

DEVELOPMENT OF LEVEL OF SAFETY USING FUZZY LOGIC SYSTEM FOR REAR END COLLISIONS BASED ON MICROSCOPIC DRIVING BEHAVIORS

SONG, Ki Han

Ph. D. Candidate

Dept. of Civil, Urban and Geo-systems
Engineering

Seoul National University

San 56-1 Shillim-dong, Gwanak-gu

Seoul, Republic of Korea

Fax: +82-02-889-0032

E-mail: willkh@hanmail.net

CHUNG, Sung Bong

Research Fellow

Center for Transport Infrastructure
Investment

The Korea Transport Institute

2311, Daehwa-dong, Ilsan-gu, Goyang-si

Gyeonggi-do, 411-701, Korea

Fax: +82-31-910-3224

E-mail: bbaqui@koti.re.kr

RHEE, Sung Mo

Professor

Dept. of Civil, Urban and Geo-systems
Engineering

Seoul National University

San 56-1 Shillim-dong, Gwanak-gu

Seoul, Republic of Korea

Fax: +82-02-889-0032

E-mail: rheesm@snu.ac.kr

KIM, Se Hwan

Graduate Student

Dept. of Civil, Urban and Geo-systems
Engineering

Seoul National University

San 56-1 Shillim-dong, Gwanak-gu

Seoul, Republic of Korea

Fax: +82-02-889-0032

E-mail: ksehwan78@hanmail.net

Abstract: The purpose of this study is to develop ‘Level of Safety’ of rear end collision using fuzzy theory considering microscopic driving behaviors. The factors for accidents can be represented by microscopic driving behaviors, so traffic condition data are investigated by field surveys of the test vehicle on the expressway of Seoul, and revised by wavelet function. Then, a fuzzy rule is generated based on the risk evaluation model developed by Chung (2003) and rough set theory, and risk degrees of each two vehicle are calculated using the other set. Finally, each safety degrees are aggregated using membership function values of each safety degree, and ‘Level of Safety’ is suggested based on the relation of aggregated degrees and average speed. Level of safety suggested using fuzzy logic system based on microscopic driving behaviors would be an efficient and reasonable countermeasure for identifying the real risk conditions in various fields.

Key Words: Level of safety, Accident, Safety, Fuzzy logic system

1. INTRODUCTION

There are many requirements for a road to be operated and managed properly, but one of most important things is that it should be safe for all to drive. However, although every endeavor has made to prevent accident, there are still many accidents on the roads, and the first step to settle this problem is to identify the risk situation. Despite of trying to develop the standard to assess the risk, there is no clear standard of level of safety due to the difficulty in evaluation risk on accident. Generally, accidents would be caused by road environment-related factors, by driver-related factors, by vehicle-related factors or different combinations of these factors so that it can't be explained distinctly, and it is characterized by uncertainty, subjectivity, imprecision and ambiguity to understand what the risk situation is. The first problem of accident analysis can be fixed to use microscopic approach because macroscopic analysis is not able to explain mechanism of complicated factors, but microscopic approach starts from situation of each vehicle. Then, fuzzy theory can deal with a uncertainty, subjectivity, imprecision and ambiguity problem so that it brings the second problem of evaluating risk situations to a settlement.

Therefore, in order to fix these problems, level of safety should be developed using microscopic driving behaviors and fuzzy logic system for rear end collisions. First of all, the complex factors for accidents can be represented by microscopic driving behaviors, so data of the microscopic driving factors such as the deceleration rate of each vehicle, the distance gap between vehicles, and the speed of each vehicle are investigated by field surveys using the test vehicle on the expressway of Seoul and revised by wavelet function. Then, the real accidents and the traffic conditions data were collected, compared, and combined with field data by unit section to construct fuzzy sets and membership functions.

In the next process, the available data set was divided into two subsets, and a fuzzy rule is generated based on the risk evaluation model developed by Chung (2003) using the first set, and each risk degrees of vehicles relation are calculated. In order to make fuzzy reasoning system, the fuzzy rule set is deduced by rough set theory. After the fuzzy system is established, each risk degree between two vehicles is aggregated using fuzzy membership function values. Then, Level of Safety is suggested on the basis of the relation between these aggregated degrees and average speeds. Then, the important assumptions of this study are that the scope is focused on the straight sections of an expressway, and gradient of vertical alignment is same along the all sections, and that the elements of accidents such as traffic condition, speed differences can be represented by microscopic behaviors of each car itself.

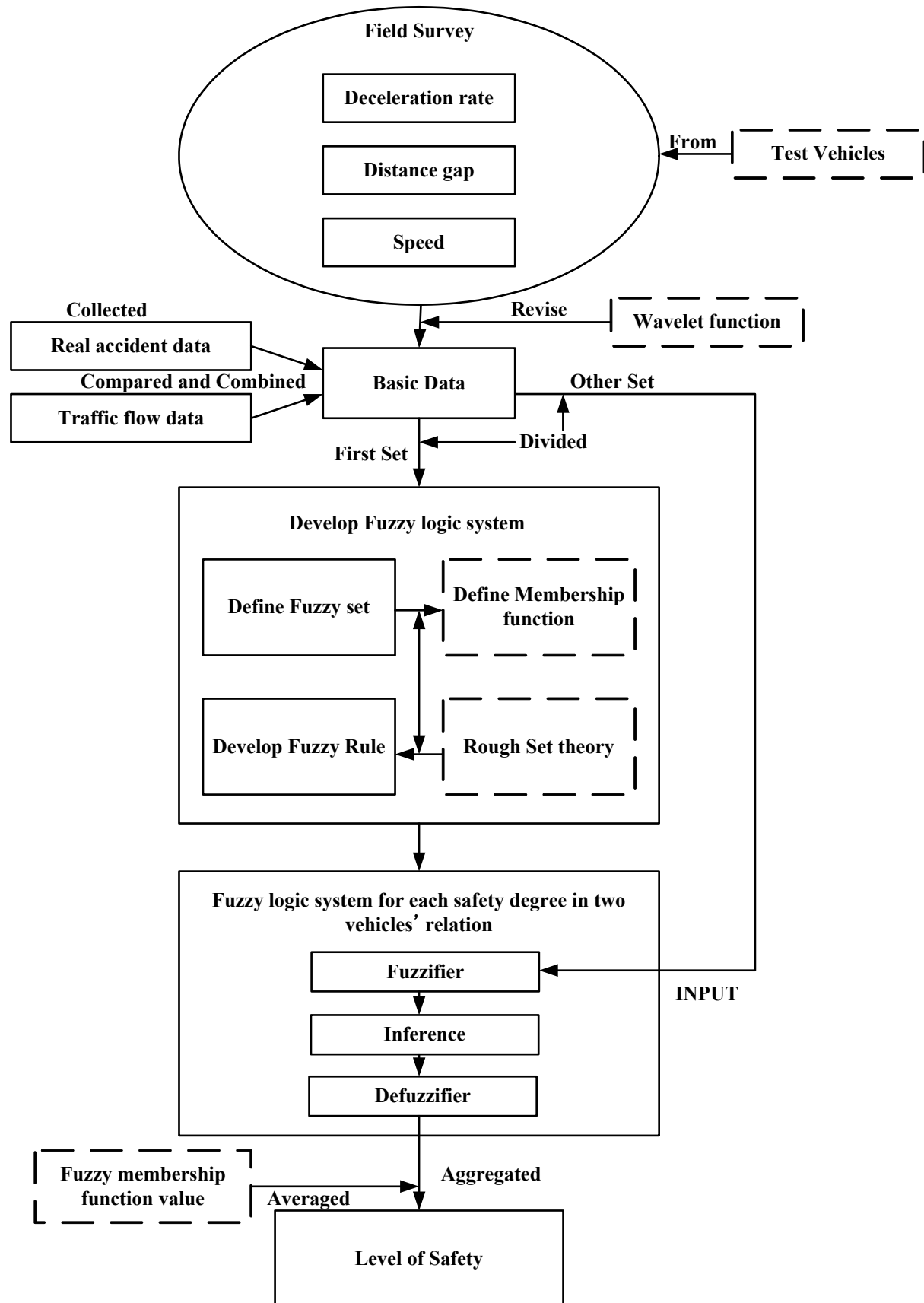


Figure 1. Flowchart

2. LITERATURE REVIEW

2.1 Methods to Evaluate the Safety of Roads

Methods to evaluate safety of roads are largely divided into two categories according to whether accident data are used or not. The models developed with accident data, such as accident prediction models, judge variables related to real accidents and predict future number of accident using regression analysis. However, they have such serious problems as real accident data should be accumulated for at least 3 years and there are limits not to explain the characteristics of accidents such as complexity and randomness of accident occurrence clearly. Moreover, there exist defects of methods in themselves by simplifying various accidents, so they are considered not to be suitable methods to appraise safety of roads effectively.

However, non-accident based models, which are methods to develop adequate index from considering elements directly related to accidents, are able to show safety of roads quantitatively, to compare relative safety of each subject objectively. Moreover, the models are useful for making countermeasures through obvious analysis of accident risk, even though they do not clarify the objective mechanism of accident occurrences.

Table 1. Method to Evaluate the Safety of Roads

Classification	Representative Methods
Based on accident data	past accident numbers, past accident ratio, accident prediction models, EB method etc.
Based on non-accident data	speed gap, continuity of geometry characteristics, driver's fatigue and complex elements models, conflict method, exposure index etc.

Especially, previous studies on the risk of rear-end collisions are difficult to explain safety degrees of these accidents clearly, because they simply deal with relations between distance gap and minimum safety distance to avoid collisions. Therefore, recently many researchers try to develop LOSS(Level of Service Safety), and one of recent results is Kononov(2003)'s paper which developed the concept of LOSS and countermeasures to solve safety problems. Moreover, this paper showed that potential number of accident and severity in certain level of AADT can be obtained, but information about accidents happenings themselves cannot. Therefore, this paper develops method to evaluate 'Level of Safety' based on microscopic driving behaviors.

2.2 A Risk Evaluation Model for Rear End Collisions using Driving Behaviors¹

Chung (2003) established the relation between risk and accidents using driver-related factors in accident occurrences.

- Potential risk: The risk as it is on the road-vehicle system, in which the behavior or response of driver is not considered.
- Responded risk: The risks, which are ignored or wrong responded to by a driver.
- Accident: The unusual and unexpected event, which happens in a situation where the potential or the ignored risks increase suddenly and can not be responded and handled properly.

Based on the concepts, a new factor (R_{prob}) was introduced to model the risk of rear end collision. Considering the relationships between the risk itself and the wrong responded risk, the accident occurrence probability (AOP) can be modeled as the ratio of responded risk (R_d) to the risk which exists potentially in the road-vehicle system (R_{sys}) as is shown in the following formula.

$$R_{\text{prob}} = \frac{R_d}{R_{\text{sys}}} \quad (1)$$

Finally, from the definition of the accident occurrence probability, the risk of the rear end collision is calculated as follows:

$$R_{\text{prob}} = \frac{\int_{a_a^{\text{mod}}}^{a_a^{\text{max}}} \int_{a_b^{\text{mod}}}^{a_b^{\text{max}}} \{t_r^{\text{max}} - t_r(a_b)\} da_b da_a}{\int_{a_a^{\text{mod}}}^{a_a^{\text{max}}} \int_{a_b^{\text{mod}}}^{a_b^{\text{max}}} \{t_r^{\text{max}} - t_r^{\text{min}}\} da_b da_a} \quad (2)$$

where, a_a : deceleration rate of lead vehicle (mps)

a_b : deceleration rate of following vehicle (mps)

t_r : response time (sec)

This values from formula (2) was used as the basic standard output of microscopic two vehicle's risk in our paper.

¹ Chung, 2003.

2.3 Fuzzy Set Theory and Fuzzy Logic System

Zadeh(1965) has introduced fuzzy set theory as a mathematical useful tool for modeling uncertain(imprecise) and vague data in real situations. The essential assumption of fuzzy set is that many sets in real world do not have precisely defined bounds and each element has degree of belonging to some sets called as membership. This theory has been practiced in many engineering fields as various algorithms such as Fuzzy Logic System. This paper use Fuzzy Theory to aggregate degrees of risk.

The concept of fuzzy logic system is ‘Approximate Reasoning’, and Zadeh (1973) and Mamdani and Assilian (1975). Mamdani (1974), Kickert and van Nauta Lemke (1976), Ostergard (1976), and Tong (1976) are the pioneers in this field, and a control engineering review of fuzzy systems made by Tong (1977). The concept of a fuzzy logic system (FLS) by Mendel (1995) is as follows: ‘In general a FLS is a nonlinear mapping of an input data (feature) vector into a scalar output (the vector output case decomposes into a collection of independent multi-input/single-output systems)’. Every fuzzy logic system are composed of rules, fuzzifier, inference engine and defuzzifier (Fig 2.).

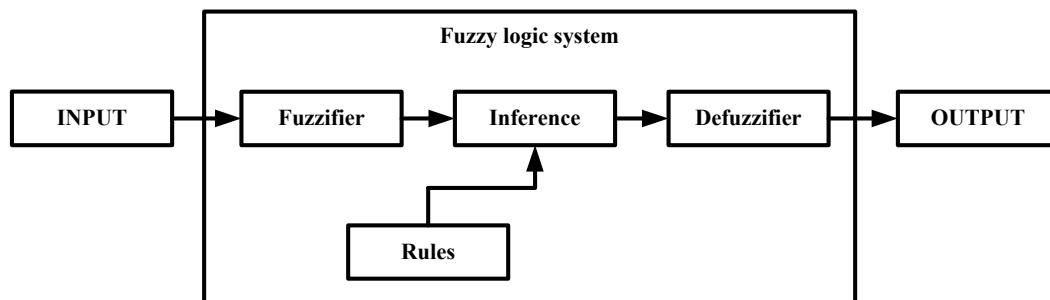


Figure 2. Fuzzy Logic System

The advantages of fuzzy controllers based on fuzzy logic systems are intuitive design, reflecting the behavior of human operator, the fact that the model of the controlled process is not necessary (an important feature when ill-defined processes are to be controlled), and good control quality (not worse than that of classical controllers). (E. Czogala, 1993) However, The main disadvantages are the necessity of acquisition and preprocessing of the human operator’s knowledge about the controlled process, sequential search through rule bases, and time-consuming defuzzification methods. (E. Czogala, 1993)

In this paper, these concepts of fuzzy logic system are used to calculate risk degrees of each vehicle.

2.4 Rough Set Theory

Pawlak (1982) proposed the rough set concept on the assumption that there is some information that can be associated with every object of the universe. He said that the approximation of completely and precisely known pieces of information is essential in this approach. Such pieces of information constitute equivalence classes of equivalence relation, which is called an indiscernibility relation. (E. Czogala, 1995)

The rough set approach can control imperfect data due to the capability to control imperfect and vague data, and the rough set theory supplements for other approaches dealing with data uncertainty such as probability theory, evidence theory, and fuzzy set theory, etc. In this study, we extract rules for inference engine of fuzzy logic system using rough set approach.

3. DATA COLLECTION

The data in surveys consist of 3 groups. The first data group is accident number by lane and by time and the second data is macroscopic traffic flow data for constructing fuzzy sets and membership functions. The last one is microscopic data of each vehicle for input data of the model.

3.1 Accident Data

As one of methods for constructing fuzzy logic system, accident data were collected with the help of transportation management center of Seoul. Usually, accident data used in analyzing a model is 3 years' data but in this study the accident data was used for comparing the model with the number of accident so that the data used in validation covers just the period from March to December of the year 2002. The data is for the rear end collision occurred on the 1st and 3rd lane of the survey fields during the period.

3.2 Macroscopic Traffic Flow Data

The data such as speed, traffic volume was collected from video detector equipped on each road section. Based on these data the traffic flow conditions were classified into four groups by means of speed-volume curve as shown in Figure 3.

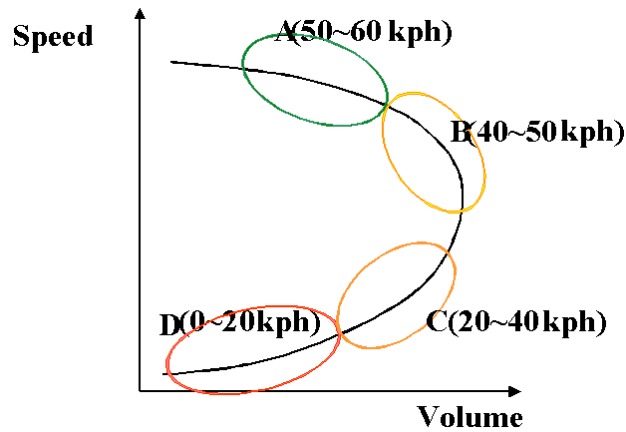


Figure 3. Traffic Flow Conditions

3.3 Microscopic Traffic Flow Data

The eight days of field surveys including 2 days of preliminary survey were exerted for collecting the data such as speed of test vehicle, spacing and deceleration rate on the expressway of Seoul. To consider the characteristics of traffic flow pattern and ramp connection of each lane and section, the subject road was divided into six sections and surveyed for 12 hours, from 7 a.m. to 7 p.m. for weekdays.

For this field survey, it was very important to choose proper drivers for objective data collection. Thus, based on the driving career and sex, test drivers were classified into 4 groups as follows:

Group 1: Novice (Driving Career is under a year, Sample number is 4 persons)

Group 2: Practiced (Driving Career is 1 year ~ 2 years, Sample number is 2 persons)

Group 3: Experienced (Driving Career is 2 years ~ 3 years, Sample number is 7 persons)

Group 4: Routine (Driving Career is Over 6 years, Sample number is 7 persons)

In addition, to collect the microscopic data of each vehicle, the test vehicles equipped with tachometer analyzer and data login system were used. The collected data from these test vehicles were processed through the code-conversion program in the login system and was calculated and analyzed with excel S/W 2002 and Matlab S/W version 6.1.

3.4 Revision of Raw Data

To filter the noises caused by data conversion from the tachometer, namely, non-flatness of the surface and the difference of driving distance, two correction steps were chosen. At first,

the difference between traveling distance by a vehicle and the distance in the map was corrected by means of average dividing method. The noise produced by data conversion is filtered by eliminating abnormal data, and then the noise was filtered by using the wavelet tool in Matlab S/W ver 6.1. (Stollnitz, 1995)

4. METHOD TO DEVELOPMENT OF LEVEL OF SAFETY

The process of developing level of safety consists of three steps, which are defining level of safety, calculating each degrees of risk between two vehicles, and aggregating these degrees to level of safety with average speeds in some sections.

To deduce risk degrees of each vehicle, fuzzy logic system is structured, and the base elements, fuzzy sets and their membership functions, are defined by using survey data and degrees of risk by Chung (2003). Then, if-then rules of inference engine are made by rough set theory. Finally, to get the level of safety in some sections, fuzzy membership function values of each safety result is averaged, and a method to get 'Level of Safety' based on these degrees related with average speeds is suggested.

4.1 Definition of Level of Safety

There can be many definitions of safety, but this paper assumes that level of safety in a road section means the grades which people feel about the possibility to experience rear-end collision including severity in the section. This definition is composed of three elements related with roads in themselves, driving behaviors in this road, and relation between drivers and roads. This paper assumes that these three factors are mixed in microscopic driving behaviors on roads, and five microscopic traffic condition variables are selected such as velocity and acceleration of lead and following cars, and the gap distance between these cars divided the minimum safety distance. The minimum safety distance (MSD) is the distance that following car needs to avoid a rear-end collision (3). The traffic condition in itself can be included into velocity, and drivers' behaviors are able to be included into fluctuations of accelerations in every two seconds, and degree of risk in the system can explain the gap distance divided the minimum safety distance (MSD).

$$MSD = v_b t_r + \frac{v_b^2}{2a_{max}} \quad (3)$$

Where, v_b : following car speed

t_r : response time

a_{\max} : possible deceleration rate

However, these results are not level of safety but risk degrees of two vehicles, so after the aggregation process using fuzzy theory, level of safety that we define is suggested.

4.2 Definition of Fuzzy Sets and Membership Function

Before constructing fuzzy logic system, fuzzy sets and membership functions should be fixed, and we made membership functions on the basis of triangle membership method using 2 times standard error. Speed fuzzy sets are composed of three sets, 'high speed', 'medium speed', and 'low speed'. Their membership functions are based on macroscopic traffic condition data and number of accident. Acceleration fuzzy sets also consist of three sets, 'positive acceleration', 'no acceleration', and 'negative acceleration', and membership functions are based on microscopic field survey data and maximum and common acceleration rates of vehicles. The gap distance/MSD sets are divided into three fuzzy sets, 'more than 1', 'around 1', and 'less than 1' using microscopic data. At last, the risk degrees sets are composed of 5 fuzzy sets, 'very danger', 'danger', 'common', 'safe', and 'very safe'. The membership functions are reproduced based on dividing the risk degrees uniformly (Table 2 and Figure 4).

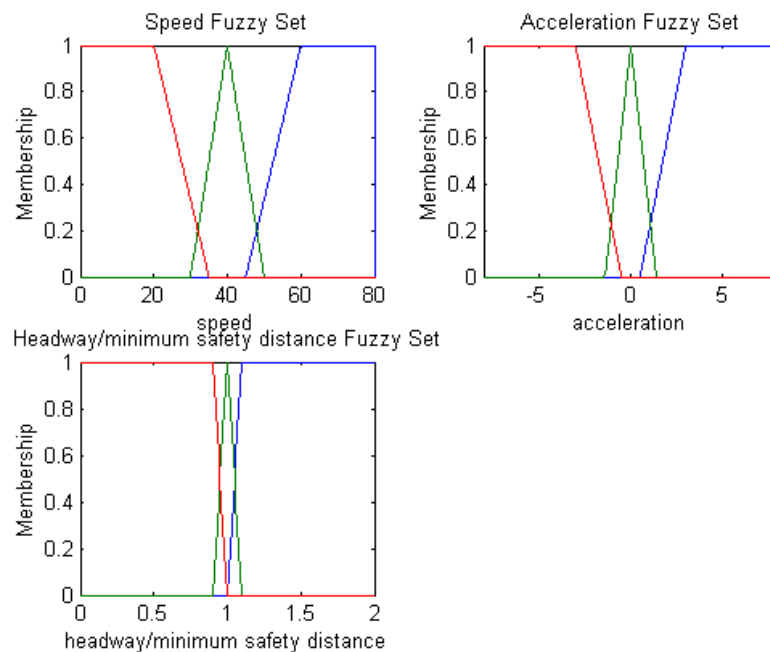


Figure 4. Fuzzy Sets and Membership Functions

Table 2. Fuzzy Sets and Membership Functions

Classification	Fuzzy sets	Membership Function shape	Function value range		
			Left intercept	Value equals 1	Right intercept
Speed (km/hr)	High	Trapezoid	45	60-80	80
	Medium	Triangle	30	40	50
	Low	Trapezoid	0	0-20	35
Acceleration Rate (m/sec ²)	Positive	Triangle	0.5	3-8	8
	Zero	Triangle	(-1.39)	0	1.39
	Negative	Triangle	(-8)	-8-(-3)	(-0.5)
Gap/MSD (no dimension)	More	Triangle	1	1.1-2	2
	Around	Triangle	0.9	1	1.1
	Less	Triangle	0	0-0.9	1
Risk degree (Chung, 2003)	Very safe	Trapezoid	0	0-0.1	0.2
	Safe	Triangle	0.15	0.2	0.35
	Common	Triangle	0.3	0.4	0.5
	Dangerous	Triangle	0.45	0.65	0.85
	Very dangerous	Trapezoid	0.8	0.9-1	1

4.3 Development of Inference System and De-fuzzification Method

Fuzzy rules are extracted from the information table (Table 3) using rough set theory based on the first set of data including field survey of one day. The rows of the table are objects, the columns are attributes and the intersections of rows and columns are filled with attribute values, which are represented by linguistic information. This information is made from fuzzy sets that included fuzzy membership function maximum value of attributes. Then, we find that cores of this information are all of 5 variables, and optimum rule set has five condition elements and one decision class.

Table 3. Example of Information Table

No.	Condition					Decision
Object	Lead speed	Lead acceleration	Following speed	Following acceleration	Gap/MSD	Risk degree
#1	High	Zero	Low	Negative	1.7	A
...

From a rule set, the fuzzy relationship is founded by max-min method, and the center of membership function method to find the output of fuzzy logic system is used as de-fuzzification.

4.4 Aggregation of each safety degrees

Now, degrees of risk between each car are deduced, but this set is not risk degrees in a road section. Therefore, to get risk degrees aggregated in road section, the grades of membership function of each two vehicle are averaged, and this aggregated grade of membership is de-fuzzified to output value as in fuzzy logic system. Then, from this result, this paper suggests a method to deduce 'Level of Safety'.

5. RESULT

Risk degrees from the other set of data in 5 days are calculated by each field survey, and compared by 6 road sections (Table 4) and with each average speed (Figure 4).

Table 4. Results of Risk Degree

Classificaiton		Average speed (km/h)	The degree of risk
Section 1	First lane	24.75	0.3955
	Second lane	32.56	0.3978
	Third lane	41.04	0.4388
Section 2	First lane	23.38	0.3569
	Second lane	27.09	0.3703
	Third lane	27.09	0.3760
Section 3	Second lane	52.64	0.5195
	Third lane	52.17	0.5224
	Fourth lane	45.92	0.4914
Section 4	Second lane	63.36	0.5690
	Third lane	52.30	0.5238
	Fourth lane	50.17	0.5179
Section 5	First lane	56.43	0.5188
	Second lane	49.51	0.5036
Section 6	First lane	58.57	0.5317
	Second lane	52.83	0.5169

Note: Lane numbers are ordered from median.

Section 1 and 2 are safer than other sections in a point of risk degrees' view, and average speeds in section 1 and 2 are slower than others. From this result, we can find that our

aggregated degree of risk includes severity more than risk situation simply, which cannot be explained in each degree of risk between two vehicles, because severity of accident is in proportion to velocity. The aggregated risk degrees are about from 0.4 to 0.55 that corresponds to common situation defined in fuzzy set, and this result means that people drives more or less safely bearing some risk because there are possibility to happen accidents in traffic condition in itself but drivers believe that they can response properly to a risk situation. Moreover, this result shows that there are some risk situations in each two vehicle, but in a road sections the risk degrees become normalized.

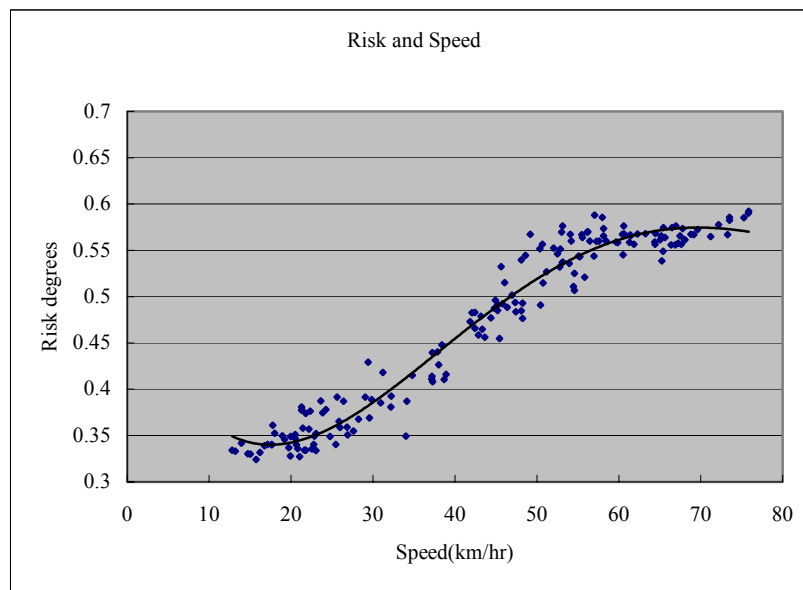


Figure 5. Relation between Speed and Risk Degrees

Therefore, 'Level of Safety' should not include the aggregated risk degree directly, and should be deducted from relationship between speeds and risk degrees. In order to find their relation, pairs of average speed and risk degree are arranged in figure 5. We find that risk degrees are low in low speed level and high in fast speed level, and the level of change is not high in low and rapid speed situations. However, in medium speed case, risk degrees are increased rapidly, and there are two points of inflection. If risk degrees do not change rapidly, drivers would react properly because their expectations to the road conditions are fixed, but if they change fast, the situation on a road section would be dangerous because the expectation of drivers cannot be fixed. Consequently, the simple possibility of accidents depends on the grades of change in risk degrees, and the severity depends on the quantity of risk degrees.

6. SUGGESTION AND CONCLUSION

6.1 Suggestion

From this inference, this paper suggests 'Level of Safety' such as in Figure 6. First of all, range of 'Level of Safety' in which severity and possibility of accident is high is defined as 'very dangerous situation', E. Similarly, that of range which severity or possibility is high is suggested as 'dangerous situation', D, and which severity and possibility is usual as 'common situation', C, and which possibility is low and severity is high as 'safe situation', B, and which possibility and severity is low as 'very safe situation', A (Table 5). Intercepts of each level of safety is developed by relation of risk degrees and average speeds, but it needs to be more precisely defined by further study based on more investigation.

Table 5. Level of Safety

Classification	Definition	The possibility	The severity	The range(km/hr)
A	Very safe	Low	Low	- 18
B	Safe	Low	High	63-
C	Common	Medium	Medium	25-40
D	Dangerous	High	(or) High	18-25, 40-53
E	Very dangerous	High	High	53-63

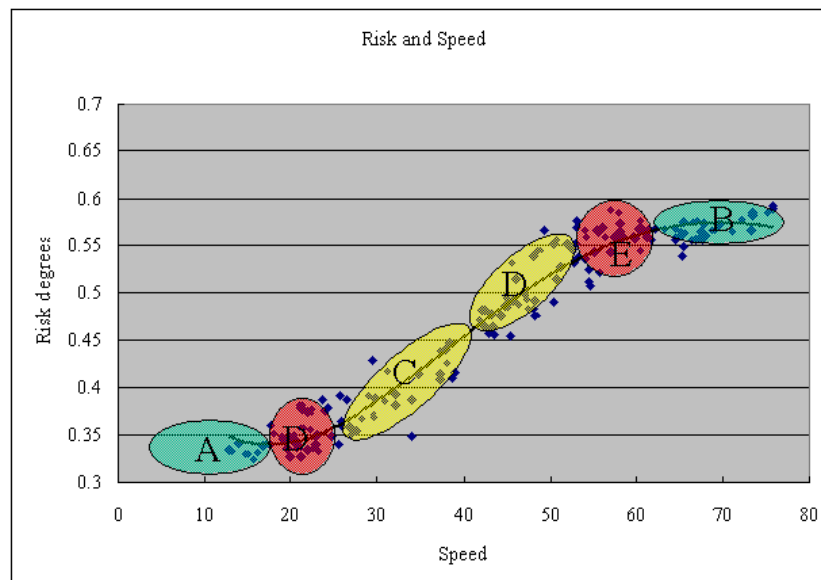


Figure 6. Level of Safety Range

6.2 Conclusion

This paper develop method to evaluate safety degrees on a road section, and suggests 'Level of safety' based on microscopic driving behaviors. The method to develop 'Level of Safety' starts from field surveys of microscopic data, and each degrees of risk are calculated and aggregated using fuzzy theory, and aggregated risk degrees are used to define level of service with average speeds. This is the first trial to define 'Level of Safety' to include severity and possibility of accidents using microscopic driving behaviors. However, this paper just investigate relation between risk degrees and speeds, so in further study, relation between risk degrees and other traffic conditions, and 'Level of Service' should be compared and mixed to new 'Level of Service including Safety' based on more investigation.

'Level of Safety' developed using fuzzy logic system based on microscopic driving behaviors would be an efficient and reasonable countermeasure for identifying the real risk conditions in various fields.

REFERENCES

a) Books and Books chapters

Kyung-il, M. and Hyun-yup, L. (2003), **Intelligent Information System Using MATLAB**, A-JIN Publishing Co., Korea, Seoul.

Zdzislaw Pawlak (1991), **Rough Sets Theoretical Aspects of Reasoning about Data**, Kluwer Academic Publishers B. V., Dordrecht/Boston/London.

b) Journal papers

Dusan Teodorovic (1999), Fuzzy logic systems for transportation engineering: the state of the art, **Transportation Research Part A**, Vol. 33, 337-364.

E. Czogala, A. Mrozek and Z. Pawlak (1995), The idea of a rough fuzzy controller and its application to the stabilization of a pendulum-car system, **Fuzzy Sets and Systems**, Vol. 72, 61-73.

Stollnitz, E. J., T. D. DeRose and D. H. Salesin. (1995a), Wavelets for Computer Graphics: A Primer, Part 1., **IEEE Computer Graphics and Applications**, Vol. 15, No. 3, 75-85.

Stollnitz, E. J., T. D. DeRose and D. H. Salesi. (1995b), Wavelets for Computer Graphics: A Primer, Part 2., **IEEE Computer Graphics and Applications**, Vol. 15, No. 4, 75-85.

c) Papers presented to conferences

E. Czogala (1993), Fuzzy logic controllers versus conventional controllers, **16th Seminar on Fundamentals of Electrotechnics and Circuit Theory**, Gliwice-Ustron Col. 1, 23-29.

E. Czogala (1993), On the Modification of Rule connective in Fuzzy logic Controllers Using Zimmermann's Compensatory Operators, **EUFIT '93 September 7-10**, Aschen (Germany), 1329-1333.

Kononov J., Allery B. (2003), Level of Service of Safety: A Conceptual Blueprint and the Analytical Framework, **Transportation Research Board Annual Meeting '03 January**, Washington (USA).

d) Other documents

Chung, Sung Bong (2003), Development of Risk Evaluation Model for Traffic Flow on the Base of Microscopic Driving Behavior, Doctorial Dissertation, Seoul National University.