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**Fuzzy Logic Modeling Approach for Risk Area
Assessment for Hazardous Materials
Transportation**

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ABSTRACT

The assessment of area in risk of HazMat transportation is very beneficial for the planning of the management of such area. We prioritized the affected area using HazMat-Risk Area Index (HazMat_{RAI}) developed on the basis of Fuzzy Logic. The purpose of such development is to reduce limits of the criteria used for the assessment which we found exist when displaying data related to Hazmat represented by iceberg. In this regard, we categorized type of Membership Function according to Fuzzy set method in order to match the existing criteria, both solid and abstract ones. The conditions of Fuzzy Number and Characteristic are used respectively so that all risk levels are covered. However, the displaying of HazMat-Risk Area Index needs weighing of each criterion that is used for the assessment which significance of each level varies. We used Saaty's Analytic Hierarchy Process (AHP) to establish weighing value obtained from such assessment. Therefore it is beneficial for the preparation of area with HazMat_{RAI} value is high, hence proper preparation for the management in case of critical situation.

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1. Introduction

Recently industrial sector has been growing rapidly. Industry involved with chemical substances, nuclear, electrics, and petroleum are beneficial to the world, but at the same time they come with complicated problems. These industries are generator where they need hazardous material for the manufacturing process. Besides, some type of industry also produces hazardous wastes. Major affects include the transportation of hazardous materials which occur everywhere in pipe, rail, and road. It increases risk of people's safety, life, property, and environment of the area where transportation takes place. In the United States, we found that the transportation of hazardous materials generates economic activities a great deal, for example, the transportation that costs more than 2 billion dollars in the United States. Over all transportation increases to 20% during 1997 – 2002 (USA Census Bureau, 2002) and transportation by truck is as high as 52.9%, accidents on high way is 89%. For the accident, the serious ones are caused by the transportation of hazardous material such as leaking or death, damage costs up to 31 billion dollars (about 80,000 dollars for 1 accident) (USA DOT, 2003). Despite our awareness that accident from hazardous materials does not occur frequently ($10^{-8} - 10^{-6}$ per vehicle per mile) (Erkut and Verter, 1995; Zografos and Davis, 1989), the consequence is much to be concerned for every involved person or everyone who is affected by the transportation of hazardous materials, involved people in the area, government sector, transportation company, transportation vehicle, and people in risk. The reduction of risk of transportation is the main purpose of every people involved in the transportation of hazardous materials.

The National Fire Protection Agency (NFPA), 2008 has defined HazMat Risk that it is the possibility and severity of sequence from the exposure to hazardous material. The result from this definition is that the perception of hazardous material is always involved with leakage, and the consequence of such leakage. Frequency of leakage depends on many factors e.g. possibility of accident, possibility of leakage, and numbers of hazardous material transportation. Consequence from the leakage depends on types of hazardous materials, amount of leakage, and duration from the occurrence until the management. Hazardous material transportation can make people's life harmful, especially people who are living near transportation route. Besides, it also affects environment. Although not frequent, if it occurs, it can lead to major disaster.

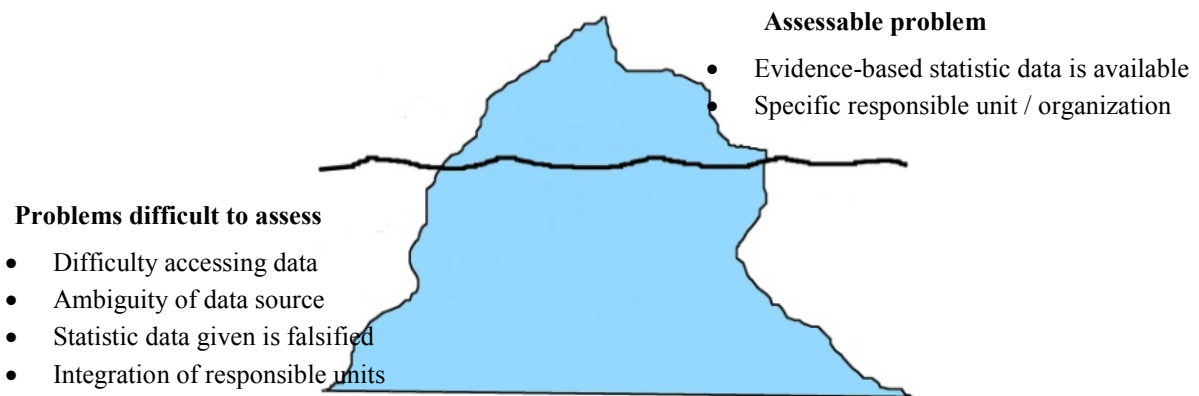


Figure 1: The problem of hazardous material transportation is like an iceberg.

The inevitable truth in many countries is that the problem of hazardous material transportation is like an iceberg. It is difficult to access the truth data about such transportation i.e. pipe, rail, or road to see if it was operated with transparency. Avoidance and failure to comply to the law, false information, ambiguous source of information, and the operation of officers that does not cover all aspects, and the integration of involved units are all problems that have been hidden. The preparation to handle the accident from hazardous material transportation plays an important role in the safety of such transportation that results in the loss of life, property, and environment. The major contributions of this paper are the guideline for the assessment of risk area from hazardous materials using the theory of Fuzzy Set. The assessment is conducted under the limitation of ambiguous factors in terms of both objective and subjective. Purpose of the assessment is to obtain index for the identification of risk area from hazardous materials

2. Literature Review

In the past, problems of route management were handled by the development of model for solving problems using single or multiple criteria. Purpose of single criteria model is to identify one route or one network that minimizes risk (Glickman, 1983; Batta and Chiu, 1988; Karkazis and Boffey, 1995). Multiple criteria model refers to route management on the basis of expense such as travel time, expense of transportation, risk of accident, estimated numbers of affected people, risk

of some special population group, and property damage (Zografos and Davis, 1989; McCoord and leu, 1995; List and Turnquist, 1994). Route management and scheduling help us find out the problems. In this regard, we need to identify travel time and the point that mitigation team has to stop before reaching the scene (Cox, 1984; Cox and Turnquist, 1986; Nozick et al., 1997). Research by Lassarre (1993) and Lepofsky et al (1993) has explained the Decision Support System: DSS covering the analysis of danger from transportation and accident management, identifying following topics a) risk assessment on the basis of accident possibility, leakage, consequence, and risk b) identify optimum route between two points on the basis of multiple criteria such as duration, possibility of accident, and population in risk c) identification of the outcome from hazardous material and the assessment of evacuation and the identification of existing road usage d) traffic management on the affected scene.

Weigkricht and Fedra (1995) and Brainard et al (1996) introduced management of hazardous material transportation route indicating the route between two points by using multiple criteria and weighing. Coutinho – Rodrigues et al (1997) introduced DSS for routing and positioning of rescue team. Feature of DSS is the geographical display of the unaffected route for problem solving and decision making. The system integrates various techniques for solving various problems. When making consideration, users might create his/her own way of problem solving by changing weight of expense under the decision or setting the lowest point to the highest point of expense. Frank et al (2000) developed DSS to choose the route between origins to destinations, each point matched. Criteria used for route selection includes population who are in risk and travel time. Erkut et al (2007) discussed about the routing of hazardous material transportation that it is a very important decision to reduce risk. To be specific, risk of hazardous material transportation can be dramatically reduced if it is well planned i.e. selecting the route with least possibility of accident, control consequence, and try to find the way to rescue without obstacles. Zografos and Androutsopoulos (2008) studied supportive system for making decision about hazardous material transportation and how to respond emergency situation, and scope of risk management includes logistics for hazardous material and the decision to respond emergency situation. The developed system can be applicable to a) the preparation of route selection for hazardous material transportation with lowest expense and risk b) identification of rescue team that can access the scene with minimum travel time and safety before service arrives c) finding out the route for rescue

team d) identification of the best evacuation plan. The developed system is used for the management of hazardous material being transported in road network under the area of Thriasion Pedion at Attica, Greece.

Research related to the study of criteria used for risk assessment includes Saccomanno and Chan (1985). It introduced the model that let us see the consequence of accident towards population. In face, this model needs two criteria which are minimum risk and minimum possibility of accident. The third criteria is the economic aspect of problems such as expense of truck. Zografos and Davis (1989) developed a method for making decision with multiple objectives. The 4 objectives that were considered include I) population in risk II) property damage III) expense of truck operation and IV) risk of expansion by establishing capacity of network connecting point.

Leonelli et al (2000) developed optimum route using mathematical program for route calculation. Result of the calculation is the selection of route that only reduces expense. Frand et al (2000) developed spatial decision support system (SDSS) for selecting the route for hazardous material transportation. GIS environment model has been developed to create route image, while a mathematical program has also been set to evaluate the use of such route. The purpose of this model is to reduce travel time between origin and destination. However the actual goal is to emphasis on the limitation, travel time, possibility of accident on such route, involved population, and risk of population, all of the mentioned help establish the limitation of this model. Risk of population has been established by the possibility of accident, multiplied by number of population in that area.

Most of the studies emphasis on the analysis of transportation route to find out the route with minimum risk, and the importance has been given to road network with highest chance of accident. In this study, we assess the risk of area that might be affected from hazardous material transportation including piping system, railing system, and road network. The result from assessment can identify level of risk of each area so that each area is able to get prepared for the prevention of accident in an appropriate manner.

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3. Fuzzy Set Theory

Recently there has been an attempt to establish model and develop mathematical process for solving problems of the system that is quite complicated including statistics, formula, or equation that most fits to specific problem. Most engineering solution analyzes data in two ways that is subjective and objective. General problem of engineering task is the necessity to manage uncertain data i.e. uncertainty of numbers from the measurement or experiment, and the certainty of the denotation. Fuzzy set theory is a new field of mathematical originated to handle subjective data. It is accepted that it is a theory that can handle such problem properly.

The analysis for making decision regarding the area in risk of hazardous material transportation for the management of disastrous situation under the certainty and limitation to data access needs the analysis and decision making with multiple criteria. The main challenges of this study are the consideration of criteria that might make the transportation harmful, either through piping or railing system, road network, area categorization on the basis of Boolean Logic, and evaluation limitation. Therefore we need to use Fuzzy Logic to solve problems that are still ambiguous or unidentified. Besides, the process used for making decision can be implemented in both quantitative and qualitative criteria, and some criteria are very outstanding.

The first person who introduced Fuzzy Set theory is Lofti A Zadeh, a professor of Computer of California University, Berkley. He introduced his article regarding “Fuzzy Sets” (Zadeh L.A., 1965). Zadeh defined fuzzy sets as sets whose elements have degrees of membership. Considered sets are viewed in a function called Membership Function. Each member of the set is represented by Membership Value which ranges between 0 – 1. When considering the Ordinary Sets, we found that degree of membership of each set is represented by either value between 0 and 1, which means no membership value at all, or complete value of membership respectively. Generally we found that sometimes we cannot be so sure that something is qualified enough to be a member of that set or not. We can see that fuzzy set theory if more flexible as partial membership is allowed in the set, which is represented by degree, or the acceptance of change from being a non-member (0) until being a complete member (1). Fuzzy Set theory (Zadeh L.A., 1965) leads to the idea of fuzzy mathematics in various fields, especially in Electronic Engineering and Control that still uses the fundamental of fuzzy set theory (Zadeh L.A., 1973). I hereby would like to mention fundamental idea of fuzzy set, as mentioned by Zadeh, that fuzzy set can explain mathematics as follow:

According to the definition of fuzzy set that needs function of membership as a method to establish qualification, fuzzy set A can be represented by member x, and membership degree of such value as follow:

$$A = \{(x, \mu_A(x)) | x \in U\} \quad (1)$$

Given that U has degree of membership for A, following symbols are used:

$$A = \int_U \mu_A(x)/x \quad (2)$$

Fuzzy set A in Relative Universe (U) is set from characteristic by membership function $\mu_A : U \rightarrow [0, 1]$ i.e. $\mu_A(x)$ is value of each member x in U which identifies grade of membership of x in fuzzy set A. In this regard, fuzzy set is considered classical set or crisp set. This Membership function is called characteristic function. For classical set, there are only 2 value which are 0 and 1 i.e. 0 and 1 represents non-membership, and membership in the set respectively. The example of Figure 2 represents characteristic of Boolean set and fuzzy set. Here we use “fuzzy set” to explain, which means the set defined in function (1) where A and B represent any fuzzy set and U represents Relative Universe (U). We found that fuzzy set is different from classical set because fuzzy set has no specific scope. Concept of fuzzy set facilitates the establishment of framework that goes along with ordinary framework, but it is even more ordinary. Fuzzy framework lets us have natural way to handle problems of uncertainty, which is involved with the uncertainty of how to categorize membership, rather than random method.

4. The Risk Assessment Criteria

The risk assessment of area with the consideration of piping system, railing system, and road is a complicated process. Basically we need to consider many aspects including location, route significance and geographical characteristics. Researches in the past used various tools for assessment, which can be categorized as follow: safety, minimum travel time, minimum transportation time, population in risk, environmental quality, and geographical characteristics as shown in Table 1. When considered these factors, we have two topics that reflect the risk of area: a) risk caused by various criteria used for the assessment and b) risk as a result from route

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significance. In accordance to the assessment of risk are, we divided risk scale into 5 subsets as follow

$$R = \{R_1, R_2, R_3, R_4, R_5\} \quad (3)$$

$$= \{\text{most risk, much risk, risk, less risk, least risk}\}$$

4.1 Membership Function Deviation

To successfully use fuzzy set, it depends on appropriateness of membership function either quantitative assessment or qualitative assessment, which can be used for the identification of membership function. When considered the complication and ambiguous source of information, we can use 2 types of membership function

Table 1: Assessment Criteria for the Area in Risk of Hazardous Material Transportation

Main-Criteria	Sub-Criteria	Membership Function	Weight	
Type of transportation in the area	Distance to transportation system if transported by road	Function I	0.045	0.062
	Distance to transportation system if transported by rail	Function I	0.013	
	Distance to transportation system if transported by pipe	Function I	0.004	
Significance of being a route for HazMat transportation	Transportation system to manufacturer / pier / industrial area is available in the area	Function II	0.027	0.040
	Number of gas station available in transportation system	Function II	0.009	
	Transportation system available in the area that reduces distance / duration of transportation	Function II	0.004	
Risk condition of road in the area	Road characteristics that are risks of accident	Function II	0.027	0.131
	Number of accidents occurred in the past	Function II	0.020	
	Number of Hazmat transportation trucks	Function II	0.084	
Danger if accident occurs	Distance to transportation system in case of explosion / fire	Function I	0.283	0.314
	Distance to transportation system in case of leakage	Function I	0.031	
Benefits of the area	Characteristics of urban	Function II	0.237	0.453
	Population density	Function II	0.173	
	Distance to town center	Function I	0.043	

4.1.1 Membership Function I of Fuzzy Number Model

The criteria for risk assessment of the area in risk as indicated in the manual of emergency response 2008 indicated different dangerous area in case of hazardous material leakage depending on the severity of each hazardous material such as hazardous liquid (ammonia), flammable liquid gas (LPG), and flammable liquid (fuel). All of these are hazardous materials used for model development. According to the manual, it suggested that the area be restricted 100 – 200 meters from the scene. In case of fire, evacuate the area in the radius of 1.6 kilometers (DOT, 2008). The recommended distance is used for setting up impact area.

Table 2: Sample of membership function for distance to transportation system in case of explosion/fire.

Risk Scale	Membership Function	Thresholds
Most risk	$U(x) = 1$ $U(x) = (400-x)/200$ $U(x) = 0$	$x \leq 200$ m 200 m < $x \leq 400$ m $x > 400$ m
Much risk	$U(x) = 0$ $U(x) = (x-200)/200$ $U(x) = (600-x)/200$ $U(x) = 0$	$x \leq 200$ m 200 m < $x \leq 400$ m 400 m < $x \leq 600$ m $x > 600$ m
risk	$U(x) = 0$ $U(x) = (x-400)/200$ $U(x) = (800-x)/200$ $U(x) = 0$	$x \leq 400$ m 400 m < $x \leq 600$ m 600 m < $x \leq 800$ m $x > 800$ m
Less risk	$U(x) = 0$ $U(x) = (x-600)/200$ $U(x) = (1000-x)/200$ $U(x) = 0$	$x \leq 600$ m 600 m < $x \leq 800$ m 800 m < $x \leq 1000$ m $x > 1000$ m
Least risk	$U(x) = 0$ $U(x) = (x-800)/200$ $U(x) = 1$	$x > 800$ m 800 m < $x \leq 1000$ m $x > 1000$ m

Criteria for the assessment of risk area from hazardous material transportation in terms of distance had been used to set Membership Function in this article. For example, Membership Function for distance from the scene is the function of Fuzzy Number, as shown in Figure 3 and Table 2.

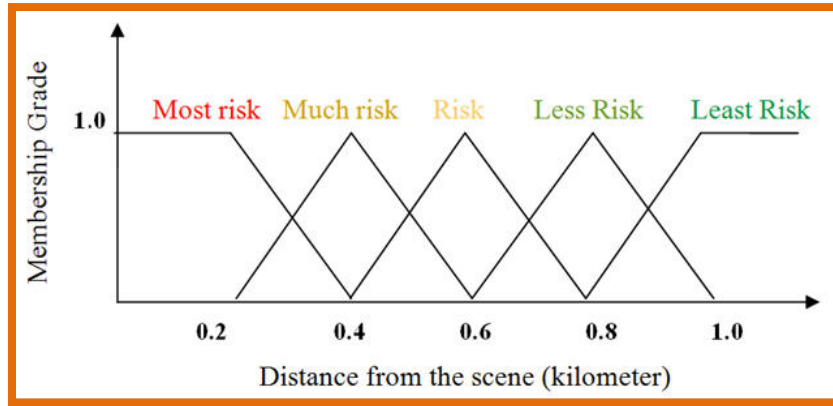


Figure 2 Sample of Membership Function: Fuzzy Number

4.1.2 Membership Function II of Character

For Membership Function II of characteristics just like in Figure 3, generally it has mathematical formula as follow

$$U(x) = \begin{cases} 0 & \text{when } x = V_i \\ 1 & \text{when } x \neq V_i \end{cases} \quad i = 1, 2, 3, \dots, m \quad (4)$$

Characteristic Membership Function is seen as special type of fuzzy set. Actually normal set can be used just like this. Or we can say that when $U(x)$ has only point 0 and 1, fuzzy set will automatically become non fuzzy set. In this research, characteristic function is used for the assessment of risk area such as the area with transportation to manufacturer / pier / industrial area in the area, and amount of hazardous material being transported. However they do not indicate that there is a clear frame or it is difficult to check. Characteristic function will be used for the cases that these data is not available, and it is difficult to establish characteristic function from the assessment according to Membership Function I of Fuzzy Number. Therefore, the membership function value has only 0 or 1. Regarding danger, it can be categorized into 5 levels as usual. The estimation of involved amount of each criteria that uses Membership Function II for the assessment makes us know that it can occur in 2 types which are i) amount and risk level with direct variation and ii) amount and risk level with reverse variation, as shown in the Figure 3.

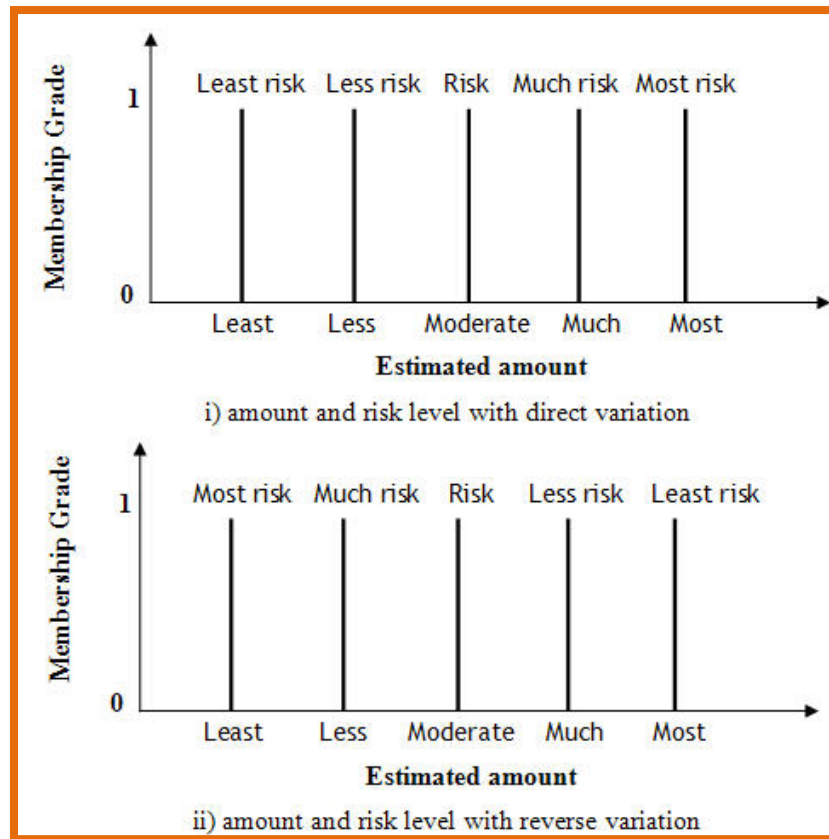


Figure 3: Sample of Characteristic Membership Function.

4.2 Weighting

The assessment of risk area uses Saaty's Analytic Hierarchy Process (AHP) to set weight of each criteria related to the risk area. AHP is a mathematics method used for setting priority of each criteria for making decision. The process consists of 3 parts which are identification and ordering, assessment and comparison of elements in order, and integration using solution algorithm of comparison result of every step. Scale for the comparison of priority (Huizingh and Virolijik, 1994) consists of 9 levels of qualitative value: Equally Preferred, Equally to Moderately, Moderately Preferred, Moderately to Strongly, Strongly Preferred, Strongly to Very Strongly, Very Strongly Preferred, Very Strongly to Extremely, Extremely Preferred. Quantitative value had been set from 1 to 9 respectively. Calculation result from AHP is shown in Table 1.

5. Risk Assessment Model for Areas in Risk of Hazardous Materials Transportation Developed from Fuzzy Sets

We can see that there are 14 criteria for the assessment, as shown in Table 1. Each criteria is different from each other and can be described as criteria set as follow:

$$M = \{M_1, M_2, \dots, M_i, M_n\}$$

Where M_i ; $i = 1, 2, 3, \dots, n$ represents membership value of each risk area according to the criteria used for assessment.

As mentioned in 4.2, each criteria has different significance which can be represented in form of sets as follow:

$$W = \{W_1, W_2, \dots, W_i, W_n\}$$

Where W_i ; $i = 1, 2, 3, \dots, n$ represents weight of criteria used in the assessment and size of matrix is $n \times 1$

To divide sets for decision making for the assessment of area R, it can be done as follow:

$$R = \{R_1, R_2, \dots, R_j, R_m\}$$

Whereas R_j ; $j = 1, 2, \dots, m$ represents decision value of each level. Value of each risk set consists of 5 levels including 0.9, 0.7, 0.5, 0.3, and 0.1 ranging from most risk to least risk and matrix size is $1 \times m$

The area to be assessed has criteria data at i -th, which can be displayed in fuzzy matrix of M as follow:

$$M_{ij} = \begin{bmatrix} M_{11} & M_{12} & \cdot & \cdot & \cdot & M_{1m} \\ M_{21} & M_{22} & \cdot & \cdot & \cdot & M_{2m} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & M_{ij} & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ M_{n1} & M_{n2} & \cdot & \cdot & \cdot & M_{nm} \end{bmatrix} \quad (\text{Matrix 1})$$

Matrix displaying M_{ij} shows membership value of the area to be assessed where i is in risk level j

Matrix 1 with M_{ij} is level of membership of area to be assessed of criteria i . It is a significant model of how fuzzy is represented by data used for the assessment. M_{ij} can be calculated using membership value that is related to risk level. When combined with set of weight, the assessment to find index value for the categorization of area in risk of hazardous material transportation will be using model that uses set of R and M before going to weighing of each criteria with W .

The calculation for HazMat-Risk Area Index: $\text{HazMat}_{\text{RAI}}$ needs the relation of M_{ij} through weighing using W_i on the basis of the significance of each criteria, just like Saaty's Analytic Hierarchy Process (AHP) as follow:

$$\text{HazMat}_{\text{RAI}} = \sum_{i=1}^N W_i \sum_{j=1}^M M_{ij} R_j \quad (5)$$

This Fuzzy Number model was developed due to the limitation of Boolean logic. Boolean logic uses simple scope to identify risk level of an area e.g. most risk, much risk, risk, less risk, or least risk. Area that has distance from transportation system less than 200 meters is considered most risk, 200 – 600 meters is much risk, 600 – 800 meters is risk, 800 – 1,000 meters is less risk, and more than 1,000 meters is least risk. When there are two areas which have distance from transportation system 395 meters and 405 meters respectively, if fire occurs, these two areas are assessed R_1 (most risk) and R_2 (much risk) although these two areas are close to each other. We can avoid this limitation by using membership function of Fuzzy Number. With this method, the two areas will be assessed by calculating membership function in order to obtain changes of risk in the area. It can be clearly seen when using membership function i.e. the assessment of 395-meter area will be $(R_1|0.025, R_2|0.975, R_3|0, R_4|0, R_5|0)$ and the 405-meter area will be $(R_1|0, R_2|0.975, R_3|0.025, R_4|0, R_5|0)$ instead of being assessed as two completely different areas. However, these two areas are considered much risk as they are in the scope of $\mu R_2 = 0.975$. This method also tell us that the 395-meter area tends to “have most risk” ($R_1|0.025$) and it will be never be categorized as “much risk” ($R_3|0.025$), while the 405-meter area tends to become the area with only “risk”

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($R_3|0.025$) as well. We can clearly see changes of risk level when using membership function of Fuzzy Number.

The calculation of HazMat-Risk Area Index ($HazMat_{RAI}$) as mentioned above is the evaluation of every criterion for weighing. It is reliable enough to be used for the assessment of area in risk of hazardous material transportation, and it accommodates area diversity under the limitation of data access. Such index can be used to identify risk level by making comparison of the calculated values as $HazMat_{RAI}$ that uses comparison of related value ranging from biggest one to smallest one.

6. Conclusion

Planning for the management of disaster caused by hazardous material transportation needs to pay much attention to transportation system. This study has established criterions for the assessment of area in risk and it covers all land transportation, with most emphasis on road. We found that transportation by road has more risk of accident than other systems. However facts about areas in risk of hazardous material transportation are rare and difficult to access. that's why the analysis cannot be done clearly. Using Fuzzy Set for the assessment of both objective and subjective criteria is another way to develop model in order to obtain value that can be used in the comparison of risk in the area. Literature reviews and relevant researches tell us that criterions used for the assessment always emphasis on transportation by car and route network. Implementation of study result has much effect towards the management of disaster for the local authority, including the planning for establishment of HazMat team.

Result obtained from Fuzzy Set model is HazMat-Risk Area Index ($HazMat_{RAI}$) which is used to identify value of such area. Besides it can be used for comparison of risk level ranging from biggest one to smallest one.

The next step of model development is to find the value of HazMat-Risk Area Index. In this regard, many things can be done such as establishing weighing value of each criteria using various expertise to establish such weighing value. Besides, the establishment of membership level of each objective criteria can use Geographic Information System (GIS) to help categorize in order to display geographical data more clearly. However, the idea of this study is to support decision making for the assessment under ambiguous context in an appropriate manner.

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