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Research Article

Risk Assessment Methodology for incorporating uncertainties using Fuzzy concepts: A Case Study for Construction Industry

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Abstract

The rapid developments in science and technology have led to the availability of improved techniques in the construction industry. However, even as the technology has progressed, the hazards and risks associated with the construction sites have still persisted. Amongst the various risk assessment tools available for the purpose of risk assessment, the Decision matrix risk assessment (DMRA) technique is a widely used approach for the purpose of Occupational Health and Safety (OSH) assessment. The risk factor value was evaluated by the use of two hazard parameters namely the likelihood of hazard and the severity associated with the hazard. To deal with the shortcomings of a crisp risk factor value calculation and to address the inconsistency in decision making of DMRA technique, this paper presents a framework for risk assessment of activities in the construction site using fuzzy set theory, fuzzy logic approximation and composition. The parameters associated with risk likelihood and severities were analyzed and were given as linguistic variables. This proposed model was applied for evaluating and assessing the risk factor values of the activities in the construction site in Chennai Metropolitan Area and also throws light on the advantages of the fuzzy-DMRA methodology when compared to a standard DMRA technique.

Keywords: OHS Risk assessment; DMRA technique; Fuzzy logic; Construction industry.

Introduction

The occurrences of major accidents are increasing across the world. These accidents have caused significant damage to the organization and had significant consequences such as multiple fatalities or potential for multiple fatalities or causing significant social unrest. The construction industry has been identified as one of the most hazardous industries and complex industries in many parts of the world [1]. It is complex because of extensive use of sophisticated plants, equipments, modern methods of construction, multidisciplinary and multitasked aspects of its project workforce [2].

The concept of risk became popular in economics during the 1920s due to the great depression environment. Since then, it has been successfully used in theories of decision making in various fields [3]. One important field where risk analysis is extensively used is in the field of construction for purpose of analyzing the accidents. Accidents can adversely affect the firm's image and reputation, provoking a severe deterioration in its public relations [4]. The risks and unsafe conditions present in the construction sites tend to affect the industrial climate and in turn it affects the productivity of the workers and their morale and motivation. The risk of a fatal accident in the construction industry is five times more likely than in other industries and whilst the risk of a major injury is two and a half time higher. This can ultimately lead them to leave the firm, and the firm can have difficulty in finding qualified workers to replace them [5]. The risk analysis of an accident in the construction site is increasingly being done with advanced computing techniques to predict the amount of risk associated with the event.

Risk management usually consists of the following three approaches [6].

- Risk identification
- Risk assessment
- Risk mitigation

The objective of risk identification is to identify and evaluate the risks and the unintended events, which could cause an accident. The first task usually is to identify the risks that are inherent to

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the process and/or plant and then focus on the evaluation of the events, which could be associated with hazards. There are various approaches for analyzing the risks in various industries.

These can be classified into three types namely

- Qualitative analysis
- Semi-quantitative analysis and
- Quantitative analysis.

Qualitative analysis is the commonly used analysis as it is a simpler approach and easily covers a larger gambit of hazard identification. Some of the commonly used qualitative analysis are checklists, preliminary hazard analysis and Hazard and Operability studies. Alternative method is the semi-quantitative analysis which is not as accurate as the quantitative analysis but uses concrete data for analysis. Some of the commonly used methods are Matrix method, Line method and Failure Mode and Effect Analysis (FMEA). The most accurate amongst these approaches is the quantitative analysis [7]. Some of the analysis methods used are the Fault Tree Analysis, the Decision Tree Analysis, Sensitivity Analysis, Decision Matrix Risk Assessment (DMRA) etc.

Many studies have been performed for the risk assessment and prevention of hazards in the construction sites. The use of soft computing tools for the theoretical and practical examination of hazards was investigated it was concluded that these can be used for the purpose of risk assessment [8]. Analytical Hierarchy Process (AHP) as a decision making criteria has been investigated which considers both the subjective and objective factors when performing the risk assessment as well as providing the overall support for all the stakeholders involved [9]. The methodology of incorporating fuzzy logic into conventional risk assessment frameworks has been investigated [7,9]. Fuzzy logic has been integrated into the methodology of AHP to develop a fuzzified AHP which deals with the risks associated with the construction industry [11]. Similarly, the process of fuzzy logic was incorporated with FMEA [7]. In this paper, an attempt has been made to incorporate the concept of fuzzy logic into the existing DMRA methodology.

Decision matrix risk-assessment (DMRA) technique is a quantitative analysis tool that combines the dual methods of the experience and valuable human knowledge with the purpose of achieving the following [12]. Identifying the potential hazards associated with the activity, evaluating the probability of the occurrence of the hazard and the severity of the hazard, calculating the risk associated with the identified hazard and assisting the personnel in the site to initiate the corrective measures.

In the DMRA methodology, two parameters are utilized to categorize the hazard on a 1-5 scale. Severity rate is the rate of seriousness associated with the activity in the construction site. Probability rating is the likelihood of the event which is likely to occur and is ranked from a scale of 1 to 5 with 1 being the least probable and 5 being the most probable for the activity to occur. However, the occasional method of DMRA, when applied in a real life scenario, faces a lot of difficulties. It is difficult to obtain a reliable and accurate result from the DMRA methodology as there are lots of uncertainties.

The Risk factor of DMRA is obtained by multiplying the probability and the Severity of the identified activity. However, the relative importance of each parameter dims the risk representations. For example, the product of 4,3 and 3,4 though both give the result of 12 have different priority for taking the corrective action. There is a need to develop a knowledge-based risk assessment system for the DMRA methodology. However, the diversity and the ability of the expert members assessing the risk is equally important. In response to the above pointed out defects, a fuzzy risk assessment based on a quantitative risk assessment technique “the Decision matrix Risk Assessment (DMRA) technique” is proposed for analyzing the hazards in the construction site.

The present paper aims to investigate the important types of hazards, their causes as well as the risk factor of the hazards by the proposed fuzzy model. A construction site in the Chennai Metropolitan area was taken as an example to perform an in-depth risk assessment for the causes of hazards present in the site.

Methodology

Risk matrix for risk assessment

A number of hazards have been identified in the construction sites namely fall hazards, trip

hazards, work at height, working with inflammable chemicals, hazards in excavation works, gantry crane operations, hazards associated with sheet piling operations.
Following methods are listed out for the Hazard identification [13]:

- Hazard identification checklist
- Workplace inspection (observation and interview)
- Job Hazard Analysis
- Accident and incident investigations.

In general, two parameters are normally associated with every activity in construction industry. These can be termed as Likelihood of occurrence of activity and the severity of the accident associated with the activity. Let the likelihood of occurrence associated with each activity be 'L' and the severity of the accident associated with the activity be 'S'. Then the risk ranking associated with each activity is given by R=LxS.

Risk matrix is a very important component in hazard and risk assessment and is an integral part in the risk assessment. There are two variables which are to be broadly computed to attain risk rating. The two parameters are likelihood and severity and they may again be classified in qualitative and quantitative terms to improve the accuracy of the results. The obtained risk ranking is briefly classified into the category of hazards based on the risk assessment matrix. Various risk matrices are used depending on the range of the likelihood and severity values. Some are of the simple 3x3 cell matrix, some are of the 5x5 cell matrix and some even reach a higher structure of 7x4 cell matrix. There are five levels of likelihood and severity parameters used as shown in Tables 1-3 [12].

Table 1. Likelihood values for hazard identification

Probability / Likelihood	Enter Value
Almost Impossible or very unlikely of the occurrence	1
Unlikely or the occurrence is less than once per year	2
Possible or the occurrence is once or twice per year	3
Probable or the occurrence is once or twice per month	4
Very likely or the occurrence is on a weekly frequency	5

Table 2. Severity values in hazard identification

Nature of Severity	Enter Value
There is no injury but only property damage.	1
There is a minor injury, first aid injury like laceration:	2
There is a serious injury, like reportable injury, property damage	3
There is a major injury which may lead to a permanent Disability or property damage beyond repair	4
There is a fatal injury, loss of limb, loss of property and damage to a total plant, equipment or machinery etc.,	5

Fuzzy Risk Analysis Model

In a complex environment like construction industry where multiple activities are performed at the same time, decision making is an important activity. There are three ways to make a decision in this complex environment [14]. They are

1) Building a mathematical model
2) Seeking human expert's advice
3) Building expert system or controller

Out of these, a mathematical model description of the complex environment is an accurate and useful way.

Hence, fuzzy logic acts as a powerful tool to the analyst to evaluate the risks associated with the failures associated with the activities in a natural way. The traditional issues of vagueness, impreciseness, ambiguousness associated with the risk assessment matrix can be eliminated by using this mechanism. The methodology of fuzzy logic is given below [15]:

1) Input value phase is one in which the risk values are taken.
2) Fuzzification refers to selection of values obtained from the ranking of the activities of the risk assessment and combining elements with it

3) Fuzzy inference phase is the use of If-Then-Else statements for assigning values to the risk assessment values.
4) Defuzzification is the process of converting the outputs of fuzzy logic inference to the desired output values. The output from fuzzy inference logic needs to be converted in to linguistic output variable from which it needs to be converted into a definite value. The defuzzification method uses a mean average criterion and a maximum criteria method.

Table 3. Risk assessment decision matrix

Likelihood / Severity	Rare (1)	Remote (2)	Occasional (3)	Frequent (4)	Almost Certain (5)
Catastrophic(5)	5	10	15	20	25
Major(4)	4	8	12	16	20
Moderate(3)	3	6	9	12	15
Minor(2)	2	4	6	8	10
Negligible (1)	1	2	3	4	5

Insignificant Risks (1)	No need to plan any control measures
Acceptable risks (2 3 4 5 6)	No need to plan for control measures. But, the existing controls should be maintained and monitored
Intermediate risks (8,9,10,12)	Suitable action should be taken to reduce the risks which are identified
High Risks (15,16,20)	Stoppage of work until the identified risk is rectified. All activities should be stopped and emergency precautions must be kept in place.
Intolerable Risks (25)	Complete stoppage of work. All ongoing activities must be stopped. Only if it is possible to bring down the risks to an As Low As Reasonably Practicable (ALARP) level, one can proceed.

Fuzzy Rules and Membership Function

In the proposed methodology fuzzy DMRA methodology, triangular and trapezoidal membership functions are used (Fig.1 and Fig. 2).

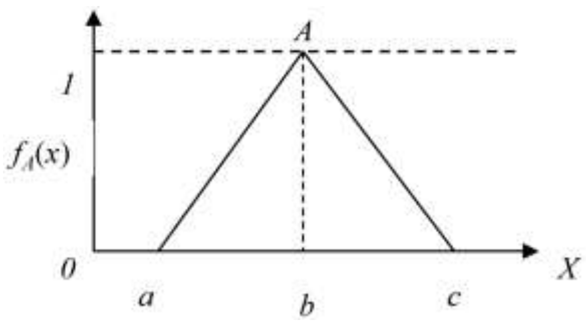

Fig. 1. Triangular Membership function

Linguistic variables are used to represent the likelihood and severity of the activity. Each input variable has five linguistic variable has five terms associated with them.

A triangular membership function is defined by three parameters a, b and c and given by the expression

$$\mu(x)=\begin{cases} 0 & x < a \\ \frac{x-a}{b-a} & a \le x < b \\ \frac{x-c}{b-c} & b \le x < c \\ 0 & c \le x \end{cases} \qquad \text{……………………..(1)}$$

where the parameters a and c points to the feet of the triangle and parameter ‘b’ refers to the peak of the triangle.

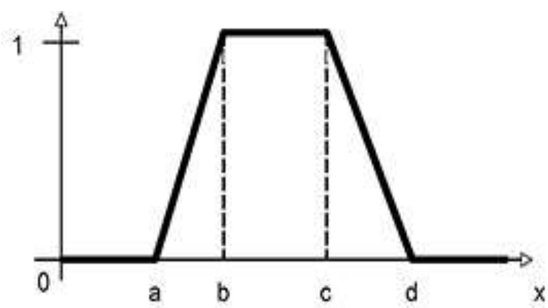

Fig. 2. Trapezoidal membership function

A trapezoidal membership function can be described by four parameters, a,b,c and d and is given by the expression

$$\mu(x) = \begin{cases} 0 & x < a \\ \frac{x-a}{b-a} & a \le x < b \\ 1 & b \le x < c \text{ or } \mu:(a,b,c,d) \\ \frac{x-d}{c-d} & c \le x < d \\ 0 & d \le x \end{cases} \quad \text{.... (2)}$$

where a and d represent the "feet" of the trapezoid, b and c represent the "shoulder".

This approach uses linguistic variables to represent the likelihood and severity of each activity. Each linguistic variable has five linguistic terms associated with it. The linguistic terms associated with likelihood are *Almost Impossible*, *Unlikely*, *Possible*, *Probable*, and *Very Likely*. The linguistic terms associated with severity are *No injury*, *Minor Injury*, *Serious Injury*, *Major Injury* and *Fatal Injury*.

The output variable factor is the Risk Factor Value, is utilized for representing the priorities to be given to the activities to take suitable corrective action. This is represented by five linguistic terms, *Insignificant Risks*, *Acceptable Risks*, *Intermediate Risks*, *High Risks* and *Intolerable Risks.* The fuzzy sets and membership functions for likelihood and severity parameters are depicted in Fig. 3 and Fig. 4.

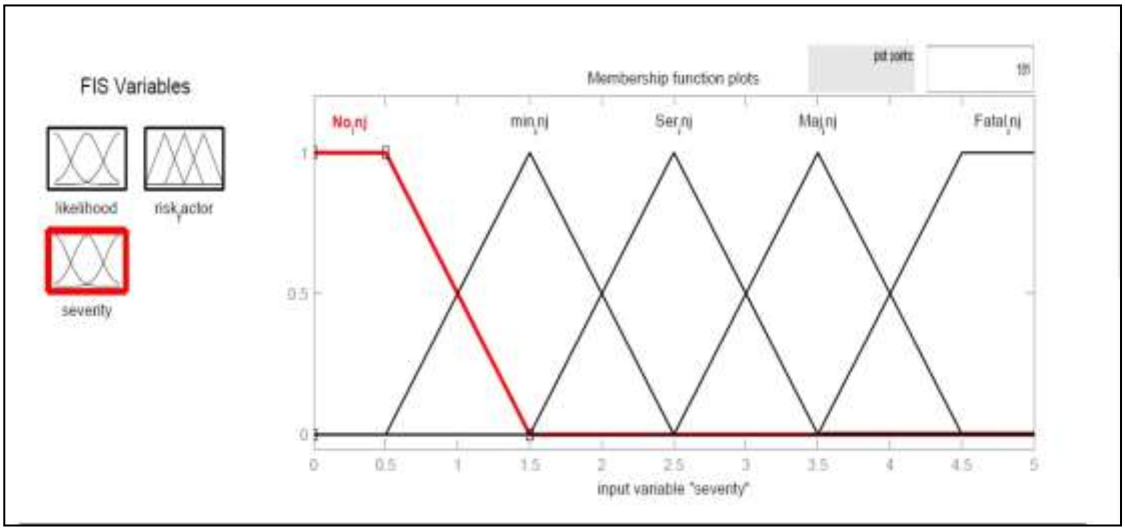

Fig. 3. Fuzzy membership function for severity

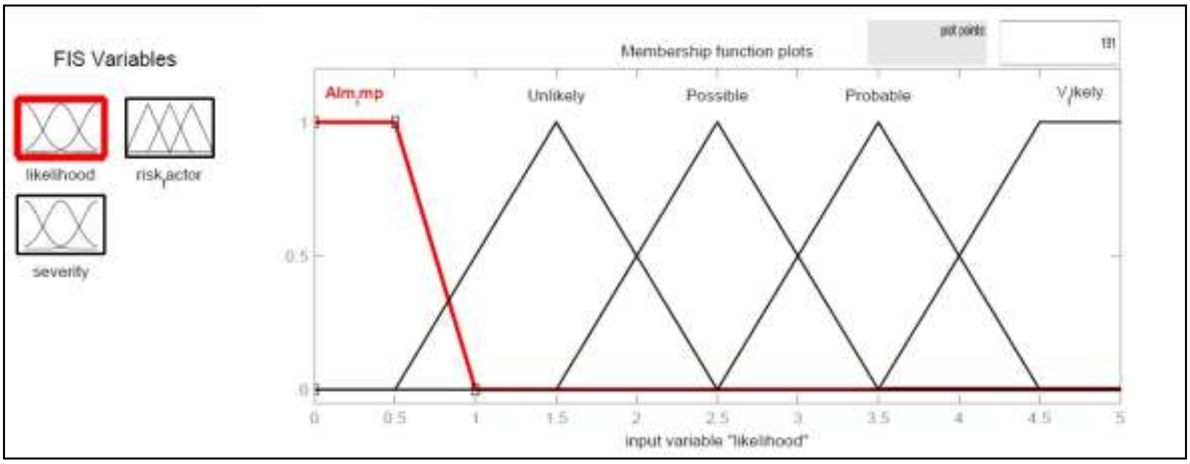

Fig. 4. Fuzzy membership function for Likelihood

Fuzzy Rule Base and Evaluation

Fuzzy rule base is a collection of the IF-THEN rules which are constructed by combining the experience and the judgement of the experts. The antecedent part of the fuzzy IF-THEN rule base i.e.,(IF part) is selected and is compared with the fuzzy input variables. Then, the consequent part of the fuzzy rule base (the THEN-part) is taken as the output of the resultant fuzzy rule base. The fuzzy IF-THEN rule is expressed as:

If **likelihood** is *Almost Impossible* and **severity** is *No Injury* then **risk factor** is *Insignificant Risk.*

The two input linguistic variables have five linguistic terms, the total number of such IF-THEN combinations are 25 (5 x 5). All these combinations should be utilized to generate the fuzzy rule base. The examples of such rules are presented as follows:

1. If (likelihood is Almost impossible) and (severity is No injury) then (risk value is Insignificant risk)

2. If (likelihood is Almost impossible) and (severity is Minor injury) then (risk value is Acceptable risk)

3. If (likelihood is Almost impossible) and (severity is Serious injury) then (risk value is Acceptable risk)

4. If (likelihood is Acceptable risk) and (severity is Major injury) then (risk value is Acceptable risk)

5. If (likelihood is Acceptable risk) and (severity is Fatal injury) then (risk value is Acceptable risk)

6. If (likelihood is Unlikely) and (severity is No injury) then (risk value is Acceptable risk)

7. If (likelihood is Unlikely) and (severity is Minor injury) then (risk value is Acceptable risk)

8. If (likelihood is Unlikely) and (severity is Serious injury) then (risk value is Acceptable risk)

9. If (likelihood is Unlikely) and (severity is Major injury) then (risk value is Intermittent risk)

10. If (likelihood is Unlikely) and (severity is Fatal injury) then (risk value is Intermittent risk)

11. If (likelihood is Possible) and (severity is No injury) then (risk value is Acceptable risk)

12. If (likelihood is Possible) and (severity is Minor injury) then (risk value is Acceptable risk)

13. If (likelihood is Possible) and (severity is Serious injury) then (risk value is Intermittent risk)

14. If (likelihood is Possible) and (severity is Major injury) then (risk value is Intermittent risk)

15. If (likelihood is Possible) and (severity is Fatal injury) then (risk value is High risk)

16. If (likelihood is Probable) and (severity is No injury) then (risk value is Acceptable risk)

17. If (likelihood is Probable) and (severity is Minor injury) then (risk value is Intermittent risk)

18. If (likelihood is Probable) and (severity is Serious injury) then (risk value is Intermittent _risk)

19. If (likelihood is Probable) and (severity is Major injury) then (risk value is High risk)

20. If (likelihood is Probable) and (severity is Serious injury) then (risk value is High risk)

21. If (likelihood is Very likely) and (severity is No injury) then (risk value is Acceptable risk)

22. If (likelihood is Very likely) and (severity is Minor injury) then (risk value is Intermittent risk)

23. If (likelihood is Very likely) and (severity is Serious injury) then (risk value is High risk)

24. If (likelihood is Very likely) and (severity is Major injury) then (risk value is High risk)

25. If (likelihood is Very likely) and (severity is Fatal injury) then (risk value is Intolerable risk)

Defuzzification

For determining the risk ranking of each hazard, the fuzzy set was converted to a crisp value. The defuzzification process converts the linguistic variables defined in the fuzzy rule base to a single crisp value. This value helps in taking corrective actions and redesigning of faulty equipment, if any, properly. Defuzzification is required to achieve the following:

a) Untangling the meaning of the various meanings of fuzzy rule base and the membership values
b) Resolving the instances of uncertainty which may have cropped up during the evaluation.

The centre of gravity (or centroid) method was applied to defuzzify the fuzzy set. The defuzzification formula was given as

$$x = \frac{\int \mu(x).x dx}{\int \mu_R(x) dx} \qquad ......(3)$$

where 'x' is the aggregated value of the total calculated risk 'R'. $\mu_R(x)dx$ is the membership function associated with the calculated risk 'R'.

Results and Discussion

A Case Study: Risk Assessment of Construction Site

To analyze the important hazard types and hazard causes of the construction site by the proposed fuzzy-DMRA methodology, the Chennai metropolitan area was taken as case study. The hazards identified in the construction site were identified and listed down in Table 4. Consider the activities of 2,6,9 & 17, the risk factor values associated with them are 8,9,10, and 5 (Table IV). By the conventional DMRA methodology, the activities 2,6,9 were classified as "Intermediate Risks" and activity 17 was classified as "Acceptable risks". Thus the priority levels associated with the identified activities are in the range of Intermediate to acceptable. However, if we incorporate the Fuzzy methodology to the conventional DMRA methodology, the risk factor values change to 13.4, 13.4, 13.4 & 9.62 respectively. It can be clearly seen that the identified risk factor values change when compared to the values ranked by DMRA methodology and hence, the priority levels were changed from "Acceptable to High" and more importance have to be given to the identified activities in accordance to the fuzzified risk factor values. The sample calculations for activity 17 are presented in Appendix. It was found that the fuzzy-DMRA methodology is more accurate than the traditional DMRA, since the fuzzy logic framework takes into account the uncertainties associated with the identified activities as well as with the ranking of hazards. As a result of more accurate results, the corrective measures can be implemented more properly and the risks can be brought down to ALARP (As Low As Reasonably possible) levels.

Table 4. Traditional DMRA and Fuzzified risk factor

S. No.	Activity	Potential Hazards	Likelihood (L)	Sever-ity(S)	Risk Factor	Fuzzified Risk Factor
1	O_2 Deficiency	It leads to either deficiency or makes the atmosphere combustible	4	3	12	13.4
2	Toxic Atmosphere	Leads to asphyxiation, nausea, giddiness	4	2	8	13.4
3	Loose And Unstable Material	Can lead to caving in thus trapping the workers inside the space.	4	2	8	13.4
4	Slip Trip And Fall Hazards	Leads to injury amongst personnel	4	3	12	13.4
5	Moving Parts Of Equipment And Measurement	Leads to fatality and injuries to the workers	4	2	8	13.4
6	Poor Visibility	No visibility in darkness leads to many accidents and fatalities in the confined space environments	3	3	9	13.4
7	Temperature Extremes	Leads to heat stress, heat exhaustion and possibly heat stroke	3	2	6	10.9
8	Noise	Leads to Deafness, Hearing problems, Hypertension and Increased blood pressure	3	3	9	13.4
9	Cave In	Death to personnel, injury to life, damage to equipment	5	2	10	13.4
10	Hazardous	Asphyxiation, nausea, headache,	4	2	8	13.4

	atmosphere	giddiness to the personnel. If it is a combustible gas it will lead to damage of the entire work space.				
11	Working with heavy machinery	Injury to personnel, fatalities may be possible	4	3	12	13.4
12	Working in proximity to traffic	1. Collapse of equipment on the road. 2.Crane radius coming in the traffic zone	4	2	8	13.4
13	Manual Handling of material	Sprains, Fracture, and in worst case fatality to worker	4	3	12	13.4
14	Electrical Hazards from overhead/underground utilities	Electrocution and sparks from the damaged equipment leading to shocks and even death to the personnel	4	3	12	13.4
15	Authority of Lift (Unauthorised lifting operation) Wrong operation of crane, confusion due to non-familiarity with signals. Unable to judge the load to be lifted.	Serious injury, Crane Damage	4	3	12	13.4
16	Falling of Loose items from height such as reinforcement rod cut piece, concrete cover block etc during lifting of reinforcement cage.	Injury requiring Medical treatment	3	2	6	10.9
17	Communication With Lifting Team & General Communication (mis-communication between the lifting crew & crane operator	Serious injury to member of work force, damaging of Cranes and nearby property. Boom and cage collapse in public area (Adjacent road) or Within site premises.	1	5	5	9.62
18	Illumination	Injuries due to lower visibility, Equipment damage and possible fatalities	3	4	12	13.4

Conclusions

The fuzzy concepts were employed to assess the risk factor in the construction site. While conducting risk assessment using DMRA, the risk factor of each hazard was calculated by Likelihood and Severity ratings. The traditional DMRA results were inaccurate and uncertain when compared to fuzzified risk factor. The usage of linguistic terms in fuzzy logic allows the experts to interpret reasonable information for the Likelihood and Severity parameters and to construct rules more realistically. Using the IF-THEN rules, it can be incorporated into the DMRA tool to remove the uncertainty associated with the risk ranking of the identified hazards in the construction site. It can be seen as refreshing alternative to the traditional qualitative approach towards the risk assessment. Thus the risk assessment performed by integration of fuzzy set theory into the DMRA provides a broad picture of risk as influential factor for systematic maintenance of technical issues in the construction site.

Conflict of interest

Authors declare there are no conflicts of interest.

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