Assessment of occupational health and safety risks in a Turkish public hospital using a two-stage hesitant fuzzy linguistic approach

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Abstract

Occupational health and safety (OHS) risk assessment studies have gained importance recently as a result of increasing occupational accidents and occupational diseases. The health sector has a greater risk than many sectors for occupational accidents and occupational diseases. Although the health sector is one of the priority sectors in Turkey, OHS practices have not been fully implemented in this field. For this reason, this study adopts a two-stage approach to assess the OHS risks in the health sector by combining the Fine-Kinney and multi-criteria hesitant fuzzy linguistic term set (HFLTS) methods. The proposed method was applied to the OHS risks in the operating room of a public hospital in Turkey. As a solution to the problem, first, the potential hazards and related risks in the operating room were determined by the experts. In this first stage, 44 hazards were determined from the opinions of experts and records of past incidents. Parameter weights were then determined using the multi-criteria HFLTS method. The multi-criteria HFLTS method was used to evaluate seven hazards to be categorized as substantial-risk or higher according to the Fine-Kinney method, taking into account parameter weights. Sensitivity analysis was then carried out. Finally, actions were taken to mitigate the risks.

Keywords Occupational health and safety · Risk assessment · Public hospital · Fine-Kinney · Hesitant fuzzy linguistic term sets

Introduction

Hazard is one of the most important concepts in occupational health and safety (OHS). It comprises a set of investigations and practices designed to ensure the protection of employees. It identifies any situation that exists in the workplace or impact from the outside that has the potential to cause injury, disease, or death, or to damage property, material, or the workplace environment as a hazard. Risk is the possibility or the likelihood of death, injury, illness, or other harmful consequences that may result from a hazard. The

comprehensive study conducted to estimate the magnitude of the risk arising from the hazard and to decide whether the risk is acceptable taking into account the adequacy of the existing controls is described as the risk assessment (HSA 2006). OHS risk assessment techniques are divided into two categories: qualitative and quantitative. In qualitative techniques, a numerical value is assigned to each parameter, such as the probability and severity of the hazard. These values may be processed by mathematical and logical methods and a risk value calculated. A list of qualitative and quantitative techniques can be found in Ilbahar et al. (Ilbahar et al. 2018).

OHS risk assessment studies have recently gained importance as a result of the increase in occupational accidents and occupational disease due to technological developments and the industrialization process. In 2017, there were over 3.3 million non-fatal accidents and 3552 fatal accidents in the EU-28 (Eurostat 2019). Turkey is placed near the top in terms of occupational accidents in Europe and the world and ranks first in fatal accidents in Europe. In Turkey, in 2016, there were 286,068 occupational accidents, and 1405 employees lost their life as a result of occupational accidents and disease, 36 of whom were women and 1369 were men

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(MMO 2018). In Turkey, the health sector has a high risk for occupational accidents and occupational disease. Hospitals are the largest sector of healthcare. For this reason, this study undertook a comprehensive study on OHS risk assessment in the hospital. The study utilizes an approach that combines Fine-Kinney and multi-criteria hesitant fuzzy linguistic term set (HFLTS) for OHS risk assessment. The proposed approach has been applied to the operating room of a public hospital in Turkey. First, hazards were identified, and a risk assessment was then undertaken on the 44 hazards determined using the Fine-Kinney method. Multi-criteria HFLTS was used to determine the parameter weights and to prioritize the hazards and their related risks that are rated as substantial or higher. Finally, these hazards were ranked, and control measures were proposed and implemented to mitigate the hazards.

OHS risk assessment studies in the literature can be summarized as follows. Leigh and Miller examined the job-related diseases of workers and the occupations related to those diseases (Leigh and Miller 1998). Larsson and Field analyzed the occupational injury incidence and severity, and they calculated the relative distribution of occupational injury risks in Victoria (Larsson and Field 2002). Macedo and Silva analyzed the occupational accidents in work environments in Portugal. The most important economic activities in terms of occupational accidents were construction and manufacturing (Macedo and Silva 2005). Chen et al. administered a survey to evaluate the occupational health and safety management systems (OHSMSs) and examine important performance indicators in the printed circuit board industry in Taiwan (Chen et al. 2009). Morillas et al. provided a comparative analysis of OHS risk prevention practices in Sweden and Spain (Morillas et al. 2013). Sousa et al. proposed a quantitative model that conducts cost–benefit analysis for OHS risk management in the construction industry (Sousa et al. 2015). Bayatian et al. applied a dynamic model for risk assessment of occupational exposure to benzene (Bayatian et al. 2018). Mohammadyan et al. performed health risk assessment of occupational exposure to styrene in the electronic industries (Mohammadyan et al. 2019a). Abad et al. built a Bayesian model for occupational health surveillance in workers exposed to silica (Abad et al. 2019). Mohammadyan et al. carried out quantitative and semi-quantitative risk assessment of occupational exposure to lead among electrical solderers (Mohammadyan et al. 2019b). Jalali et al. performed a risk assessment for occupational exposure to formaldehyde (Jalali et al. 2021). Rachidi et al. launched a qualitative and quantitative study to assess occupational risks in the food industry in Morocco during the COVID-19 pandemic (Rachidi et al. 2021).

OHS risk assessment generally consists of gathering information, identifying hazards, quantifying the risks associated with those hazards, and assessing the severity of

those risks. Fuzzy logic and multi-criteria decision-making (MCDM) methods have been used in OHS to overcome the deficiencies in traditional risk assessment approaches to determine the relationships between the factors and their effects on the risks. Murè et al. presented a risk assessment method based on fuzzy logic to assess the risks of occupational accidents (Murè et al. 2006). Gürçanlı and Müngen proposed an occupational safety risk analysis approach using fuzzy sets (Gürçanlı and Müngen 2009). Grassi et al. proposed a fuzzy multi-attribute risk evaluation model for safety in workplaces (Grassi et al. 2009). Liu and Tsai developed a risk assessment method that combines QFD, fuzzy ANP, and fuzzy FMEA for the construction industry (Liu and Tsai 2012). Mahdevari et al. proposed a model based on fuzzy TOPSIS to assess the OHS risks in underground coal mines in Iran (Mahdevari et al. 2014). Liu et al. suggested a model for evaluating the risk of failure modes based on fuzzy logic and the MULTIMOORA method for a healthcare facility (Liu et al. 2014). Ghasemi and Talebi Brijani proposed a risk management framework for flexible manufacturing system selection decisions using fuzzy AHP-PROMETHEE integrated approach (Ghasemi and Talebi Brijani 2014). Dağsuyu et al. utilized the classical and fuzzy FMEA for risk analysis in a sterilization unit (Dağsuyu et al. 2016). Chang et al. evaluated the marketability of certificates for OHS management in Taiwan using fuzzy AHP, fuzzy ANP, and VIKOR methods (Chang et al. 2016). Kokangül et al. conducted a risk analysis in a manufacturing company using AHP and Fine-Kinney methods (Kokangül et al. 2017). İnan et al. built a multiple attribute decision-making model to determine and compare the OHSMS performances of the firms (İnan et al. 2017). Gul et al. proposed a model based on fuzzy AHP and fuzzy VIKOR methods for OHS risk assessment in hospitals (Gul et al. 2017). Gul and Ak used Pythagorean fuzzy AHP and fuzzy TOPSIS to quantify risk ratings in OHS risk assessment (Gul and Ak 2018). Ilbahar et al. proposed an integrated approach including Pythagorean fuzzy AHP and fuzzy inference system for OHS risk assessment (Ilbahar et al. 2018). Gul and Celik proposed a risk assessment approach that includes a combination of Fine-Kinney and a fuzzy rule-based expert system for rail transportation systems (Gul and Celik 2018). Mohandes and Zhang developed a comprehensive hybrid fuzzy-based occupational risk assessment model for construction workers (Mohandes and Zhang 2019). Stefanović et al. ranked the workplaces in terms of risk assessment using the PROMETHEE method (Stefanović et al. 2019). Khan et al. proposed a model based on modified-SIRA and fuzzy TOPSIS methods for OHS risk assessment in the construction industry in Pakistan (Khan et al. 2019). Liu et al. used integrated SWARA-MABAC model under bipolar fuzzy environment for OHS risk assessment (Liu et al. 2020). Gul and Ak proposed a new integrated approach using fuzzy

BWM and fuzzy MAIRCA for occupational risk assessment (Gul and Ak 2020). Tang et al. developed risk prioritization method for Fine-Kinney using generalized TODIM, BWM, and interval type-2 fuzzy set (Tang et al. 2021). Khalilzadeh et al. used the fuzzy SWARA, FMEA, PROMETHEE approaches, and multi-objective programming model for risk assessment in the planning phase of the oil and gas construction projects in Iran (Khalilzadeh et al. 2021). Liu et al. developed an OHS risk assessment framework by integrating TODIM and PROMETHEE methods under linguistic spherical fuzzy environment (Liu et al. 2021).

HFLTS has been applied successfully to various study areas that include performance evaluation, supplier selection, healthcare risk analysis, site selection, and selection of health tourism strategy (Table 1). The current study

contributes to the literature on OHS risk assessment in the following aspects:

- (1) HFLTS reduces the difficulty that decision makers experience in defining linguistic terms and provides flexibility in their evaluations
- (2) HFLTS allows decision makers to assign a weight to parameters (unlike Fine-Kinney and other classical OHS risk assessment techniques)
- (3) According to the authors' best knowledge, there are no studies that combine Fine-Kinney and multi-criteria HFLTS methods for OHS risk assessment in the health sector. This study aims to fill this gap.

Table 1 Summary of HFLTS studies in the literature

Author and year	Method	Objective	Type
Rodríguez et al., 2012	HFLTS	Method proposal	Illustrative
Beg and Rashid, 2013	HFLTS, TOPSIS	Method proposal	Illustrative
Liao et al., 2014	HFLTS	Evaluation of the quality of movies	Illustrative
Liu and Rodríguez, 2014	HFLTS, Fuzzy TOPSIS	Supplier selection	Illustrative
Liao and Xu, 2015	HFLTS, TOPSIS, VIKOR	Selection of an ERP system	Illustrative
Montes et al., 2015	HFLTS	Development of a web tool for the housing market	Case Study
Wang et al., 2015	HFLTS, ELECTRE	Method proposal	Illustrative
Wei et al., 2015	HFLTS, TODIM	Evaluation of the telecommunications service providers	Illustrative
Yavuz et al., 2015	Multi-criteria HFLTS	Evaluation of alternative-fuel vehicles	Case Study
Chen et al., 2016	Proportional HFLTS (PHFLTS)	Evaluation of the university faculty	Illustrative
Da and Xu, 2016	HFLTS	Urban waterfront redevelopment	Case Study
Fahmi et al., 2016	HFLTS, ELECTRE I	Supplier selection	Illustrative
Liu et al., 2016	HFLTS, FMEA	Healthcare risk analysis	Case Study
Gou et al., 2017	Double hierarchy HFLTS (DHHFLTS), MULTI-MOORA	Evaluation of the implementation status of haze controlling measures	Case Study
Khishbandar et al., 2017	HFLTS	Assessment of bioenergy production technologies	Case Study
Tüysüz and Şimşek, 2017	HFLTS, AHP	Performance evaluation	Case Study
Adem et al., 2018	HFLTS, SWOT	Assessment of occupational safety risks in the life cycle of wind turbine	Case Study
Feng et al., 2018	HFLTS, PROMETHEE	Facility location selection	Illustrative
Liao et al., 2018	HFLTS, ELECTRE II	Method proposal	Illustrative
Huang et al., 2019	PHFLTS, QFD	Method proposal	Illustrative
Wu et al., 2019	HFLTS, VIKOR, TOPSIS	Method proposal	Illustrative
Çalış Boyacı, 2020	HFLTS, ARAS	Selection of eco-friendly cities	Case Study
Wang et al., 2020	HFLTS, GIA	Resource allocation in water pollution treatment	Illustrative
Büyüközkan and Güler, 2020	HFLTS, SAW, ARAS	Smart watch evaluation	Case Study
Çalış Boyacı et al., 2021	HFLTS, TOPSIS, GIS	Site selection for waste vegetable oil and waste battery collection boxes	Case Study
Rodríguez et al., 2021	HFLTS, CRP	Method proposal	Illustrative
Büyüközkan et al., 2021	HFLTS, SWOT, AHP, MABAC	Health tourism strategy selection	Case Study
Ghorui et al., 2021	HFLTS, TOPSIS, Fuzzy AHP	Identification of dominant risk factor involved in spread of COVID-19	Case Study

Methodology

This study investigates the combination of the Fine-Kinney and multi-criteria HFLTS methods for OHS risk assessment. These two methods are explained in detail in this section.

Fine-Kinney method

The Fine-Kinney risk assessment method was first proposed by Fine in 1971 as a mathematical assessment method for hazard control (Fine 1971). Kinney and Wiruth further developed the method in 1976 and transformed its application from a mathematical approach to a graphical approach (Kinney and Wiruth 1976). In this method, a risk score (R) is calculated by multiplying the probability (P), frequency (F), and severity (S) of a potential hazard, and this score is then mapped to a risk scale and the requirement for mitigation. It is formulated as follows:

$$R = P \times F \times S \quad (1)$$

The risk scale and requirement for mitigation are given in Table 2 (Kinney and Wiruth 1976).

Multi-criteria HFLTS method

Uncertain knowledge is effectively dealt with using fuzzy logic and fuzzy set theory. However, when two or more sources of uncertainty exist at the same time, fuzzy sets are constrained (Rodríguez et al. 2012). Hesitant fuzzy sets, which allow us to describe situations in which different membership functions are considered possible, are a generalization of fuzzy sets. They can overcome the difficulties in deciding the membership degree of an element (Torra 2010). In traditional fuzzy linguistic approaches, a single expression should be chosen to restrict the experts. Experts, on the other hand, may hesitate to use suitable linguistic expressions (Onar et al. 2016). When experts hesitate between several linguistic expressions, they can use HFLTS.

Rodríguez et al. suggested a hesitant linguistic group decision-making model with a single-criterion (Rodríguez et al. 2013). This algorithm was extended by Yavuz et al. to consider a multi-criteria decision-making problem, and

the steps of the suggested algorithm are as follows (Yavuz et al. 2015):

Step 1. The semantics and syntax of the linguistic term set S are defined using Eq. (2) (Rodríguez et al. 2013).

$$S = \left\{ \begin{array}{l} no\ importance(n),\ very\ low\ importance(vl), \\ low\ importance(l),\ medium\ importance(m), \\ high\ importance(h), \\ very\ high\ importance(vh), \\ absolute\ importance(a) \end{array} \right\} \quad (2)$$

Step 2. A context-free grammar G_H is defined, where $G_H = \{V_N, V_T, I, P\}$ and V_N is the set of nonterminal symbols, V_T is the set of terminals' symbols, I is the starting symbol, and P is the production rules that are defined in an extended Backus–Naur form (Rodríguez et al. 2012).

Step 3. The preference relations p^k for both criteria and alternatives are elicited from the experts.

Step 4. The preference relations are transformed into HFLTS.

Step 5. The envelopes $[p_{ij}^{k-}, p_{ij}^{k+}]$ are obtained for each HFLTS.

Step 6. A linguistic aggregation operator (φ) is selected, and the pessimistic and optimistic collective preference relations (P_C^-, P_C^+) are obtained. The arithmetic mean given in Eq. (3) is used for φ :

$$\bar{x} = \Delta \left(\frac{1}{n} \sum_{i=1}^n \Delta^{-1}(s_i, \alpha_i) \right) = \Delta \left(\frac{1}{n} \sum_{i=1}^n \beta_i \right). \quad (3)$$

Step 7. The pessimistic and optimistic collective preferences for the alternatives are calculated from φ .

Step 8. The vector of the intervals for the collective preferences is built.

Step 9. The obtained interval utilities are normalized.

Step 10. The weighted scores are calculated.

Implementation of the proposed approach

The application of the proposed method is described in detail in the following sections. The methodology is shown in diagrammatic form in Fig. 1. The method comprises three phases: preparation, analysis, and proposals for mitigation.

Problem definition

The proposed risk assessment method was applied to the operating room of a public hospital in Turkey. Three experts, who are responsible for the operation and OHS procedures and policies of the unit, took part in the analysis process.

Table 2 Risk scale (Kinney and Wiruth 1976)

Risk score	Situation
> 400	Very high risk (consider discontinuing operation)
200 to 400	High risk (immediate correction required)
70 to 200	Substantial risk (correction needed)
20 to 70	Possible risk (attention indicated)
< 20	Risk (perhaps acceptable)

Fig. 1 Framework of the proposed approach

Expert 1 is an OHS specialist, Expert 2 is an operating room supervisor, and Expert 3 is an operating room nurse. The experts have 7, 25, and 20 years of experience respectively. Following the process, all potential hazards and their related risks in the operating room were first determined by the experts. Forty-four (44) hazards including, “Exposed electrical installation elements,” “Improper storage of chemicals,” “Storage of waste in unsuitable containers,” “Exposure to radiation,” and “Not preparing an emergency plan,” were identified based on the opinion of the experts and from records of past incidents.

Analysis

Prioritization of the risks using the Fine-Kinney method

After the potential hazards and their respective risks were identified, the risks were prioritized using the Fine-Kinney method. Seven hazards and their related risks were identified as being substantial or higher according to the Fine-Kinney method. Table 3 shows the hazards, their respective risk, and the risk scores as calculated using the Fine-Kinney method.

Table 3 Hazards and associated risks in the substantial-risk and higher categories

Hazard code	Definition	Risk code	Definition	Risk score
Hazard 1 (H1)	Lack of suitable fire extinguishers	Risk 1 (R1)	Injury, death as a result of failure of fire extinguisher tubes	80
Hazard 2 (H2)	Failure of alarm and warning systems	Risk 2 (R2)	Injury, death in case of fire	120
Hazard 3 (H3)	Exposed electrical installation elements	Risk 3 (R3)	Injury, death as a result of fire, sabotage, and electric shock	240
Hazard 4 (H4)	Unsuitable materials to fix electrical triple sockets to the wall	Risk 4 (R4)	Injury, death as a result of electric shock	120
Hazard 5 (H5)	Unauthorized access by non-employees	Risk 5 (R5)	Extortion, sabotage, robbery, injury, death	120
Hazard 6 (H6)	Dangerous use and misuse of work equipment	Risk 6 (R6)	Injury, death as a result of fire and electric shock	240
Hazard 7 (H7)	Unsuitable materials in front of fire cabinets and electrical panels	Risk 7 (R7)	Injury, financial loss, death as a result of delayed fire intervention	120

Table 4 Expert evaluations for the parameters

	Probability	Frequency	Severity
<i>Expert 1</i>			
Probability	-	<i>m</i>	Between <i>vl</i> and <i>l</i>
Frequency	<i>m</i>	-	<i>l</i>
Severity	Between <i>h</i> and <i>vh</i>	<i>h</i>	-
<i>Expert 2</i>			
Probability	-	<i>vh</i>	Between <i>m</i> and <i>h</i>
Frequency	<i>vl</i>	-	<i>l</i>
Severity	Between <i>l</i> and <i>m</i>	<i>h</i>	-
<i>Expert 3</i>			
Probability	-	<i>h</i>	<i>vl</i>
Frequency	<i>l</i>	-	At most <i>vl</i>
Severity	<i>vh</i>	At least <i>vh</i>	-

Table 5 Envelopes for HFLTS

	Probability	Frequency	Severity
<i>Expert 1</i>			
Probability	-	<i>[m,m]</i>	<i>[vl,l]</i>
Frequency	<i>[m,m]</i>	-	<i>[l,l]</i>
Severity	<i>[h,vh]</i>	<i>[h,h]</i>	-
<i>Expert 2</i>			
Probability	-	<i>[vh,vh]</i>	<i>[m,h]</i>
Frequency	<i>[vl,vl]</i>	-	<i>[l,l]</i>
Severity	<i>[l,m]</i>	<i>[h,h]</i>	-
<i>Expert 3</i>			
Probability	-	<i>[h,h]</i>	<i>[vl,vl]</i>
Frequency	<i>[l,l]</i>	-	<i>[n,vl]</i>
Severity	<i>[vh,vh]</i>	<i>[vh,a]</i>	-

Determination of the weights of parameters and prioritization of hazards using HFLTS

The parameter weights were determined using the multi-criteria HFLTS method. Table 4 shows the linguistic evaluations of the experts for the parameters. Table 5 shows the envelopes obtained for each HFLTS. Table 6 shows the scale to be applied to the pessimistic and optimistic collective preference relations, where 0 indicates “no importance” and 6 indicates “absolute importance.” Table 7 presents the pessimistic collective preference values, and Table 8 presents the optimistic collective preference values.

As an example, the pessimistic and optimistic collective preference values for *S* in relation to *P* are calculated using Eqs. (4) and (5), respectively.

$$\begin{aligned}
 P_{31}^{-} &= \Delta \left(\frac{1}{3} \left(\Delta^{-1}(h, 4) + \Delta^{-1}(l, 2) + \Delta^{-1}(vh, 5) \right) \right) \\
 &= \Delta \left(\frac{1}{3} (4 + 2 + 5) \right) = \Delta(3.67) = (h, -0.33)
 \end{aligned} \quad (4)$$

Table 6 The scale for HFLTS

<i>n</i>	<i>vl</i>	<i>l</i>	<i>m</i>	<i>h</i>	<i>vh</i>	<i>a</i>
0	1	2	3	4	5	6

Table 7 Pessimistic collective preferences

	Probability	Frequency	Severity
Probability	-	<i>(h,0)</i>	<i>(l, -0.33)</i>
Frequency	<i>(l,0)</i>	-	<i>(vl, +0.33)</i>
Severity	<i>(h, -0.33)</i>	<i>(h, +0.33)</i>	-

Table 8 Optimistic collective preferences

	Probability	Frequency	Severity
Probability	-	<i>(h,0)</i>	<i>(l, +0.33)</i>
Frequency	<i>(l,0)</i>	-	<i>(l, -0.33)</i>
Severity	<i>(h, +0.33)</i>	<i>(vh, -0.33)</i>	-

Table 9 Weights of the parameters

Parameters	Linguistic intervals	Interval utilities	Midpoints	Weights
Probability	$[(m, -0.17), (m, +0.17)]$	$[(2.83), (3.17)]$	3.00	0.333
Frequency	$[(l, -0.33), (l, -0.17)]$	$[(1.67), (1.83)]$	1.75	0.195
Severity	$[(h, 0), (vh, -0.50)]$	$[(4.00), (4.50)]$	4.25	0.472

Table 10 Weights for the hazards

Parameter	Weight	Hazard						
		H1	H2	H3	H4	H5	H6	H7
Probability	0.333	0.028	0.044	0.063	0.041	0.050	0.067	0.040
Frequency	0.195	0.017	0.038	0.029	0.025	0.019	0.041	0.026
Severity	0.472	0.094	0.082	0.086	0.041	0.046	0.057	0.066
Weight of hazards		0.139	0.164	0.178	0.107	0.115	0.165	0.132

Table 11 Ranking obtained with S1

Parameter	Weight	Hazard						
		H1	H2	H3	H4	H5	H6	H7
Probability	0.333	0.028	0.044	0.063	0.041	0.050	0.067	0.040
Frequency	0.333	0.030	0.064	0.049	0.043	0.033	0.070	0.044
Severity	0.333	0.066	0.058	0.061	0.029	0.033	0.040	0.046
Weight of hazards		0.124	0.166	0.173	0.113	0.116	0.177	0.130

Table 12 Ranking obtained with S2

Parameter	Weight	Hazard						
		H1	H2	H3	H4	H5	H6	H7
Probability	0.333	0.028	0.044	0.063	0.041	0.050	0.067	0.040
Frequency	0.472	0.042	0.091	0.070	0.061	0.047	0.099	0.062
Severity	0.195	0.039	0.034	0.035	0.017	0.019	0.024	0.027
Weight of hazards		0.109	0.169	0.168	0.119	0.116	0.190	0.129

$$\begin{aligned}
 P_{31}^+ &= \Delta \left(\frac{1}{3} (\Delta^{-1}(vh, 5) + \Delta^{-1}(m, 3) + \Delta^{-1}(vh, 5)) \right) \\
 &= \Delta \left(\frac{1}{3} (5 + 3 + 5) \right) = \Delta(4.33) = (h, +0.33)
 \end{aligned}
 \quad (5)$$

Table 9 shows the weights of the parameters obtained from the values in Tables 7 and 8. Table 9 indicates that Severity is the most significant parameter with a weight of 0.472, whereas Frequency is the least important with a weight of 0.195. The procedure was repeated for the hazards taking into account the parameter weights, and the weights of the seven hazards are shown in Table 10. H3 is the most important hazard, whereas H4 is the least important hazard. The order of priority of the hazards is $H3 > H6 > H2 > H1 > H7 > H5 > H4$.

Sensitivity analysis

A sensitivity analysis was undertaken to investigate how a change in the weight of a parameter affects the ranking of the

hazards. The value of each parameter weight was adjusted between two settings, and the hazards reassessed. Table 11 shows the results of Scenario 1 (S1), in which all criteria (parameters) were given an equal weight, and Table 12 shows the results of Scenario 2 (S2), in which the weight of the parameter with the highest weight (Severity) was swapped with the weight of the parameter with the lowest weight (Frequency).

Results and discussion

Figure 2 shows the ranking of the hazards for the original weights, S1 and S2. H3 is seen as the highest ranked hazard from the proposed method using the original weights. H6 is seen as the most important hazard for the two scenarios. For each scenario, H2, H3, and H6 remain the three most important hazards, and the ranking of H5 is unchanged. In general, as the weight of the severity parameter decreases,

Fig. 2 Ranking of the hazards for original weights, S1 and S2

the importance of H3 decreases, and the importance of H6 increases.

These findings compare with those of Dağsuyu et al. (2016) and Gul et al. (2017). Dağsuyu et al. (2016) applied fuzzy FMEA for risk analysis in the sterilization unit of a hospital. Their results indicate that risks related to electric shock had high priority. Gul et al. (2017) applied the FAHP-FVIKOR method for OHS risk assessment in a hospital. Their results also indicate that risk related to electricity was the most significant hazard in the emergency department.

Mitigation of hazards

The expert opinions gave the ranking of the hazards as: $H3 > H6 > H2 > H1 > H7 > H5 > H4$. The experience of the experts and the records of past incidents were then used to determine actions that should be taken to mitigate the risks associated with each hazard. These included:

- Electrical panel covers must be securely closed
- High power electric equipment such as electric heaters, tea makers, electric cookers should not be plugged into the same triple socket, and electrical extension cables should not be added to each other
- Periodic checks of alarm and warning systems should be made
- Periodic checks of fire extinguishers should be made
- The front of fire cabinets and electrical panels should be cleared, and placing material in these areas should be prohibited
- Security checks should be made at the entrances and exits during working hours
- Electrical extension cables should not be left on the floor and should be fixed to the wall or to the table with the equipment

Improvements were made in the unit in line with proposals for R3, R6, R7, R5, and R4, and a schedule for periodic checks for R2 and R1 was adopted.

Mitigation for R3

Figure 3 shows the covers of electrical panels were left open exposing live electrical components that presented a risk to employees. After mitigation, the covers of all electrical panels are kept closed and locked.

Mitigation for R6

Figure 4a shows an electric tea maker was plugged into the same triple wall socket as other high power electrical appliances. Figure 4b shows multiple electrical extension cables were connected together resulting in overloaded sockets. Figure 5 shows the mitigation where triple wall sockets were replaced by multiple double sockets to prevent multiple high power appliances such as electric heaters, tea makers, and

Fig. 3 Mitigation for R3: Covers of all electrical panels are kept closed and locked

Fig. 4 Mitigation for R6: **(a)** Multiple high power appliances plugged into the same triple wall socket. **(b)** Multiple extension sockets connected together

Fig. 5 Mitigation for R6: Triple wall socket replaced with extra double wall sockets to prevent high power appliances being plugged in the same triple socket, and extension cables removed and replaced by extra wall sockets

electric stoves being plugged into the same triple socket. Extension electrical cables were replaced by multiple wall sockets and were only allowed to be used in places with the permission of an electrician.

Mitigation for R7

Figure 6a shows how all materials placed in front of fire cabinets and electrical panels were removed (Fig. 6b) to ensure unrestricted access to necessary equipment in case of emergency. Employees were informed that any material placed in front of a fire cabinets or electricals panel would be immediately removed.

Mitigation for R5

Access to the operating rooms by unauthorized persons was previously controlled by a security guard which proved

inadequate in some instances. A card entry system (Fig. 7) was added in addition to having a security guard at each entrance.

Mitigation for R4

Unsuitable materials were used to fix electrical triple sockets, and extension sockets were left trailing on the floor (Fig. 8a) rather than being fixed to the wall. Extension sockets were fixed to the wall with suitable fasteners as shown in Fig. 8b.

Conclusions and future works

Unfavorable working conditions caused by technological developments and industrialization pose a threat to human health and safety in the workplace. In order to prevent

Fig. 6 Mitigation for R7: All materials in front of electrical panels and fire cabinets removed

(a)

(b)

Fig. 7 Mitigation for R5: Access to restricted areas controlled by card access in addition to a security guard at each entrance

(a)

(b)

Fig. 8 Mitigation for R4: Extension sockets fixed to the wall

(a)

(b)

occupational accidents and diseases that may occur in the workplace, a risk assessment should be made and protective and preventive measures taken to mitigate risks. This study, which presents a new approach to OHS risk assessment, combines the Fine-Kinney and multi-criteria HFLTS methods to identify hazards, and assess, prioritize, and mitigate risks. The proposed approach was applied to the operating room of a public hospital in Turkey. Three experts with responsibilities for OHS in the unit participated in the analysis process. The potential hazards and related risks in the operating room were first determined by the experts. Forty-four hazards were determined initially, and the risks were prioritized using the Fine-Kinney method. The parameter weights were then determined using the multi-criteria HFLTS method. Severity (S) was the most significant parameter with a weight of 0.472, whereas Frequency (F) was the least important parameter with a weight of 0.195. The procedure was repeated for the seven hazards to be categorized as substantial-risk or higher according to the Fine-Kinney method, taking into account parameter weights. A sensitivity analysis was performed on the weights, and H2, H3, and H6 remained as the three most important hazards; the ranking of H5 was unchanged. The final stage was to determine and implement mitigation for the risks.

This study contributes to OHS risk assessment in two ways:

- (1) The parameters in the Fine-Kinney method have equal weight, and so the risk scores can be equal, even though the values for the hazards differ. In this paper, the experts assign parameter weights to overcome this situation when using multi-criteria HFLTS.
- (2) HFLTS provides a solution when experts hesitate between several linguistic expressions.

For future work, the methodology of this study can be applied in other units of the hospital. In addition, other types of fuzzy sets can be investigated, and the results compared.

Author contribution AÇB: conceptualization, methodology, validation, formal analysis, data curation, writing—original draft, writing—review and editing, visualization, supervision. AS: methodology, formal analysis, data curation, writing—original draft, writing—review and editing, visualization. This study was produced from the master's thesis of the second author under the supervision of the first author. It was carried out at the Ondokuz Mayıs University, Institute of Graduate Studies, Department of Intelligent Systems Engineering in 2021.

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Declarations

Ethics approval and consent to participate Not applicable.

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