PREDICTION OF TRANSPORTATION SPECIALIZED VIEWS OF MEDIAN SAFETY BY USING FUZZY LOGIC APPROACH

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ABSTRACT

A transportation expert may be asked to support a decision, determine a preference, rank influencing factors, or assess alternatives through various methods including surveys, interviews, panel meetings, and expert analyses. In many of these cases, before the experts render their opinion they formulate it through the use of linguistic information and their own subjective decision criteria. An efficient method to analyze subjective and linguistic information employed by people, whether expert or layman is to apply a fuzzy set concept. The primary strength of a fuzzy approach is that it is applicable for the analysis of human knowledge and subjective human perception, which are represented by linguistic terms rather than numerical terms, and the deductive process. Various applications of fuzzy sets have been applied to analyze many types of information, such as fuzzy decision making analyses, fuzzy aggregation methods, and fuzzy inference systems. The fuzzy inference system, which mimics the human perception and decision making processes, is a deductive process of mapping given inputs to certain outputs based on fuzzy membership functions and fuzzy rules. It has been widely applied in various analysis of subjective and ambiguous information.

1.0 INTRODUCTION

Fuzzy inference systems have been applied in various areas. However, many studies reported limitations of the conventional fuzzy inference system when dealing with multiple variables. The number of rules in a conventional fuzzy system increases exponentially with the number of variables involved. Normally, three or four variables are the maximum number that can be considered as part of a conventional fuzzy inference system. One of the ways to solve this “rule-explosion problem” is to use a fuzzy inference system with a hierarchical structure called a hierarchical fuzzy system. The hierarchical fuzzy system, proposed by Roju...
et al. (1991), can reduce the computational complexity of a multivariable fuzzy system and the number of rules. This rule explosion problem is more complex when fuzzy logic is applied to study transportation user perception. This is because transportation user perception regarding transportation service or safety is usually affected by many factors, such as roadway geometry, traffic flows, driver characteristics, and other driving conditions. It may not be able to be determined by only a few factors. Also, each driving condition has many sub elements. For example, geometric conditions consist of many measures of cross section elements, horizontal and vertical alignment, and roadside environments. To select variables to be used for the fuzzy inference system, the five highest ranked variables and the variables for which data were available in the median safety database were considered. Since the crash data were used for corroborating the results of the proposed fuzzy inference system, the availability of each variable in the database was also a critical issue in this variable selection procedure. Additionally, current design manuals were reviewed to select relevant variables for the fuzzy inference system. For the current median barrier warrant in the AASHTO Roadside Design Guide, ADT and median width are employed. These two variables have been known as the most critical factors in assessing median safety. From these reviews, five variables to evaluate geometric conditions and one variable to evaluate traffic flow conditions were selected. The five geometric variables were median width, horizontal curvature, operating speed, median cross-slope, and shoulder width. ADT was used to describe the traffic flow condition.

2.0 CONSTRUCTION OF FUZZY MEMBERSHIP FUNCTIONS

There are various ways to determine fuzzy membership functions. Generally, the methods of formulating fuzzy membership functions can be classified into three approaches: constructing the membership functions through the analyst’s judgment, constructing the membership functions through experiments, or constructing the membership functions from a given numerical data set. Selecting a method to determine the membership functions depends on many conditions including the characteristics of the study and the available data set associated with the study. In this study, the method based on analyst’s judgment was used to determine the fuzzy membership functions. It is the most common means used to construct fuzzy membership functions because of its simplicity and wide applicability. In this method, an analyst employs their own knowledge and information gleaned from relevant literature to compose the membership functions. In the proposed study, fuzzy membership functions for the selected variables were constructed through four resources: the authors’ own knowledge; a review of the experts’ opinion; a review of the literature and the state of the practice related to transportation safety, typically median safety; and a basic review of the roadways for which crash data were collected. A review of relevant literature and associated practice is usually the most significant resource for determining reasonable and appropriate fuzzy membership functions in the analyst intuition method. Since there are few studies that have investigated the relationship between controlling factors and CMC, the general safety effects of the selected variables were also reviewed. Through a review of the experts’ opinion regarding the influence of the various factors on median safety, the relative importance of each factor was investigated. This relative importance was used to determine the weight of each variable. A basic review of the roadways within the crash database was conducted without any statistical analysis. The variable type (e.g., binary, continuous), the number of classes for each variable, and the range of values were mainly considered in this review. Using these resources, two types of fuzzy membership functions were determined. The first fuzzy membership functions represented how significantly each factor influences median safety. The second fuzzy membership functions represented the relative importance of each geometric factor.
3.0 FUZZY MEMBERSHIP FUNCTION FOR THE FACTORS CONTROLLING MEDIAN SAFETY

The initial construction of the fuzzy membership function for the six factors influencing median safety was accomplished through the review of references and common engineering judgment. They were then slightly modified to reflect Pennsylvania Interstate highways or expressways because the review results represented general or universal information regarding driving environments and not specifically the driving environments of Pennsylvania. The review results, which allowed for the construction of the preliminary fuzzy membership function, are explained in the paragraphs below. The first variable, average daily traffic (ADT) represents the traffic condition. ADT is known as a significant factor influencing median safety, and it is used as one of two criteria of the median barrier warrant. The median barrier warrant in the AASHTO Roadside Design Guide uses two categories to determine the barrier installation guideline. For ADTs less than 20,000, barrier is optional, but for ADTs greater than 20,000, barrier is warranted, depending on the median width. This category is also applied in the PennDOT design manual. In the expert survey, four categories: 15,000 to 30,000, 30,000 to 50,000, 50,000 to 75,000, and greater than 75,000, were considered to investigate the safety effects of the traffic flow condition. The second variable is median width which represents a geometric condition. Median width is one of the most significant factors used to evaluate median safety in conjunction with ADT. To determine the fuzzy membership function for median width, AASHTO’s A Policy on Geometric Design of Highways and Streets AASHTO’s Roadside Design Guide, and other references were reviewed. The 2001 Green Book indicates that median widths of 50 to 100ft are common on rural freeways. In AASHTO’s Roadside Design Guide, median barrier warrant is based on three categories of median width. Barrier is warranted for medians less than 30ft, and barrier is not considered for medians greater than 50ft. Barrier is optional for medians between 30 and 50ft. However, the creation of the fuzzy membership function for horizontal curvature and median cross slope was restricted to reflect the review results. The previous studies emphasized that various features of horizontal curvature can affect roadway safety as mentioned above. Given their findings, the fuzzy membership functions representing the effect of horizontal curvature on median safety should be determined by taking into consideration various features of a horizontal curve. Three condition levels, poor, fair, and good, have commonly been used for evaluating the effect of horizontal curves on safety in previous studies. However, the median crash data used for comparison with the safety index, which is based on the proposed fuzzy inference system, included only the presence of horizontal curvature as binary information, such as 0 for no curve and 1 for a curved alignment. Due to this limitation of the database, the fuzzy membership functions for horizontal curvature were determined with just two levels in this study even though it is not as desirable as the multi-condition level described above. The median cross slope data in the crash database was also binary data with 0 indicating flatter than 6:1 and 1 indicating steeper than 6:1. This limitation of the median crash database necessitated the creation of two levels of fuzzy membership functions, such as poor and acceptable or steeper and flatter for median cross slopes steeper than 6:1 or flatter than 6:1, respectively.
4.0 APPLICATION OF PROPOSED THE HIERARCHICAL FUZZY INFERENCE SYSTEM

The results of the developed HFIS were compared with observed crash data for the purpose of validation. For this application, the Pennsylvania median safety database was used per the previous discussion. This database included various elements, such as crash type, severity, and roadway inventory data. Out of those data, the number of CMC crashes and the inventory data of the six variables used in the fuzzy inference system described above were applied. Five years of data on traffic volumes (ADTs) and the geometric features covered by the five variables discussed above for 12,781 roadway segments were used as input values for the lower level or the upper level fuzzy inference system. However, since the safety database did not include an operating speed but posted speed, posted speed was used as a surrogate input variable in place of operating speed. Through the developed HFIS and a defuzzification procedure, FMSIs for each roadway segment were produced and compared with the observed median crash data of the same roadway segments. First, the relationship between ADT and FGI of the given roadway segments was examined. Through this procedure, the fuzzy partition and rule mapping conducted for the upper level fuzzy inference system were verified. The data for the roadway segments reflect the results of the partition and rule-mapping relatively well. Most of the roadway segments FGI ranged from 0.3 to 0.7 and their ADTs vary widely. The minimum ADT is 481 and maximum ADT is 84,939 vehicles per day. However, most (84.6 percent) of the roadway segments have less than 20,000 ADT. Therefore, most of the given roadway segments have relatively acceptable geometric conditions and uncongested traffic flow conditions. There were many other median safety factors that were not used in this study due to the limited availability of data, such as weather, radius of horizontal curves, and factors regarding drivers. However, the proposed HFIS can produce an indicator, FMSI, which explains well the degree of median safety on Interstate highways or expressways. It is one of the advantages of the fuzzy approach to analyze or infer well with ambiguous or incomplete information. Therefore, it can be concluded that the proposed HFIS, in terms of FMSI values, reflect well the real median crash problem, and the incorporated transportation expert opinions appear to be valid.

![FIGURE 1. Fuzzy Median Safety Index & CMC Frequency](image-url)
In this paper, a new approach to incorporate transportation experts’ opinions using the HFIS was developed. Generally, transportation experts use linguistic information and their own subjective decision criteria to formulate and express their opinion. However, it is difficult to aggregate those linguistic and subjective experts’ opinions using conventional methods. The proposed method allows for the analysis and aggregation of the subjective and linguistic expert opinions taking into consideration the unique characteristics and decision criteria of an individual expert.

To apply this method, variables in the HFIS were selected through the transportation expert survey results of a previous study. The fuzzy membership functions for the selected six variables were constructed using common engineering knowledge garnered from a review of the experts’ opinions, a review of the references related to transportation safety, and the authors’ own knowledge. A hierarchical structure for the fuzzy system was applied to reduce the complexity of a multivariable fuzzy system, which can lead to the fuzzy rule explosion problem. The fuzzy weighted average method was used in the process of formulating the
fuzzy inference system to avoid the difficulty of fuzzy rule mapping with a large number of variables. The incorporated experts’ opinions regarding median safety were finally expressed by FMSI as an indicator of the degree of median safety. Then, the values of FMSI computed using roadway inventory data were compared with observed median crashes to validate the fuzzy results. Since the roadway type used in this study was the Interstate highway and expressway, most of roadway segments in the database have relatively favorable driving conditions. For this reason, most of the roadway segments were less than 0.5 FMSI. To avoid a biased interpretation of the results from the unbalanced data, the mean of CMC crash frequency and the CMC crash rate were used for the validation process. The mean of CMC frequency increases exponentially with an increase of FMSI. Typically, a roadway segment with an FMSI equal to or greater than 0.7 included more CMC crashes than those segments with an FMSI less than 0.7. Through these comparisons, the developed HFIS based on experts’ opinions was evaluated as the system that can explain relatively well the degree of median safety for Interstate highways and expressways.

REFERENCES