Selcuk Cebi
Emre Akyuz
Yasin Sahin

http://dx.doi.org/10.21278/brod68102 ISSN 0007-215X
eISSN 1845-5859

DEVELOPING WEB BASED DECISION SUPPORT SYSTEM FOR EVALUATION OCCUPATIONAL RISKS AT SHIPYARDS

UDC 629.5(05):629.5.081
Professional paper

Summary

In this study, a web based decision support system (WBDSS) has been developed to provide decision aid for risk analysis on occupational health and safety at shipyards. The system has been constructed as a modular structure to make its application easy for all kind of firms. The WBDSS is rule based and its database includes safety measures and risks for each tool and machine used in shipbuilding process. In addition, probability and hazard values have been involved in the case of violated measures. The frequencies of the violations that occurred in the work environment are entered to the system by the user. Hence, the system provides a decision support about the risks related to facilities and the cautions to be taken in the workplace. The developed WBDSS has the capability of determining accident, almost accident, and threat formation factors at workplace according to the changing parameters. In this aspect, it enables one to constantly monitor, check and evaluate risk preventive measures. Then, the capabilities of the suggested decision support system have been tested with different scenarios for shipyard processes. When the developed WBDSS is applied to all workplaces, it is aimed at providing a decrease in the number of accidents which cause death, occupational illness, injury, and temporary incapability.

Key words: *Web based decision support system; Risk Management; Occupational safety and health; Accident prevention*

1. Introduction

Shipyard is considered as one of most risky working environment since a lot of workers have drastically injured or dead in the last decades in Turkey. Although shipyard industry can pose potential harm to human life, the popularity of industry has not been affected thanks to increased shipping activity in worldwide. There have been various hazardous processes undertaken in the shipyard such as manufacturing, pre-fabrication, mechanical workshop, blasting, painting, welding which may directly affect the human health and the environment. To complete these challenging processes, different types of comprehensive tasks are performed. These processes require utmost attention to prevent loss of life, injury as well as the environmental pollution [1]. Therefore, shipyard managers have been seeking alternative solutions to minimize potential hazards by addressing occupational accidents. There is a wide range of common accident causes such as heavy construction materials, flammable and explosive materials, toxic, dangerous gases, mobile machineries, fire, failure or incorrect using of equipment, high elevation, insufficient illumination, electric shock, poor ergonomics, improper working environment and inadequate personal protection clothing [2, 3]. Some fatal consequences including loss of life and injury might arise as a result of these accidents. The statistics show that hundreds of serious occupational accidents occur in shipyards annually and most of them result in death [4, 5].

In this context, preventing occupational accident is vital to enhance safety control level in operational aspect at shipyards. Particularly, a practical approach to predict risk exposure can be beneficial to shipyard managers and occupational health & safety experts to prevent occupational accident and loss of lives. To achieve this purpose, this paper proposes a web based decision support system (WDSS) to assess potential occupational risks at shipyard. In this research, proposed algorithm of WDSS is based on fuzzy rules and fuzzy inference system [6]. Thus, a smart practical tool can be developed to prevent occupational accidents in course of different types of processes.

In the view of that, the paper organized as follows: this section gives motivation behind the research. The next section provides a comprehensive literature review about occupational accident and risk assessment performed at shipyards. Then, section three introduces the methodology. The final section gives conclusions and contribution of the study to marine and shipyard industry.

2. Literature Review

Whilst preventing occupational accident at shipyards can pose a significant concern, it has been few studies in conjunction with occupational accidents in the literature. Most of the papers have remained in theory and could not be applicable in practice. Nevertheless, the limited research gives a point of view on the occupational accident mitigation at shipyard industry. For instance, there are some specific studies performed in the past to focus on occupational accident at shipyards [7- 9]. The studies underline potential root causes of occupational accidents and transform statistical information into useful information. Likewise, Krstev et al. [10] performed a comprehensive investigation about occupational accidents and mortality rate in US Coast Guard shipyard. The authors gathered a detailed database from the shipyard and statistically analysed to reach realistic outcomes. Furthermore, a similar study has been conducted to investigate and classify occupational accidents and causes in Turkish shipyards [2, 11]. The author analysed 115 work-related fatal accidents in Turkish shipyard occurred between 2000 and 2010 years. Necessary mitigation measures were recommended for the highest number of accidents observed at shipyards workshops. In addition, Shinoda et al. [12] investigated occupational accidents in Japanese shipyards and classified them according to the accident types, occurrence date, occurrence site etc. The authors constructed a database covering hazards, incidents, injuries, near-misses, etc. to analyse occupational accidents properly.

Although limited studies conducted upon occupational accidents analysis at shipyard industry, further studies related to risk assessment have been conducted. For instance, Celebi et al. [13] discussed potential risks of occupational safety and health in shipbuilding industry. In the paper, an extensive research was performed including entire processes being held in shipyard to ascertain critical hazards affecting shipyard workers. To validate outcomes, actual data was utilized. Since one of the substantial issues in risk assessment is to deal with uncertainty, there is a tendency to apply fuzzy logic in most of the papers [5, 14-18]. The authors benefit from fuzzy logic to handle vagueness of expert judgments and express in decision-making through risk analysis. Another risk based approach has recently been introduced to predict occupational risks in the shipbuilding industry [3]. In the paper, Multivariable Linear Regression (MVLR) and Genetic Algorithm (GA) methods have been integrated to evaluate occupational risk in the working place of shipyards by utilizing occupational accidents data.

In the view of literature review, it appears that there still exists a gap in occupational accident and risk analysis research at shipbuilding industry. Most of the studies are far from being applicable in the industry. To remedy this gap, this paper introduces a web based supporting system to evaluate potential occupational risks at shipyard.

3. Theoretical Framework of the WBDSS

In this section, theoretical framework of the WBDSS approach is introduced to perform an extensive risk analysis in shipyard industry. The WBDSS is developed based on the risk preventive model proposed by Acuner and Cebi [6]. It consists of four main phase: identification, analysis, response and monitor & review. Accordingly, the main phases of the proposed model are expressed as follows [6];

Phase 1. Identification: In this phase, a risk assessment team which consists of experts with different background on maritime is established. Then, operation is defined and potential hazards are determined at shipyards. At first, production process is divided into small work stations based on similarities of operations. Then, potential hazards arising from operations are identified. Then, relevant risks are determined. Each expert in risk assessment team has to review all information related to the operation in order to determine the risks.

Phase 2. Analysis: In this phase, determined risks are analyzed in order 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, risk likelihood (RL) and risk severity (RS), in order to determine risk magnitude (RM). The 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 the RM [19]. Since the risk assessment process includes uncertainties and subjectivities, it is essential to use fuzzy techniques to cope with the aforementioned limitations [20]. The following procedures are carried out.

Step 2.1. Determine likelihood: In this step, likelihoods of the determined risks, which represent the probabilities of accidents, are determined by risk assessment team. To accomplish this, risk assessment team uses FAHP technique. The 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 determining risks. In this study, the FAHP technique developed by Buckley in 1985 is used [21, 22]. Accordingly, a pairwise comparison matrix given by Eq. (1) is constructed by any expert.

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

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

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

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

Table 1. Linguistic scale for the weight matrix [22].

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:

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

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

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. Each expert presents own preferences on the parameter and then co-decision matrix is obtained by arithmetic mean method. The linguistic scale given in Table 2 is used to evaluation.

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)*

Step 2.3. Obtain the risk magnitude: In this step, fuzzy inference system proposed by Mamdani in 1977 [23] is used to obtain risk magnitude (*RM*) since it is an effective tool to cope with imprecise and vague information [20]. The steps of Mamdani Fuzzy Inference technique

are given in the following. The aggregated fuzzy numbers of *RL*, RS^H, *and F (frequency)* 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. On 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, and *F*) and output (*RM*). To illustrate if-then rule type, Eq. 5 is given.

$$R^k : IF\ RL\ is\ \mu^k_{RL},\ RS^H\ is\ \mu^k_{RSH}, F\ is\ \mu^k_F,\ THEN\ RM\ is\ \mu^k_{RM},\quad k = 1,2,..,K \tag{5}$$

where μ^k_{RL}, μ^k_{RSH}, μ^k_F and μ^k_{RM} presents membership value of *RL*, RS^H, *F*, *and RM*, respectively. By using max-min operation (Eq.6), the value of *RM* is obtained.

$$\mu^k_{RM}(y) : \vee^K_{k=1}\left(\mu^k_{RL}(x_1) \wedge \mu^k_{RSH}(x_2) \wedge \mu^k_F(x_3)\right) \tag{6}$$

where $y \in Y, x_1 \in X_1, x_2 \in X_2, and\ x_3 \in X_3$ represents universe of *RM*, *RL*, RS^H, and *F* 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 Eq. 7 is used.

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

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

Phase 3. Response: In this phase, risks are ranked from highest to lowest based on their risk magnitude. Then, the best control option is selected. Following steps are used during selection of control options.

i. Eliminate hazards at its source
ii. Replace source of hazard with a less dangerous source of hazard
iii. Take engineering controls on the source
iv. Take organizational administrative controls on the source
v. Use personal proactive equipment (PPE)

Phase 4. Monitor and Review: In this phase, selected control options are monitored and reviewed respectively.

4. Proposed Method: Web Based Decision Support System

To develop the structure of the WBDSS, the steps given in Section 3 are followed and the obtained data are added the knowledge base of the developed system. The WBDSS utilizes the fuzzy inference system proposed to obtain risk magnitude (RM), and then, based on the risk magnitude, the WBDSS proposes best control option to prevent potential risks.

4.1. Structure of the WBDSS

The basic structure of the WBDSS includes the user interface, a knowledge base, and an inference engine. The user interface provides an interaction among users, inference engine, and knowledge base. It consists of inputs and outputs menus. The function of the user interface is to present questions and outputs. The knowledge base includes data related probabilities and severities for each risk. The structure of the developed WBDSS is given in Figure 1. The Rule Base given in Figure 1 incudes the rules which define relations between inputs (including *RL*, RS^H, *F*) and output (*RM*). The structure of a rule is presented in a form of if-then rule as given in Eq. 5. Based on the inputs, 125 rules have been defined in the rule base in order to obtain risk magnitude.

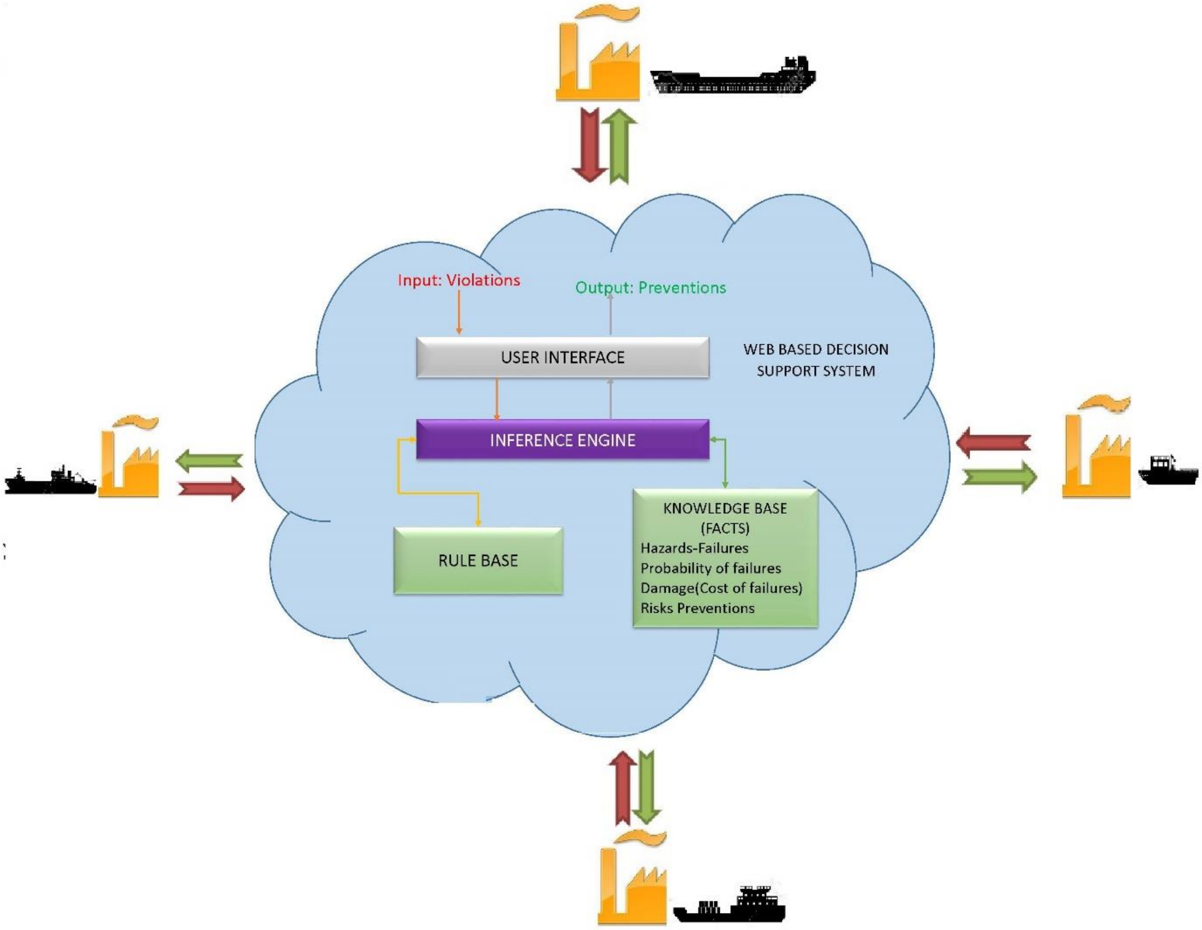

Fig. 1 Structure of the proposed WBDSS.

4.2. Components of the WBDSS

Mainly the system is divided into two parts. One of them is administrator side and the other one is user side. The proposed system is implemented by using web programming language PHP (Personal Home Page) and MySQL Server is used as database. In order to avoid dependency on a single computer, a web programming language is used. Administrator or user can access the system wherever he/she needs. The flow diagram of the system is illustrated in Figure 2.

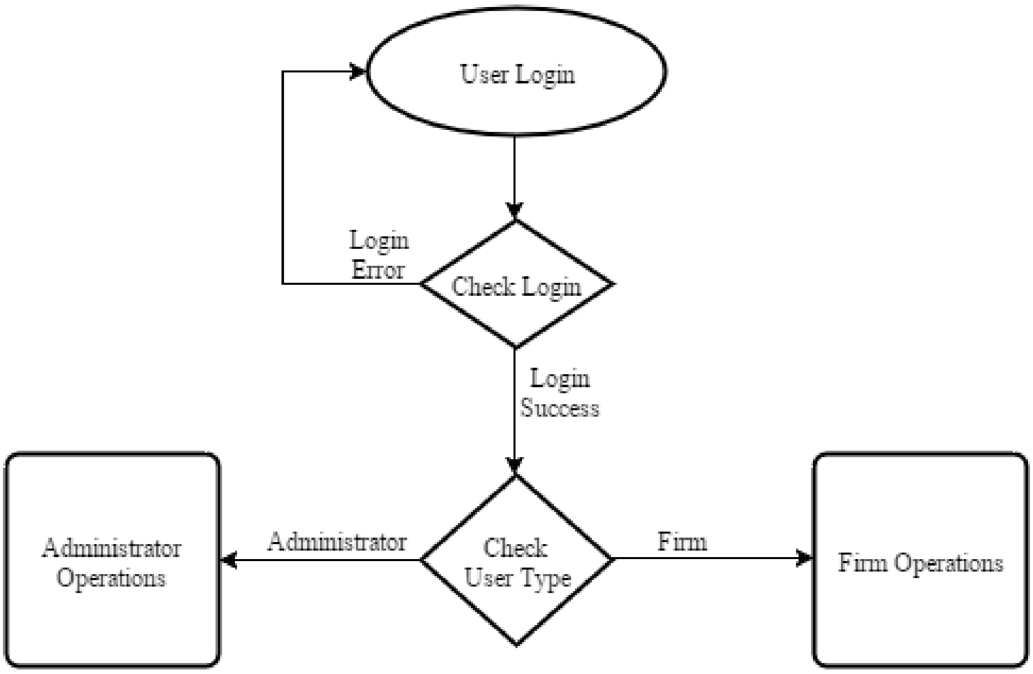

Fig. 2 Flow diagram of the system

4.2.1. Administrator Side

Administrator side of the system is only accessible to system administrators. System checks the login information and decide that the information belong to administrator or any other user. If information belong to administrator system redirect to administrator side else redirect to user side. In administrator side, administrator of the system makes some definitions on the purpose of use. These definitions are as follows: adding firm, adding user, adding sector, adding operation, adding environment, adding activity, adding equipment, adding risk and adding question. With all these menus create information that will be used on user side. Information must be given step by step to system. Because menus are connected to each other. For example, to add any activity, the environment that activity belongs to must be defined before. The system can think as a tree. The website of proposed system's administrator side starts with adding sector. After adding sector, administrator adds operations that can be done under defined sector. In this way all required information define and store on database.

The other function of administrator side is adding firm. If any firm wants to be member of this system, does membership application by using website of proposed system. After this firm registration information add to system and user login details send to firm as e-mail. With sent information firm can login to system's user side.

Last function of administrator side is adding user. In administrator side there may be users more than one. Because control of the system grows more difficult. The users added in administrator side only see the administrator side.

Administrator flow schema like this:

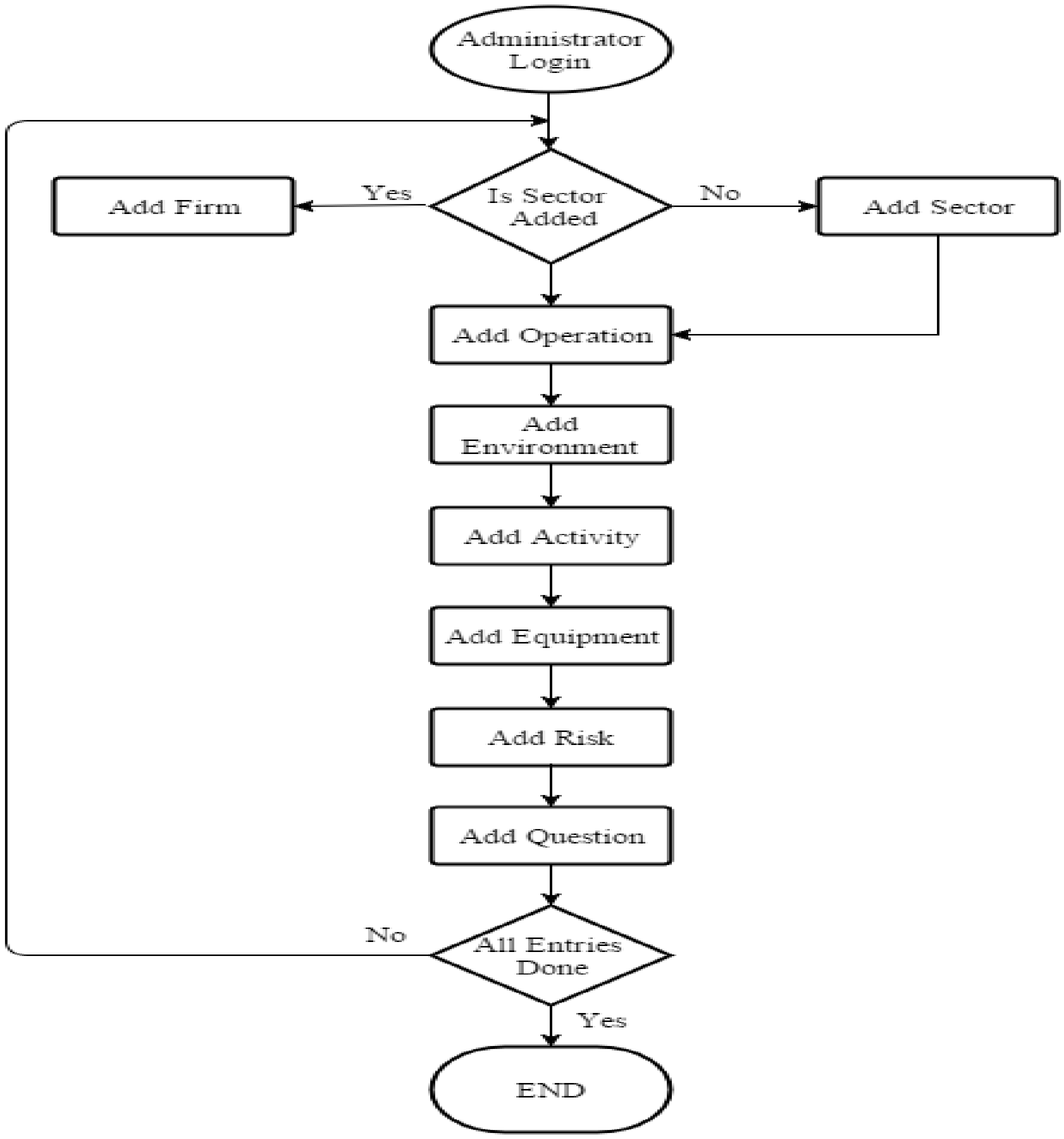

Fig. 3 Flow schema of administrator side.

4.2.2. User Side

As mentioned, the system introduces two main parts. The second part of the system is user side. In this side, registered firms have authorized user(s) to register new users for risk assessment team. Every authorized user has different authority in user side of the system.

Firm's Authorized User: After firms request to be member by using new user button on login page, administrator registers the firm and firm's login information like user name and password, and then, system send an e-mail to firm's mail address including membership info. Firms authorized user logins system with these information. This user makes definitions and confirmation on risk reports of his/her own firm. Definitions can be divided into two main categories such as *Risk Assessment Team of Data Entry* and *Part or Section Information Data Entry*:

Risk Assessment Team of Data Entry: The main purpose of the system is to prepare a report on risk analysis. And this report has to be confirmed by some experts in firm. These experts define something using this menu. In this menu contains five different user type.

1. Define Occupational Safety Specialist: This user has a primary responsibility for risk analysis report.

2. Define Occupational Physician: This user is also important for forming a risk report.

3. Define Occupational Safety Consultant: Firms may have a consultant other than its own occupational safety specialist.

4. Define Support Member: Support member is one of the firm's own employees and helps report creation.

5. Define Employee or Employee Representative: Employee or employee representative also joins the report process. And he/she is one of the approving person for the risk report created by occupational safety specialist.

Part or Section Information Data Entry: Firm's authorized user also has authorization that define part or section. Workplace can be divided to more than one part and all parts have different processes. These parts must be defined because there may have different equipment used for the process. Under this menu authorized users have two defining menu.

1. Define Part or Section: In this menu, authorized user defines parts or sections for different processes. And for all parts responsible persons defined in the risk assessment team are assigned. After creating parts and assigning responsible person, authorized user can add equipment defined before by system administrator from the administrator side of the system for this part.

2. Add or Remove Equipment from Defined Sections: Authorized user may not add equipment to the defined part or they may need to change the equipment or remove it.

Report Transactions: Authorized user in this menu can see all reports for all sections. This menu is divided into two: (i) *confirmed reports:* here authorized user can list the reports confirmed before, (ii) *pending reports:* here authorized user can list the reports that are not confirmed yet. When a pending report is confirmed, it will be seen on confirmed reports.

Firm's Occupational Safety Specialist User: Occupational safety specialist user has main responsibility with risk report for the related section. This user can see two menus after login

1. Add or Remove Equipment from Section: Defined sections may be required to add or remove equipment. With this menu, occupational safety specialist user can add or remove equipment from the sections that she/he is responsible for.

2. Calculate Risk and Prepare Risk Report: The system's main purpose is to calculate risks and prepare risk report for each section. Occupational safety specialist user lists the sections that she/he is responsible for and select one by one. For all sections, user prepares risk report. Firstly, user selects section, and then system calls the check lists which is prepared for the related section. Step by step, system asks the questions belong to risky factors of the section. User chooses yes or no answer defined before which activates the question for each question. At the end, user checks the risk report including risky factors, risk magnitude, suggested preventions, and then, assign workers for responsible for preventions that must to be taken. For example, section A is defined and in this section there are two equipment, (i) painting and (ii) electric arc welding. The equipment painting has five risks, (i) uninformed employee causes accident have three questions, (ii) poisoning caused by chemicals used have twelve questions, (iii) caused by the chemicals used in fire or explosion injuries have nine questions, (iv) paint activity during the process of injuries resulting from falling have four questions. The equipment electric arc welding has five risks, (i) burr splash / Vision Loss Due to UV rays have one question, (ii) serious injury or death from electrocution have nine questions, (iii) injury due to fire during the operation have three questions, (iv) respiratory irritation or poisoning due to fumes from

welding operations have three questions, (v) injury due to welding in a confined space has four questions. After answering all of these questions, user obtains a list of activated questions. The list contains the information such as, equipment as a source of danger, definition of each risk, probability value, severity value, frequency, magnitude value of each risk and preventions to be taken. The last two columns include deadline that preventions to be and specialists who apply the determined preventions. Finally, occupational specialist creates and saves the report. The save report is automatically confirmed by occupational safety specialist user.

Other Users: System's other defined users, occupational physician, support member, employee or employee representative, also have authority over registered report. These users list the reports about related sections and confirm.

5. Application

In this section, a comprehensive risk analysis is performed by using WBDSS. After registering to the WBDSS, the main page of the system appears. To illustrate the system, Figure 4 shows main page of WBDSS.

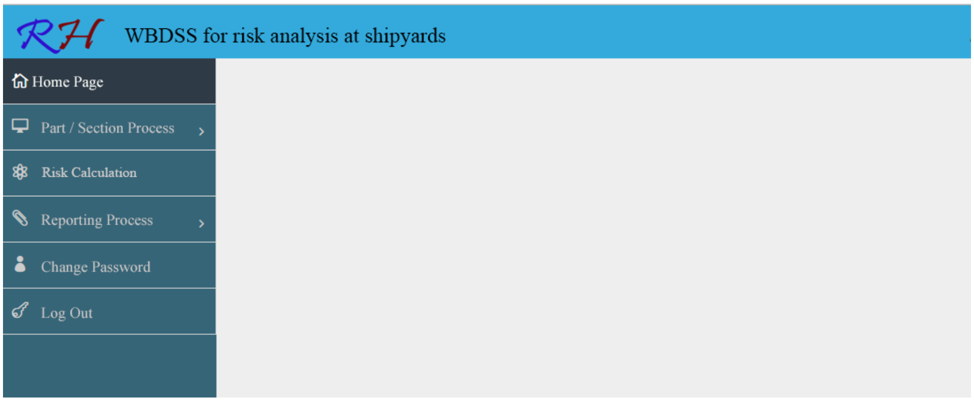

Fig. 4 Main page of WBDSS.

As shown in the figure, a column includes alternatives such as part/section process, risk calculation, reporting process, changing password and logging off. Before performing risk analysis, the environment, operation and activity must be defined. To achieve this purpose, the first step is to select part/section process which is illustrated in Figure 5.

There are two main parts appeared on the screen. A user must select the first row to identify part/section, operation and the environment. In this application, potential risks which have been identified for panting activity at open yard under ship environment were analyzed for risk assessment. Accordingly, Figure 6 shows user interface where open yard, ship maintenance and ship environment were selected by the user. In the user interface, the system presents various activities such as painting, electric arc welding, lifting and handling, welding, cutting and working at high. In this application, painting is selected as an activity to perform a risk analysis.

After saving the operation, environment and activity in the WBDSS, the risk calculation is exercised by selecting "calculating risk" section on the main screen. Figure 7 provides relevant user interface screen shot. Once the process is initiated, identified part/section appears on the screen. In this application, open yard, illustrated in Figure 7, was selected by the user. Thereafter, potential risks which were identified for painting activity at open yard under ship environment presented by the WBDSS.

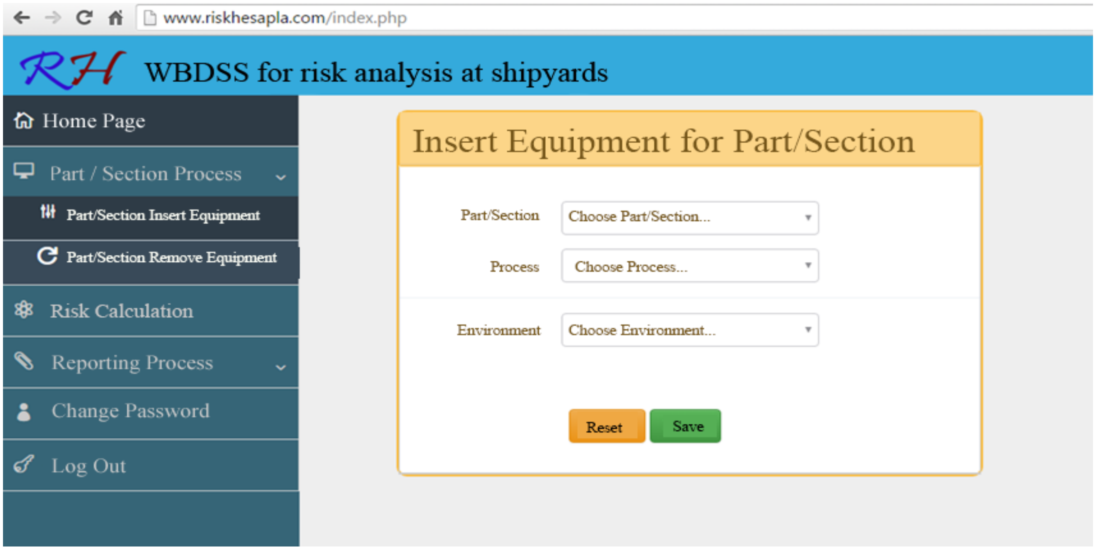

Fig. 5 User interface: selecting part/section process.

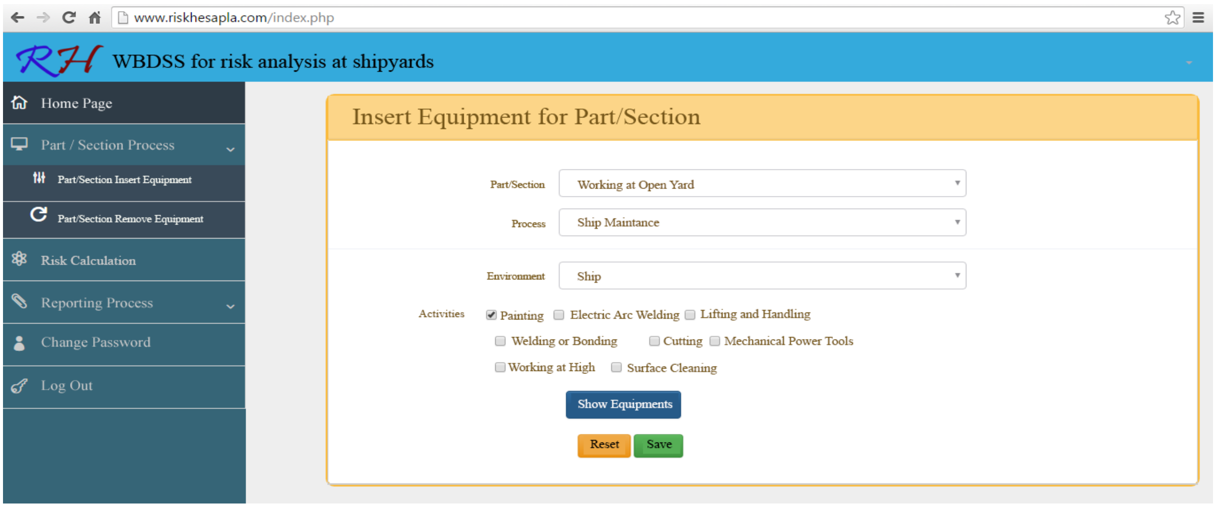

Fig. 6 User interface: selecting operation, activity and environment.

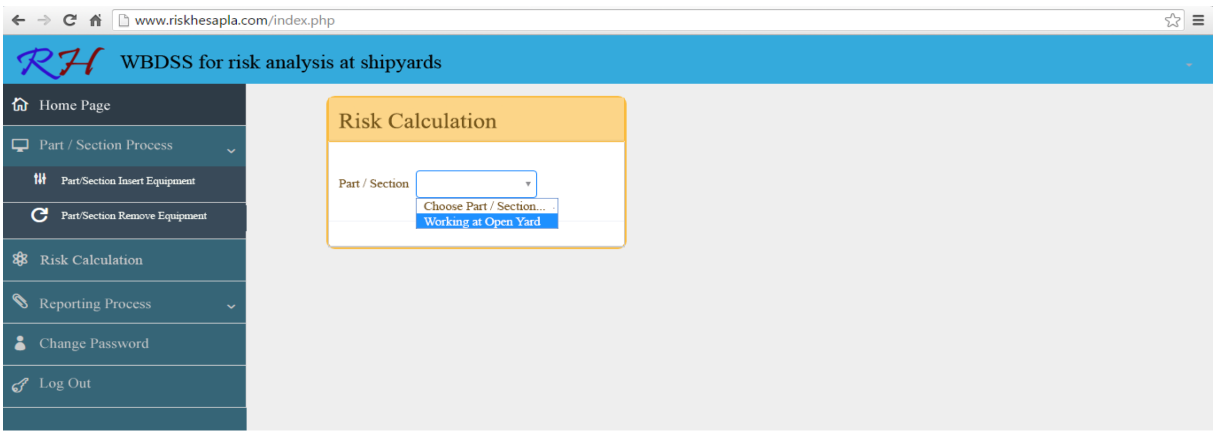

Fig. 7 User interface: risk calculation

The user answers yes/no questions in accordance with the environment. If the answer is negative, then the frequency section appears just right on the answer. Figure 8 shows user interface screenshot accordingly.

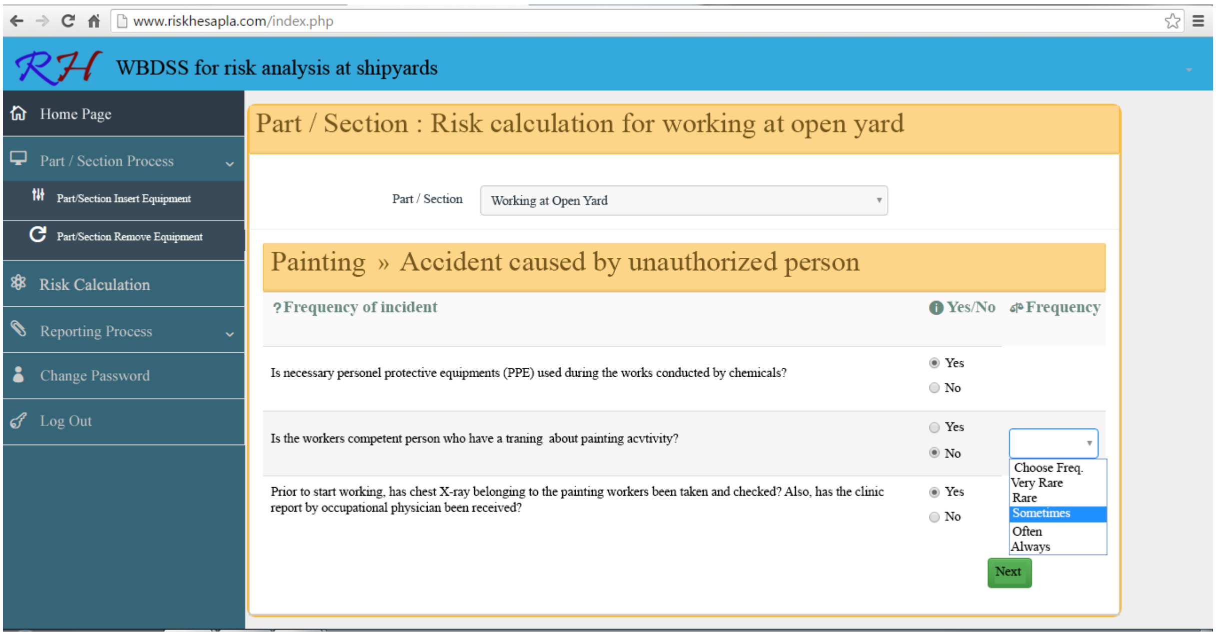

Fig. 8 User interface: answering question and frequency

Each question defined under different potential risks is answered and frequency is selected in case the answer is negative. Once the page is completed, system allows user to pass on to the next pages. After completing the questions, the WBDSS calculates the risk and presents a detailed result which is illustrated in Figure 9.

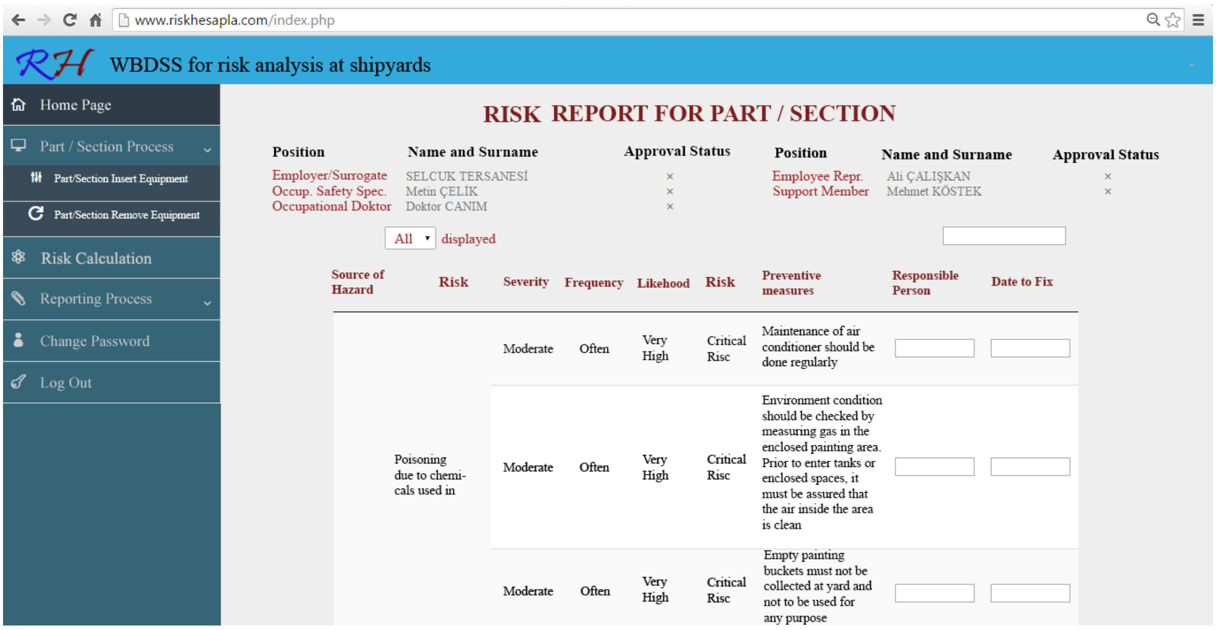

Fig. 9 User interface: risk analysis report.

As illustrated in Figure 9, the WBDSS calculates risk level along with extended findings which include severity, frequency and likelihood of hazards during painting activity at open yard. In case the level of risk associated with the hazards is higher than acceptable level, a set of preventive measures are recommended by the WBDSS.

6. Conclusion

In the scope of the proposed paper a web based decision support system (WBDSS) has been developed in order to analyse and prevent risk at shipyards. Shipyards that have chronically work accident problems are chosen as application fields for the study. The theoretical structure of the proposed system is based on the risk assessment method proposed by Acuner and Cebi [6]. In the first phase of the study, the possible threat sources are determined based on the used technologies and working area at the shipyard by detailing of work processes. In the second phase, the risks arising from threat sources are defined and analysed. As it is hard to define likelihood and severity definitions of the determined risks precisely, fuzzy logic based model is used. In the third phase, a decision support system is constructed based on the theoretically developed model. By ensuring accordance with laws and regulations of decision support system's user interface and database including critical processes like new building, transformation, maintenance-repair, it is aimed at planning to design a suitable environment for whole shipyard organizations. The developed decision support system is capable of determining accident, almost accident, and threat formation factors at shipyards according to changing parameters. In this aspect, it is one to constantly monitor, check and evaluate risk preventive measures. Then, the capabilities of the proposed WBDSS are tested with different scenarios for shipyard processes.

By application of the developed decision support system at industry, it is objected to provide a decrease in the number of accidents which cause death, occupational illness, injury and temporary incapability. In this regard, the study supports current efforts on improving occupational health and safety in our country. Viewed from this angle, life quality of workers improves and production loss is prevented by decreasing the number of accidents. By this means, business performance increases and directly/indirectly costs drop. This also improves competitiveness of the shipyards in the global market. In general, preventing work accidents in industrial organizations improves the reputation and competitiveness of a country at national and international level.

Acknowledgements

This study was supported by a grant from Republic of Turkey Ministry of Science, Industry and Technology with the project number 0025.TGSD.2015

REFERENCES

[1] Akyuz, E. 2015. Quantification of human error probability towards the gas inerting process on-board crude oil tanker ships. Safety Science 80: 77 – 86. http://dx.doi.org/10.1016/j.ssci.2015.07.018.

[2] Barlas, B., 2012. Shipyard fatalities in Turkey. Safety Science 50: 1247 – 1252. http://dx.doi.org/10.1016/j.ssci.2011.12.037.

[3] Tsoukalas, V.D. and Fragiadakis, N.G. 2016. Prediction of occupational risk in the shipbuilding industry using multivariable linear regression and genetic algorithm analysis. Safety Science 83: 12 – 22. http://dx.doi.org/10.1016/j.ssci.2015.11.010.

[4] ILO, 2011. Safety and health at work. < http://www.ilo.org/global/topics/safety-and-health-at-work/lang–en/index.htm > (accessed 7.02.11).

[5] Ozkok, M., 2015. Risk evaluation of pin jing work unit in shipbuilding by using fuzzy AHP method. Brodogradnja/Shipbilding, Vol. 66, Number 1: 39 -53.

[6] Acuner, O., and Cebi, S., 2016. An Effective Risk-Preventive Model Proposal for Occupational Accidents at Shipyards, BRODOGRADNJA, 67(1), 67-84.

[7] Baginsky, E., 1976. Occupational illness and accidents reported from California shipyards. Environmental Research 11: 271 – 279. http://dx.doi.org/10.1016/0013-9351(76)90086-4.

[8] Petronio, F., 1984. Severity rate of work accidents in a shipyard. Igiene Moderna 81: 539 –551.

[9] Saari, J. and Naesaenen, M., 1989. The effect of positive feedback on industrial housekeeping and accidents: A long-term study at a shipyard. International Journal of Industry Ergonomics 4: 201 – 211. http://dx.doi.org/10.1016/0169-8141(89)90003-6.

[10] Krstev, S., Stewart, P., Rusiecki, J., Blair, A., 2007. Mortality among shipyard Coast Guard workers: a retrospective cohort study. Occupational and Environmental Medicine 64: 651 -658. http://dx.doi.org/10.1136/oem.2006.029652.

[11] Barlas, B., 2011. Work Accidents in Turkish Shipbuilding Industry and Precautions to be Taken. The Chamber of Turkish Naval Architects and Marine Engineers Publications, Istanbul.

[12] Shinoda, T., Tanaka, T., and Kano, Y. Risk analysis for occupational safety management in shipyard, Proceedings of the Twentieth International Offshore and Polar Engineering Conference, Beijing, China, June 20-25, pages:. 581 - 588, 2010.

[13] Celebi, U.B., Ekinci, S., Alarcin, F., and Unsalan, D. The risk of occupational safety and health in shipbuilding industry in Turkey, Proceedings of the 3rd Int. Conference Maritime and Naval Science and Engineering, pages: 178 - 185, 2010.

[14] Akyuz, E., 2016. Quantitative human error assessment during abandon ship procedures in maritime transportation. Ocean Engineering 120: 21-29. http://dx.doi.org/10.1016/j.oceaneng.2016.05.017.

[15] Akyuz, E., Akgun, I., Celik, M., 2016. A fuzzy failure mode and effects approach to analyse concentrated inspection campaigns on board ships. Maritime Policy & Management. http://dx.doi.org/10.1080/03088839.2016.1173737.

[16] Lavasani, S.M., Ramzali, N., Sabzalipour, F., Akyuz, E., 2015. Utilisation of Fuzzy Fault Tree Analysis (FFTA) for quantified risk analysis of leakage in abandoned oil and natural-gas wells. Ocean Engineering 108: 729 – 737. http://dx.doi.org/10.1016/j.oceaneng.2015.09.008.

[17] Abou, S. C. 2012. Fuzzy-logic-based network for complex systems risk assessment: Application to ship performance analysis. Accident Analysis & Prevention 45: 305-316. http://dx.doi.org/10.1016/j.aap.2011.07.017.

[18] Fragiadakis, N.G., Tsoukalas, V.D., Papazoglou, V.J., 2014. An adaptive neuro-fuzzy inference system (anfis) model for assessing occupational risk in the shipbuilding industry. Safety Science 63: 226 – 235. http://dx.doi.org/10.1016/j.ssci.2013.11.013.

[19] Pluess, D.N., Groso, A., Meyer, T. 2013. Expert Judgements in Risk Analysis: A Strategy to Overcome Uncertainties", Chemical Engineering Transactions, 31, 307-312.

[20] Zeng, J., An, M., Smith, N., J.: 2007. Application of a Fuzzy Based Decision Making Methodology to Construction Project Risk Assessment, International Journal of Project Management, 25, 589–600. http://dx.doi.org/10.1016/j.ijproman.2007.02.006.

[21] Chen, S., J. and Hwang, C., L.: 1992. Fuzzy Multi Attribute Decision Making: Methods and Applications, Springer-Verlag, New York, http://dx.doi.org/10.1007/978-3-642-46768-4.

[22] Hsieh, T., Y., Lu, S., T. and Tzeng, G., T., 2004. Fuzzy MCDM Approach for Planning and Design Tenders Selection in Public Office Buildings, International Journal of Project Management, Vol. 22, pp. 573–584.

[23] Mamdani, E. H., 1977. Applications of Fuzzy Set Theory to Control Systems: A Survey. in Fuzzy Automata and Decision Processes, M. M. Gupta, G. N. Saridis and B. R. Gaines, eds., North-Holland, New York, pp. 1-13.

Submitted: 16.08.2016.
Accepted: 05.10.2016.

Selcuk Cebi, scebi@yildiz.edu.tr
Department of Industrial Engineering, Yildiz Technical University, Besiktas Istanbul, Turkey
Emre Akyuz
Department of Maritime Management, Bursa Technical University, Osmangazi, Bursa, Turkey
Yasin Sahin
Department of Computer Technologies, Torul Vocational School, Gumuşhane University, Gumuşhane, Turkey