Brodogradnja/Shipbuilding/Open access Volume 67 Number 1, 2016

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http://dx.doi.org/10.21278/brod67104 ISSN 0007-215X
eISSN 1845-5859

AN EFFECTIVE RISK-PREVENTIVE MODEL PROPOSAL FOR OCCUPATIONAL ACCIDENTS AT SHIPYARDS

UDC 629.5.081:614.8.084
Original scientific paper

Summary

According to the statistics of occupational accidents, it is observed that the number of accidents occurred in shipbuilding industry is high and the rate of deaths and serious injuries among these accidents is higher than in other industries. However, the number of the studies to prevent these accidents in both industrial and scientific practices is considerably low. Therefore, the objective of this study is to develop an efficient risk preventive model in accordance with occupational health and safety regulations for industrial organizations. The approach proposed in this study differs from those described in the literature, because it is based on fuzzy set theory in order to cope with uncertainties on probability and severity definitions in terms of occupational health and safety. Furthermore, in this paper, risk severity is considered in terms of harm to worker, harm to environment, and harm to hardware, whereas in the literature, risk severity is generally considered solely in terms of only harm to worker. Then, risk magnitude is obtained by utilizing fuzzy inference system. The proposed approach is applied to a shipyard located in the Marmara Region in order to illustrate the applicability of the model.

Keywords: *occupational safety and health; shipyard's work process; risk assessment and analysis; accident prevention*

1. Introduction

Efforts to reduce work accidents and occupational diseases at industries are getting widespread in Turkey. Especially, reestablishment actions of organizations concerning safety are being tried to get under control with the Occupational Health and Safety Law. In the world, the number of accidents occurred at shipbuilding industry is higher than in other industries [16]. According to studies on accidents in Turkey, the number of accidents occurred in shipyards is high and compensations for deaths and injuries are more expensive [1]. Although shipyards have constantly work accident problems, the number of studies to prevent these accidents in both industrial and scientific practices is considerably low. Therefore, in this paper, a risk-preventive model has been proposed in order to prevent accidents and occupational diseases at shipyards.

A proactive approach analyzing possible risks of organizations is required to prevent occupational accidents and diseases [8]. Thus, it is aimed at avoiding accidents before they happen through risk assessment. In terms of the theoretical perspective, there are various techniques for risk analysis and assessment in the literature [6] such as qualitative, quantitative, and hybrid techniques. The success of the qualitative techniques is based on both analytical estimation processes and expertise of safety managers or engineers. However, quantitative techniques present risk magnitude by a mathematical relation based on the real accidents data recorded at a work site [14]. The mathematical relations used in the quantitative techniques are generally based on the probability of occurrence of accidents and prediction of severity of accidents when they occur. However, it is hard to define precisely probability and severity of incidents taking place at work place because accident statistics are not completely recorded by organizations. Furthermore, magnitude of the severity cannot be measured precisely. Therefore, most of these techniques use linguistic terms and categorical data to obtain risk magnitude by multiplying probability with severity. Hence, based on the traditional risk assessment techniques, there are two obstacles; the first one is that the distribution of risk magnitude obtained by the result of multiplication presents an inconsistent variability [20] and the second is that the definitions for probability and severity include uncertainty because of the categorical structure of the collected data. In the literature, fuzzy sets are widely used to cope with uncertainties in real case problems [27]. Therefore, in this study, a risk assessment method that is based on fuzzy set theory and fuzzy AHP has been developed in order to consider uncertainties on probability and severity definitions. In the proposed model, risk severity is considered in terms of harm to worker, harm to environment, and harm to hardware. Then, risk degree is obtained based on risk severity and risk likelihood of the determined risks under fuzzy environment. The proposed approach is applied to work stations in ship production process.

The rest of this paper is organized as follows: literature review related to the topic is given is Section 2. Section 3 presents the mathematical foundation of the proposed algorithm. Section 4 deals with the application of the proposed algorithm on ship production process in order to illustrate the proposed algorithm. Finally, concluding remarks are given in Section 5.

2. Literature review

The studies in the literature for the shipyard industry regarding occupational accidents and risk assessment processes are limited although the results of these accidents are serious. These studies can be summarized as follows: Ozkok [17] presented a risk assessment application on pin jig work unit by using fuzzy analytical hierarchical process (AHP). In another study, Ozkok [18] obtained the failure statistical data of the shipyards and then comprehensive process analysis was done on shipyard workstations by using the Failure Mode and Effects Analysis (FMEA). Barlas [1] presented a study which analyzed the fatality rate and the causes of fatality accidents in Turkish shipbuilding industry. In another study, Barlas [2] used AHP to analyze fatal occupational accidents at shipyards. Yun and Park [26] developed an industry safety management system for the risk-free backward operation of forklift trucks at shipbuilding industry in Korea. Mora et al. [16] investigated accident records between the years 2000 and 2010 to demonstrate the severity of the accidents which occurred at the shipbuilding industry. Jeong et al. [13] analyzed risks of the cancer incidence in shipyard workers in Korea. Celebi et al. [7] presented a detailed study about all processes in shipbuilding in order to investigate risks of the occupational safety and health. Jacinto and Silva [12] proposed a semi-quantitative risk assessment methodology by using bow-tie method for shipbuilding industry. Cherniack et al. [10] presented a study on sensory nerve conduction velocity in shipyard workers who were occupationally exposed to hand-arm vibration. Mattorano et al. [15] investigated human health hazard of metal exposure during ship repair and production operations.

Finally, there are a few studies in the literature about occupational health and safety and they refer to various accidents. In some papers in the literature, risk scores were generated by depending on severity and possibility of accidents [17; 18; 2], risky workstations were specified, a situation analysis was executed based on statistical evaluation of accidents [16; 13; 1] or detailed research was done about the causes of only one of the types of these accidents [26; 24; 5; 8]. However, these papers consider types or causes of these accidents. It is clear that all of these studies are reactive and a proactive approach towards preventing accidents has not been proposed yet. Therefore, in this paper, a proactive and systematic approach has been proposed in order to prevent occupational accidents and illnesses. Furthermore, none of these studies utilizes fuzzy set theory although risk assessment procedure includes qualitative evaluation. Fuzzy sets are widely used as an effective tool for the evaluation of qualitative data including uncertainties [27]. In the literature, there are some applications which used the fuzzy logic successfully for accident analysis. Celik and Cebi [8] wrote an article which analyses an accident based on fuzzy set theory. Beriha et al. [3] presented a model using fuzzy approach in order to evaluate the safety performance in industry. Tadic et al. [23] demonstrated that fuzzy modeling for evaluating occupational risks can be applied successfully. Also, Pinto et al. [19] pointed out advantages of using fuzzy sets approach in order to cope with ill-defined situations in the article on occupational risk assessment methods used in the construction industry. Zeng et al [28] proposed a risk assessment model on completing construction project in order to evaluate risks for construction sector. Cebi [6] proposed a fuzzy based risk assessment model to evaluate the risks of timely incompletion of construction projects which are received by the contractor firms. Bragatto et al. [4] also presented a study which assessed the impact of occupational safety control programs in the industry by using a fuzzy model.

Most of the risk assessment techniques in the literature are based on two parameters which are the probability of risks and the potential hazards of related risks. Furthermore, these techniques obtain risk magnitude by using multiplication of risk severity with risk likelihood. However, Plues et al. [20] have stressed that the distribution of risk magnitude obtained by multiplication showed an inconsistent variability as well as in the FMEA technique while determining the risk magnitude depending on the expert opinion. In the risk assessment studies, risk magnitude, risk severity and risk likelihood are usually evaluated linguistically. In this study, which differs from those presented in the literature, we aimed at determining the risk magnitude based on probability of risk, severity of risk, and frequencies of events by using fuzzy set theory in order to consider uncertainty on probability and risk severity definitions.

3. Proposed methodology

A risk assessment structure is generally based on identification (I), analysis (A), response (R), and review and monitor (RM). Identification phase includes determining risks caused by potential hazards. The analysis phase is to calculate risk magnitude based on two parameters, (i) risk likelihood and (ii) risk severity. The response phase includes determining risk control options. Finally, the review phase is to monitor whether the selected risk control options eliminate or decrease risk magnitude or not. In this paper, we propose a methodology for the systematic and quantitative measurement of risk magnitude. The structure of the proposed methodology is given in Figure 1. The steps of the proposed approach are as follows;

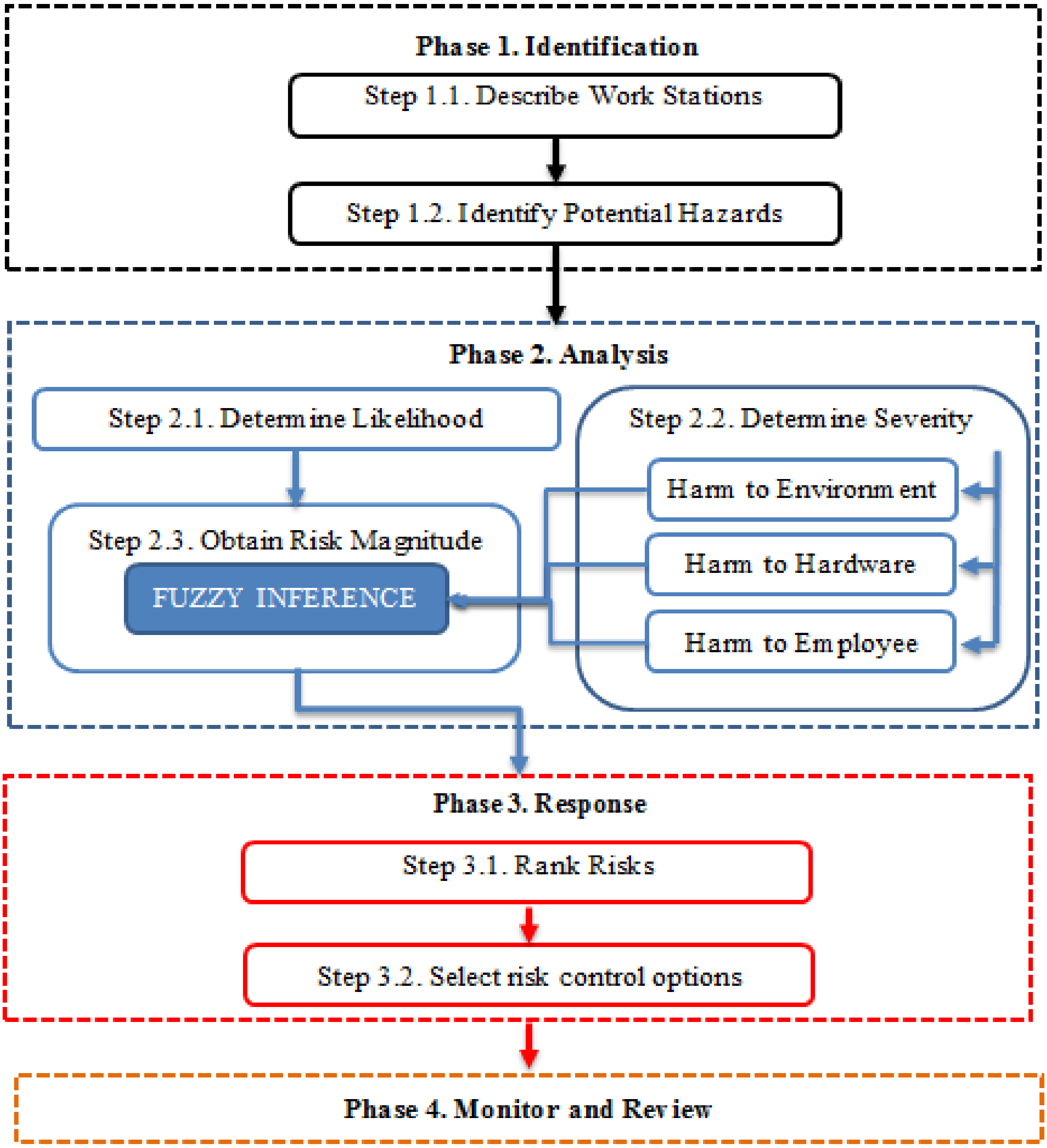

Figure 1 The structure of the proposed method

3.1 Identification phase

First, a risk assessment team consisting of experts with different maritime-related background is established. Then, operation is defined and potential hazards are identified.

Step 1.1 Describe operations: In this step, production process is divided into small work stations based on the similarities of operations. This classification procedure makes it easier for risk evaluation.

Step 1.2 Identify potential hazards: In this step, potential hazards resulting from operations are identified and risks are determined. The sources of any hazard can be classified into five categories; (*i*) physical factors, (*ii*) chemical factors, (*iii*) biological factors, (*iv*) mechanical factors, and (*v*) human factors. Each expert in the risk assessment team has to review all information related to the operation under consideration in order to determine the risks.

3.2 Analysis phase

In this phase, determined risks are analyzed to obtain risk magnitude. In the literature, most of the techniques, such as L-Type Matrix, X-Type Matrix, Preliminary Hazard Analysis (PHA), utilize two parameters to obtain risk magnitude (*RM*). These parameters are risk likelihood (*RL*) and risk severity (*RS*). *RM* for a risk is generally obtained by scalar multiplication of *RL* and *RS*. However, there is an inconsistent variance of the risk score distribution when a multiplication-based formula is used to obtain *RM* [20]. Furthermore, the risk assessment process includes uncertainties and subjectivities. Therefore, it is essential to use fuzzy techniques in order to cope with these uncertainties and subjectivities [28].

Step 2.1 Determine likelihood: In this step, likelihoods of the determined risks, which represent the probabilities of accident occurring, are determined by the risk assessment team. For this, the risk assessment team utilizes FAHP to determine likelihoods. Experts in the risk assessment team are asked to evaluate each risk by using a set of pairwise comparisons. The main aim of this step is to obtain an importance degree that presents likelihood for the determined risks. In this study, FAHP developed by Buckley (1985) is used [9; 11].
The pairwise comparison matrix given by Equation (1) is constructed by any expert.

$$\tilde{C}_k = \begin{vmatrix} 1 & \tilde{c}_{12} & \dots & \tilde{c}_{1n} \\ \tilde{c}_{21} & 1 & \dots & \tilde{c}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{c}_{n1} & \tilde{c}_{n2} & \dots & 1 \end{vmatrix}, \qquad k=1,2,3,....K \tag{1}$$

where $\tilde{C}_k$ is a pairwise comparison matrix which belongs to k^{th} expert. The triangular fuzzy numbers given by Equation (2) are utilized for pairwise comparisons

$$\tilde{c}_{ij} = \begin{cases} (1,1,3),(1,3,5),(3,5,7),(5,7,9),(7,9,9), & \text{if } i \text{ is more important than } j \\ (1,1,1), \quad \text{if } i \text{ and } j \text{ have the same importance}, & \\ (1,1,3)^{-1},(1,3,5)^{-1},(3,5,7)^{-1},(5,7,9)^{-1},(7,9,9)^{-1} & \text{if } i \text{ is less important than } j \end{cases} \tag{2}$$

The linguistic scale for triangular fuzzy numbers in Equation (2) is explained linguistically in Table 1.

Table 1 Linguistic scale for the weight matrix [11]

Linguistic scales	Abbreviation	Fuzzy numbers
Equally important	(Eq)	(1,1,3)
Weakly important	(Wk)	(1,3,5)
Essentially important	(Es)	(3,5,7)
Very strongly important	(Vs)	(5,7,9)
Absolutely important	(Ab)	(7,9,9)

Then, the fuzzy weighted design matrix is calculated by Buckley's Method as follows:

$$\tilde{r}_i = (\tilde{c}_{i1} \otimes \tilde{c}_{i2} \otimes ... \otimes \tilde{c}_{in})^{1/n} \tag{3}$$

$$\tilde{w}_{RL} = \tilde{r}_i \otimes (\tilde{r}_1 + \tilde{r}_2 + ... + \tilde{r}_n)^{-1} \tag{4}$$

where $\tilde{c}_{in}$ is the fuzzy comparison value between the related risks and $\tilde{r}_i$ is the geometric mean of fuzzy comparison values. $\tilde{w}_{RL}$ represents likelihood for the related risk. When there are more than one expert in the evaluation process and if each expert presents own judgements, geometric mean method is used to aggregate the experts' preferences.

Step 2.2 Determine severity: In this study, different from the literature, severity (*RS*) is taken into consideration in terms of three parameters. These parameters are *Harm to Employee* (RS^H), *Harm to System* (RS^S), and *Harm to Environment* (RS^E). Each expert presents own preferences on these parameters and then co-decision matrix is obtained by arithmetic mean method. For the evaluations, linguistic scale given in Table 2 is used.

Table 2 Linguistic scale for risk severity

Type	Risk Severity	Linguistic Term
RS^H	No loss of working time	Very Low (VL)
	No loss of working days (There is loss of working time)	Low (L)
	Loss of working days	Medium (M)
	Loss of working weeks	High (H)
	Permanent Unfitness/Occupational Disease/Death/	Very High (VH)
RS^S	No damage on the system	None (N)
	There is a little damage but system still works	Very Low (VL)
	Damage on the system causes loss of working time	Low (L)
	Damage on the system causes loss of working days	Medium (M)
	Damage on the system causes loss of working weeks	High (H)
	Damage on the system causes out of service	Very High (VH)
RS^E	No damage on environment	None (N)
	Damage on environment can be removed in a short time	Very Low (VL)
	Damage on environment can be removed in a short term	Low (L)
	Damage on environment can be removed in a medium term	Medium (M)
	Damage on environment can be removed in a long term	High (H)
	Damage on environment cannot be removed	Very High (VH)

Step 2.3 Obtain the risk magnitude: In this step, fuzzy inference system proposed by Mamdani (1977) is used to obtain risk magnitude (*RM*) since it is an effective tool to cope with imprecise and vague information [28]. The steps of Mamdani Fuzzy Inference technique are given in the following.

The aggregated fuzzy numbers of *RL*, RS^H, RS^S, *and* RS^E are converted into matching fuzzy sets in order to obtain membership value of input data since fuzzy numbers cannot be directly used in a fuzzy inference system. In the basis of the fuzzy inference, there is a knowledge base including several rules defined by experts. A rule (R^k) is presented in a form of if-then rule and it present relations among input parameters (*RL*, RS^H, RS^S, *and* RS^E) and output (*RM*). To illustrate if-then rule type, Equation 5 is given.

$$R^k : IF\ RL\ is\ \mu_{RL}^k,\ RS^H\ is\ \mu_{RSH}^k, RS^E\ is\ \mu_{RSE}^k,\\ RS^S\ is\ \mu_{RSS}^k\ THEN\ RM\ is\ \mu_{RM}^k,\quad k = 1,2,..,K \tag{5}$$

where μ_{RL}^k, μ_{RSH}^k, μ_{RSE}^k, μ_{RSS}^k and μ_{RM}^k represents membership value of RL, RS^H, RS^E, RS^S, and RM, respectively. By using max-min operation (Equation 6), the value of *RM* is obtained.

$$\mu_{RM}^k(y) : \vee_{k=1}^K \left(\mu_{RL}^k(x_1) \wedge \mu_{RSH}^k(x_2) \wedge \mu_{RSE}^k(x_3) \wedge \mu_{RSS}^k(x_4)\right) \tag{6}$$

where $y \in Y, x_1 \in X_1, x_2 \in X_2, x_3 \in X_3, and\ x_4 \in X_4$ represents universe of RM, RL, RS^H, RS^E, and RS^S since the obtained output from fuzzy inference system is a fuzzy set, it is required to defuzzify output into a crisp value. For the defuzzification process, center-average method given by Equation 7 is used.

$$RM = \frac{\sum_{i=1} z_i \mu_{RM}(y)}{\sum_{i=1} \mu_{RM}(y)} \tag{7}$$

where Z_i represents the center of the i^{th} fuzzy term set of *RM.*

3.3 Response phase

In this phase, risks are ranked from highest to lowest based on their risk magnitude and the best control option is selected. The following steps are used during selection of control options.

1. Eliminate hazards at their source
2. Replace a source of hazard with a less dangerous source of hazard
3. Take engineering controls on the source
4. Take organizational administrative controls on the source
5. Use personal proactive equipment (PPE)

3.4 Monitor and review phase

In this phase, the selected control options are monitored and reviewed.

4. Application

Apart from requiring great skills in metal-working techniques, the shipbuilding process requires a professionalism and knowledge of numerous technical sectors, such as erection of scaffolding for constructing the hull and plating, electrical wiring, raising and moving operations, sandblasting, cleaning and painting and all the details of fitting-out [25]. Each of these activities is hard and complex. Therefore, various accidents occur during the implementation of these activities. In this paper, the risk assessment of a shipyard which performs the construction of new vessels in the Marmara Region has been considered in order to illustrate the proposed approach.

4.1 Identification phase

First, it is necessary to create a risk assessment team. The risk assessment team in this study consists of two different groups. The first one is a risk assessment team in the shipyard. Since the risk assessment team should include experts who are employees in the related firm, for the needs of this study, it has been the risk assessment team of the shipyard under consideration. The second group consists of three people who have expertise both in shipyard applications and in academic studies.

Step 1.1 Describe operations: Since ship production process includes thousands of work activities and requires various types of work stations, it is an extremely complex process. The production process starts with cutting of steel and it ends with joining hull blocks. Figure 2 roughly presents the work flow chart of ship production process [18].

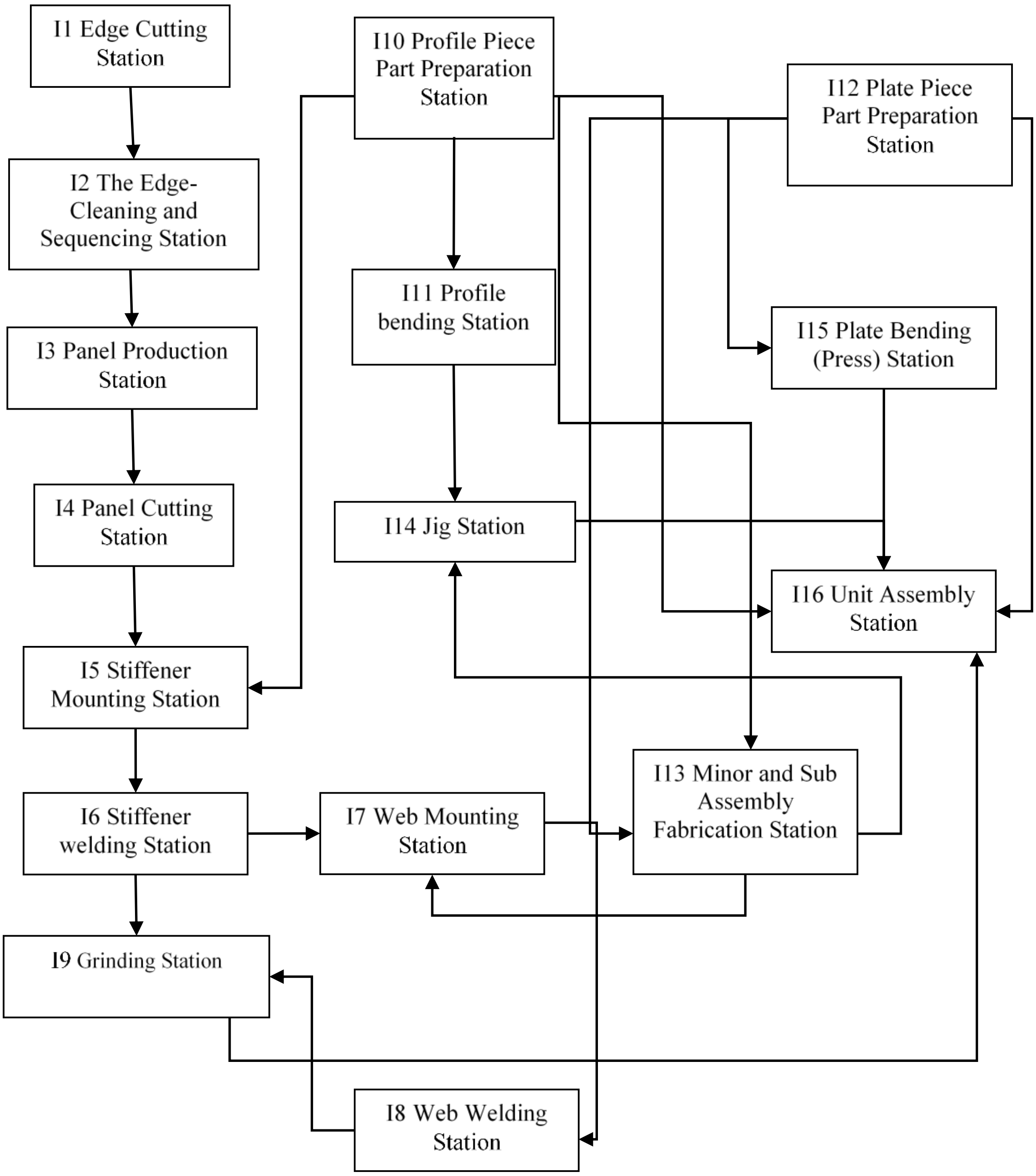

Figure 2 Workflow chart of the work stations in the ship production process [18]

Step 1.2 Identify potential hazards: All risks should be grouped depending on the equipment used during production process. In this step, fourteen potential hazards were identified. The potential hazards and their risks are given in Table 3.

Table 3 The risks identified for the processes carried out in the shipyard

	Risk Codes	Risk Identification
Forklift transport	F1	Unsuitable placing of load
	F2	Passenger transport by forklift
	F3	Unbalanced loading of forklift
	F4	Discharge of forklift hydraulic
	F5	Forklift capsizing
	F6	Crashing into surrounding workers with fork
	F7	Working in non-ergonomic body posture
Overhead crane operation	V1	Removal of load the more than lifting tonnage/Overloading the crane
	V2	Lifting load up to the rafters with the cob
	V3	To go off the rails of cranes/Derailing of the crane
	V4	Unhooking of sling during lifting
	V5	Power loss during load in crane hook/Power failure during operation
	V6	Falling crane, slipping load, bleeding of brake
	V7	Falling from height
	V8	Hit one another cranes moving on the same rail
	V9	Working in non-ergonomic body posture
Turning machine	TO1	Maintenance or tip replacement without switching of the power supply
	TO2	Splashing burr to the eye during operation
	TO3	Cleaning turnings by hand
	TO4	Splashing material on the turning machine during operation
	TO5	Electrical leakage at the turning lathe
	TO6	Entrapment of worker’s limb in the rotating part of the lathe
	TO7	Working in non-ergonomic body posture
Drill	M1	Worker’s body is pulled over the drill
	M2	Splashing burr to the eye during operation
	M3	Doing maintenance while the drill is running
	M4	Cleaning turnings by hand
	M5	Unfavorable securing of the work piece
	M6	Tip replacement while the drill is running
	M7	Working in non-ergonomic body posture
Sling	S1	Using a wrong sling
	S2	Using a damaged sling
	S3	Connecting unfavorable to load of sling
Electric Welding	EK1	Emission of toxic gases and fumes during welding
	EK2	Exposure to UV radiation
	EK3	Electric shock
	EK4	Working in non-ergonomic body posture
Inert-Gas Welding	GK1	Splashing burr onto the eye during welding
	GK2	Emission of fumes during welding
	GK3	Exposure to released UV radiation during welding
	GK4	Electric shock
	GK5	Working in non-ergonomic body posture

Table 3 The risks identified for the processes carried out in the shipyard (cont.)

Submerged Welding	TK1	Emission of fumes during welding
	TK2	Exposure to released UV radiation during welding
	TK3	Electric shock
	TK4	Splashing burr onto the eye during welding
	TK5	Working in non-ergonomic body posture
Oxygen Welding	O1	Idle operation of torch
	O2	Leaving off the locality of the welding torch during breaks and rest
	O3	Non-closure of the tube valves during breaks and rest
	O4	Exposure to released UV radiation
	O5	Disregarding the use of oxy-acetylene
	O6	Working in non-ergonomic body posture
Dovetail	K1	Oscillating of the lifted load
	K2	Exceeding the lifting capacity
	K3	Lifting long plate or profile with one apparatus
	K4	Unfavorable connecting of load to dovetail
	K5	Routing manually of load
	K6	Working in non-ergonomic body posture
Storage Process	D1	Storage of hazardous materials in the main storage
	D2	Storage done so as to prevent the use and operation of the fire extinguishing installation
	D3	Danger of tipping over rolling of materials such as rod and pipe
	D4	Materials falling from the shelves in the store
	D5	Stacking materials for transition and exit roads
Material Cutting	MK1	Perform cutting without fastening materials
	MK2	Tipping over and falling on operating machines
	MK3	Hand contact with the cutting area while the machine is operating
	MK4	Splashing burr onto the eye during cutting
	MK5	Removing the machine protective cover/covers
	MK6	Working in non-ergonomic body posture
Grinding	T1	Lathes grinders cut
	T2	Stone bursting
	T3	Stone bursting
	T4	Power blackout and leaving the device open during grinding
	T5	The presence of flammable and / or burning objects close to the place of work
	T6	Disk compression and rebound in confined work areas
	T7	Not well-screwing the stone
	T8	Turning on the engine while machine is plugging
	T9	Inhalation of generated dust and smoke during grinding
General Risks	G1_1	The presence of unauthorized persons in the work area
	G1_2	The lack of qualified employees
	G1_3	Improper maintenance
	G1_4	Not providing the required personal protective equipment
	G1_5	Not using the necessary personal protective equipment
	G1_6	Lack of necessary training
	G1_7	Working in non-ergonomic body posture

4.2 Analysis phase

Step 2.1 Determine likelihood: In this step, decision matrices on likelihoods of the identified risks in the previous step were constructed by providing consensus among the experts. Pairwise comparisons related with the risks of grinding are shown in Table 4 in order to illustrate this step. Linguistic expressions in Table 4 were converted into fuzzy numbers using the scale given in Table 1. Then the probabilities of risks were obtained by using Equations 3 and 4. Fuzzy values of the risks' probability for grinding operation are as follows: wT1 [0.44, 0.8, 2.27], [wT2 (0.11, 0.2, 0.5)], [wT3 (1.4, 2.84, 6.28)], [wT4 (0.39, 0.8, 2.01)], [wT5 (0.1, 0.2, 0.44)], [wT6(1.24, 2.84, 5.55)], [wT7 (0.34, 0.8, 1.78)], [wT8 (0.3, 0.8, 1.58)] and [wT9 (0.27, 0.71, 1.4)].

Table 4 Pairwise comparison matrix for the risks of grinding

	T1	T2	T3	T4	T5	T6	T7	T8	T9
T1		Es	1/Es	Eq	Es	1/Es	Eq	Eq	Eq
T2			1/Vs	1/Es	Eq	1/Vs	1/Es	1/Es	1/Es
T3				Es	Vs	Eq	Es	Es	Es
T4					Es	1/Es	Eq	Eq	Eq
T5						1/Vs	1/Es	1/Es	1/Es
T6							Es	Es	Es
T7								Eq	Eq
T8									Eq
T9									

Step 2.2 Determine severity: The severity of the risks are evaluated in terms of harm to the workers, harm to the environment and harm to the machine by using linguistic expressions given in Table 2 by the expert team. Table 5 is given to illustrate the evaluation of the severity. The linguistic expressions given in Table 5 are converted into fuzzy numbers by using the scale given in Figure 3.

Table 5 Risk severities for grinding operation

	Linguistic Expressions for Severity							Fuzzy Numbers for Severity		
	RSH	RSM			RSE			RSH	RSM	RSE
		E1	E2	E3	E1	E2	E3			
RS_T1	H	L	VL	VL	L	VL	M	(5, 7.5, 10)	(0, 0.8, 3.3)	(0.8, 2.5, 5)
RS_T2	H	L	M	M	H	M	H	(5, 7.5, 10)	(1.7, 4.2, 6.7)	(4.2, 6.7, 9.2)
RS_T3	H	VL	VL	VL	VL	VL	L	(5, 7.5, 10)	(0, 0, 2.5)	(0, 0.8, 3.3)
RS_T4	L	H	M	L	VL	L	L	(0, 2.5, 5)	(2.5, 5, 7.5)	(0, 1.7, 4.2)
RS_T5	VH	H	VH	L	H	VH	VH	(7.5, 10, 10)	(4.2, 6.7, 8.3)	(6.7, 9.2, 10)
RS_T6	VL	M	H	M	M	L	M	(0, 0, 2.5)	(3.3, 5.8, 8.3)	(1.7, 4.2, 6.7)
RS_T7	L	M	M	H	M	M	M	(0, 2.5, 5)	(3.3, 5.8, 8.3)	(2.5, 5, 7.5)
RS_T8	L	M	H	M	VL	H	M	(0, 2.5, 5)	(3.3, 5.8, 8.3)	(2.5, 4.2, 6.7)
RS_T9	L	VL	L	M	VL	L	H	(0, 2.5, 5)	(0.8, 2.5,5)	(1.7, 3.3, 5.8)

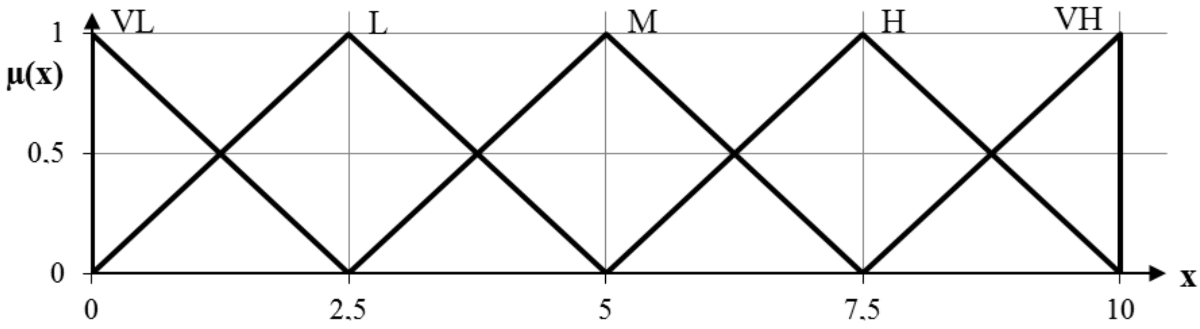

Figure 3 The scale of the triangular fuzzy numbers

Step 2.3 Obtain the risk magnitude: The membership values for the fuzzy numbers obtained in Step 2.1 and Step 2.2 are calculated by using the scale given in Figure 3. Table 6 and Table 7 show the obtained membership values for risk likelihood and risk severity of grinding operation, respectively.

Table 6 Membership values of the risk likelihood for grinding operation

	Membership degrees for RL				
	VL	L	M	H	VH
μ_{RLT1}	0.73	0.63	0.07		
μ_{RLT2}	0.93	0.19			
μ_{RLT3}	0.28	0.93	0.64	0.22	
μ_{RLT4}	0.73	0.54			
μ_{RLT5}	0.93	0.16			
μ_{RLT6}	0.32	0.93	0.59	0.12	
μ_{RLT7}	0.73	0.51			
μ_{RLT8}	0.74	0.49			
μ_{RLT9}	0.76	0.44			

Table 7 Membership values of the risk severity for grinding operation

	RSH					RSM					RSE				
	VL	L	M	H	VH	VL	L	M	H	VH	VL	L	M	H	VH
μ_{RST1}			0.50	1.00	0.50	0.76	0.66	0.16			0.40	1.00	0.50		
μ_{RST2}			0.50	1.00	0.50	0.16	0.67	0.84	0.34			0.16	0.67	0.84	0.35
μ_{RST3}			0.50	1.00	0.50	1.00	0.50				0.76	0.66	0.16		
μ_{RST4}	0.5	1.00	0.50				0.50	1.00	0.50		0.60	0.84	0.34		
μ_{RST5}				0.50	1.00		0.16	0.66	0.85	0,20			0.17	0.66	0.75
μ_{RST6}	1.0	0.50					0.34	0.84	0.66	0,17	0.16	0.67	0.84	0.34	
μ_{RST7}	0.5	1.00	0.50				0.34	0.84	0.66	0,17		0.50	1.00	0.50	
μ_{RST8}	0.5	1.00	0.50				0.34	0.84	0.66	0,17		0.60	0.84	0.34	
μ_{RST9}	0.5	1.00	0.50			0.40	1.00	0.50			0.20	0.80	0.66	0.16	

Risks magnitude is calculated using Equations 5-6 and the rule base which is given in Appendix.

Table 8 The risk magnitudes related to the identified risk

	Membership degree for RM					The risk values for RM			
	N	Mi	Ma	C	RM	N	Mi	Ma	C
RM_F1	0.5	0.5	0.87	0	4.59		70.50%	29.50%	
RM_F2	0.78	0.46	0.46	0	3.44		100%		
RM_F3	0.77	0.5	0.41	0	3.36		100%		
RM_F4	0.4	0.4	0.4	0	4		100%		
RM_F5	0.34	0.84	0.6	0	4.44		78%	22%	
RM_F6	0.66	0.84	0.5	0	3.76		100%		
RM_V1	0	0.32	0.84	0.16	6.64			100%	
RM_V2	0	0.84	0.33	0	4.85		57.50%	42.50%	
RM_V3	0	0.5	0.76	0	5.81		9.50%	90.50%	
RM_V4	0	0.58	0.66	0	5.6		20%	80%	
RM_V5	0	0.85	0.5	0	5.11		44.50%	55.50%	
RM_V6	0	0.66	0.75	0	5.6		20%	80%	
RM_V7	0	0.5	0.84	0	5.88		6%	94%	
RM_V8	0.34	0.5	0.84	0	4.89		55.50%	44.50%	
RM_TO1	0	0.75	0.44	0	5.11		44.50%	55.50%	
RM_TO2	0	0	0.75	0.82	8.57			21.50%	78.50%
RM_TO3	0.5	0.5	0.41	0	3.81		100%		
RM_TO4	0.76	0.5	0.38	0	3.3		100%		
RM_M1	0.5	0.76	0.36	0	3.74		100%		
RM_M2	0	0	0.76	0.69	8.43			28.50%	71.50%
RM_M3	0	0.76	0.32	0	4.89		55.50%	44.50%	
RM_M4	0.76	0.5	0.34	0	3.21		100%		
RM_M5	0.5	0.5	0.82	0	4.53		73.50%	26.50%	
RM_EK1	0.34	0.5	0.76	0.41	5.85		7.50%	92.50%	
RM_EK2	0.34	0.5	0.84	0	4.89		55.50%	44.50%	
RM_GK1	0.5	0.6	0.63	0	4.23		88.50%	11.50%	
RM_GK2	0.16	0.5	0.76	0.11	5.61		19.50%	80.50%	
RM_GK3	0.35	0.5	0.82	0	4.84		58%	42%	
RM_GK4	0.5	0.84	0.22	0	3.46		100%		
RM_TK1	0.5	0.5	0.88	0.2	5.13		43.50%	56.50%	
RM_TK2	0.5	0.65	0.84	0	4.51		74.50%	25.50%	
RM_TK3	0	0.84	0.28	0	4.75		62.50%	37.50%	
RM_TK4	0	0.61	0.64	0	5.54		23%	77%	
RM_O1	0.5	0.81	0.36	0	3.75		100%		
RM_O2	0.5	0.76	0.31	0	3.64		100%		
RM_O3	0	0.46	0.76	0.32	6.73			100%	
RM_O4	0	0	0.93	0.69	8.28			36%	64%
RM_O5	0.8	0.5	0.18	0	2.74	13%	87%		
RM_K1	0	0	0.84	0.75	8.42			29%	71%
RM_K2	0	0.62	0.72	0.21	6.21			100%	
RM_K3	0	0.63	0.67	0	5.55		22.50%	77.50%	
RM_K4	0	0.64	0.64	0	5.5		25%	75%	
RM_K5	0	0.65	0.57	0	5.4		30%	70%	
RM_S1	0	0.08	0.8	0.6	8.05			47.50%	52.50%
RM_S2	0	0.23	0.76	0.7	7.83			58.50%	41.50%
RM_S3	0	0.3	0.83	0.55	7.45			77.50%	22.50%
RM_D1	0.28	0.66	0.76	0	4.85		57.50%	42.50%	
RM_D2	0.36	0.76	0.5	0	4.26		87%	13%	
RM_D3	0.34	0.7	0.76	0	4.7		65%	35%	
RM_D4	0.17	0.61	0.63	0	4.98		51%	49%	
RM_MK1	0.84	0.25	0.25	0	2.68	16%	84%		
RM_MK2	0.5	0.53	0.77	0	4.45		77.50%	22.50%	
RM_MK3	0.5	0.5	0.8	0.34	5.37		31.50%	68.50%	
RM_MK4	0.5	0.84	0.5	0	4		100%		
RM_MK5	0.67	0.56	0.5	0	3.71		100%		

The risk magnitudes of the identified risks are given in Table 8. The risk magnitudes given are calculated as an absolute numerical value using Equation 7 by utilizing the scale given in Figure 4. The risk magnitude in Figure 4 is divided into four levels: negligible (*N*), minor (*Mi*), major (*MA*) and critical risk (*C*). For example, the risk magnitude of T2 is calculated as 3.73 by using Equation 7. When this value is plotted in the graph given in Figure 4, the risk magnitude of T2 falls within the minor risk class.

$$\mathrm{RM} = \frac{0.5 * 1 + 0.84 * 4 + 0.35 * 7 + 0 * 10}{0.5 + 0.84 + 0.35} = 3.73$$

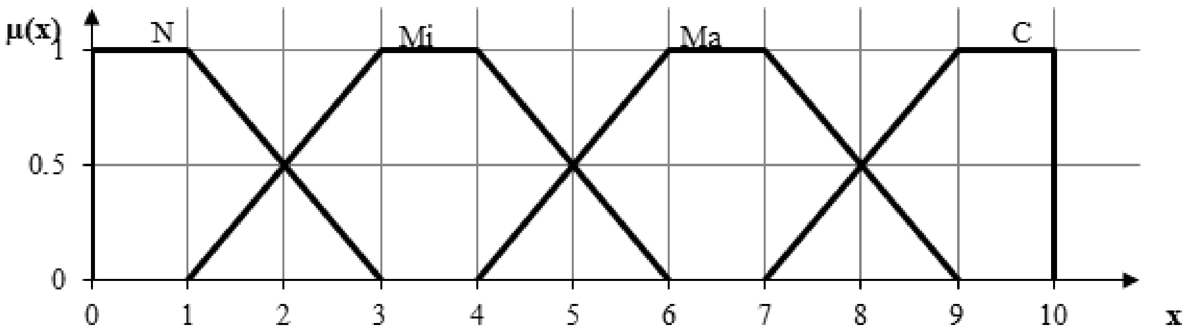

Figure 4 Rectangular fuzzy numbers for risk magnitudes

4.3 Response phase

The risk groups initially formed in Step 1.2 are ranked according to their risk magnitudes. The rank from the biggest to lowest is as follows: use of slings (7.78), dovetail transport (6.21), crane transport (5.55), electric arc welding operation (5.37), turning operation (5.20), oxygen cutting operation (5.03), submerged welding operation (4.98), use of drill (4.96), storage (4.70), inert-gas welding operation (4.53), grinding operation (4.08), material cutting operation (4.04), forklift transport (3.93).

It is observed that the most of these risks are of tolerable degrees. For this risk group, periodic maintenance applications for machines and equipment are usually sufficient. For this group, it is possible to prevent problems that may occur in the future and are associated with the conditions such as occurrence of changes in the materials and equipment, in the technology, and in the production methods by ensuring continuous control and by informing workers in advance.

The current critical risks obtained from this study are defined as (1) Splashing burr on to eye during operation, (2) Exposure to released UV radiation, (3) Oscillating of the lifted load during dovetail transport use, and (4) risks related to the use of slings. For the first and second groups of risks, it is required to improve the awareness of employees and to promote the use of protective equipment. In order to obtain the appropriate risk magnitude for the third and fourth groups of risks, it is necessary to provide personnel training, continuous control, and supervision service.

4.4 Monitor and review phase

Within the scope of this study, the magnitudes of the identified risks are analyzed. The establishment of the monitor and review process is one of the most critical steps of the organization's risk management process. For this purpose, daily, weekly and monthly check lists have been prepared for the each work station in order to make sure that the specified management action plans remain relevant and updated.

5. Conclusion

In this paper a new risk assessment approach has been proposed. The differences of the proposed methodology can be summarized as follows. (i) Risk severity is considered taking into account three parameters: harm to worker, harm to environment, and harm to hardware. In other words, the proposed method uses three inputs for risk severity. Traditional techniques, however, utilize only one parameter for risk severity combining all types of severities. The advantage of this feature is that the severity of any accident can be considered in detail and so precautions can be better designed. (ii) In the literature, risk severity and risk probability parameters are widely used to obtain risk magnitude. However, the collected data for these parameters are in linguistic or categorical form. This presents an uncertainty. To overcome this difficulty, fuzzy set theory is utilized in the proposed method. (iii) In the literature, while obtaining risk magnitude, scalar multiplication is generally used. However, the result of multiplication presents an inconsistent variability [20]. Therefore, in the proposed method Fuzzy Inference System (FIS) has been used to calculate risk magnitudes.

The proposed approach has been applied to shipyards. For this purpose, fourteen work stations have been constructed based on the work process and utilized technology in the process. Possible sources of hazard are defined and the risks associated with these hazards are identified for these work stations. Then, experts evaluate these risks by using linguistic scale. In the evaluation, risk severity is considered in terms of harm to environment, harm to employee, and harm to hardware. The probabilities of the defined risks for each work station are determined based on the pairwise comparisons. Furthermore, a rule based system associated with relations among risk magnitude, risk probability, and risk severities (harm to employee, harm to environment, and harm to hardware) has been developed. Then, the risk magnitude for each risk is calculated based on these data by using fuzzy inference system. Hence, the most risky operations have been determined in the shipbuilding process for the considered shipyard.

The strengths of the proposed risk model are as follows: (i) the model considers risk severity, probability, and risk magnitude terms by using fuzzy set theory in terms of occupational health and safety. (ii) Risk severity term is considered by using three different terms: harm to hardware, harm to environment and harm to employee. Furthermore, it is the first time that the proposed method has been used for risk evaluation for ship production process. In the literature, there is not any study to evaluate risks in terms of occupational health and safety in the whole ship production process. However, the weakness of the proposed model is that the model includes a set of complex computations. This makes the calculation process hard and unpractical. Therefore, in the further work, a decision support system may be developed based on proposed model in order to make computation process easy and provide a decision support for experts.

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Submitted: 3.08.2015.
Accepted: 11.02.2016.

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APPENDIX

App. Table 1 Fuzzy rule based for risks

			RL				
RSH	RSE	RSM	VL	L	M	H	VH
		VL	N	N	N	N	N
		L	N	N	N	N	N
	VL	M	N	N	N	N	N
		H	N	N	N	N	Mi
		VH	N	N	N	N	Mi
	L	VL	N	N	N	N	N
		L	N	N	N	Mi	N
		M	N	N	Mi	Mi	Mi
		H	N	N	Mi	Mi	Mi
		VH	N	N	Mi	Mi	Mi
	M	VL	N	N	Mi	Mi	Mi
		L	N	N	Mi	Mi	Mi
VL		M	N	N	Mi	Mi	Ma
		H	N	N	Mi	Mi	Ma
		VH	N	Mi	Mi	Ma	Ma
	H	VL	N	Mi	Mi	Ma	Ma
		L	N	Mi	Mi	Ma	Ma
		M	N	Mi	Mi	Ma	Ma
		H	N	Mi	Mi	Ma	Mia
		VH	N	Mi	Mi	Ma	Ma
	VH	VL	N	Mi	Mi	Ma	Ma
		L	N	Mi	Mi	Ma	Ma
		M	N	Mi	Mi	Ma	C
		H	N	Mi	Mi	Ma	C
		VH	N	Ma	Ma	Ma	C
	VL	VL	N	N	N	N	N
		L	N	N	N	N	N
		M	N	N	N	N	N
		H	N	N	N	N	Mi
		VH	N	N	N	Mi	Mi
	L	VL	N	N	N	N	Mi
		L	N	N	N	N	Mi
		M	N	N	N	Mi	Mi
		H	N	N	Mi	Mi	Mi
		VH	N	N	Mi	Mi	Mi
	M	VL	N	Mi	Mi	Ma	Ma
		L	N	Mi	Mi	Ma	Ma
L		M	N	Mi	Mi	Ma	Ma
		H	N	Mi	Ma	Ma	Ma
		VH	N	Mi	Ma	Ma	C
	H	VL	N	Mi	Ma	Ma	Ma
		L	N	Mi	Ma	Ma	Ma
		M	N	Mi	Ma	Ma	Ma
		H	N	Mi	Ma	Ma	Ma
		VH	N	Mi	Ma	Ma	C
	VH	VL	N	Mi	Ma	Ma	C
		L	N	Mİ	Ma	Ma	C
		M	N	Mi	Ma	Ma	C
		H	N	Ma	Ma	Ma	C
		VH	N	Ma	Ma	Ma	C

			RL				
RSH	RSE	RSM	VL	L	M	H	VH
	VL	VL	N	Mi	Ma	Ma	Ma
		L	N	Mi	Ma	Ma	Ma
		M	N	Mi	Ma	Ma	Ma
		H	N	Mi	Ma	Ma	Ma
		VH	N	Ma	Ma	Ma	Ma
	L	VL	N	Mi	Ma	Ma	Ma
		L	N	Mi	Ma	Ma	Ma
		M	N	Ma	Ma	Ma	Ma
		H	N	Ma	Ma	Ma	Ma
		VH	N	Ma	Ma	Ma	Ma
	M	VL	N	Ma	Ma	Ma	Ma
		L	N	Ma	Ma	Ma	Ma
M		M	N	Ma	Ma	Ma	Ma
		H	N	Ma	Ma	Ma	Ma
		VH	N	Ma	Ma	Ma	Ma
	H	VL	N	Ma	Ma	Ma	Ma
		L	Mi	Ma	Ma	Ma	Ma
		M	Mi	Ma	Ma	Ma	Ma
		H	Mi	Ma	Ma	Ma	Ma
		VH	Mi	Ma	Ma	Ma	C
	VH	VL	Mi	Ma	Ma	Ma	C
		L	Mi	Ma	Ma	Ma	C
		M	Mi	Ma	Ma	Ma	C
		H	Mi	Ma	Ma	Ma	C
		VH	Mi	Ma	Ma	Ma	C
	VL	VL	Mi	Ma	Ma	Ma	C
		L	Mi	Ma	Ma	Ma	C
		M	Mi	Ma	Ma	Ma	C
		H	Mi	Ma	Ma	Ma	C
		VH	Mi	Ma	Ma	Ma	C
	L	VL	Mi	Ma	Ma	Ma	C
		L	Mi	Ma	Ma	Ma	C
		M	Mi	Ma	Ma	Ma	C
		H	Mi	Ma	Ma	Ma	C
		VH	Mi	Ma	Ma	Ma	C
	M	VL	Mi	Ma	Ma	Ma	C
		L	Mi	Ma	Ma	Ma	C
H		M	Mi	Ma	Ma	Ma	C
		H	Mi	Ma	Ma	Ma	C
		VH	Mi	Ma	Ma	Ma	C
	H	VL	Mi	Ma	Ma	Ma	C
		L	Mi	Ma	Ma	Ma	C
		M	Mi	Ma	Ma	Ma	C
		H	Mi	Ma	Ma	Ma	C
		VH	Mi	Ma	Ma	Ma	C
	VH	VL	Mi	Ma	Ma	Ma	C
		L	Mi	Ma	Ma	Ma	C
		M	Mi	Ma	Ma	Ma	C
		H	Mi	Ma	Ma	Ma	C
		VH	Mi	Ma	Ma	Ma	C

			RL				
RSH	RSE	RSM	VL	L	M	H	VH
	VL	VL	Mi	Ma	Ma	Ma	C
		L	Mi	Ma	Ma	Ma	C
		M	Mi	Ma	Ma	Ma	C
		H	Mi	Ma	Ma	Ma	C
		VH	Mi	Ma	Ma	Ma	C
	L	VL	Mi	Ma	Ma	Ma	C
		L	Mi	Ma	Ma	Ma	C
		M	Mi	Ma	Ma	Ma	C
		H	Mi	Ma	Ma	Ma	C
		VH	Mi	Ma	Ma	C	C
	M	VL	Mi	Ma	Ma	C	C
		L	Mi	Ma	Ma	C	C
VH		M	Mi	Ma	Ma	C	C
		H	Mi	Ma	Ma	C	C
		VH	Mi	Ma	Ma	C	C
	H	VL	Mi	Ma	Ma	C	C
		L	Mi	Ma	Ma	C	C
		M	Mi	Ma	Ma	C	C
		H	Mi	Ma	Ma	C	C
		VH	Mi	Ma	Ma	C	C
	VH	VL	Mi	Ma	Ma	C	C
		L	Mi	Ma	Ma	C	C
		M	Ma	Ma	C	C	C
		H	Ma	Ma	C	C	C
		VH	Ma	Ma	C	C	C