UDC 331.46:629.5.081

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# Occupational Fatalities in Shipyards: an Analysis in Turkey

Professional paper

This study investigates the Turkish shipyard fatalities for a span of 10 years between January 2000 and July 2011 by applying the Analytic Hierarchy Process (AHP) technique. Detailed survey was conducted at Turkish shipyards located in Tuzla, Istanbul region. It was carried out by analysing a workplace questionnaire appropriate for the AHP technique. The purpose of this questionnaire was to determine the order of importance for precautions to be taken. Classification of fatal occupational accidents revealed five major fatality reasons for shipyards; namely, falling from higher elevation, exposure to electric shock, fire and/or explosion, being struck by or struck against objects, and being caught in between. Five precautions were determined for each fatal accident group.

**Keywords:** *occupational accident, fatality, AHP technique, shipyard, prevention*

## Nesreće na radu sa smrtnom posljedicom u brodogradilištima: analiza u Turskoj

Stručni rad

Ovaj rad istražuje nesreće na radu sa smrtnom posljedicom u turskim brodogradilištima u razdoblju od 10 godina, od siječnja 2000. godine do srpnja 2011. godine, i to koristeći *Analytic Hierarchy Process* (AHP) tehniku. Detaljno istraživanje je provedeno u turskim brodogradilištima smještenim u Tuzli, u području Istanbula. Izvedeno je na način da je analiziran upitnik o radnom mjestu koji je prikladan za AHP tehniku. Svrha ovog upitnika je da se odredi redoslijed važnosti mjera sprečavanja koje treba provesti. Razredba nesreća na radu sa smrtnom posljedicom razotkrila je pet glavnih uzroka ovakvih nesreća u brodogradilištima; naime, to su padovi s većih visina, izloženost udarima električne struje, požar i/ili eksplozije, udarci od strane objekata ili udari u njih, te uklještenje između objekata. Za svaku skupinu ovakvih nesreća sa smrtnom posljedicom definirano je po pet mjera sprečavanja istih.

**Ključne riječi:** *nesreća na radu, nesreća sa smrtnom posljedicom, AHP tehnika, brodogradilište, mjere sprečavanja*

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**Received (Primljeno):** 2011-09-29
**Accepted (Prihvaćeno):** 2011-10-24
**Open for discussion (Otvoreno za raspravu):** 2013-03-31

## 1 Introduction

Shipbuilding is an extremely complex business, which means quite complicated tasks have to be performed in parallel. In addition, sufficient space must be provided for the storage of massive amounts of material and equipment. The handling and processing of steel through the production processes requires a great amount of facilities and space in a shipyard. After the steel plates and profiles have been received, inspected and stored, they must also be blasted, primed, cut to shape, formed to the proper design, and welded to make assemblies. The assembly procedure is made up of panel fabrication, block assembly, pre-outfitting, grand assembly, pipe routing, air conditioning, electrical cable fitting, surface preparation and coatings. Besides, the time between order and delivery must be strict and in time, so the above-mentioned tasks should be performed in a smooth manner. Besides, in Turkish shipyards, some parts of the work are being subcontracted on almost all projects. Therefore, the workers at each shipyard come from several different companies, which makes the organization and integration problems more complicated, and if these resulting problems cannot be solved, the safety of work and health may be affected negatively.

Carelessness of the workers, insufficient safety training and education, unawareness of costs of accidents, erroneous series of human operations, and inadequate work site environment remain the key risk factors for occupational accidents. The occupational accidents are followed by costs; namely, injury, fatality, material and/or environmental damages. Common causes of occupational accidents are high elevation, toxic, flammable and explosive materials, fire, moving machinery, dangerous gases, work on/close to haphazard established heavy structures, misuse or failure of equipment, poor ergonomics, untidiness, poor illumination, exposure to general hazards including electricity, and inadequate protective clothing. Fatality rate refers to the number of occupational fatal accidents per 100,000 workers. The fatality rate in Turkish shipbuilding industry has been compared with all other industry groups in Turkey, and it has been found unacceptably high.

In Turkey, some studies on the statistics of occupational accidents related to shipbuilding industry have been reported by the Port and Shipyard Workers Union of Turkey [1], the Chamber of Turkish Naval Architects and Marine Engineers [2] and the Turkish Presidency the State Supervisory Board [3]. However, all these studies were hindered by information bias, the scope of data, and lack of comparability. Some other researchers have focused on the risk of occupational safety and health in shipbuilding industry [4, 5]. Internationally, there have been studies on shipyard health problems and occupational accidents in other shipyards [6 — 13]. There are some additional studies as outlined in Barlas [14,15].

From January 2000 to July 2011, shipyard activities resulted in the death of 117 workers. The highest rates of accidents were found among welders, blasters, painters and substructure workers. The aim of this work is to analyze the fatal occupational accidents in Turkish shipbuilding industry by using the Analytic Hierarchy Process (AHP) technique and propose precautions for them. Classification of fatal occupational accidents in shipyards revealed five major fatality reasons; namely, falling from a higher elevation to a lower level, exposure to electric shock, fire and/or explosion, being struck by or struck against objects, and being caught in between. Five precautions were determined for each fatal accident group to perform a survey suitable for AHP technique. The purpose of this survey is to determine the order of importance for precautions to be taken.

## 2 Materials and methods

The use of multi-criteria quantitative evaluation methods influencing the evaluation results associated with the criteria weights for solving social problems has grown considerably. Several theoretical and practical methods of determining the weight of criteria are known, pairwise comparison of criteria is widely applied, and mathematically established technique is the AHP. The AHP is a structured technique for analysing complex decisions in a scenario affected by multiple independent factors. It has particular application in group decision making. In the analysis, the group decision-making problem is divided into several sub level problems that are organized according to hierarchical levels. Each level has a set of criteria related to each sub level problem. The AHP technique gives the suitable decision that best suits the goals and evaluates alternative solutions. The AHP technique was first introduced by Myers and Alpert [16], then developed by Saaty [17,18] as a useful model and it has been accepted as a robust and widely applied multicriteria decision-making tool to deal with complex decision problems. The AHP has been used by several researchers as outlined in Bottero et al. [19] and Podvezko [20]. The main advantage of the AHP is its ability to rank choices in the order of their effectiveness in meeting differing objectives. If the judgments are made about the relative importance of the objectives, then the AHP technique guides inevitably to the logical consequence of those judgments [21]. In brief, the AHP is a useful technique for discriminating between competing options taking a range of objectives to be met into consideration. The theory and mathematics behind the AHP method is given in the Appendix.

In Turkey, most of the shipyards are located in Tuzla, Istanbul region; other areas are Yalova, and Eregli regions. There is 1.3 million m$^2$ total amount of shipbuilding area for 53 shipyards and yacht manufacturers in Tuzla, Istanbul region. From small sized to mid-sized chemical tankers, and container ships, up to 70,000 DWT bulk carriers, general cargo ships, tugs, ocean supply vessels and other types of ships are constructed at Turkish shipyards. As Tuzla, Istanbul shipbuilding region was established in the early 1980s with limited capacity, pre-manufactured blocks are constructed in other areas and then transported to the yards due to the lack of shipyard manufacturing areas. Following the shipbuilding boom in the period between 2005 and 2008, every space in the shipbuilding area has been utilized heavily under the time restraints of delivery schedules. Hence, the organization in the shipbuilding area is very complicated. The frequency of fatal accidents has also been affected by these heavy work schedules and organization. For the identification of the database about occupational accidents at shipyards, a study was conducted by analysing a workplace survey appropriate for the AHP technique.

## 3 Analysis and results

Because of the work force requirement under hard working conditions and the relatively high fatality count for the employment group, the production process in shipyards can be identified as dangerous work.

Providing a safer environment at Turkish shipyards remains an urgent and important issue to be addressed. Turkish shipyard workers suffer injury, disability, and death from occupational accidents. In the period between January 2000 and July 2011, 117 workers died from occupational accidents. The number of employed workers, number of fatalities, and fatality rates in Turkish shipyards are shown in Table 1. The data were obtained from the Undersecreteriat of Maritime Affairs of Turkey [22]. From 2004 to 2008, the number of fatalities rose dramatically from 6 to 29. The fatal cases resulting from shipyard site accidents peaked to 29 in 2008, coinciding with the shipbuilding boom, and then fell to 11 in 2010, which was during the recession in shipbuilding industry because of the global economic downturn, while the new-building orders shrank.

In Turkey, the data on the national statistics of occupational accidents related to all industry groups are being managed by the Social Security Institution [23]. The number of employed workers, number of fatalities, and fatality rates for all industry groups in Turkey between the years 2000 and 2009 are given in Table 2. The fatality rates for shipyards are also given in Table 2 for comparison.

Table 1 **Number of employed workers, fatalities, and fatality rates in Turkish shipyards occurring between January 2000 and July 2011 [22]**

Tablica 1 **Broj zaposlenih, broj nesreća sa smrtnom posljedicom i postotak njihove učestalosti u turskim brodogradilištima u razdoblju od siječnja 2000. do srpnja 2011. godine [22]**

| Years | Number of employed | Number of deaths | Fatality rate (1/100,000) |
|---|---|---|---|
| 2000 | 5250 | 5 | 95.2 |
| 2001 | 5750 | 1 | 17.4 |
| 2002 | 13,545 | 7 | 51.7 |
| 2003 | 14,150 | 6 | 42.4 |
| 2004 | 14,750 | 6 | 40.7 |
| 2005 | 24,200 | 13 | 53.7 |
| 2006 | 28,580 | 10 | 35.0 |
| 2007 | 33,000 | 12 | 36.4 |
| 2008 | 26,910 | 29 | 107.8 |
| 2009 | 19,179 | 15 | 78.2 |
| 2010 | 21,449 | 11 | 51.3 |
| 2011 July | 21,600 | 2 | 9.3 |
| | | Total=117 | Average=51.6 |

The average fatality rate between the years 2000 and 2009 in Turkish shipbuilding industry is 55.9, and during the same period, all other industry groups' average fatality rate in Turkey is 16.0. As a result, the shipyard fatality rate is 3.5 times higher than the average of all other industry groups in Turkey, which is unacceptably high.

Table 2 **Number of employed, fatalities, and fatality rates for all industry groups in Turkey between the years 2000 and 2009 [23]**
Tablica 2 **Broj zaposlenih, broj nesreća sa smrtnom posljedicom i postotak njihove učestalosti za sve industrijske grane u Turskoj u razdoblju od 2000. do 2009. godine [23]**

| Years | Number of employed | Number of deaths | Fatality rate general (1/100,000) | Fatality rate shipyard (1/100,000) |
|---|---|---|---|---|
| 2000 | 5,005,403 | 1173 | 23.4 | 95.2 |
| 2001 | 4,886,881 | 1008 | 20.6 | 17.4 |
| 2002 | 5,223,283 | 872 | 16.7 | 51.7 |
| 2003 | 5,615,238 | 810 | 14.4 | 42.4 |
| 2004 | 6,181,251 | 841 | 13.6 | 40.7 |
| 2005 | 6,918,605 | 1072 | 15.5 | 53.7 |
| 2006 | 7,818,642 | 1601 | 20.5 | 35.0 |
| 2007 | 8,505,390 | 1044 | 12.3 | 36.4 |
| 2008 | 8,802,989 | 866 | 9.8 | 107.8 |
| 2009 | 9,030,202 | 1171 | 13.0 | 78.2 |
| | | Total=10458 | Average = 16.0 | Average = 55.9 |

### 3.1 Causes of accidents and human error types

The causes of occupational accidents can be grouped under two main headings; personal factors that cause dangerous behaviours, and dangerous situations due to the environmental factors. Personal factors include inadequate knowledge, education and skills, insufficient training, lack of physical strength and reflex action, poor motivation, exposure to stressful life events, ignoring details and cutting corners, sociological, psychological and physiological problems. The negative effects of environmental factors are apparent in the form of occupational accidents. Environmental factors include high elevation, toxic, flammable and explosive materials, fire, moving machinery, dangerous gases, haphazard established structures, heavy structures, faulty machinery, poor ergonomics, being untidy, poorly illuminated areas, and improper labour standards. Classification of human errors is shown in Table 3. Other human error classification types can be found in Suzuki et al. [24] and Chiba et al. [25].

Table 3 **Classification of human errors**
Tablica 3 **Razredba pogrešaka - ljudski faktor**

| Error type | Definition |
|---|---|
| Learning gap error | Lack of skill, knowledge and education, insufficient training. |
| Memory and forgetting error | Unable to use knowledge, forgetting due to lack of concentration. |
| Carelessness error | Reaction time problems because of recklessness. |
| Inconsistency error | Inconsistent and incompatible performance. |
| Action error | Due to insufficient skills, application of incorrect actions. |
| Decision error | Due to wrong judgment, and inappropriate choice. |
| Inaccuracy error | Ignoring details, cut corners. |

### 3.2 Classification of fatal occupational accidents in Turkish shipyards

After an intensive study of fatal accidents between January 2000 and July 2011, the occupational accidents at Turkish shipyards can be classified in five major categories as shown in Table 4. The five major typical occupational accidents at shipyards in order of occurrence are falling from higher elevation, exposure to electric shock, fire and/or explosion, being struck by or struck against objects, and being caught in between (squeeze).

The most frequent types of tasks performed when fall accidents occurred were falling from the deck, from the scaffoldings during welding, blasting, and painting. During the shipbuilding process, various structures and scaffoldings are mounted, and various operations such as welding, cutting, blasting and painting carried out on the vessel. Wiggles and sometimes crashes, unprotected scaffoldings, use of inexpert personnel, unprotected deck, and workers without the necessary safety equipment increase the risk potential of these accidents.

Accidents caused by electric shock with high current and voltage are mainly fatal. During welding operation, perspiration from the body becomes conductive and the chance of electric shock because of contact with electrical current during the accidents is high. The following items raise the risk of electric shock accidents: exposed electrical distribution panels, absence of grounding systems, absence of leakage current relay systems, scattered cables, and inappropriately insulated cables.

Shipyards frequently encounter fires caused by flammable and explosive gases. LPG, LNG, oxygen, hydrogen, acetylene and other gases can cause these types of fires. Explosion occurs because of a buildup of gas when there is lack of proper ventilation in closed areas. During welding operation, oxygen and acetylene hoses for welding gas incontinence and improper lay up of flammable and combustible materials can cause explosion and fire. The tanks would need to be ventilated during entry.

The most frequent types of tasks when "struck" accidents occurred were struck by a motor vehicle, and falling materials, especially from cranes. On the scaffoldings while construction workers are working and trying to ship material, the pieces of material, equipment, or a variety of hand tools may fall. The most fundamental reason for the fatalities caused by falling materials is simply not wearing helmets. Accidents occur frequently in lifting and hoisting operations such as in the case of crane ropes and eyebolts rupture, lifting wire ropes break, and consequently wire strikes the workers.

The most frequent types of tasks when "squeeze" accidents occurred were pressing between hydraulic hatches and ship blocks, and for the hoisting crane accident risks, falling because of disconnection of load bearing elements of the crane wire. Ship blocks, ship plates and hatch covers can weigh hundreds of tons. Stocking and transport of material omissions and during the hatch cover assembly and repair carelessness can lead to very serious accidents. While transporting heavy equipment by vehicle or by crane, the worker may get jammed between parts of a structure or object.

Other risks are in closed chambers where drowning or poisoning may occur because of the insufficient ventilation. Additionally, if the worker cannot swim, there is a risk of drowning, if he falls into the sea.

Table 4 **Classification of fatal occupational accidents in Turkish shipyards occurring between the January 2000 and July 2011**

Tablica 4 **Razredba nesreća na radu sa smrtnom posljedicom u turskim brodogradilištima u razdoblju od siječnja 2000. do srpnja 2011. godine**

| Fatality reason | Number | % |
|---|---|---|
| Falling from a height | 46 | 39.3 |
| Exposure to electric shock | 18 | 15.4 |
| Fire and/or explosion | 18 | 15.4 |
| Being struck by or struck against objects | 15 | 12.8 |
| Caught in between (squeeze) | 9 | 7.7 |
| Other causes | 11 | 9.4 |
| Total | 117 | 100 |

### 3.3 Survey

The survey was carried out with the aim to prevent occupational accidents, and a number of workers, foremen, and engineers working for 10 years or more at Turkish shipyards located in Tuzla/Istanbul region were interviewed and surveyed. All of the 21 respondents were male and resided in Istanbul. The application of the AHP technique to the study case was performed using the SuperDecisions software. Five precautions were determined for each cause of a fatality reason (Table 5). The purpose of this survey was to determine the order of importance for precautions to be taken. The survey form (questionnaire) for "falling from a height" is given in Table 6. When filling out the survey, the respondents were asked to rate the relative importance of each item against the others in the precautions listed in each group given in Table 5. The screen shot of the questionnaire comparisons of SuperDecisions software for "falling from a height" is given in Figure 1. For each item, the left side is compared against the right side. If a number on the right side is selected, as in the first line, it weights more importance to the item on the right. On the other hand if the number on the left is selected, as in the third line, it weights more importance to the item on the left. Finally, if it is given unity, as in the ninth line, both items are equally important. The scale for judgments is shown in Table 7. After every questionnaire is entered in the comparison screen one can see the results of the pairwise comparison. Fatality reasons, precautions, and ranks of the considered alternatives according to the AHP technique given in Table 5 are arranged from the highest priority (rank 1) to the lowest priority (rank 5). For all the fatality reasons, the consistency index *CI* is less than 0.1, so no correction of judgments is needed (please see the Appendix for consistency index definition).

Figure 1 **The screen shot of the questionnaire comparisons of SuperDecisions software for "falling from a height"**

Slika 1 **Prikaz na ekranu usporedbe upitnika za slučaj uzroka nesreće „pad s većih visina" korištenjem programskog sustava *Super Decisions***

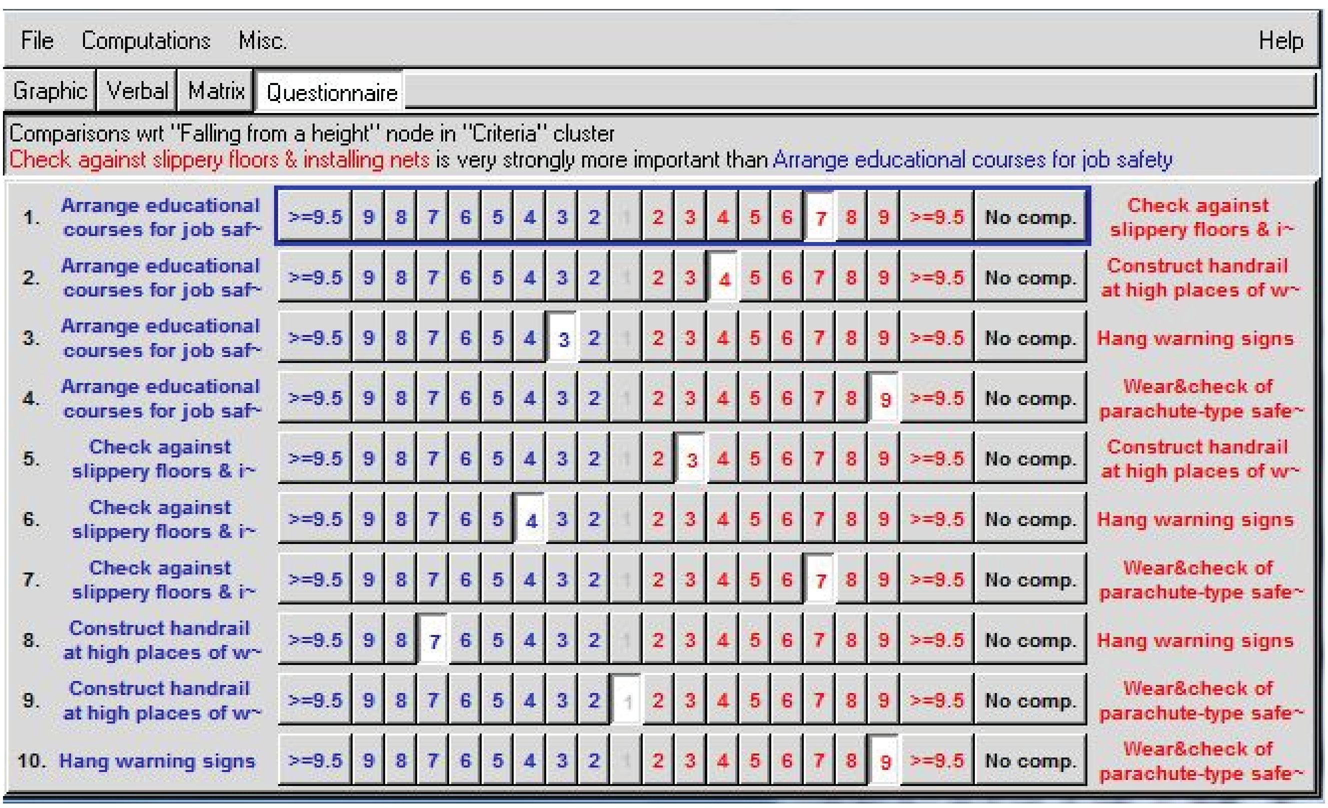

Table 5 **Fatality reasons, precautions and priorities of the considered alternatives**
Tablica 5 **Uzroci nesreća na radu sa smrtnom posljedicom, mjere sprečavanja i prioriteti razmotrenih alternativa**

| Fatality reason | Precautions | AHP | Rank |
|---|---|---|---|
| Falling from a height | Wear and check the parachute-type safety belts | 0.34 | 1 |
| | Construct handrail at high places of work | 0.29 | 2 |
| | Check against slippery floors, and installing nets where needed | 0.27 | 3 |
| | Arrange educational courses for job safety | 0.07 | 4 |
| | Hang warning signs | 0.03 | 5 |
| Electric shock | Use insulated boots and suitable work clothes | 0.31 | 1 |
| | Install electrical grounding systems and ground leakage relay | 0.30 | 2 |
| | Check cables regularly | 0.25 | 3 |
| | Arrange educational courses for job safety | 0.08 | 4 |
| | Hang warning signs | 0.06 | 5 |
| Fire and explosion | Gasfree regularly and strict control measures | 0.34 | 1 |
| | Produce hot action report where needed | 0.30 | 2 |
| | Make good ventilation | 0.25 | 3 |
| | Arrange educational courses for job safety | 0.06 | 4 |
| | Hang warning signs | 0.05 | 5 |
| Being struck by or struck against objects | Always work with a rigger | 0.27 | 1 |
| | Comply with operating rules of crane | 0.26 | 2 |
| | Use supporting materials as appropriate | 0.26 | 2 |
| | Arrange educational courses for job safety | 0.11 | 4 |
| | Hang warning signs | 0.10 | 5 |
| Caught in between (squeeze) | Make environment suitable for operation | 0.34 | 1 |
| | Install a voice warning system in shipyard | 0.24 | 2 |
| | Weld stopper for the steel sheets | 0.24 | 2 |
| | Arrange educational courses for job safety | 0.10 | 4 |
| | Hang warning signs | 0.08 | 5 |

Table 6 **The questionnaire for "falling from a height"**
Tablica 6 **Upitnik za uzrok nesreća „pad s većih visina“**

| **Precautions** | Most important ← | | | | | | | | Equal | | | | | | | | → Most important | **Precautions** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
| Arrange educational courses for job safety | | | | | | | | | | | | | | | | | | Hang warning signs |
| Arrange educational courses for job safety | | | | | | | | | | | | | | | | | | Construct handrail at high places of work |
| Arrange educational courses for job safety | | | | | | | | | | | | | | | | | | Wear and check the parachute-type safety belts |
| Arrange educational courses for job safety | | | | | | | | | | | | | | | | | | Check against slippery floors, and installing nets where needed |
| Hang warning signs | | | | | | | | | | | | | | | | | | Construct handrail at high places of work |
| Hang warning signs | | | | | | | | | | | | | | | | | | Wear and check the parachute-type safety belts |
| Hang warning signs | | | | | | | | | | | | | | | | | | Check against slippery floors, and installing nets where needed |
| Construct handrail at high places of work | | | | | | | | | | | | | | | | | | Wear and check the parachute-type safety belts |
| Construct handrail at high places of work | | | | | | | | | | | | | | | | | | Check against slippery floors, and installing nets where needed |
| Wear and check the parachute-type safety belts | | | | | | | | | | | | | | | | | | Check against slippery floors, and installing nets where needed |

Table 7 **The scale for judgments**
Tablica 7 **Mjerilo procjene**

| Scale | Judgments |
|---|---|
| 1 | Equal |
| 2 | Between Equal and Moderate |
| 3 | Moderate |
| 4 | Between Moderate and Strong |
| 5 | Strong |
| 6 | Between Strong and Very Strong |
| 7 | Very Strong |
| 8 | Between Very Strong and Extreme |
| 9 | Extreme |

In general, as defined in Table 3, the carelessness error, inaccuracy error and action error types dominate fatalities resulting from falling from a height. Three precautions for falling from a height are more important than others: wear and check the parachute-type safety belts ranks first place. In high working places, installation of handrails ranks as the second important precaution, and finally regular check against slippery floors, and installing nets where potentially hazardous open areas are ranked as third.

The learning gap error, memory and forgetting error, decision error, and inaccuracy error types generally result in fatalities in electric shock accidents. The precautions given the top ranking are grounding electrical systems and installing a ground leakage relay, and the use of insulated boots and suitable work clothes. Regular check of the cables is ranked third.

Memory and forgetting error and inaccuracy error types generally result in fatalities for fire and explosion accidents. Gasfree measures rank first, works involving high temperatures must be allowed only after a clearance check in the area, this point ranks as the second, and finally good ventilation is ranked third.

In general, the carelessness error, inconsistency error, and action error types result in fatalities in being struck by or struck against objects accidents. The precautions: comply with operating rules of crane, use supporting materials as appropriate, and always work with a rigger have the same rank.

The memory and forgetting error, carelessness error, and decision error types result in fatalities in caught in between accidents. The precaution: make environment suitable for operation ranks first, while the precautions: install a voice warning system in the shipyard, and weld stopper for the steel sheets both rank in second place.

For all the fatality reasons, the precautions ‘hang warning signs, and arrange educational courses for job safety’, which are more common precautions to be taken, were on the bottom row. Although the educational activity and hanging warning signs are considered as the priority precautions against accidents by the shipyards, the workers claimed opposite, as according to the survey these are the least important precautions of all.

## 4 Conclusions

This study was based on case investigation of 117 fatal occupational accidents in Turkish shipyards that occurred during the period between January 2000 and July 2011, and on the conducted workplace survey suitable for AHP technique. Fatal occupational accidents in Turkish shipyards are classified in five categories, and five precautions are determined for each category of fatal accident type. Employees’ active role is emphasized in the prevention of accidents, in detecting and correcting safety and health problems, ensuring a risk free work environment. However, ensuring a safe work environment often costs shipbuilding speed and money.

There are many methods of reducing risk of occupational accidents, including safety training, warning signs, control banding and safety barriers, suitable protective equipment and clothing, and safety guards. The basic rules of safety management system should be identified and applied to shipyards to control occupational accidents and reduce fatalities. Accidents should be decreased if complete safety awareness is formed. For prevention from accidents, making workers aware of the hazards of falling-off scaffoldings and decks is suggested. In order to reduce the rate of crane and forklift accidents, operators and riggers should be qualified and requalification should be required. To reduce the accidents, prevention programmes for fatal events require awareness of the hazards of falling-off decks, ladders, scaffoldings, and other places. The success of preventing occupational accidents depends on continuous implementation of actions and inspection. To increase safety awareness among workers, safety culture must be somehow gained. Strength of supervision and adjustment of safety management policy are needed to decrease the occurrence rate of fatal accidents. The questionnaire shows that the workers do not want to control the risks themselves, they want someone to check them. The workers want to be guided and supervised.

## Acknowledgements

This research was supported by the Scientific Research Foundation of Istanbul Technical University, the Chamber of Turkish Naval Architect and Marine Engineers, and Türk Loydu Foundation.

## Appendix

The mathematics of the AHP method is explained in numerous references [26, 27]. In the pairwise comparison method, alternatives are presented in pairs. The alternatives are given by $\{A_1, A_2, ..., A_n\}$, n is the number of compared alternatives, their current weights by $\{w_1, w_2, ..., w_n\}$, and the matrix of the ratios of all weights by,

$$W = \left[\frac{w_i}{w_j}\right] = \begin{bmatrix} w_1/w_1 & w_1/w_2 \ ... & w_1/w_n \\ w_2/w_1 & w_2/w_2 \ ... & w_2/w_n \\ ... & ... & ... \\ w_n/w_1 & w_n/w_2 \ ... & w_n/w_n \end{bmatrix}$$

The matrix of pairwise comparisons A = [aij] represents the intensities of the questionnaire respondent’s preference between individual pairs of alternatives ($A_i$ versus $A_j$ for all $i,j = 1,2,...,n$), chosen from a given scale (Table 7). Given n alternatives $\{A_1, A_2, ..., A_n\}$, the questionnaire respondent compares pairs of alternatives for all the possible pairs, and a comparison matrix $A$ is obtained, where the element $a_{ij}$ shows the preference weight of $A_i$ obtained by comparison $A_j$.

$$A = \left[a_{ij}\right] = \begin{bmatrix} 1 & a_{12} & \dots & a_{1j} & \dots & a_{1n} \\ 1/a_{12} & 1 & \dots & a_{2j} & \dots & a_{2n} \\ 1/a_{1j} & 1/a_{2j} & \dots & a_{ij} & \dots & a_{in} \\ 1/a_{1n} & 1/a_{2n} & \dots & 1/a_{in} & \dots & 1 \end{bmatrix}$$

If matrix $A$ is absolutely consistent, one may notice that $A = W$ and the principal eigenvalue is equal to $n$, i.e. $\lambda_{max} = n$. The relations between the weights and the judgments defined by $w_i/w_j = a_{ij}$ for $i,j = 1,2,...,n$. The weights are obtained using the eigenvector method. If $A$ is an $n$x$n$, nonnegative, primitive matrix, then one of its eigenvalues $\lambda_{max}$ is positive and greater than or equal to all other eigenvalues. There is a positive eigenvector $w$ corresponding to that eigenvalue:

$$A_W = \lambda_{max} w$$

where, $w$ is the weight vector. The eigenvector method for obtaining the weights in the AHP method yields a way of measuring the consistency of the questionnaire respondent's preferences arranged in the comparison matrix. If a pairwise comparison matrix is not consistent, two different situations may be considered; a contradictory matrix and a matrix neither totally consistent nor contradictory. The consistency index can be defined as

$$CI = \frac{\lambda_{\max} - n}{n - 1}$$

Small changes in $a_{ij}$ imply small changes in $\lambda_{max}$, with the difference between this and $n$ being a good measure of consistency. If the questionnaire respondent is completely consistent, then consistency index $CI = 0$. However, it is idealistic to require $CI = 0$. In practical applications, it should be less than 0.1. If the $CI$ is greater than 0.1, than a correction of judgments is needed.

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