International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347-6435 (Online) Volume 3, Issue 2, August 2014

Safety Assessment of Construction Operation of Contractors for Industrial Buildings Using Fuzzy Inference Methods

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***Abstract*—Construction of industrial buildings is one of important tasks in civil engineering practice. Research reported that very high proportion labor injury occurs in the employees of contractors. Reliable safety assessment system for construction operation is required. However, the risk factors are inherently uncertain as well as vague. Traditional risk analysis based on probability theory can only treat the uncertainty. The paper is aimed at safety assessment of construction operation of contractors of industrial buildings using fuzzy inference methods. Two approaches fuzzy reasoning-based methods are employed: (1) fuzzy inference method using MATLAB Fuzzy Logic Toolbox; (2) Fuzzy Analytic Hierarchy Process (FAHP). Safety influence factors are first arranged in hierarchical structure wherein three major influence factors are contractor's capacity, construction safety and construction cost, from which some sub-sets of influence factors are included such as manufacturer scale, training, planning ability, moving works, high altitude works and fire-related works, etc. Each sub-item covers several influence factors respectively. Totally 80 items are included in the safety assessment system. Trapezoidal membership functions and appropriate inference rules are employed in analysis using MATLAB Fuzzy Logic Toolbox and the results are compared with those investigated by FAHP. Three actual contractors are taken to be testing examples and the results obtained are shown to be reasonable as expected.**

***Keywords*—Construction Safety, FAHP, Fuzzy Inference, Fuzzy Logic, Safety Assessment**

I. INTRODUCTION

Construction of industrial buildings for manufacturing or producing has become important operation in civil engineering in modern developing countries. However, the requirement of quick completion under limited budget usually leads to quality loss of final product or safety decrease during operation periods. The occurrence of occupational accidents or injuries of a contractor for construction of an industrial building will results in tremendous loss of highly-trained labors and property [1, 2].

For example, a research on the occupational accidents of Taiwan Power Company show that during ten years from 1997 to 2006 totally 331 employee related accidents occurred in the contractors wherein 158 labors being dead and disaster proportion of employees of contractors is greater than that of employees of Taiwan Power Company [3].

It is well known that in the beginning stage of assessment of a project of construction, not only the overall construction fee, the technique and confidence need to be evaluated, but the safety of construction process of the contractors also needs to be taken into consideration. Especially nowadays ISO9000 and ISO14000 are important international quality and environmental standard certification criteria employed in many industrial and engineering constructions.

In practical engineering safety assessment there usually arise a situation that vague and ambiguous terms appears where traditional crisp logic or Boolean (Yes/No, On/Off, etc.) binary logic fair to be applied. In order to conduct the risk or safety assessment, decision making or system analysis there exists many approaches can be employed. Among these methods, fuzzy inference method based on fuzzy set theory, fuzzy logic and fuzzy linguistics is a famous one [4-10]. This approach has been considered as one of important type of expert systems [11]. A lot of leading research works have been conducted by Zadel, L. A. and others [12-16].

The application of fuzzy sets to civil engineering has been attempted for many researchers [17-18]. Huang et al. (2007) applied fuzzy inference method to safety assessment of cable-stayed bridge in south Taiwan [19]. Huang and Zhu (2007) employed the fuzzy inference method to risk assessment of fire disaster of hospitals [20]. Huang et al. (2010) also extended the fuzzy inference method for safety assessment of foundation of bridge systems [21]. Huang et al. (2011) then attempted to adopt fuzzy assessment approach for investigation of structure subjected to blaster loadings [22].

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On the other hand, Saaty, T. L. (1980) had proposed the so-called Analytic Hierarchy Process (AHP) for multiple criteria decision making problems [23]. Many researchers employed this technique to commercial and engineering applications [24-26]. Later on, an analysis approach combining fuzzy logic and analytic hierarchy process, termed Fuzzy Analytic Hierarchy Process (FAHP), has been studied and applied to decision making, safety or risk assessment for commercial and engineering practices [27-34]. In the application to civil engineering, Pan (2006) has attempted to apply FAHP to assessment of construction techniques for deep excavation and soil-retaining in Kaohsiung Area [30].

This paper is therefore aims at the application of both fuzzy inference method using MATLAB Fuzzy Logic Toolbox and FAHP for safety assessment of construction operation of contractors. Analysis approaches are first built up and then case study is investigated along the way.

II. Influence Factors

The basic and important step for safety assessment is to collect and decide the influence factors related to the construction operation. This can be completed either by consulting with highly experienced managers and/or conducting questionnaire survey from employees. However, after collecting these data the final influence factors for investigation should be arranged and organized well (e.g. they are exclusive to each other; most of influence factors have been included, etc.). These influence factors are classified into four levels with three major sub-divisions: (1) contractor capacity, (2) construction safety, and (3) construction cost. Some of them are list in Table I. These influence factors also appear in the criteria levels 1 to 4 when FAHP is employed. It is noticed that the analysis items list in table form is very convenient for FAHP analysis.

III. Safety Assessment Methods

Two different approaches are employed for the study and comparison, i.e. the fuzzy inference method with the aid of MATLAB Fuzzy Logic Toolbox as well as Fuzzy Analytic Hierarchy Process (FAHP).

A. *MATLAB Fuzzy Logic Toolbox*

In this approach we adopt standard scheme of fuzzy inference method. The major tasks in this safety assessment method can be divided into the following steps [35]:

(1) Fuzzification of the influence factors:

Totally 80 items are included.

(2) Selecting of membership functions:

Trapezoidal functions are employed for input and output variables which can be expressed as

$$f(x;a,b,c,d)=\max[\min(\frac{x-a}{b-a},1,\frac{d-x}{d-c}),0] \quad (1)$$

in which the parameters a and d locate the feet of the trapezoid and he parameters b and c locate the shoulders. The number of membership functions for each input and output can be decided by the analyst. In the present preliminary study we choose three levels (Low, Medium and High) with trapezoidal functions.

(3) Building the rule banks:

And/or logic inference rules are built up for each inputs to output at each level. For example in the first level there are two inputs and single output with three membership functions, we have totally $3^3=27$ rules. If the varied characteristic of influence factor is not linear, smooth functions such as Gaussian distribution can also be employed as the membership functions.

(3) Aggregation of implication:

Maximal areas are employed for accumulating each results of implication.

(5) Defuzzification of output of safety assessment:

There are many schemes for defuzzification, e.g. centroid, bisector, mom, lom and som, etc. In this study centroid method is taken into account for obtaining the final crisp value of safety of the construction operation project.

The parameters selected for the usage of MATLAB fuzzy logic toolbox employed in the inference process is summarized as follows:

(1) FIS Type: Mamdani
(2) And Method: Minimal
(3) Or Metrhod: Maximal
(4) Implication: Minimal
(5) Aggregation; Maximal
(6) Defuzzification; Centroid
(7) Rules: 32
(8) MFs: Trapmf (Trapezoidal)
(9) Range of MFs : 0-1

International Journal of Recent Development in Engineering and Technology
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B. FAHP

In this approach we first build up the hierarchical structure of safety evaluation system for all the influence factors and then assign each influence factors appropriate weights based on practical experience in safety management. From the data in the grouped and classified influence factors, we can calculate the assessment results in each level from down to top. And finally we can obtain the overall safety assessment for the construction operation of industrial buildings. This calculation process can be conducted by trained engineers or managers manually and regularly. The basic steps are summarized as follows:

1. Clarifying the final goal;
2. Identifying influence factors and building up the hierarchical structure of FAHP;
3. Setting up appropriate membership functions;
4. Assigning and calculating fuzzy matrices and weights for attributes and targets (positive reciprocal matrix);
5. Calculating the evaluation values for each target;
6. Evaluating the consistency.
7. Assuring the final target.

IV. CASE STUDY AND RESULTS

A. Case Description

A real case of construction operation of an industrial building of high technology in Tai-nan District in Southern Taiwan is considered. The total budget of construction project is more than 100 millions, the construction period limited within one year, working hours are within 100 thousands. There are three contractor candidates to be assessed, termed Con-A, Con-B and Con-C, respectively.

B. Safety Assessment based on MATLAB Fuzzy Logic Toolbox

The top level framework of safety assessment of construction operation using MATLAB Fuzzy Logic Toolbox is shown in Figure 1. Three inputs are the criteria, Influence factors, I. II and III, and single output is the final purpose results of safety of construction. Three trapezoidal membership functions (Low, Medium, and High) are selected for all the inputs and output for convenience of inference analysis as shown in Figure 2 and 3. In this level totally $3^3 = 27$ rules were employed for inference, and the typical surface view for the relationship of safety assessment to two selected influence factors can be observed from a 3D plot as shown in Figure 4.

The results of fuzzy safety assessment using MATLAB Fuzzy Logic Toolbox are summarized in Table I to IV and shown in Figure 6(a). The final safety evaluations for three contractors, from the results of MATLAB Fuzzy Logic Toolbox, are

Con-A: 0.635, Con-B: 0.638, Con-C: 0.555

C. Safety Assessment based on FAHP

Figure 5 shows the hierarchical structure for safety assessment of construction operation using FAHP. The top level is the purpose level, i.e., safety assessment of construction operation; the second level is the criteria level (Influence factors, I, II and III) which is furthermore divided into three sub-levels (A, B, C,…J; A1, A2; A1.1, A1.2, A1.3, …etc.); and the bottom is target level in which three candidate contractors (Con-A, on-B, and Con-C) are list.

The results of safety assessment based on FAHP are summarized in Table I to IV and shown in Figure 6(b). The final safety evaluations for three contractors, based on FAHP, are

Con-A: 0.647, Con-B: 0.670, Con-C: 0.513

D. Final Result of Safety Assessment

Based on the assessment results from MATLAB fuzzy logic toolbox (0.638) and FAHP (0.670), the second contactor (Con-B) is the best one among these three candidates, the results can be observed from Figure 7.

V. CONCLUDING REMARKS

Both fuzzy inference method using MATLAB fuzzy logic toolbox and FAHP are employed for safety assessment of construction operation of three contractors has been successfully conducted. Overall 80 influence factors are included for safety assessment. Three trapezoidal membership functions are adopted for input and output of inference. Results show that these two approaches results in similar results and can be employed for comparison study. Fuzzy rule-based expert system can be an effective and systematic safety assessment for practical applications.

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International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347-6435 (Online) Volume 3, Issue 2, August 2014

TABLE I
Classification of Influence Factors for Safety of Construction

1st Level	2nd Level	3rd Level	4th Level	Factors	Items	Range	Cases
T SAFETY ASSESSMENT OF CONSTRUCTION OPERATION	I. Contractor Capacity	A Technique Level	A1 Contractor Capacity	A1.1 Annual Turnover	> 300 Million	7~10	a9
					200~300 Million	4~9	b6
					50~200 Million	1~6	c9
					< 50 Million	0~3	
				A1.2 Engineering Performance	> 225 Million	7~10	a7
					2.25~75 Million	4~9	b5
					6~22.5 Million	1~6	c8
					< 6 Million	0~3	
				A1.3 Capital Amount	> 22.50 Million	7~10	a9
					> 10 Million	4~9	b6
					> 3 Million	1~6	c8
					< 3 Million	0~3	
			A2 Vendor Capacity	A2.1 Annual Turnover	> 300 Million	7~10	a7
					200~300 Million	4~9	b5
					50~200 Million	1~6	a9
					< 50 Million	0~3	b6
				A 2.2 Engineering Performance	> 225 Million	7~10	a7
					2.25~75 Million	4~9	b6
					6~22.5 Million	1~6	c7
					< 6 Million	0~3	
				A2.3 Capital Amount	> 22.50 Million	7~10	a7
					> 10 Million	4~9	b5
					> 3 Million	1~6	c7
					< 3 Million	0~3	
		B. Staff and Training	B1 Safety Management	B1.1 No of Managers	>100	6~10	a9
					30~100	2~8	b5
					3< 0	0~4	c7
				n c e of	> 10 yrs	6~10	a9
					4~10 yrs	2~8	b7
					< 3 yrs	0~4	c7
				B1.3 Maximal Working Periods	>1000000 Hrs	6~10	a5
					500000~ 1000000 Hrs	2~8	b5
					<500000 Hrs	0~4	c5
			B2 Training of Contractor	B2.1 Professional Licenses	> 5	6~10	a7
					3~5	2~8	b8
					<3	0~4	c7
				B2.2 Training Certificates	> 5	6~10	a7
					3~5	2~8	b6
					< 3	0~4	c7
				B2.3 Training Hours	> 500 hrs	7~10	a7
					300~500 hrs	4~9	b7
					100~300 hrs	1~6	c7
			B3 Training of Vendor	B2.1 Professional Licenses	>5	6~10	a7
					3~5	2~8	b7
					<3	0~4	c3
				B2.2 Training Certificates	> 5	6~10	a7
					3~5	2~8	b6
					< 3	0~4	c8
				B2.3 Training Hours	> 500 hrs	7~10	a7
					300~500 hrs	4~9	b7
					100~300 hrs	1~6	c7
		C Planning Capacity	C1 Planning Proposal	C 1.1 Construction Proposal	85~100%	6~10	a7
					70~85%	2~8	b7
					< 70%	0~4	c7
				et y p	85~100%	6~10	a7

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International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347-6435 (Online) Volume 3, Issue 2, August 2014

					70~85%	2~8	b7
					< 70%	0~4	c7
				C1.3 Emergency Proposal	85~100%	6~10	a7
					70~85%	2~8	b7
					< 70%	0~4	c7
			C2 Safety Detection	C2.1 Staff	Labors	6~10	a7
					Engineers	2~8	b7
					Managers	0~4	c7
				C2.2 Timing	Before and After	6~10	a7
					Before	2~8	b7
					After	0~4	c7
				C2.3 Treatment	Immediate	6~10	a7
					After	2~8	b7
					Nothing	0~4	c7
			C3 Safety Check	C3.1 Check Unit	From Outside and Inside	6~10	a5
					From Outside Only	2~8	b5
					From Inside Only	0~4	c3
				C3.2 Check Frequency	Monthly, Seasonly, Yearly	6~10	a8
					Seasonly, Yearly	2~8	b5
					Yearly	0~4	c8
				C3.3 Risk Retrofit	85~100%	6~10	a5
					70~85%	2~8	b6
					< 70%	0~4	c7
	etc.	etc.					
	etc						

TABLE II
TYPICAL INFLUENCE FACTORS AND WEIGHTS

Influence Factors	Weights
I Capacity of Company	0.327
II Construction Safety	0.417
III Construction Cost	0.256
A Technique Level	0.581
B Staff and Training	0.270
C Planning Skill	0.149
D Movement Operation	0.581
E High Altitude Operation	0.270
F Fire-related Works	0.149
A1 Contractor Capacity	0.695
A2 Vendor Capacity	0.305
A1.1 Annual Turnover	0.600
A1.2 Engineering Performance	0.274
A1.3 Capital Amount	0.126
A2 Vendor Capacity	0.305
A2.1 Annual Turnover	0.590
A2.2 Engineering Performance	0.283
A2.3 Capital Amount	0.127
B1 Safety Management	0.488
B1.1 No. of Managers	0.488
B1.2 Experience of Managers	0.315
B1.3 Maximal Working Periods	0.196
B2 Training of Contractor	0.315
B2.1Professional Licenses	0.488
B2.2 Training Certificates	0.315
B2.3 Training Hours	0.196
B3 Training of Vendor	0.196
etc.	

TABLE III
SAFETY ASSESSMENT OF EACH ITEM FROM MATLAB AND FAHP

Factors	MATLAB Fuzzy Logic Toolbox			FAHP		
	Con-A	Con-B	Con-C	Con-A	Con-B	Con-C
T	0.635	0.638	0.555	0.647	0.670	0.513
I	0.847	0.646	0.649	0.775	0.596	0.747
A	0.847	0.529	0.847	0.806	0.559	0.811
A1	0.847	0.627	0.826	0.852	0.572	0.860
A1.1	9	6	9	9	6	9
A1.2	7	5	8	7	5	8
A1.3	9	6	8	9	6	8
A2	0.847	0.627	0.847	0.700	0.528	0.700
A2.1	7	5	7	7	5	7
A2.2	7	6	7	7	6	7
A2.3	7	5	7	7	5	7
B	0.847	0.847	0.612	0.759	0.636	0.649
B 1	0.847	0.627	0.627	0.821	0.563	0.661
B1.1	9	5	7	9	5	7

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International Journal of Recent Development in Engineering and Technology

Website: www.ijrdet.com (ISSN 2347-6435 (Online) Volume 3, Issue 2, August 2014

B1.2	9	7	7	9	7	7
B1.3	5	5	5	5	5	5
B2	0.627	0.847	0.627	0.700	0.729	0.700
B2.1	7	8	7	7	8	7
B2.2	7	7	7	7	7	7
B2.3	7	6	7	7	6	7
B3	0.627	0.627	0.69	0.700	0.669	0.536
B3.1	7	7	3	7	7	3
B3.2	7	6	8	7	6	8
B3.3	7	7	7	7	7	7
C1.3	7	7	7	7	7	7
C2	0.627	0.627	0.627	0.700	0.700	0.700
C2.1	7	7	7	7	7	7
C2.2	7	7	7	7	7	7
C2.3	7	7	7	7	7	7
C3	0.847	0.5	0.69	0.595	0.520	0.536
C3.1	5	5	3	5	5	3
C3.2	8	5	8	8	5	8
C3.3	5	6	7	5	6	7
Ⅱ	0.562	0.847	0.5	0.521	0.778	0.385
D	0.5	0.847	0.5	0.500	0.800	0.354
D1	0.5	0.847	0.5	0.500	0.800	0.354
D1.1	5	8	2	5	8	2
D1.2	5	8	5	5	8	5
D1.3	5	8	5	5	8	5
D2	0.5	0.847	0.5	0.500	0.800	0.354
D2.1	5	8	2	5	8	2
D2.2	5	8	5	5	8	5
D2.3	5	8	5	5	8	5
D3	0.5	0.847	0.5	0.500	0.800	0.354
D3.1	5	8	2	5	8	2
D3.2	5	8	5	5	8	5
D3.3	5	8	5	5	8	5
E	0.5	0.847	0.471	0.544	0.583	0.468
E1	0.557	0.847	0.5	0.547	0.595	0.532
E1.1	5	5	5	5	5	5
E1.2	6.5	8	6	6.5	8	6
E1.3	5	5	5	5	5	5
E2	0.5	0.5	0.373	0.500	0.500	0.339
E2.1	5	5	3	5	5	3
E2.2	5	5	3	5	5	3
E2.3	5	5	5	5	5	5
E3	0.5	0.627	0.373	0.609	0.689	0.515
E3.1	5	5	3	5	5	3
E3.2	5	7	3	5	7	3
E3.3	5	5	5	5	5	5
E3.4	7	8	6	7	8	6
F	0.654	0.5	0.5	0.406	0.500	0.469
F1	0.174	0.5	0.5	0.220	0.500	0.500
F1.1	2	5	5	2	5	5
F1.2	2	5	5	2	5	5
F1.3	3	5	5	3	5	5
F2	0.627	0.5	0.5	0.598	0.500	0.402
F2.1	7	5	3	7	5	3

F2.2	5	5	5	5	5	5
F2.3	5	5	5	5	5	5
F3	0.847	0.5	0.5	0.559	0.500	0.500
F3.1	5	5	5	5	5	5
F3.2	5	5	5	5	5	5
F3.3	8	5	5	8	5	5
Ⅲ	0.66	0.513	0.5	0.686	0.588	0.423
G	0.847	0.529	0.521	0.706	0.563	0.382
G1	0.847	0.627	0.646	0.706	0.563	0.413
G1.1	8	5	2	8	5	2
G1.2	5	7	5	5	7	5
G1.3	8	5	8	8	5	8
G2	0.847	0.627	0.373	0.706	0.563	0.314
G2.1	8	5	2	8	5	2
G2.2	5	7	5	5	7	5
G2.3	8	5	3	8	5	3
G3	0.847	0.627	0.373	0.706	0.563	0.413
G3.1	8	5	2	8	5	2
G3.2	5	7	5	5	7	5
G3.3	8	5	8	8	5	8
H	0.5	0.529	0.5	0.498	0.522	0.427
H1	0.5	0.5	0.5	0.453	0.469	0.437
H 1.1	5	5	5	5	5	5
H 1.2	3.5	4	3	3.5	4	3
H 1.3	5	5	5	5	5	5
H 2	0.5	0.5	0.373	0.500	0.500	0.339
H 2.1	5	5	3	5	5	3
H 2.2	5	5	3	5	5	3
H 2.3	5	5	5	5	5	5
H3	0.5	0.627	0.5	0.609	0.689	0.543
H 3.1	5	5	7	5	5	7
H 3.2	5	7	3	5	7	3
H 3.3	5	5	5	5	5	5
H 3.4	7	8	6	7	8	6
J	0.646	0.612	0.5	0.625	0.539	0.469
J 1	0.847	0.627	0.5	0.780	0.539	0.500
J 1.1	8	5	5	8	5	5
J 1.2	8	5	5	8	5	5
J 1.3	7	7	5	7	7	5
J 2	0.5	0.627	0.5	0.500	0.539	0.402
J 2.1	5	5	3	5	5	3
J 2.2	5	5	5	5	5	5
J 2.3	5	7	5	5	7	5
J 3	0.5	0.69	0.5	0.441	0.536	0.500
J 3.1	5	3	5	5	3	5
J 3.2	5	8	5	5	8	5
J 3.3	2	7	5	2	7	5

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347-6435 (Online) Volume 3, Issue 2, August 2014

TABLE IV
FINAL SAFETY EVALUATION FROM MATLAB AND FAHP

Factors	MATLAB Fuzzy Logic Toolbox			FAHP		
	Con-A	Con-B	Con-C	Con-A	Con-B	Con-C
Overall	0.635	0.638	0.555	0.647	0.670	0.513
I	0.847	0.646	0.649	0.775	0.596	0.747
II	0.562	0.847	0.5	0.521	0.778	0.385
III	0.66	0.513	0.5	0.686	0.588	0.423

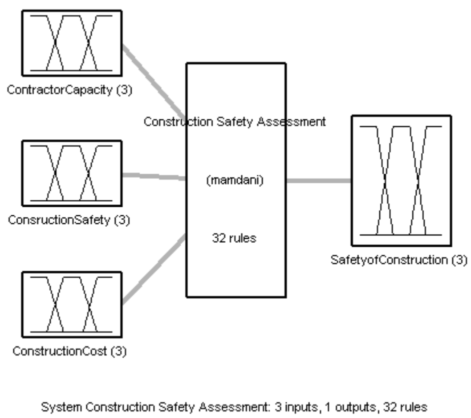

Figure 1 Fuzzy Inference Framework

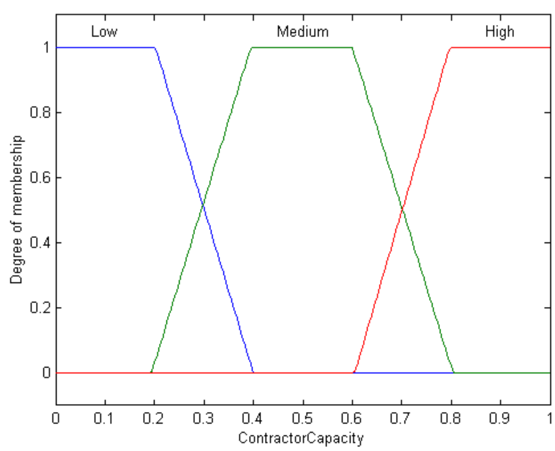

Figure 2 Typical membership function for input

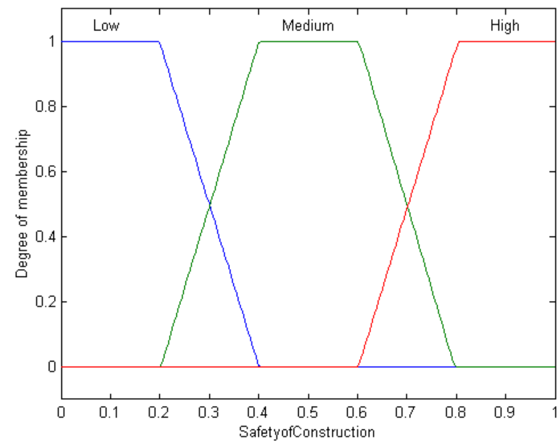

Figure 3 Typical membership function for output

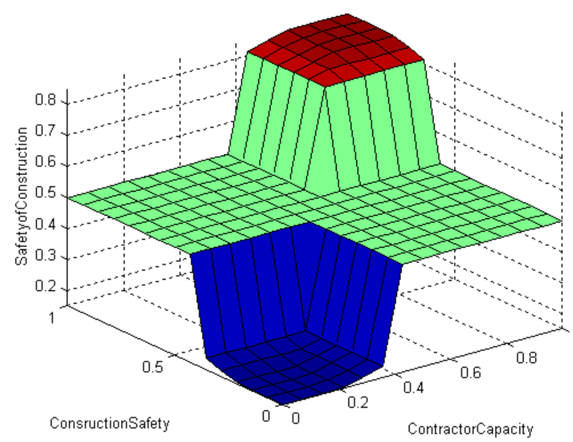

Figure 4 Typical results of surface viewer

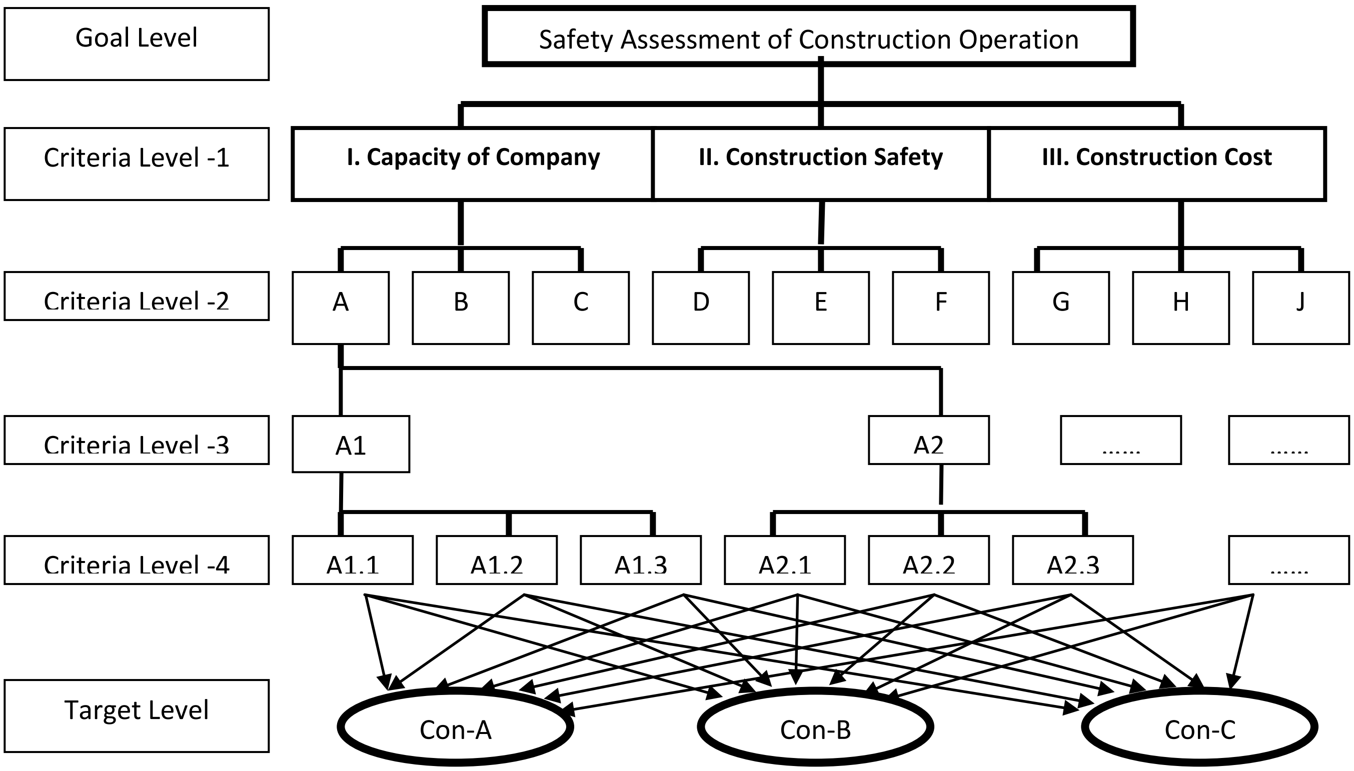

Figure 5 Typical diagram of hierarchical structure for safety assessment of construction operation using FAHA

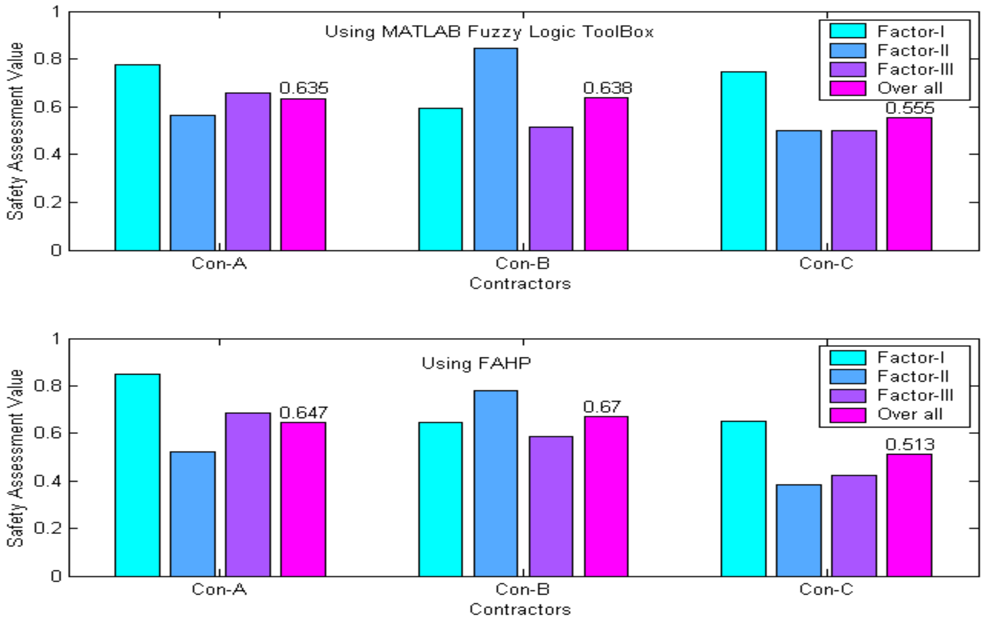

Figure 6 Safety assessment results of construction operation for three contractors using two schemes

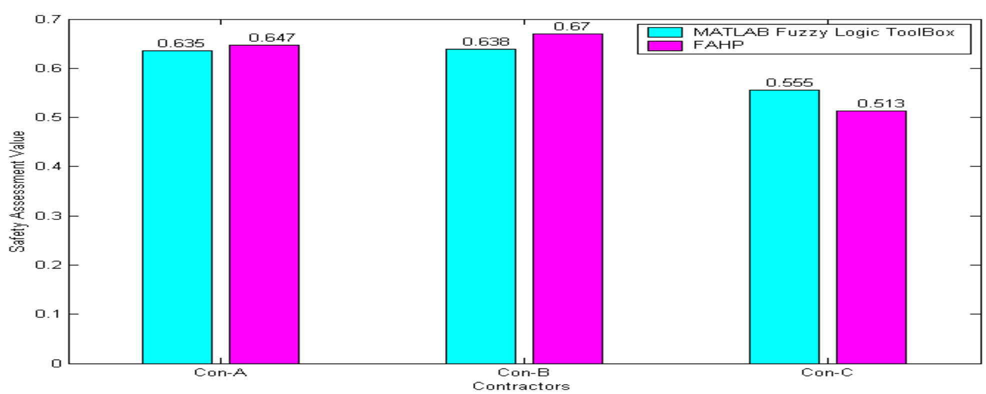

Figure 7 Final safety assessment results of construction operation for three contractors