2014

ISSN : 0974 - 7435 Volume 10 Issue 20

BioTechnology

An Indian Journal

FULL PAPER

BTAIJ, 10(20), 2014 [12451-12458]

Risk assessment of waterway emergencies in Yangtze river by using fuzzy logic

Deng Shou Cheng[1,3], Wu Qing*[,1], Chu Xiu Min[2]
[1]School of Logistics Engineering, Wuhan University of Technology,
Wuhan 430063, (CHINA)
[2]Intelligent Transport System Research Center, Wuhan University of Technology,
Wuhan 430063, (CHINA)
[3]School of Computer & Information, Three Gorges University,
Yichang 443000, (CHINA)
E-mail: wq@whut.edu.cn

ABSTRACT

Emergency response level and emergency capability are the critical factors for risk assessment of waterway emergencies in inland rivers. Emergency response level is determined by the consequence or possible impact caused by disaster or a serious accident, and emergency capability identifies the capabilities and resources available to reduce the damage of the emergency events. In this paper, a fuzzy logic method for risk assessment of waterway emergencies is suggested. First, fuzzy weighted average approach was proposed for the assessment of emergency response level. Triangular fuzzy number is defined to present the uncertain and vague judgment which exists in the criteria of emergency response level in Yangtze River. The detailed calculation of finding fuzzy weighted average is given. Second, fuzzy synthetic evaluation approach was applied for the assessment of emergency capability. The index system is established where capability attributes are distracted according to the formal four-phases of risk management in Yangtze River. At last, the risk level of waterway emergencies is defined in considering the combination of the emergency response level and emergency capability. It is hoped that the risk assessing method would provide decision support in dealing with waterway emergencies in Yangtze River.

KEYWORDS

Waterway emergency; Emergency response level; Emergency capability; Fuzzy weighted average (FWA); Fuzzy synthetic evaluation (FSE).

INTRODUCTION

Yangtze River, Chinese Chang Jiang, is the longest inland river in China and the third longest in the world. Its basin extends for some 3,200 km from west to east and for more than 1,000 km from north to south. The mainline of Yangtze River is 2,838 km from ShuiFu in Yunnan province to its mouth in Shanghai city, and it is divided into upper, middle and lower reaches. Yangtze River is the busiest inland waterway in the world. In 2013, its cargo transportation reached 1,920 million tons, making high density of vessel traffic on the river. Nevertheless, waterway emergency has attracted more and more attention. According to the latest statistics, there are 1,067 maritime accidents from 2009 to 2013 in the jurisdiction of Chang Jiang Maritime Safety Administration (CJMSA). These accidents led to 147 victims and 85 wrecks, caused economic loss of about ¥91.66 million. Waterway emergency in Yangtze River means an actual or imminent event that endangers or threatens human lives and properties, results in environmental contamination on the river, or interrupts waterway transportation. Nature of waterway emergency in Yangtze River includes collision, grounding, contact, machine failure, fire/explosion, spill of oil, escape of harmful substance, etc. CJMSA is committed to ensuring that its emergency management teams and rescue resources are well-prepared and ready to respond to waterway emergencies instantly. The objective of response operations in the context of maritime emergencies by CJMSA is to save people who are dangerous onboard or have fallen into the water, prevent damage to vessels and cargo, and have the obligation to preserve the river environment.

Many researchers have focused on the topic of maritime risk assessment. Wang[1] presented the formal ship safety assessment framework, and discussed the five steps in Formal Safety Assessment for which the guidelines for use in the IMO rule-making process approved in 2002. Yang et.al.[2] proposed a subjective security-based assessment and management framework using fuzzy evidential reasoning approaches, the framework can be used to assemble and process subjective risk assessment information on different aspects of a maritime transport system from multiple experts in a systematic way. Balmat et.al.[3] developed a modular and hierarchical structure using fuzzy logic to define automatically an individual ship risk factor which could be used in a decision making system. Zhang et.al.[4] established a grid-based collision risk assessment model based on the analysis and research of traffic flow, channel status and the environment. However, rare attention has been paid to the risk assessment of ongoing maritime emergencies in inland rivers.

Risks associated with waterway emergencies can be attributed to their complexity and dynamics, and risk assessment can provide technical support to decision making and rescue operations. In next two sections, the assessment of emergency response level and emergency capability based on fuzzy weighted average and fuzzy synthetic evaluation is studied respectively. Then, risk level of the waterway emergency is determined according to the results of emergency response level and the static emergency capability of the sub-branch of CJMSA. At last a case study is given to demonstrate the proposed method and the conclusions are made.

EMERGENCY RESPONSE LEVEL ASSESSMENT USING FWA

Emergency response level (ERL) of waterway emergency indicates the severity of the consequence in aspects of casualty, economic and environment impact, and transportation and social influence. ERL shows the degree of urgency in the emergency responding. According to the contingency plan, waterway emergencies are divided into four levels according to its severity. The higher the ERL is, the higher level of government, industry and business, maritime safety administrator are responsible to deal with the emergency. The impacts of waterway emergencies have been caused or may be caused in later time. Some consequence is clear and it is easy for the administrator to prejudge the level. But some consequence is potential and uncertain (e.g. the degree of environmental contamination) under some special circumstance.

Under the circumstance of assessing and dealing with waterway emergencies, experts from various fields would aid the decision making. The expert panel includes maritime safety administrator, experienced captain, fire authority, dangerous and chemical goods processer, etc. Therefore, fuzzy weighted average approach is applied to synthesize the experts' opinions to determine the ERL.

Fuzzification of emergency response level

Emergency response level in Yangtze is determined by its actual or potential damage. According to the severity, TABLE 1 give the suggest criteria for the ERL which is divided in four grades: extremely great, very great, great and ordinary. The corresponding data involved in the levels referred to both the contingency plan for waterway transportation emergencies issued by Ministry of Transportation of China[5] and the related contingency plan established by CJMSA.

As some impacts of the emergency event are potential and uncertain, triangular fuzzy number is applied to describe the uncertainty and vagueness of them. The triangular fuzzy number is defined to present the value of ERL in term of Expert's judgment. And it is written as

$$\tilde{v}_i = \left(\underline{v_i}, v_i, \overline{v_i}\right) \qquad \textbf{(1)}$$

Where $\underline{v_i}$, v_i and $\overline{v_i}$ denote the low, medium and high value respectively according to expert's judgment.

Four reference intervals corresponding to the four ERLs are also defined so as that the experts can give the scores of $\underline{v_i}$, v_i and $\overline{v_i}$. The intervals is shown in TABLE 2, as can be seen, $0 \le \underline{v_i} \le v_i \le \overline{v_i} \le 40$.

TABLE 1 : Suggested criteria for ERL

ERL	Criteria: severity of casualties, economy, and environment, or influence area
Level 1 (Extremely great)	Fatalities are more than 30 or human lives of this number are threatened; Cause significant area on environment impact and recovery may take months; Cause extreme damage to navigation facilities such as ship lock, bridge, etc.; Cause 12 hours' interrupt or 24 hours' congestion for the channel or port; Require deployment of jurisdiction resources of multiple provinces
Level 2 (Very great)	Fatalities are more than 10 and less than 30, or human lives of this number are threatened; Cause significant impact on environment and recovery may take weeks; Cause huge damage to navigation facilities such as ship lock, bridge, etc.; Duration of channel or port interrupt is more than 8 and less than 12 hours, or congestion of more than 12 and less than 24 hours; Require deployment of jurisdiction resources within one province jurisdiction or Ministry of Transportation
Level 3 (Great)	Fatalities are more than 3 and less than 10, or human lives of this number are threatened; Cause moderate environmental impact and recovery may take weeks; Cause moderate damage to navigation facilities such as ship lock, bridge, etc.; Duration of channel or port interrupt is more than 4 and less than 8 hours, or congestion of more than 6 and less than 12 hours; Require deployment of jurisdiction resources within CJMSA or one city jurisdiction
Level 4 (Ordinary)	Fatalities are less than 3 a, or human lives of this number are threatened; Cause isolated impact on environment or natural recovery expected within weeks; Cause damage to navigation facilities such as ship lock, bridge, etc.; Duration of channel or port interrupt is less than 4 hours, or congestion of less than 6 hours; Require local or initial resources only

TABLE 2 : Suggested reference interval corresponding to different level

ERL	Level 1	Level 2	Level 3	Level 4
Reference interval	30-40	20-30	10-20	0-10

The fuzzy weighted average method

Fuzzy weighted average (FWA) approaches are common operations in the analysis of risks and decisions to illustrate the context of multi-participant decision making. Dong and Wong[6] proposed a FWA algorithm to computer the fuzzy weighted average based on Zadeh's extension principle, the algorithm used α-cut representation of fuzzy sets and corresponding intervals of both the criteria and the relative weights. Liou and Wang[7] further improved Dong and Wong's computation, which sharply reduces the complexity of the VFWA algorithm. Afterward, Guh et al.[8] improvement the algorithm based on the max-min paired elimination FWA (PFWA) concept, so as that the level of its computational complexity is relative lower. More recenty studies, Qian et al.[9] used the extension principle, α-cut representation of fuzzy sets and intervals analysis to find FWA. For its simple calculation process and accurate results, Qian's algorithm is chosen for the calculation.

Suppose n experts participate in the ERL assessment. Triangular fuzzy number $\tilde{v}_i = (\underline{v_i}, v_i, \overline{v_i})$, $\tilde{w}_i = (\underline{w_i}, w_i, \overline{w_i})$ denotes the assessed value and the relative weight about the i'th expert respectively. The decision weight assigned to each expert participating in the assessment depends on the expert's experience and the role he played.

The calculation steps of FWA are presented as follows:

Step 1: discretize the range of membership function into a finite number of value $\alpha_1, \alpha_2, \ldots, \alpha_m$, where $\alpha_j \in [0,1]$. The larger the number m, the more accurate the results are.

Step 2: for each α-cut, find the intervals of the ERL $[\underline{y_i}(\alpha), \overline{y_i}(\alpha)]$, and the intervals of the relative weight $[\underline{x_i}(\alpha), \overline{x_i}(\alpha)]$, where $\underline{y_1}(\alpha) \le \underline{y_2}(\alpha) \le \cdots \le \underline{y_n}(\alpha)$, and $\overline{y_{1'}}(\alpha) \le \overline{y_{2'}}(\alpha) \le \cdots \le \overline{y_{n'}}(\alpha)$, $i = 1, 2, \ldots, n$.

Step 3: compute k using Eq. (2) and (3). If $g(r-1) < 1$ and $g(r) \ge 1$, then $k = r$; If $g'(r-1) > 1$ and $g'(r) \le 1$, then $k' = r'$.

$$g(r)=\sum_{l=1}^{r}\overline{x_i}(\alpha)+\sum_{l=r+1}^{n}\underline{x_i}(\alpha) \quad (2)$$

$$g'(r')=\sum_{l'=1}^{n-r'}\underline{x_i}(\alpha)+\sum_{l'=n-r'+1}^{n}\overline{x_i}(\alpha) \quad (3)$$

Step 4: compute x_k and $x_{k'}$ using Eq.(4) and (5), and obtain weight vector X and X'.

$$x_k=1-\sum_{i=1,\neq r}^{n}x_i \quad (4)$$

$$x_{k'}=1-\sum_{i'=1,\neq r'}^{n}x_{i'} \quad (5)$$

Step 5: compute the final desired interval of the α-cut.

$$[\sum_{l=1}^{n}x_l\underline{y_l}(\alpha),\sum_{l'=1}^{n}x_{l'}\overline{y_{l'}}(\alpha)] \quad (6)$$

Step 6: repeat step (2) - (6) for each α_j, with j = 1, 2, …, m.

Aggregate the emergency response level

After the panel of experts assesses the ERL and presents the values in triangular fuzzy number referring to Eq. (1), the FWA algorithm can be applied to aggregate ERL using the calculation steps mentioned above. The synthetic assess value can be obtained as one triangular fuzzy number $v=(\underline{v},v,\overline{v})$, where $\underline{v}\leq v\leq\overline{v}$. If $\underline{v},v,\overline{v}$ are within the same interval of one level provided in TABLE 2, the ERL is obtained. Otherwise, the optimistic or pessimistic criteria can be used to acquire the final level.

EMERGENCY CAPABILITY ASSESSMENT USING FSE

Emergency capability performs important functions before and after disaster strikes. Emergency capability assessment have been conducted in the field of risk management such as national all-harzards target capability related to four homeland security mission areas of the United States[10], capability assessment for a city[11], earthquake emergency preparedness[12], and hospital emergency preparedness[13], and so on. Waterway transportation emergency capability assessment is developed to assess the factors of ability with which to carry out effective search and rescue activities on the water. To assess this capability, maritime safety administrator would have rich situation awareness ability and establish early-warning mechanisms, and take proper search and rescue actions to prevent as much as possible the potential and actual impacts caused by the emergency events.

Fuzzy synthetic evaluation is based on fuzzy logic. FSE is used to classify samples for known standards and guidelines, which is a modified version of traditional synthetic evaluation techniques[14]. It provides a synthetic evaluation of an object relative to an objective in a fuzzy decision environment with a number of factors[15]. In this study, FSE technique is applied in developing the framework for emergency capability assessment of waterway emergencies.

Establish index system of emergency capability

The index system of waterway emergency capability assessment is comprised of 28 capabilities which are listed in TABLE 3. The capability factors are categorized according to the formal four phases of emergency management - prevention, preparing, responding, and recovery from waterway emergencies. The hierarchical structure of the two layers is distracted and is used for the fuzzy synthetic evaluation.

Fuzzification of the parameters

To assess each factor of capabilities, assessment criterion is divided into four grades according to expert's opinion. And the fuzzy set of grade alternatives is expressed as E = {poor, moderate, good, very good}. Its membership function can be formed by the results of questionnaire survey. For example, the survey results on the panel of experts to take part in capability assessment indicated that 5% of the experts opined the maturity of a capability as poor, 40% as moderate, 36% as good and 9% as very good. Then the membership function of this capability factor is given by Eq. (7).

TABLE 3 : Index system of emergency capability assessment for waterway emergencies

Four phases of emergency management	Key factors
Prevention phase F1	Emergency organizations and risk manage system F11
	Clear and detailed responsibility for the organizations and personnel F12
	Allocation of maritime patrol sites and boats F13
	Emergency towage and salvage F14
	Hazard resources identification and surveillance F15
	Critical infrastructure and water areas protection F16
	Contact with jurisdictions, hospital, port and waterborne corporations F17
Preparing phase F2	Contingency plans architecture and law enforcement F21
	Professional emergency teams F22
	Response equipment and material F23
	Communication and information technology F24
	Surveillance and early warning ability F25
	training and exercise F26
	Rescue funds F27
	Information dissemination and awareness F28
Responding phase F3	Information acquisition of emergency event F31
	Normalized response procedures and on-site management F32
	Effective analysis and intelligent decision making F33
	Quick and effective dispatch of personnel and emergency resource F34
	Responder safety and health F35
	Oil spill response ability F36
	hazardous and noxious substance response ability F37
	Vessel fire incident response support F38
	Human evacuation F39
	Effective cooperation and coordination F310
Recovering phase F4	On-site restoration F41
	Event investigation and assessment F42
	Summary report and lessons F43

$$f_1 = \frac{0.05}{poor} + \frac{0.4}{\text{moderate}} + \frac{0.36}{good} + \frac{0.09}{\text{very good}} \qquad \textbf{(7)}$$

It can also be written as (0.05, 0.4, 0.36, 0.09). All the evaluation values of 28 factors in the index system form a membership function matrix of the fuzzy evaluation, so the membership function matrix has 28 rows and 4 columns, it is written with

$$U = (u_{ij})_{28\times 4} \qquad \textbf{(8)}$$

Calculate weights using analytic hierarchy process (AHP)

The weights assessment of risk factors plays an essential role in the criticality analysis. A modified AHP method is applied to work out the priority weights of risk factors, allocated based on the expert's experience, knowledge, and expertise in waterway transportation safety administration. AHP is a structured technique for organizing and analyzing complex decision. In a typical AHP method, experts needs to give a definite number within a 1-9 scale to the pair-wise comparison in the AHP matrix so that the priority vector can be calculated. The matrix has the parameters arranging a score range of 1 to 9 in the rows and columns which is selected and allocated. The scores represent from equally important to extremely important respectively. The value of u_{ij} describes the degree of importance with comparison between u_i and u_j. The corresponding reciprocals 1, 1/2, 1/3, …, 1/9 are used for the reverse comparison, i. e. $u_{ij} = 1/u_{ji}$.

After the AHP matrix is obtained by the expert judgment, the eigenvector of the maximum characteristic root is calculated, and the weight for the importance of each evaluation factor is calculated after normalization. To guarantee the reliability and application value between expert judgment data and the weight calculated, consistency inspection is needed for the AHP matrix. Consistency Index (CI) is

$$CI = \frac{\lambda_{\max} - n}{n-1} \quad \textbf{(9)}$$

Where $\lambda_{\max}$ is maximum characteristic root of the acquired AHP matrix. And n is order of the matrix.

After looking for random consistency index (RI), consistency Ratio (RI) is calculated as follow

$$CR = \frac{CI}{RI} \quad \textbf{(10)}$$

If CR < 0.1, the weight allocated is rational, or the AHP matrix needs to be adjusted until consistency is satisfied.

Aggregate the emergency capability

After the fuzzy valuation matrix is obtained and weights are determined, the fuzzy value of emergency capability is aggregated using matrix multiplication. The result is worked out in the form of cumulative 4-tuple fuzzy set. Making use of the principle of maximum membership degree, the result of emergency capability level can be obtained.

$$C = WU = \begin{bmatrix} w_1 \\ w_2 \\ \cdots \\ w_{28} \end{bmatrix}^T \begin{bmatrix} u_{11} & u_{12} & u_{13} & u_{14} \\ u_{21} & u_{22} & u_{13} & u_{24} \\ \cdots & \cdots & \cdots & \cdots \\ u_{281} & u_{282} & u_{283} & u_{284} \end{bmatrix} \quad \textbf{(11)}$$

Where W is the weights vector with twenty-eight rows corresponding to the capability factors, U is the evaluation matrix of membership function.

EVALUATE OVERALL RISK

In this paper, risk is divided into five levels – low, medium, high, very high and extremely high. And risk is also defined as a composition of emergency response level (ERL) and emergency capability (EC). The rule-base as established to determine the risk of waterway emergency which occurs. Therefore the overall risk can be obtained according the sixteen rules listed below.

TABLE 4

If ERL is level 4	and	EC is poor	then	Risk is high
If ERL is level 4	and	EC is moderate	then	Risk is medium
If ERL is level 4	and	EC is good	then	Risk is medium
If ERL is level 4	and	EC is very good	then	Risk is low
If ERL is level 3	and	EC is poor	then	Risk is very high
If ERL is level 3	and	EC is moderate	then	Risk is high
If ERL is level 3	and	EC is good	then	Risk is high
If ERL is level 3	and	EC is very good	then	Risk is medium
If ERL is level 2	and	EC is poor	then	Risk is extremely high
If ERL is level 2	and	EC is moderate	then	Risk is very high
If ERL is level 2	and	EC is good	then	Risk is very high
If ERL is level 2	and	EC is very good	then	Risk is high
If ERL is level 1	and	EC is poor	then	Risk is extremely high
If ERL is level 1	and	EC is moderate	then	Risk is extremely high
If ERL is level 1	and	EC is good	then	Risk is extremely high
If ERL is level 1	and	EC is very good	then	Risk is very high

CASE STUDY

From waterway emergencies that have occurred in the Yangtze River, an emergency scenario is constructed for the case study: A cargo ship carrying huge containers of various goods titled due to the effect of turbulent current. The officer in charge did not have enough assessment and awareness of the situation, and tried to make a turn. The improper navigation and insufficient fastening of the containers led to a serious accident – ten containers fell into the river. Some containers impeded the navigable channel. And more seriously, two of the boxes carried dangerous chemicals of corrosive potassium permanganate, sodium permanganate, and potassium hydroxide. As the emergency is reported to maritime safety administration, risk assessment is conducted and rescue operations are carried out.

The duration of impeding navigation and the severity degree on the environment caused by the emergency case are the two key factors to determine the emergency response level (ERL). They both are uncertain and there is not an accurate number can be used to describe them, so fuzzy weighted average (FWA) method is applied to the multiple criteria decision making. A panel of five experts participants the decision making. TABLE 5 gives the fuzzy assessment value $\tilde{V}_i$ in the form of Equation (1), and the fuzzy weights $\tilde{w}_i$ are allocated according to the experts' specialties and experience. The desired interval for α-cuts is computed using the steps introduced in section 3, and the results are shown in TABLE 6. Then the fuzzy weighted average can be obtained as $\tilde{V} = (19.1, 23.40, 26.56)$, which presents the comprehensive emergency response level, and the membership function of $\tilde{V}$ is located most close to reference interval of 20-30. According to TABLE 2, the emergency response level the waterway emergency can be determined as "very great".

TABLE 5 : Assessment data of fuzzy weighted average

Expert	Fuzzy assessment value $\tilde{V}_i$	Fuzzy weight $\tilde{w}_i$
1	(14,16,18)	(0.08,0.10,0.20)
2	(15,18,20)	(0.10,0.20,0.30)
3	(22,24,26)	(0.25,0.30,0.35)
4	(22,25,26)	(0.10,0.20,0.30)
5	(28,30,32)	(0.15,0.20,0.30)

TABLE 6 : α-cut values of the FWA algorithm

α-cut	The desired interval
0.1	[19.10, 26.56]
0.2	[19.52, 26.25]
0.3	[20.37, 25.63]
0.4	[20.80, 25.31]
0.5	[21.23, 25.00]
0.6	[21.66, 24.68]
0.7	[22.09, 24.36]
0.8	[22.52, 24.04]
0.9	[22.96, 23.72]

Fuzzy synthetic evaluation is a mature quantitative tool for data analysis. And its purpose is to provide a synthetic evaluation of an object relative to an objective in a fuzzy decision environment. It is widely used to assess multiple criteria decision making, so FSE is feasible to the static assessment of emergency capability of each sub-branch of CJMSA. After FSE is conducted to the emergency capability assessment combined with the questionnaire technique, the static results is obtained and stored in the emergency management system. As the emergency response level of the case is already known as 'very great', referring to TABLE 4, the risk level can be obtained as 'very high', 'high' and 'medium' relative to different condition of emergency capability.

CONCLUSIONS

A risk assessment method based on fuzzy logic is proposed in this study. For the emergency response level (ERL) assessment, the ERL were divided into four levels conforming to the actual waterway transport emergency contingency plan. The triangular fuzzy number was defined to describe the judgment of uncertainty and vagueness about emergency response level. And the preference intervals were suggested corresponding to the four levels. Using FWA approach, the comprehensive triangular fuzzy number was obtained which could be used to determine ERL. On the other hand, FSE method was proposed for emergency capability assessment. The twenty-eight capability factors were distracted according to the prevention, preparedness, response, and recover phases of waterway emergency management in Yangtze. AHP method was applied to determine the weights of the parameters, and the result was aggregated using matrix multiplication. At last, the risk level was defined and was divided into five levels. Sixteen rules were given to determine the overall risk of the waterway emergencies.

The case study demonstrated that the proposed method was appropriate to aid the decision making in the condition of vague and uncertain judgment of ERL, and also gave support to the risk assessment. It should be noted that the actual assessment of emergency capability of each sub-branch of CJMSA was not conducted, and further work is needed to accomplish this assessment.

REFERENCES

[1] J.Wang; "The current status and future aspects in formal ship safety assessment", Safety Science, **38(1)**, 19-30, **(2001)**.

[2] Z.L.Yang, J.Wang, S.Bonsall, Q.G.Fang; "Use of fuzzy evidential reasoning in maritime security assessment", Risk analysis, **29(1)**, 95-120, **(2009)**.

[3] Balmat, Jean-Francois, Lafont, Frederic, Maifret, Robert, Pessel, Nathalie; "MAritime RISk Assessment (MARISA), a fuzzy approach to define an individual ship risk factor". Ocean engineering, **36(15-16)**, 1278-1286 **(2009)**.

[4] D.Zhang, X.P.Yan, J.X.Liu, X.M.Chu; "Study of Grid-Based Collision Risk Assessment Model for Main Route of the Yangtze River", Navigation of China, **34(1)**, 44-47,53 **(2011)**.

[5] Ministry of Transportation of China; "Contingency plans for Waterway transportation emergencies". **(2009)**.

[6] W.M.Dong, F.S.Wong; "Fuzzy weighted averages and implementation of the extension principle", Fuzzy Sets and Systems, **21(2)**, 183-199 **(1987)**.

[7] T.S.Liou, M.J.J.Wang; "Fuzzy weighted average: an improved algorithm". Fuzzy Sets and Systems, **49(3)**, 307-315 **(1992)**.

[8] Y.Y.Guh, C.C.Hon, K.M.Wang, E.S.Lee; "Fuzzy weighted average: A max-min paired elimination method". Computers and Mathematics with Applications, **32(8)**, 115-123 **(1996)**.

[9] C.H.Qian, L.Zhang, B.Dai, J.Z.Wang; "Fuzzy Weighted Average with Triangular Fuzzy Numbers and Its Application to the Assessment and Decision". Operations Research and Management Science, **14(2)**, 5-9 **(2005)**.

[10] U.S.Department of Homeland Security; "Target capabilities list – A companion to the national preparedness guidelines",[Online] Available; https://www.llis.dhs.gov/, **(2007)**.

[11] "Conducting a community risk/ capability assessment for the city of Tarpon Springs, Florida", [Online] Available; http://www.usfa.fema.gov/, **(2006)**.

[12] N.Gao, G.Z.Nie, Y.Deng; "Research on earthquake emergency preparedness capability and hazard coefficient". Dizhen Dizhi, **35(4)**, 907-913 **(2013)**.

[13] V.Valdmanis, P.Bernet, J.Moises; "Hospital capacity, capability, and emergency preparedness", European Journal of Operational Research, **207(3)**, 1628-1634 **(2010)**.

[14] I.Faisal Khan, Rehan Sadiq; "Risk-based prioritization of air pollution monitoring using fuzzy synthetic evaluation technique". Environmental Monitoring and Assessment, **105(1-3)**, 261–283 **(2005)**.

[15] X.W.Ji, W.G.Weng, S.J.Ni, W.C.Fan; "Warning classification model for public emergencies", Journal of Tsinghua University (Science and Technology), **48(8)**, 1252-1255 **(2008)**.