater opinions. The relation is a comprehensive one containing all the judgment about performance that can be extracted from the opinions.

The matter of what is an acceptable roughness, the ASI, is also one of judgment, and it represents the first decision point in the global decision process. Different people will recognize a section as hazardous (i.e., in need of maintenance) at different stages of roughness, as, for example, their perception of costs and degree of hazard differ. The new scheme makes allowance for this imprecision in the decision process. Experts were asked: (1) above what PSI value is a pavement totally acceptable for traffic; (2) below what PSI is a pavement totally inadequate. The responses were used to, first, create an Acceptable Serviceability Range. This Range contains the varied judgments of the different experts as to what is acceptable. Similarly, a Non-Acceptable Serviceability Range is also created; this one is not necessarily the complement of the other, because judgments are involved and there is a domain of PSI values where decisions on acceptability are difficult to make. These two ranges are membership functions which contain a complete representation of the judgment and experience of the experts.

This report contains the mathematical bases for comparing the fuzzy PSI of a section with the fuzzy Acceptable Serviceability Range. An index describing how well the section "belongs" to the acceptable range is obtained for each section. Also obtained is a separate index for each section describing how well it belongs to the unacceptable range. The criterion in the report says if the acceptability index is the larger, the section has acceptable roughness.

The skid resistance of pavements with acceptable roughness is measured to obtain a friction number used to identify sections which are too smooth for safety. Four sources of variation affect the measurements made with a skid-tester: (1) inability of repetition; (2) variations along pavement sections; (3) uncertainty associated with conversion favors; and (4) variability due to statistically insignificant factors. It is shown in this report that, although part of this uncertainty is random in nature, system uncertainly also plays a major role and several procedures are suggested to make allowance for it. Following the approach already taken for RR and PSI, expert opinions were sought again on what is acceptable and unacceptable FN. This is followed by the assembly of those sections requiring attention, in accordance with the previous decision criterion.

For the initial screening of pavements, the "fuzzy performance data", fuzzy PSI and FN, are compared with acceptable and unacceptable serviceability and friction ranges, respectively. The comparison technique provides indices describing the degree of belongingness of a given pavement section to the acceptable and unacceptable ranges, respectively.

This provides a criterion to classify pavement sections into three categories:

	1st	2nd	3rd
PSI	OK	No	OK
FN	No	N/A	OK

Today, in Indiana, category II pavements are ranked using the PSI-RR data, FN, and traffic count (ADT). This report recommends inclusion of distress surveys. It shows how to create the membership functions which contain the judgment of each survey member on various aspects and types of distress. These components are weighted, and the results of crew members are assembled for each section. We, thus, have a fuzzy Pavement Condition Rating (PCR); it contains the combined judgments of all crew members, including their individual different perceptiveness on the import of the distress, and is a description of the distress exhibited by the section. The procedures have been created to allow inclusion of distress severity in the maintenance ranking procedure.

The Decision Process

At this stage, the goal of a pavement management system is to provide decision-makers with a ranking of pavement sections in any desired category. The ranking, or state, of a pavement belonging to any one of the three categories can be represented by a number of attributes that the decision-makers believe to be important for a decision on maintenance urgency.

For category I sections, FN, average daily traffic (ADT), and approximate cost have been deemed decision variables (or attributes). Assuming cost is related to FN, the two main attributes are FN and ADT. For category II sections, the report presumed PCR, ADT, and cost. Assuming that the cost is a function of the PCR and deflection measured under the Dynaflect, the three main attributes for this category are PCR, ADT, and deflection. For category III pavements, future service life is the key issue. Using presently established performance vs. time curves (PSI or FN vs. time), the service lives of each section can be assessed as a fuzzy number because of the imprecise nature of the input variables. These two attributes can serve in the decision process, and a ranking can be made on the basis of perceived need for future maintenance.

The selection of attributes in this study for each category was guided by present practice in IDOH. The proposed technique is not limited to these attributes. If it is felt desirable, the Indiana Department of Highways may remove some of these attributes or add other attributes. This only requires the development of the knowledge base for the new attributes, following the same approach used in this report for the above attributes. This is further discussed in the report by Andonyadis et al. (1985) where ADT, FN and PCR are used for the first category of pavements, and ADT, PSI and PCR for the second category. These latter selections were guided by discussion with engineers from IDOH and by the responses to the questionnaires.

The key to the decision making scheme presented in this report is the creation of the component of the knowledge base that can be labelled "utility functions." Techniques have been developed to construct this knowledge base from the responses of highway experts to questions such as: "If the PCR is 70.0 and the dynaflect reading is 0.001 inch for an unacceptably rough pavement with an ADT of 3000, what relative priority would you assign on a scale of 1-10?". An expert can assign such a subjective value based on heuristic rules that have come through years of pavement management experience.

A matrix of decision criteria is created from the decision-makers' judgment of relative priorities obtained for a selected combination of attribute values relevant to each category. Then, using the techniques presented in the report, the assembly of attribute data is related to the expert knowledge base to rank pavement sections within any of the three pavement categories.

It is important to note that the ranking provided by the proposed decision-making scheme is crisp. For example, processing of PCR, ADT and deflection data available for 50 sections within the second category will result in a ranking of these sections from 1 to 50. The section with the lowest rank requires maintenance first.

Concluding Remarks

The new scheme proposed in this report is founded upon the judgments of experts in various aspects of pavement performance.

There is much uncertainty present yet today in the understanding of this performance, i.e., judgment is, indeed, involved in establishing maintenance urgency. The fuzzy sets mathematics appears to be very effective in handling this uncertainty and judgment. It is fully consistent with the manner in which decisions are made, and it creates a crisp ordering of pavement sections according to maintenance priorities. Because more information about quality of pavement and severity of distress is contained in this scheme than in the conventional, the authors consider this scheme a major improvement and worthy of implementation.

The knowledge base required by the new scheme is composed of five parts:

1. variability in PSR, RR, FN, PCR;

2. ratings of a panel of users;

3. PSR-RR relationship;

4. acceptable and nonacceptable levels of PSI and FN;

5. utility values (i.e., the matrix of decision criteria).

It is important to note that once the knowledge base is established, the performance and traffic parameters for the pavements to be ranked are the only data required in the analysis. This is illustrated in Figure E.1, which shows a flow-chart of operation. The user's intervention is limited to the left side of the flow chart (input). The knowledge base and mathematical operations are entirely computerized.

As in all decision-making, the knowledge base and criteria do deserve re-examination periodically. A given knowledge base is available for use as long as IDOH considers the contents to be relevant to pavement management. It can be changed readily when new data appear more appropriate or if the state-of-the-art and/or experts' judgement changes. This would require only the development of the related component of the knowledge base, using the same approach as herein. Following this, ranking procedures are the same, using the improved reference datum.

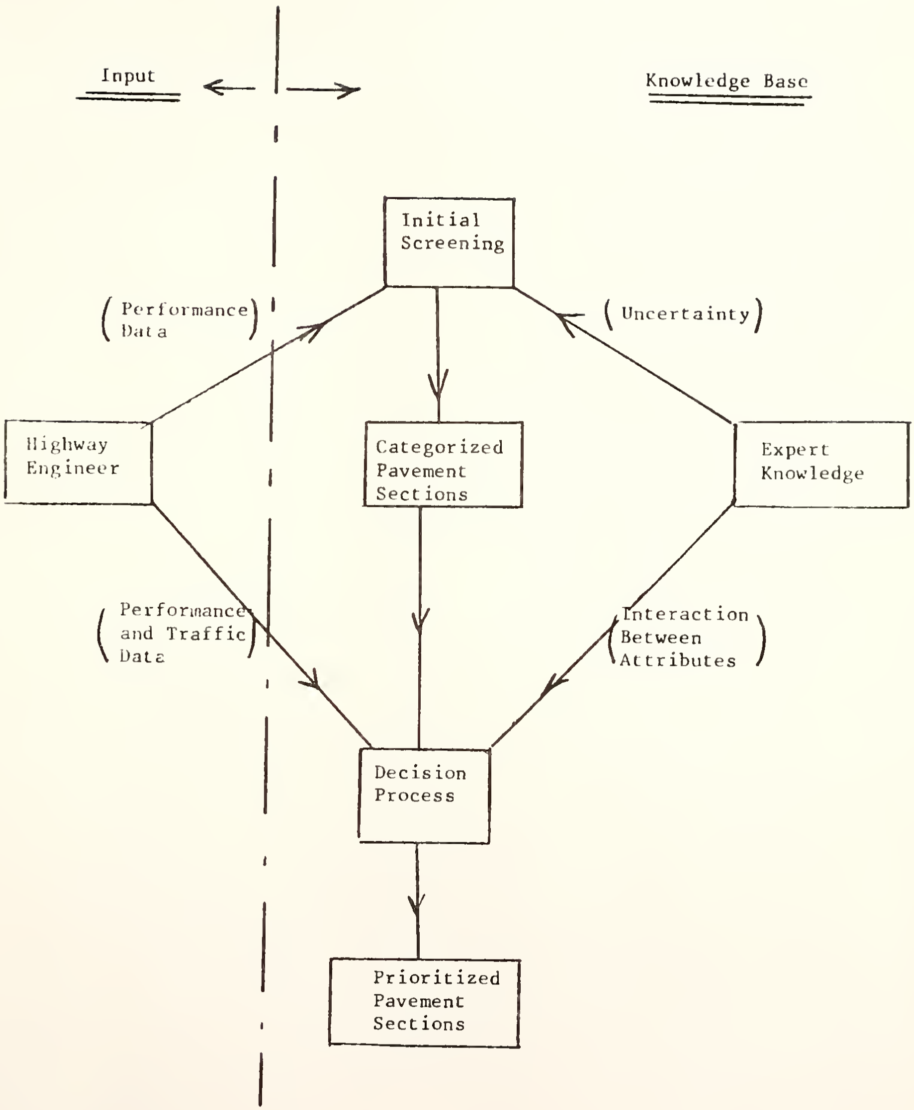

Figure E.1: Decision Flow Chart.

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