Archives of Hygiene Sciences
Qom University of Medical Sciences

https://jhygiene.muq.ac.ir
10.34172/AHS.12.1.10.36
Vol. 12, No. 1, 2023, 7-11

Original Article

Safety Risk Assessment in the Tile Industry with a New Approach

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Abstract

Background & Aims: Despite the relative comfort and welfare today's modern technology has brought to humankind, it has also been the basis for the emergence of risks and threats. These risks and risk factors should be assessed and controlled using systematic risk assessment and management methods. Numerous techniques and methods have been developed to analyze risks, each of which has its own strengths and weaknesses. One of the system risk analysis techniques, which is among qualitative techniques and identifies and analyzes system risks inductively, is the functional hazard analysis (FuHA) technique. The present study aims to identify and control risks that occur due to technical defects or system dysfunctions and can lead to an unpleasant event, as occurred in an industrial unit in 2016.

Methods: In this cross-sectional analytical study, the functional risks of an industrial unit were analyzed using the FuHA technique. By implementing the FuHA technique in the investigated industrial unit, 17 functional defects were identified.

Results: In general, according to the level of severity of different consequences caused by the identified defects, 60 functional risks were identified, of which 7 cases (11.67%) were assessed as unacceptable, 17 cases (28.33%) as unfavorable, and 36 cases (60%) as acceptable but needing revision.

Conclusion: The results of this study showed that the FuHA technique had a favorable ability to identify and analyze system and subsystem functional risks, especially software subsystems.

Keywords: Safety, Risk, Risk assessment, Functional hazard analysis

Received: March 28, 2022, **Accepted**: April 13, 2022, **ePublished**: March 18, 2023

1. Introduction

Despite the relative comfort and welfare brought to humankind, today's modern technology and advancements have also been the basis for risks and threats having the potential to cause accidents and cause harm, injury, and damage to people's lives, property, equipment, environment, and other physical and intellectual assets. Therefore, human reason dictates that these risks and risk factors be controlled. In order to control the risks, they must be identified first and then prioritized according to their magnitude and probability of occurrence. The systematic process of identifying risks, determining their magnitude, and prioritizing them is called risk assessment. Risk assessment is one of the basic stages of the risk management program, which should be performed by experts and experienced people based on efficient methods and techniques so that its results can be used as an acceptable criterion to guide managers in decision-making regarding the allocation of financial resources and other facilities for safety and risk control, according to the cost-benefit analysis [1,2].

Numerous techniques and methods have been developed to analyze the risks, the number of which reaches more than one hundred, and are classified into three general categories: Quantitative techniques, semi-quantitative techniques, and qualitative techniques [3,4]. Among these techniques are quantitative risk assessment, Dow's fire and explosion index, failure mode and effects analysis (FMEA), hazard and operability study, fault tree analysis (FTA), and dozens of other techniques, which are selected according to the type of system under study and access to sufficient data, and are used for risk assessment [5,6]. Each of these techniques has its own strengths and weaknesses [7].

One of the system risk analysis techniques, which is among qualitative techniques and identifies and analyzes

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system risks inductively, is the functional hazard analysis (FuHA) technique. In inductive techniques, unlike deductive techniques, the analysis is from part to whole, which means that risk analysis starts from the system components and ends with the whole system [8].

The primary goal of the FuHA technique is to identify and control risks that occur due to technical defects or system dysfunctions and can lead to an unpleasant event [8,9].

FuHA is a powerful tool for identifying functional defects, system risks, and their effects [10] and is especially suitable for identifying and analyzing the risks of any system, including software and functional tasks, and is broadly used for analyzing the risks associated with the performance of systems and subsystems of aircraft, spacecraft, and satellite systems [10-12]. In this regard, in a research in 1998, Wilkinson and Kelly, while explaining the principles and process of implementing the FuHA technique, expressed the problems and difficulties of using this technique in analyzing the functional risks of integrated aircraft systems and suggested solutions to overcome these problems and difficulties [11]. In another research in 2010, Hai-feng proposed the FuHA technique based on a safety-critical application development environment model. The researcher used this model to form the functional structure and functional defect structure, integrated these two structures, and used it to identify the functional risks of safety-critical systems. As a case example, the researcher implemented the presented model on the computer signaling system in railway tracks; the results showed that the proposed model could increase the accuracy and completeness of the FuHA technique [13]. In another research in 2014, Khosravirad et al used the FuHA, FMEA, and bowtie analysis techniques to analyze the root causes of process accidents in natural gas pressure reduction stations and showed that the combined method used in this study could be suitable for identifying root causes and controlling process risks [14].

The FuHA technique can be implemented in all phases of the system life cycle. However, if it is used in the initial phases of system development, such as the initial design phase or the detailed design phase, its results will be more beneficial and will result in maximum benefits because the fewer changes needed to improve the system and its functions, the less cost imposed to the system. Another advantage of implementing the FuHA technique in the initial design phase is to identify the main event used in the FTA technique because when the main event is defined and specified, the fault tree can be designed for each fault condition or event related to the system [8,15].

The FuHA technique is a predictive technique that tries to discover and identify the effects of functional defects of system components [11]. The outputs of the implementation of this technique include functional risks, safety-critical functions, causative risk factors (defects, design errors, human errors, etc), system risks, and safety requirements to reduce risks [8,14].

The present study was conducted to assess the risks of a tile production industrial unit using the FuHA technique.

2. Methods

The present study is a cross-sectional descriptive study conducted in a tile production industrial unit. The required data and information were collected through observation, checking the list, creating a flow diagram of system and subsystem functions, and interviewing experts.

The general process of implementing the FuHA technique is shown in the flow diagram of Figure 1.

The system studied in this research is the roller furnace, which is used for baking and preparing tiles and consists of different parts and systems, such as the driving system, the combustion system, the pre-furnace section, the baking section, and other sections (Figure 2). Each of these systems includes a number of functional and software subsystems. Some of these subsystems include the furnace computer subsystem to adjust the speed of the furnace motor and the burner temperature, the manometer subsystem to adjust the air pressure entering the burner, the exhaust fan subsystem to suck air, the

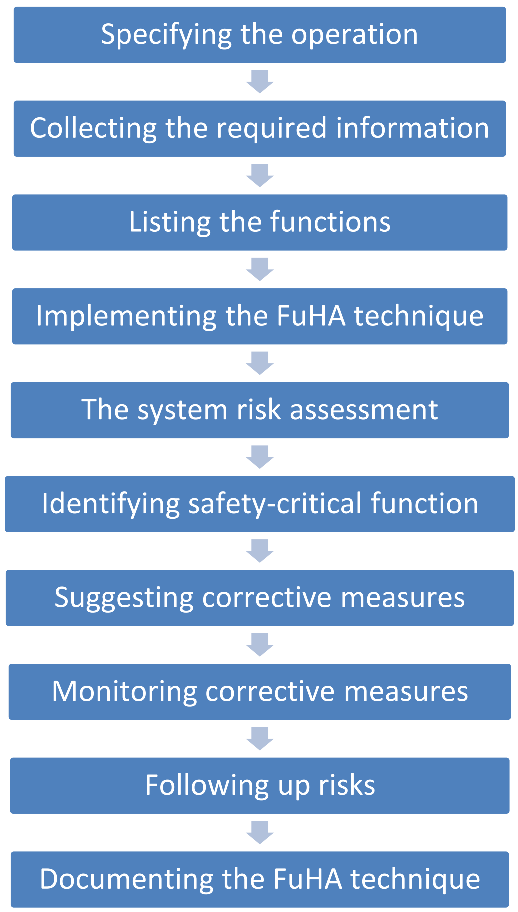

Figure 1. The flow diagram of the process of implementing the FuHA technique [8].

Figure 2. A view of the tile firing furnace in the studied process.

thermometer subsystem to measure the furnace internal temperature, and the servomotor subsystem along with the thermocouple to adjust the air in the rapid cooling section. Defective and wrong function at any time other than the appropriate time by any of these subsystems can lead to defects, breakdowns, and accidents in the furnace system. The FuHA process usually starts with preparing a list of functional operations of the system or subsystem, especially software systems, and then risks are identified based on defects or the possibility of defects in each of the mentioned functions [15]. In the next step, all the possible effects of the risk on the system and its components are determined based on the guide Table 1. After that, according to the records of past accidents and risks of the system and its subsystems and using the opinions of system experts, the probability of occurrence of the desired risk or accident is determined using the guide Table 2. Then, with the help of Table 3, the initial mishap risk index (IMRI) for each functional risk is calculated using the proposed standard method (MIL-STD-882E) and Equation 1. Finally, by using Table 4, the decision-making criterion on the risk level of each hazard is determined [16]. In order to control the identified risks, corrective solutions are proposed, and then the final mishap risk index (FMRI) is also calculated if corrective solutions are applied [8].

(Risk = Severity of accident occurrence × Probability of accident occurrence)

Risk = Probability × Severity Eq. (1)

3. Results

By implementing the FuHA technique in the furnace system of the investigated industrial unit, 17 functional defects were identified, and in general, according to the severity of the different consequences caused by the identified defects, 60 functional risks were identified, and IMRI and FMRI were determined for each one. Among these probable risks, the IMRI indices of 7 cases (0.12%) were assessed as unacceptable, 17 cases (0.28%) as

Table 1. Risk severity level

Definition	Category	Risk Type
System death or crash	1	Catastrophic
Injuries, occupational diseases, or damages to the system are severe	2	Critical
Injuries, occupational diseases, or damages to the system are small	3	Marginal
Injuries, occupational diseases, or damages to the system are very small	4	Negligible

Table 2. Risk probability level

Risk description	Risk level	Probability of occurrence
It happens frequently.	A	Frequent $X > 10^{-1}$
It occurs several times during the system life cycle.	B	Probable $10^{-2} < X < 10^{-1}$
It occurs from time to time during the system life cycle.	C	Occasional $10^{-3} < X < 10^{-2}$
The probability of its occurrence during the system life cycle is very low.	D	Remote $10^{-4} < X < 10^{-3}$
The probability of its occurrence during the system life cycle is zero.	E	Improbable $X < 10^{-4}$

Table 3. Risk assessment matrix

Probability of occurrence	Severity of risk			
	Catastrophic (1)	Critical (2)	Marginal (3)	Negligible (4)
Frequent (A)	1A	2A	3A	4A
Probable (B)	1B	2B	3B	4B
Occasional (C)	1C	2C	3C	4C
Remote (D)	1D	2D	3D	4D
Improbable (E)	1E	2E	3E	4E

unfavorable, and 36 cases (0.6%) as acceptable but needing revision. Among the identified risks, non-operation of the ventilation system of the furnace with the IMRI of 2B (unacceptable) was identified as the most critical risk in the studied system, which can lead to the poisoning of individuals and personnel due to inhalation of the gas exhausted from the furnace. Among the causative factors of this incident (the failure of the ventilation system) are the power cut, the fan's unintended operation, and the gas outlet channel breaking. On the other hand, the lack of flame and non-operation of the furnace with the IMRI of 4A were also identified as the functional defects with the least importance in the studied system. Power cuts, non-operation of the sparker, premature operation of the detector, failure and defect in the flame spreader, and breaking of the gas or air inlet pipe are considered the causative factors of this event.

Table 5 shows a part of the table of the results of implementing the FuHA technique in the investigated industrial unit.

4. Discussion

Out of the 60 functional risks identified in this study, the IMRI indices of 7 cases (11.67%) were assessed as unacceptable, 17 cases (28.33%) as unfavorable, and 36 cases (60%) as acceptable but needing revision. In order to reduce the IMRI of the identified risks, controlling solutions and measures were proposed, and the FMRI of each functional risk was also estimated. Some corrective suggestions and solutions include timely planning and implementation of preventive maintenance, purchasing higher quality parts, creating a container for the mechanical valve and manometer, calibrating the manometer, using gearbox motors instead of gear motors, and using rollers with a higher modulus of elasticity, which by applying and using these corrective measures, the risk index of all hazards will be reduced to a lower level. For example, the FMRI of non-operation of the ventilation system improves from 2B to 2C after implementing measures such as the implementation of inspection and regular maintenance programs and the use of good quality parts, or the risk of breaking the furnace gear wheels due to non-operation of the operating system improves from 3A to 3B.

In this study, the functional risks of an industrial unit were analyzed using the FuHA technique, which is one of the powerful techniques to identify and determine the effects of functional risks of systems and subsystems. In order to assess the risk of hazards using the usual method of risk assessment, the risk index of each hazard was obtained from the product of the two components of the probability of the hazard in the severity of its consequences. The results of this study showed that the FuHA technique had a favorable capability to identify and analyze the functional risks of systems and subsystems, especially software subsystems. Also, the results of the FMEA technique can be used as the input of the FuAH technique.

In general, the FuHA technique can be used in different phases of risk management in different industries. Khosravirad et al used this method to identify and determine the risk priority number of hazards in natural gas pressure reduction stations [14]. Another study [17] in the industry conducted using the FuHA technique also showed that about 11% of cases were unacceptable, which is similar to the present study, both of which were the lowest among different risk levels. On the other hand, in the previous study, most risks were at an average level, but in the current study, most risks were obtained at an acceptable level, which can be due to the type of industry and the conditions of the equipment used.

Table 4. Decision-making criteria based on the risk index

Risk classification	Risk criterion
1A, 1B, 1C, 2A, 2B, 3A	Unacceptable
1D, 2C, 2D, 3B, 3C	Unfavorable
1E, 2E, 3D, 3E, 4A, 4B	Acceptable but needs revision
4C, 4D, 4E	Negligible

Table 5. A part of the table of the results of implementing the FuHA technique in the tile production industrial unit

System	Subsystem	System Component	Defect State	Causative Factors	Effects	IMRI	Controlling Measures	FMRI
Roller furnace	Baking section	Furnace gasification system	Fueling the furnace less than enough	1. Creating a leak in the gas tank	1. Creating holes and quality defects in the product	4A	1. Timely planning and implementation of preventive maintenance	4C
				2. Clogging of the filter openings			2. Purchasing higher quality parts	
				3. Malfunction of manometer			3. Creating a container for the manometer	
				4. Leakage of gas transmission pipes	2. Failure to bake the tile	4A	4. Calibrating the manometer	4C
				5. Regulator failure	3. Possibility of explosion	1D		1E
				6. Clogging of gas transmission pipes	4. Emission of gas to the outside of the furnace	2D	5. Increasing the quality of incoming gas by using a CNG tank	4D

Abbreviations: FMRI, Final Mishap Risk Index; IMRI, Initial Mishap Risk Index.

5. Conclusion

In the end, it should be noted that since the FuHA technique deals with functions and functional risks, other risks of the system, including risks related to energy sources, risks of sneak circuit paths, risks of dangerous substances, etc., may be ignored. As a result, one should not only be content with implementing this technique and using its results in system risk assessment, but other types of risk analysis techniques, such as preliminary hazard analysis or subsystem hazard analysis, should also be used as a supplement [8].

Acknowledgments

The researchers of this study would like to thank the management and all personnel of the studied industrial unit for their cooperation and assistance in conducting this study.

Authors' Contribution

All authors contributed equally in all phases.

Competing Interests

There has been no conflict of interest.

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