A FUZZY INTEGRAL MODEL FOR MEASURE OF INTERSECTION SAFETY

Pin-Yi TSENG
Associate Professor
Department of Traffic Science
Central Police University
56, Shu Jen Road, Kwei Shan, Taoyuan, 3334, Taiwan
Tel:886-3-3282321 Ext. 4619
Fax:886-3-3963022
E-mail: una139@sun4.cpu.edu.tw

Feng-Yu LIN
Ph.D. Student
Institute of Traffic and Transportation
National Chiao Tung University
4F, 114 Chung-Hsiao W. Rd., Sec. 1, Taipei 100, Taiwan
Tel:886-2-27690202
Fax:886-2-27672323
E-mail:cib-elite@kimo.com.tw

Abstract: This paper introduces a model which is based on fuzzy multiple criteria decision making and fuzzy integral mechanism for measuring the intersection safety. This model developed can reflect the potential hazard factors and be served as reference for creating intersection safety improvements. An evaluation structure is used by the fuzzy analytic hierarchy process, and incorporated with the fuzzy integral methodology to reflect the interaction effects of different considerations. The fuzzy statistics technique is used to construct the membership functions of quantitative and qualitative factors. From the empirical study in Taipei city, a fuzzy integral evaluation model was set up taking both vehicles and road factors into consideration. The vehicle factors include five criteria: average speed, motorcycle composition, large vehicle composition, left turn and right turn rate, and potential conflicts. The road factor characteristics include four criteria: channelization situation, sign, sight distance and number of approaches. The present study shows that fuzzy integral model can sufficiently and efficiently measure the safety of intersections.

Key Words: fuzzy analytic hierarchy process, fuzzy integral, fuzzy statistics, intersection, safety

1.INTRODUCTION

The intersection safety measurements in most of the previous studies were primarily conducted based on the characteristics of accidents that had occurred. In some other cases, accident data were used to identify dangerous sections or locations. Such a methodology was developed primarily on the basis of the number, severity or causes of accidents (Deacon, 1975; Risk and Shaoul, 1982; Higle and Hecht, 1990; Ogden, 1997). To address the issue of incomplete traffic data and to further diagnose traffic safety issues, some attempts were made to explore the potentials of traffic accidents by looking into traffic conflicts (Chin and Quek, 1978; Fzra, 1982; Lund, 1992). However, using the results derived from such methodology to establish the correlations between intersection hazard factors and improvement strategies is very difficult, Since the correlations between hazard factors such as different driving behaviors, vehicle operation characteristics, geometric characteristics of the roads, traffic environments and safety improvement measures are not straight and clear. Thus, a comprehensive causal-and-effect relationship çannot be established using those conventional factors for practical applications.

This paper attempts to construct an analysis model that can reflect the safety of intersections, serve as the basis for assessing the hazards posed by intersections, identify dangerous intersections and improve intersection hazard factors. This paper first creates an assessment framework for intersection safety using a fuzzy analytic hierarchy process (FAHP) derived by Saaty (1977, 1980). Then, it identifies the major factors that affect intersection safety and other relevant factors, and derives the membership functions. Finally, performance scores can be constructed through various factors to give a general fuzzy assessment of each intersection examined in order to understand the safety performances of each intersection in all major aspects. Also, the potential hazard factors of each intersection can be identified which served as the basis for making improvement recommendations.

In addition, this paper assumes a fuzzy measure regarding the addition and independence between each assessment aspect and criteria to improve the conventional general fuzzy assessment. Further, this paper develops a fuzzy integral model for the nature of human subjective assessments which can be used to identify the potential hazards posed by each intersection and to rank such hazards as the basis for determining the sequence of improvements.

2.BASIC CONCEPTS FOR FUZZY MEASURE, FUZZY INTEGRAL

2.1 General Fuzzy Measure

Fuzzy measure is a measure for representing the degree of membership of an object in candidate sets. It assigns a value to each crisp set of the universal set, and signifies the degree of evidence or belief of the element's membership in the set. Let X be a universal set. Then, fuzzy measure is defined by the following function:

$$g:P(X)\rightarrow[0,1] \tag{1}$$

which assigns each crisp subset of X, a number in the unit interval [0,1]. The definition of function g is the power set P(X). When a number is assigned to a subset $A\in P(X)$, g(A) represents the degree of available evidence or subject's belief that a given element of X belongs to the subset A. The subset assigned with the highest value represents that the particular element is most likely to be found in the subset.

For the purpose of quantifying fuzzy measure, function g must conform to several properties. Conventionally, function g is assumed to have met the axiom of probability theory (which is probability theory measure). However, actual practices often go against such assumptions. Therefore fuzzy measure should be defined by weaker axioms, and the probability measure will also become a special type of fuzzy measure. The axioms of the fuzzy measures should include:

Axiom 1: boundary conditions

$$g(\phi)=0 \text{ and } g(X)=1 \tag{2}$$

Axiom 2: monotonicity

$$\text{For every } A,B\in P(X)\text{ , if } A\subseteq B\text{ ,then } g(A)\leqq g(B) \tag{3}$$

If the universal set is infinite, it is necessary to add the continuous axioms. We are quite sure that elements in question are not within the empty set but within the universal set, regardless of the amount of evidence that boundary conditions in axiom 1. As for axiom 2, it refers to the necessary evidence for particular elements to belong to a certain set. At least it would have to be of equivalent evidence required for the subset belonging to the set, and this is monotonicity.

Fuzzy measure is often defined with even more general function:

$$g:\beta\rightarrow[0,1] \tag{4}$$

where $\beta\subset P(X)$ so that:

(1) $\phi\in\beta$ and $X\in\beta$;

(2)if $A\in\beta$, then $\overline{A}\in\beta$;

(3) β is closed under the operation of set union; that is, if $A\in\beta$ and $B\in\beta$,then $A\cup B\in\beta$.

The set β is usually called a Borel field or σ field. The triplet (X, β,g) is called a fuzzy measure space if g is a fuzzy measure on a measurable space (X, β).

In practice, it is enough to consider the finite set. Let X be a finite criterion set, X= {x_1, x_2,…, x_n}, and P(x) be a class of all the subsets of X. It is noted that g({x_i}) for a subset with a single element x_i is called a fuzzy density. In the following statement, we'll use g_i to represent g({x_i}).

In order to differentiate from other fuzzy measure models (such as λ-fuzzy measure, F-additive measure, classical probability measure), we use the term "general fuzzy measure" to designate a fuzzy measure that requires only to satisfy the boundary conditions and monotonicity. A general fuzzy measure has the fewest number of constraints and is the most general measuring pattern.

2.2 λ-Fuzzy Measure

Since the specification of general fuzzy measures requires the values of a fuzzy measure for all subsets in X, Sugeno and Terano (1977) incorporated the λ-additive axiom in order to reduce the difficulty of collecting information. In the fuzzy measure space (X, β,g), let $\lambda \in (-1,\infty)$. If $A \in \beta$, $B \in \beta$, β and $A \cap B = \phi$, and

$$g(A \cup B) = g\ (A) + g\ (B) + \lambda g(A)g(B) \tag{5}$$

holds, then fuzzy measure g is λ-additive. This particular fuzzy measure, also named Sugeno measure, is termed as λ fuzzy measure because it has to fulfill λ-additive (Sugeno and Terano, 1977). To be differentiated from other fuzzy measures, we denote λ-fuzzy measure by g_λ. When λ=0, this indicates that the measure is additive. Based on the axioms mentioned above, λ-fuzzy measure of the finite set can be derived from fuzzy densities, as indicated in the following equation：

$$g_\lambda(\{x_1, x_2\}) = g_1 + g_2 + \lambda g_1 g_2 \tag{6}$$

where g_1, g_2 represent the fuzzy density.
Furthermore,

$$g_{\ddot{e}}(\{x_1, x_2, \ldots, x_l\}) = \sum_{i=1}^{l} g_i + \sum_{i_1=1}^{l-1}\sum_{i_2=1}^{l} g_{i_1} g_{i_2} + \ldots + \ddot{e}^{\,l-1} g_1 g_2 \cdots g_i \tag{7}$$

2.3 Fuzzy Integral

Consider a fuzzy measure space(X, β,g). Let there be a measure function from X to [0,1]. Then, the definition of the fuzzy integral of f over A with respect to g is (Sugeno, 1974; Sugeno and Kwon, 1995)：

$$\int_A f(x)dg = \sup_{\alpha \in [0,1]} [\alpha \wedge g(A \cap F_\alpha)] \tag{8}$$

where, F_α= {x | f(x) ≧ α}. A is the domain of the fuzzy integral. When A=X, A can then be taken out.

In the following we will introduce the calculation of a Fuzzy Integral. For the sake of simplification, consider a fuzzy measure g of (X,P(X)) and X is a finite set here. Let f:X→[0,1] and assume without loss of generality that the function $f(x_j)$ is monotonically decreasing with respect to j, i.e., $f(x_1) \geqq f(x_2) \geqq \cdots \geqq f(x_n)$. To assure this, the elements in X can be renumbered. Then we have

$$\int f dg = \bigvee_{i=1}^{n} [f(x_i) \wedge g(X_i)] \tag{9}$$

where X_i = {x_1, x_2,…, x_i}, i=1,2,⋯,k.

In practice, f can be considered to be the performance on a particular criterion for the alternatives and g represents the grade of subjective importance of each criterion. The Fuzzy Integral of f with respect to g gives the overall evaluation of the alternative. Besides, we can use the same fuzzy measure by Choquet's integral instead of the Fuzzy Integral ; then we obtain

$$\int f dg = f(x_n)g(x_n) + [f(x_{n-1}) - f(x_n)]g(x_{n-1}) + \ldots + [f(x_1) - f(x_2)]g(x_1) \quad (10)$$

Since the Fuzzy Integral model does not need to assume independence of each criterion, it can be used on nonlinear situations. Even if in an objective sense, any two criteria are independent, they are not necessarily reckoned to be independent from the subjective viewpoint of decision makers. This explains the fact why the fuzzy integral with synthetic evaluation would be more suitable. Furthermore, even if one criterion is physically independent from the other, the evaluation of the alternatives by subjects is according to the difference between the ideal and actual values of the criterion. But the ideal value of each person should be different and extremely difficult to measure, subjective evaluation can be effectively used. In the realistic case of evaluation problems, the number of criteria will influence the calculation complexity of evaluation problems. In this paper, we apply questionnaire surveys to derive two aspects and nine assessment criteria, assuming that all criteria of each aspect are independent. Due to applying the idea of fuzzy measure, we release the assumption of criteria independence; therefore, figuring the interrelation of each criterion is the most important part in the evaluation process.

In this paper, we apply eigenvalue method to solve the λ fuzzy measure. The information in the following matrix is obtained from the expert questionnaires, it is derived from all subsets that are used to evaluate aspect X. We can reconstruct the interrelationship between aspect X by solving the eigenvalues and the corresponding eigenvectors.

$$\begin{array}{c} \\ \{X_1\} \\ \{X_2\} \\ \vdots \\ \{X_K\} \\ \{X_1,X_2\} \\ \{X_3,X_4\} \\ \vdots \\ \{X_1,X_2,\cdots,X_K\} \end{array} \begin{array}{c} \begin{array}{cccccccc} \{X_1\} & \{X_2\} & \cdots & \{X_K\} & \{X_1,X_2\} & \{X_3,X_4\} & \cdots & \{X_1,X_2,\cdots,X_K\} \end{array} \\ \left[\begin{array}{cccccccc} 1 & a_{12} & a_{1K} & \cdots & & & & \\ 1/a_{12} & 1 & \cdots & & & & & \\ \vdots & & 1 & & & & & \\ 1/a_{1K} & \cdots & & 1 & & & & \\ \vdots & & & & 1 & & & \\ & & & & & 1 & & \\ & & & & & & 1 & \\ & & & & & & & 1 \end{array} \right] \end{array} \quad (11)$$

Therefore, the eigenvector corresponding the maximum value of eigenvalues represents the importance of each combination and aspect. For example, the vector $[w_1,w_2,w_{12}]$ represents the relative weights of importance of 2 aspects situation $[x_1,x_2,\{x_1,x_2\}]$.

3.CONSTRUCTION OF MEMBERSHIP FUNCTION

Through 10 expert questionnaires, this work converts the results into membership through fuzzy statistics. The performance levels for measuring the safety of intersection are separated into "good", "moderate" and "poor", according to the degree of different memberships.

3.1Continuous Membership Functions

To count the responses on each performance level from questionnaires, we calculate the frequency. By the way of curve fitting, we can establish the membership function of each quantitative criterion for each performance level. In actual applications, one needs to assign the actual performance values (e.g., vehicle speed of 35 km/hr) of each assessment criterion employed for each intersection to the membership function of each quantitative indicator for each level to identify the extent of safety level. Table 1, and Figures 1 and 2 contain examples involving "vehicle speed."

Table 1. Membership Frequency of "Good" Speed Safety

Speed(km/hr)	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
Membership Events	8	8	8	4	3	2	1	1	0	0	0	0	0	0	0	0	0
Membership Frequency	0.8	0.8	0.8	0.4	0.3	0.2	0.1	0.1	0	0	0	0	0	0	0	0	0

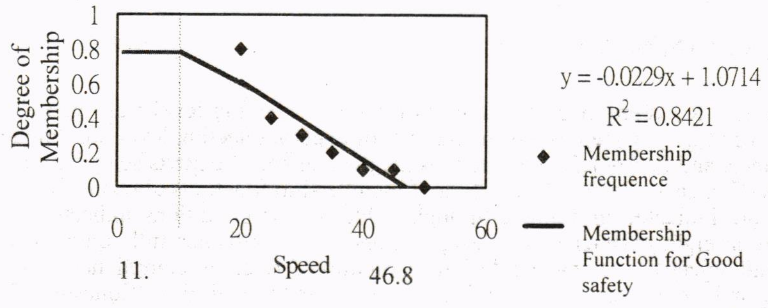


Figure 1. Membership Functions for Good Speed Safety

Membership Functions	Degree of Membership	Range of Parameters
u_{good} =	0.8	0<x≦11.8
	-0.0229x+1.0714	11.8<x≦46.8, R^2=0.84
	0	46.8<x
$u_{moderate}$ =	0	x≦32.5
	0.024x-0.78	3.25<x≦54.2, R^2=0.98
	-0.05x+3.2333	54.2<x≦64.7, R^2=0.9868
	0	64.7<x
u_{poor} =	0	x≦55.2
	0.0357x-1.9714	55.2<x≦83.2, R^2=0.9776
	1.0	83.2<x

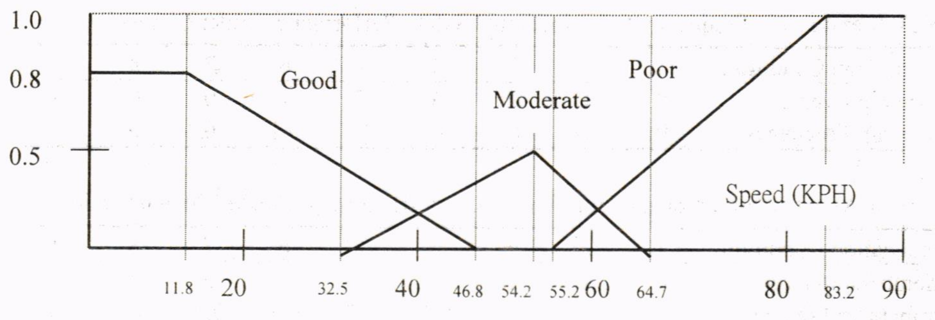


Figure 2. Membership Functions for Speed Safety

3.2 Discrete Membership Functions

Since discrete membership functions are limited subsets, the safety assessment of qualitative indicators should be obtained through semantic conversions of expert opinions solicited from questionnaires regarding the extent to which such qualitative factors are related to each performance level. To obtain the degree of membership of each qualitative indicator on different safety levels, this paper employs fuzzy statistics by creating a membership frequency table which categorizes various safety levels into "good", "moderate" and "poor". The degree of safety membership (good, moderate, and poor) for the safety level r of the assessment criterion y_{kj} is represented as follows:

$$u_{ki}\ (y_{kj}, z_r) = (N_r/N,\ O_r/N,\ P_r/N) \tag{12}$$

Where N_r (r=1,2,···,R) represents the number of experts selecting level r as "good" safety performance, O_r (r=1,2,···,R) represents the number of experts selecting level r as "moderate" safety performance, and P_r (r=1,2,···,R) represents the number of experts selecting level r as "poor" safety performance. Taking the creation of membership functions of channelization for example, there are indicated in Table 2 through Table 4. The conditions indicated in such tables are based on eight channelization designs. Condition 1 indicates full compliance with the principles and objectives of channel designs. Condition 2 refers to compliance with seven such principles and objectives, and Condition 3 six, Condition 4 five, Condition 5 four, Condition 6 three, Condition 7 two and Condition 8 one. Condition 9 represents total incompliance. The membership functions are represented as follows:

$u_{\text{channelization (good, moderate, poor)}}$ = (membership degree of good safety performance under condition r, membership degree of moderate safety performance under condition r , and membership degree of poor safety performance under condition r) (13)

In addition, in Figure 3, a bar chart juxtaposing "good", "moderate" and "poor" safety performance level is created to indicate changes of membership degrees.

Table 2. Membership Frequency for "Good" Safety Performance under Channelization

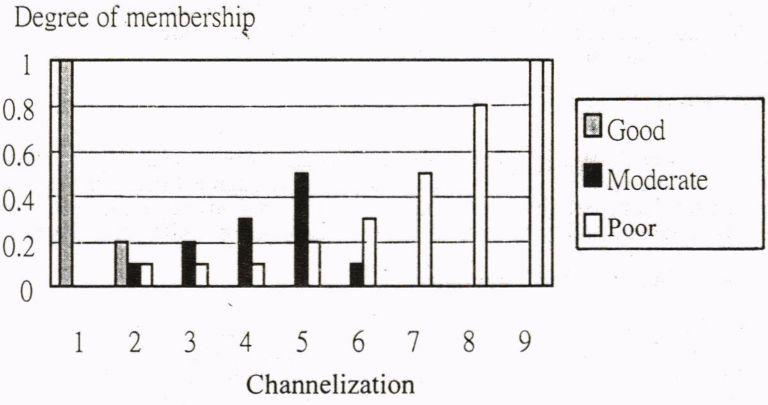
Channelization Condition	1	2	3	4	5	6	7	8	9
Membership Events	10	2	0	0	0	0	0	0	0
Membership Frequency	1.0	0.2	0	0	0	0	0	0	0

Table3. Membership Frequency for "Moderate" Safety Performance under Channelization

Channelization Condition	1	2	3	4	5	6	7	8	9
Membership Events	0	1	2	3	5	1	0	0	0
Membership Frequency	0	0.1	0.2	0.3	0.5	0.1	0	0	0

Table 4. Membership Frequency for "Poor" Safety Performance under Channelization

Channelization Condition	1	2	3	4	5	6	7	8	9
Membership Events	0	1	1	1	2	3	5	8	10
Membership Frequency	0	0.1	0.1	0.1	0.2	0.3	0.5	0.8	1.0



$u_{\text{full compliance with principles and objectives of channelization design}}$ = (1.0, 0.0, 0.0),

$u_{\text{compliance with seven principles and objectives of channelization design}}$ = (0.2, 0.1, 0.1),

$u_{\text{compliance with six principles and objectives of channelization design}}$ = (0.0, 0.2, 0.1),

$u_{\text{compliance with five principles and objectives of channelization design}}$ = (0.0, 0.3, 0.1),

$u_{\text{compliance with four principles and objectives of channelization design}}$ = (0.0, 0.5, 0.2),

$u_{\text{compliance with three principles and objectives of channelization design}}$ = (0.0, 0.1, 0.3),

$u_{\text{compliance with two principles and objectives of channelization design}}$ = (0.0, 0.0, 0.5),

$u_{\text{compliance with one principle and objective of channelization design}}$ = (0.0, 0.0, 0.8),

$u_{\text{no compliance with any principles and objectives of channelization design}}$ = (0.0, 0.0, 1.0)

Figure 3. Membership Function of Channelization

4.MODEL CONSTRUCTION

As indicated in Figure 4, the model construction process of this paper involves two stages. For the first stage, expert questionnaires are used to identify the assessment criteria, based on which the questionnaires for the second stage are designed to determine the relative weights of such criteria. Fuzzy statistics is used to create the membership function of each criterion. The eigenvalue method is used to obtain λ value and create a fuzzy integral model.

The steps for constructing the intersection safety assessment model in this research is discussed as follows.

4.1 Identification of Assessment Criteria

Regarding the safety aspects and assessment criteria contemplated in this paper, safety factors considered in relevant literature are considered, followed by the selection of twenty-one assessment criteria chosen on the basis of principles such as the accuracy, ease of measurement, improvability, representation and economy of acquired data. The safety degree of intersections is preliminarily divided into four aspects: people, vehicles, roads and environments. Each assessment criterion and its description are provided in Table 5. From the first expert survey, scores are assigned to represent the importance of each factor to obtain the assessment value of each factor. The significant criteria are chosen by the fuzzy trigonometric function, which is the geometric mean over the threshold value 7.62. And, it is derived two aspects, such as the "vehicle" and "road" aspects, and nine assessment criteria (See Figure 5), such as vehicle speed, motorcycle percentage, truck percentage, turning ratio, potential conflicts, channelization, signage conditions, visibility conditions, and approaches of intersections. Since there is a high degree of correlation among the respondents regarding "conflict points" and "potential conflicts", we choose the latter which is easier to calculate and used as the representation.

4.2 Weights of Criteria

Based on the assessment criteria selected in above procedure, the second-stage questionnaire is designed to calculate the relative weight of each criterion through a fuzzy analytical hierarchy process. After consolidating relative weightings of expert opinions regarding each aspect and the calculations of relative weights, the overall fuzzy weightings are indicated in Figure 5.

4.3 Construction of Membership Functions

The membership functions on each safety level of assessment criteria include quantitative and qualitative indicators. The safety levels are categorized into "good", "moderate" and "poor" levels. Regarding the construction of membership functions, this paper utilizes fuzzy statistical analyses to construct quantitative and qualitative membership functions (as described in section 3). The conversion coefficient is normally assigned by the research based on the evaluation preferences. In this paper, [0.0, 0.5, 1.0]' is used as the conversion coefficient.

4.4 Fuzzy Multiple Criteria Evaluation

Fuzzy multiple criteria evaluation is conducted based on finalized assessment criteria, their weightings and membership functions (Hwang and Yoon, 1981; Chen and Hwang, 1992), and the assessment outcome is defuzzied to obtain the safety level of each safety aspect of intersections.

4.5 Fuzzy Integral

In order to obtain the importance of road and vehicle aspects, the eigenvalue method (as described in section 2.3) is applied to the results of the second questionnaires to solve λ_i. The safety assessment value of each aspect as derived from the above-mentioned procedure is then incorporated into the general assessment conducted via the fuzzy analytic hierarchy process to obtain the overall safety level of each intersection studied.

5. CASE STUDY

In this work, four out of ten accident-prone intersections in Taipei City in 1999 are selected as the subjects of assessment. Such intersections include Citizen Boulevard and Linshen North Road, Minchuan East Road and Chienkuo North Road, Hoping East Road and Keelung Road, and Minchuan East Road and Sungchiang Road, with annual accidents of 39, 29, 27 and 26, respectively. The above-mentioned methods are employed to assess the safety level of each intersection. The weightings of each assessment criterion are shown in Figure 5.

5.1 Safety Membership of Each Assessment Criterion

The performance value of each assessment criterion is calculated based on the actual data obtained from the four intersections and assigned to each quantitative and qualitative membership functions constructed in section 3 to obtain the safety membership of each assessment criterion for each intersection under various levels. For example, the calculated results of the intersection of Citizen Boulevard and Linshen North Road are shown in Table 6.

5.2 Fuzzy Multiple Criteria Evaluation and Defuzzization

The vehicle speed at the intersection of Citizen Boulevard and Linshen North Road is taken as an example:

$$C_{11} = [0.0080, 0.1584, 0.4250] \bullet [0.0000, 0.2200, 0.1096] = [0.0000, 0.0349, 0.0466] \quad (14)$$

Table 5. Descriptions of Each Assessment Criterion

Aspects	Criteria	Unit	Descriptions
People	Ratio of Signal Violations	%	the ratio of drivers going through a red light and speeding through a yellow light.
	Speeding Ratio	%	the ratio of drivers driving through intersections at a speed exceeding the speed limits.
	Conflicts of Pedestrians and Vehicles	No./hr	the number of conflicts that may occur within certain units of time between pedestrians and vehicles.
	Ratio of Handicapped Through Intersections	%	the ratio of special pedestrians moving across the surfaces of intersections, such as the visually and physically handicapped and senior citizens.
	Pedestrian Traffic	person /hr	the traffic of pedestrians moving across the surfaces of intersections.
	Ratio of Illegal Crossings of Pedestrians	%	the ratio of illegal crossings of pedestrians.
Vehicle	Vehicle Traffic	Veh/hr	the total traffic of vehicles entering intersections.
	Vehicle Traffic Density	Veh/hr . m^2	the vehicle traffic within a unit area.
	Vehicle Speed	KPH	the 85^{th} percentile speed at which a vehicle enters an intersection.
	Motorcycle Percentage	%	This refers to the percentage of motorcycles among vehicles entering intersections.
	Truck Percentage	%	the percentage of trucks among vehicles entering intersections.
	Turning Rate	%	the ratio of turning vehicles among vehicles entering intersections.
	Potential Conflicts	Veh^2.	the potential weighted conflicts at intersections.
Road	Conflict Points	No.	the total parting, entry and intertwining points along the lines of motion at intersections.
	Intersection Area	No./m^2	the area of an intersection.
	Channelization	good/ poor	the existence of channelization, the greater the channelization, the safer.
	Signage Condition	good/ poor	whether appropriate signs are set up. the signs should be set up in ways that give the drivers adequate reaction time. The more appropriate a traffic sign, the safer.
	Visibility Condition	good/ poor	A good visibility refers to the parking and starting visibility for the 85^{th} percentile of vehicle speed..
	Number of Approaches	No.	the number of approaches at a given intersection, such as three-approach, four-approach or five-approach intersections.
Environment	Illumination	good/ poor	the degree of illumination affects the visibility conditions and visual field of a driver. Illumination may be measured by CNS DIN5044.
	Weather Conditions	good/ poor	such as sunny, rainy days, thick fogs, etc. will affect the visibility, visual field and judgment of a driver.

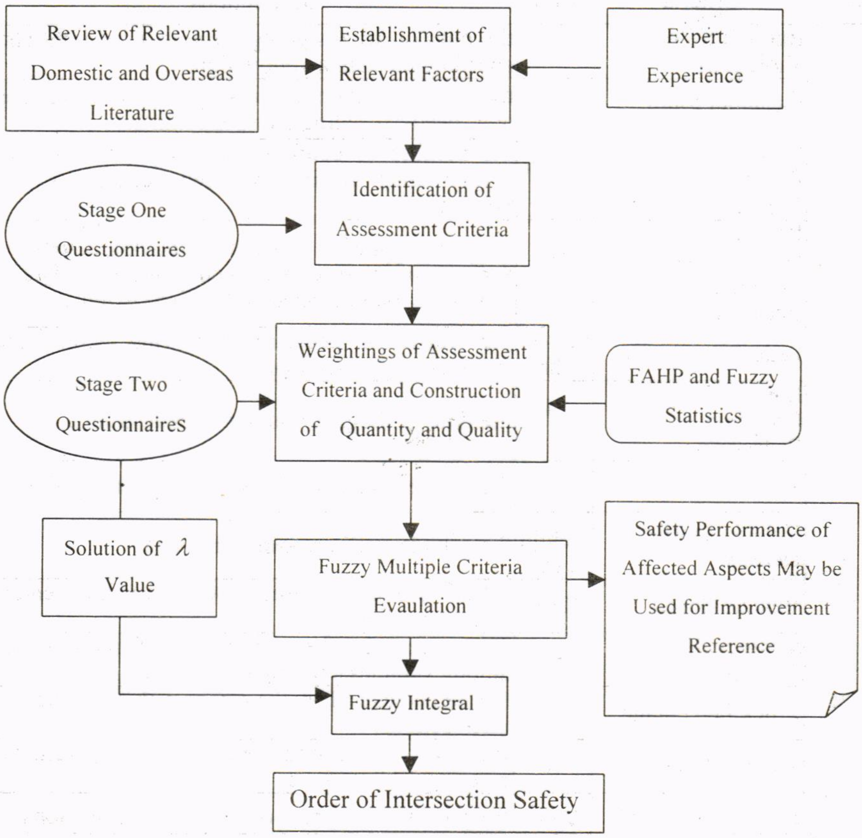


Figure 4. Construction Diagram for Intersection Safety

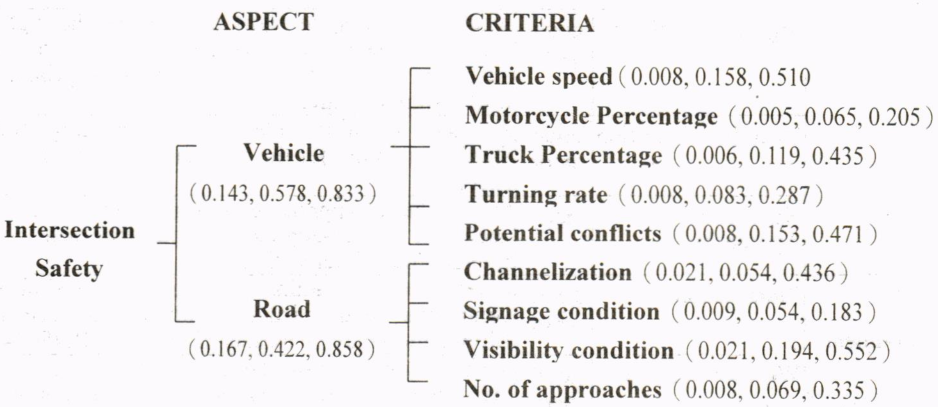


Figure 5. Fuzzy Weightings of Assessment Criteria

Table 6. Safety Membership of Each Assessment Criterion for Intersection of Citizen Boulevard and Linshen North Road

Assessment Criteria	Performance Value	Membership of Performance Values in Various Safety Levels		
		Poor	Moderate	Good
Vehicle Speed	42(KPH)	0	0.220	0.1096
Motorcycle Percentage	75(%)	0.33	0.16	0
Truck Percentage	1(%)	0	0	0.46
Turning Rate	36(%)	0.1139	0.3539	0
Potential Conflicts	1820(Vehicles^2)	0	0.0063	0.7098
Channelization	8 Compliances	0	0	1
Signage Conditions	Perfect Location	0	0	1
VisibilityConditions	No Compliance of Neighboring Roads with Visibility Requirements	1	0	0
No. of Approaches	4 Approaches	0	0	0.3

Note: This table is based on field observations.

As for defuzzization,

$$r_{11}=[0\ ,0.0349,\ 0.0466]\cdot\ [\ 0\ ,0.5\ ,1.0\ ]' = 0.0641 \text{ (defuzzied value)} \qquad (15)$$

The same procedure is applied to calculate the related values and is shown in Table 7. Based on the calculations for the general fuzzy assessment, we can compare the safety performance of various items under the categories of "vehicles" and "roads" at the intersections.

5.3 Fuzzy integral and Ranking

The safety performance data regarding the vehicle and road aspects obtained from the above procedure are used as the input data for the final fuzzy integral. The scores for the vehicle and road aspects as obtained from defuzzing the respective fuzzy multiple criteria evaluation on those intersections under study are indicated in Table 8. And the fuzzy integral is employed with the assessment process summarized as follows:

Step 1:Fuzzy Multiple Criteria Evaluation
Progressing fuzzy multiple criteria evaluation on each intersection under study, the various assessment scores for the vehicle and road aspects are obtained. Under the defuzzied process, we have the safety performance values as shown in Table 8.

Table 7. Fuzzy Multiple Criteria Evaluation of Intersections under Study

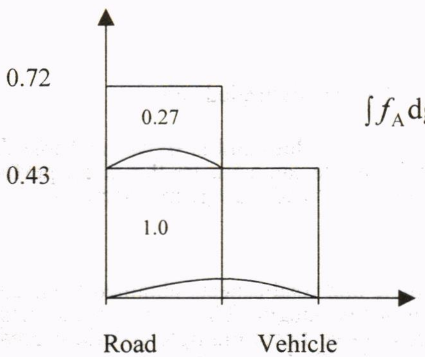
Intersection of Citizen Boulevard and Linshen North Road		
Criteria	General Assessment Values	Defuzzied Values
Vehicle Speed	(0.0000,0.0349,0.0466)	0.06410
Motorcycle Percentage	(0.0017,0.0103,0.0000)	0.0052
Truck Percentage	(0.0000,0.0000,0.0421)	0.0421
Turning Ratio	(0.0009,0.0293,0.0000)	0.0147
Potential Conflicts	(0.0000,0.0010,0.2999)	0.3000
Entire Quantity Indicator	(0.0026,0.0755,0.3886)	**0.43**
Channelization	(0.0000,0.0000,0.4356)	0.4356
Signage Conditions	(0.0000,0.0000,0.1832)	0.1832
Visibility	(0.2100,0.0000,0.0000)	0.0000
Approaches at Intersections	(0.0000,0.0000,0.1004)	0.1004
Entire Quality Indicator	(0.2100,0.0000,0.7192)	**0.72**

Table 8. Safety Performance Values of Intersection under Study

Aspects / Intersections	Safety Level for Vehicle Aspect	Safety Level for Road Aspect
Citizen Boulevard/Linshen North Road	0.43	0.72
Minchuan East Road/Chienkuo North Road	0.72	0.72
Hoping East Road/Keelung Road	0.53	0.77
Minchuan East Road/Sungchiang Road	0.55	1.21

Step2：Calculation of Importance $g(X_n)$
The results of the second questionnaires can be calculated by the eigenvalue method to obtain the following values: $g(X_{vehicle})=0.33$, $g(X_{road})=0.27$

Step3：Fuzzy Integral of Safety Level
Taken Citizen Boulevard and Linshen North Road as an example. By using the Choquet's integral measure in equation (10), the intersection effect of vehicle and road aspect and fuzzy integral of safety level are calculated and the results are shown in Figure 6.



$$\int f_A dg = (0.72 - 0.43) \times 0.27 + 0.43 \times 1.0 = 0.5$$

Figure 6. Fuzzy Integral Example of Citizen Boulevard / Linsen North Road Intersection

The same calculation procedure could apply to other intersections as well. Based on the calculated results employing the fuzzy integral method, we can compare the overall safety performance of each intersection.

Step 4: Rank of Intersection Safety
Based on Step 3, the intersection safety fuzzy integral is ranked as in Table 9. From the number of accidents in historical data, we also can rank the intersection safety and is shown in Figure 9. The safety assessment values derived from the fuzzy integral constructed via this paper by considering the additive effects of all aspects to assess the safety level of intersections correspond very well with historical accident data (in terms of the order). This attests to the practicability of this method in assessing potential hazards.

Table 9. Rank of Intersection Safety

Intersections	Citizen Boulevard /Linshen North Road	Minchuan East Road /Chienkuo North Road	Hoping East Road /Keelung Road	Minchuan East Road / Sungchiang Road
Accidents in historical data	39	29	27	26
Rank by history	4	3	2	1
Fuzzy integral of safety level	0.51	0.59	0.72	0.73
Rank by fuzzy integral	4	3	2	1

6.CONCLUSIONS

This paper develops a fuzzy integral model to assess multiple factors for intersection safety. The model can be utilized to produce an overall safety assessment, identified dangerous intersections and improved hazardous factors. With the fuzzy integral constructed, it is possible to ascertain the relative hazards of intersections under study due to certain factors, based on the safety membership of each assessment criterion. It is safer if the membership is to closer one, whereas it is more hazardous if the value is closer to zero. From the assessment score, we can find out the critical factors affecting on safety, we can also create the improvements and decide the priority of countermeasures, even there is no accident data. According to the comparison between practical assessments and historical data, which indicates a high degree of correspondence, the assessment model constructed in this paper can be put into practical use.

Two intersection safety aspects are selected here, i.e., the "vehicle" and "road" aspects, and nine assessment criteria such as the vehicle speed, motorcycle percentage, truck percentage, turning rate, potential conflicts, channelization, signage conditions, visibility conditions, and approaches of intersections are employed. In addition, the preference structure of the assessment criteria indicates that the vehicle safety aspect is more important than the road aspect. Among all the assessment criteria, the visibility conditions, potential conflicts, vehicle speed, truck percentage and channelization are more important than turning ratio, motorcycle ratio and signage conditions.

A non-additive fuzzy integral is employed in this work to assess the overall safety level of intersections. In the process of solving the fuzzy value (importance) λ, it is concluded that λ =13.7, while the importance g(vehicle) of the vehicle aspect is equal to 0.33, and the importance g(road) of the road aspect is equal to 0.22. This shows that expert subjects perceive that the impact of the factors in various aspects on intersection safety does not conform to the additive method and, instead, reveals multiplication effects.

However, since intersection safety factors are very complicated, there are still improvements that may be made to this paper. More assessment criteria and aspects, such as weather, environmental and human aspects, may be included in the future. More expert opinions and more recursive surveys will be helpful to select the assessment criteria and construct membership functions. In addition, we only choose four intersections with traffic signals in the case study, subsequent studies using more intersections are recommended so as to derive the threshold hazard values for various criteria and for intersections. Finally, there are only three levels selected for the discussion of the performance levels, more levels are recommended in the future study to reflect actual safety level more precisely.

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