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RESEARCH ARTICLE

RISK ASSESSMENT USING A NOVEL HYBRID METHOD: A CASE STUDY AT THE BIOCHEMISTRY DEPARTMENT

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ABSTRACT

Risk management has gained substantial attention for the health sector in recent years. Healthcare systems are forced to deal with risk assessment due to deadly accidents. Biochemistry department is one of the most critical units, in which occupational accidents should be controlled preventively. Thus, this paper aims at developing a risk assessment process to minimize the occupational accidents. Failure mode and effects analysis (FMEA) and 5x5 matrix (L Matrix) as most effective quantitative risk analysis methods, are developed for a biochemistry department of a hospital in Turkey to evaluate the risk types discussed in related works and discovered during this work. First, the decision makers' risk evaluation based on historical data of accidents are adopted to risk management process. Then, with regard to scoring of risk factors such as occurrence, severity and detectability, risk priority numbers and classes are obtained and preventive measures for the high-risk failure modes are determined. Analytic Hierarchy Process (AHP) method has been applied for prioritizing these measures to reduce or eliminate these risk types. Considering the results obtained from the AHP method, a goal programming model is developed to minimize the risk prevention costs. Obtained results demonstrate the effectiveness of the proposed methods.

Keywords: *Biochemistry, quantitative risk analysis, mathematical model, AHP*

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ARAŞTIRMA MAKALESİ

YENİ BİR HİBRİT YÖNTEM KULLANARAK RİSK DEĞERLENDİRMESİ: BİYOKİMYA BÖLÜMÜNDE BİR VAKA ÇALIŞMASI

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ÖZ

Son yıllarda sağlık hizmetlerinde risk yönetimi çok ilgi görmektedir. Sağlık sistemleri, ölümcül kazalar nedeniyle risk değerlendirmesi ile uğraşmak zorunda kalmaktadır. Biyokimya bölümü iş kazalarının önleyici olarak kontrol edilmesi gereken en kritik birimlerden biridir. Bu nedenle, bu makale iş kazalarını en aza indirmek için bir risk değerlendirme süreci geliştirmeyi amaçlamaktadır. Türkiye'deki bir hastanenin biyokimya bölümünde, literatürde tartışılan ve bu çalışma sırasında keşfedilen risk faktörlerini değerlendirmek için en etkili kantitatif risk analizi yöntemlerinden Hata Türü ve Etkileri Analizi (HTEA) ve 5x5 matris (L Matrix) uygulanmıştır. Öncelikle, karar vericilerin kazaların geçmiş verilerine dayalı risk değerlendirmesi risk yönetim sürecine uyarlanmıştır. Daha sonra olasılık, şiddet ve tespit edilebilirlik gibi risk faktörleri puanlanarak risk öncelik sayısı (RÖS) ve risk sınıfları elde edilmiştir ve yüksek risk sınıfları için önleyici tedbirler belirlenmiştir. Bu risk faktörlerini azaltmak veya ortadan kaldırmak amacıyla alınması gereken önlemlerin önceliklendirilmesi için Analitik Hiyerarşi Süreci (AHP) yöntemi uygulanmıştır. AHP yönteminden elde edilen sonuçlar dikkate alınarak risk önleme maliyetlerini en aza indirmek amacı ile bir hedef programlama modeli geliştirilmiştir. Elde edilen sonuçlar, önerilen yöntemlerin etkin olduğunu göstermektedir.

Anahtar Kelimeler: *Biyokimya, kantitatif risk analizi, matematiksel model, AHP*

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I. INTRODUCTION

Risk management is conducted to pay attention to the potential risks and prevent potential results of accidents in the workplace. In addition, this management aims to improve system safety. The first step for this process is the comprehensive analysis of the workplaces and to take into consideration employees' evaluations based on historical data of accidents. The process begins with the identification of hazards, continues with measures to determine the level of acceptability of possible risks and to prevent unacceptable risks. By these measures, reducing the risk to an acceptable level or eliminating is aimed in this paper.

Risk management methods are widely used across various sectors. The healthcare sector is one of these sectors due to deadly accidents related to risk types. Hospitals are institutions that affect both public health and their employees. Some units have more risk types in terms of human living. Proactive methods should be used to prevent these hazards firstly in these units.

Biochemistry laboratories are one of the critical units, in which analyses are conducted for the diagnosis, monitoring, and treatment of the patients. Biochemistry laboratories are the units, where biochemical substances are tested for the analysis of body fluids and tissues. Body fluids and chemicals used in the analysis cause risks in the hospital environment. Risk types available in a unit affect the others in the hospital (Negrichi et al., 2012). The major share of the total medical results is decided according to the reports of this laboratory analysis. Employees in these units are exposed to various risk types such as infection, radiation, chemicals, allergies, ergonomics, and violence. Risk of injury, loss of labor, and infection due to physical risk types at all stages of the tests including blood collection are available in these units. Therefore, risk analysis methods should be applied in biochemistry units in order to determine the risks involved for laboratory workers and to evaluate the current situation in terms of risk management.

FMEA, Fine Kinney, John Ridley and Risk Assessment Decision Matrix (RADM) are the most frequently used quantitative methods for risk analysis. RADM can be applied as 3x3, L type, X type matrix methods. Occurrence and severity are common risk factors used in all risk analysis methods. In some methods, risk factors such as frequency, detectability (efficiency, reputation, loss of prestige, financial loss, environmental impact, financial losses of accidents, administrative-legal sanctions, workday motivation, and performance losses for employees) are also used.

Quantitative proactive methods can influence the results due to involving subjectivity. Although the same method is used, different risk classes can be obtained in risk analyses conducted by different experts. Thus, it is aimed to better compare and evaluate the results with these two methods applied by the same teams. FMEA and 5x5 matrix are used as a proactive risk assessment method in this study. Both methods are evaluated by the same experts of the biochemistry unit. By calculating the risk scores obtained by the two methods, it was found that which risk class they belong to, and the two results were evaluated in determining the hazards. Accordingly, after the hazards that need to be taken precautions are determined, they are prioritized with the AHP method. Considering the results obtained from the AHP method, an integrated system has been developed with a goal programming model to minimize risk prevention costs. FMEA is a systematic method for examining all risks and eliminating or reducing the highest risk priority. Occurrence and severity are used as risk factors in the 5x5 matrix method, while detectability risk factor is also included in the FMEA method. In FMEA, Risk Priority Number (RPN) value is calculated and the risk score and corresponding risk class are calculated. In the 5x5 matrix method, the risk score value is calculated to determine which class is included in the A-E class. In this study, the risk scores obtained from the 5x5 matrix and FMEA methods and the corresponding risk classes are evaluated to determine whether class changes occurred by both methods. According to these classifications, measures for those high risk values are determined and action plans are prepared. Measures related with these risks are conducted to eliminate the possible cause or to decrease the probability of occurrence, reducing its severity and increasing its detectability. Reducing the risk score values is aimed as a result of action planning, implementation, and control. Determination, implementation, evaluation of the measures to be taken, and the reorganization of the necessary activities until the acceptable risk level is required (OHSAS 18001 Occupational Health and Safety Management System).

This study is conducted to evaluate and identify new hazards discovered in a hospital biochemistry laboratory and the hazards discussed in previous studies. During the FMEA application, risk factors such as “occurrence to determine the frequency of risk”, “severity to determine the severity of risk”, and “detectability” are used. This method is related to using probability risk factors multiplied by the risk severity and a detection risk factor of each risk (Carbone and Tippett, 2004).

Physical risk types related to the biochemistry laboratory are determined and the new risk priority numbers are calculated. As a result of the study, the effects of physical risk types on the health of the personnel are evaluated and preventive measures are decided. According to the results of risk analysis, risk types including unacceptable levels are determined and the AHP method is applied for prioritizing these measures to reduce and eliminate the impact of these risk types and their priorities are determined according to the weights obtained with AHP which was developed by Thomas L. Saaty in 1980, provides an analytical evaluation of criteria without numerical values by comparison methods. The Multi-Criteria Decision Making (MCDM) option AHP is used to organize and analyze complex decisions (Ocampo et al., 2020).

To the best of our knowledge, no study has, to date, focused a hybrid method based on FMEA, 5x5 matrix, AHP, and mathematical modelling approach for a biochemistry unit in Turkey. The study has also practical and theoretical implications. Regarding practical view, an illustrative case study is firstly conducted in a biochemistry unit of a large hospital which is one of the most critical units in terms of safety risk types. Risk types observed in the unit and discussed in the previous works are evaluated by a large expert team. Regarding theoretical view, integration of risk management tools, MCDM, and mathematical modelling approach could be a useful tool for decision-makers in the healthcare sector and other sectors. Furthermore, unlike the traditional hybrid methods, the costs of each prioritized measure are also calculated. Cost analysis is provided to obtain the proposed preventive measures to decrease and eliminate the failures. In addition, a sensitivity analysis is applied to conduct the risk analysis under various risk budget conditions.

II. RELATED WORKS

Most studies deal with the risk types using FMEA in the healthcare sector (Khasha et al., 2013; Reiling et al., 2003; Soykan et al., 2014; Wetterneck et al., 2004). Soykan et al. (2014) examine infectious diseases with the FMEA method. RPNs are evaluated and preventive measures are decided. Khasha et al. (2013) present a risk analysis method to prioritize surgery risks. Risk types including lack of beds, high-risk operations are examined in the study. Reiling et al. (2003) use the FMEA method for patient safety, minimizing risk types. Lin et al. (2014) address the risk analysis methods to evaluate medical devices. SHELL (Software, Hardware, Environment, Live-ware, and Central Live-ware) method and FMEA are used to decide the hazards and take measures to prevent the risks. Dağsuyu et al. (2016) use FMEA, fuzzy FMEA, and 5x5 matrix to evaluate the risk types in a sterilization unit. Class numbers are increased to compare the methods and class widths are developed for the 5-scale FMEA. Claxton and Campbell-Allen (2017) develop the FMEA method to evaluate the steps of gene mutation test laboratory system to prevent types. Kahraman et al. (2013) use FMEA with fuzzification method to decide the prioritizing of the healthcare problem. Jamshidi et al. (2015) use prioritization with fuzzy FMEA to decide the best strategy for safety standards. The strategy includes medical equipment like infant incubators, infusion pumps, computed tomography scanners.

There are articles in the literature integrating various MCDM methods and risk analysis methods. Fattahi and Khalilzadeh (2018) develop a novel method including FMEA, AHP and MULTİMOORA (Multi Objective Optimization by Ratio Analys). The weights of risks in three methods and each failure modes are handled in the study. Kutlu and Ekmekçioğlu (2012) presents a novel method of fuzzy FMEA including Fuzzy TOPSIS (Technique For Order Performance by Similarity to Ideal Solution) and fuzzy AHP. They mention that integrating of Fuzzy TOPSIS and Fuzzy AHP ensures to consider the importance of the risks. Ilbahar et al. (2018) apply a hybrid method including Fine Kinney, Pythagorean Fuzzy AHP, and FIS (Fuzzy Inference System) and FMEA, Pythagorean fuzzy AHP, and FIS to an excavation processes. Mete (2019) develops FMEA-based AHP-MOORA under Pythagorean fuzzy sets for a pipeline construction. Results demonstrate that the integrated method provide optimal results to evaluate the risk types. Mangeli et al. (2019) conduct a risk assessment problem using FMEA, nonlinear model, fuzzy TOPSIS, and support vector machine methods. They combine these methods to overcome the classical FMEA limitations. Mutlu and Altuntaş (2019) have developed an integrated method including FMEA, fault tree analysis (FTA) and fuzzy probability estimations of time (BIFPET) for fabric dyeing unit of a textile sector. The results of the study are compared with FMEA- FTA and FMEA-FTA-PERT methods. Hassan et al. (2019) provide an integrated approach based on FMEA with fuzzy-AHP. The aim of the study is to determine and reduce the failures in warehousing. Fuzzy-AHP is conducted to reduce subjectivity for assigning weights. Altuntaş and Kansu (2019) present an integrated method including service quality measurement (SERVQUAL), quality function deployment (QFD) and FMEA to improve service quality in a hospital. The results indicate that the integrated methodology can be used in practice for service quality. Hu et al. (2019) use FMEA, grey relation analysis (GRA) and TOPSIS methods for a healthcare system. They use GRA-TOPSIS to determine the risk rankings of results from FMEA. A maximizing deviation method is applied to calculate the weights of risks. Huang et al. (2019) aim to develop a novel FMEA including linguistic Z-numbers and an extended projection method. Linguistic Z-numbers are applied to decide experts' risk assessments. The projection method is applied to decide the risk priorities of failure modes. Dagsuyu et al. (2021) discussed an integrated study with FMEA and AHP methods in their study.

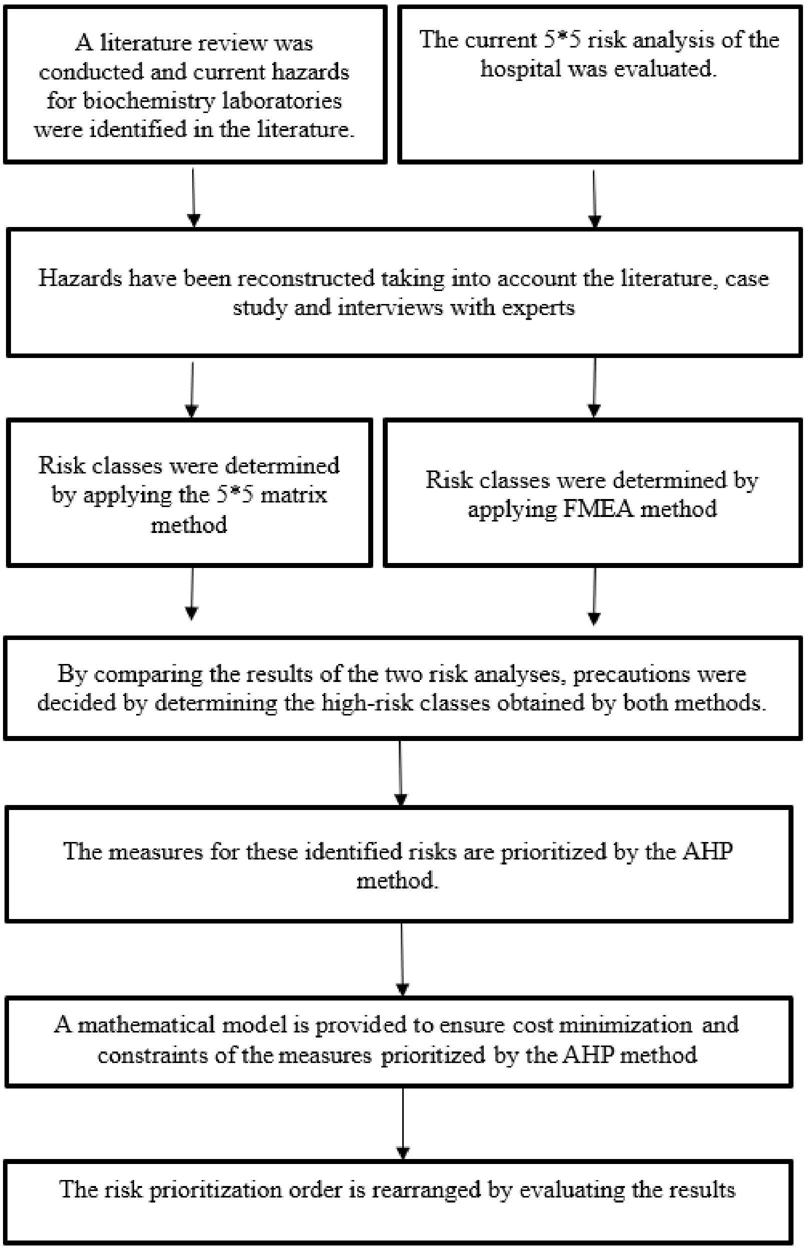
Classical risk assessment approaches with the integration of MCDM methods into risk analysis practices in the field of occupational health and safety are available in the literature (Aguiar et al., 2010). This method eliminates the difficulties to calculate a precise risk score and determine the measures (Yılmaz and Şenol, 2017). Recently, Fuzzy FMEA and Fuzzy AHP applications have been widely used in risk analysis and MCDM. In a study, risk events occurring throughout the supply chain are determined by FFMEA and five priority risk events are prioritized with FAHP (Trengonowati et al., 2021). The selection and treatment of waste (physical, chemical, biological) and disposal (incineration, storage, supercritical water oxidation/gasification) and their environmental, technological, cost and social/ergonomic assessment perspectives and risk assessment have been applied with an integrated MCDM (Adar et al., 2020). In addition, there are several studies that deal with the mathematical programming model and risk analysis in an integrated manner (Derse and Göçmen, 2021).

As mentioned in the introduction section, this work is first to deal with the healthcare problem using FMEA, 5x5 matrix, AHP and mathematical modelling methods. All methods are dependent upon the results of each other. Each output of a method is an input for other.

III. MATERIAL AND METHOD

The biochemistry laboratory, in which the case study is performed is a hospital laboratory with a capacity of 143 beds, 66 of which are intensive care units. The real-case data is obtained by the occupational health and safety experts in the hospital. The flow of the method is consisted of the following stages (Figure 1):

Figure 1. **Flowchart of the Proposed Method**



3.1. Risk analysis methods

Table 1 demonstrates the available risks of the biochemistry unit used in this paper. Main risks and sub risks demonstrated in two columns are obtained from the biochemistry unit and prior studies. The sub risks discussed in prior studies are indicated with symbol Δ .

Table 1. Risks and Sub-Risks of the Biochemistry Unit

Risk	Sub-risks
Infection	Contamination of blood and body fluids through contact with skin
	Contamination of blood and body fluids through contact with eye
	Transmission of infection-induced physical environment
	Injury with a cutting tool
	Respiratory diseases transmitted through inhalation from patients
	Infection due to medical / chemical waste / cutting-piercing tool boxes accidents
	ΔIrrigation and infection by dryness in mouth and nose mucosis as a result of moisture decrease (Sabuncu et al., 2012)
Radiation	Radiation exposure due to the use of scopy
	ΔExposure to radiation due to ionized beams (Bolukbasi, 1999)
Noise	Exposure to noise
Dangerous material	Chemical spillage-splash accident injuries, burns, allergic reactions
	Injuries and burns due to use of pressurized oxygen cylinders
	Diseases caused by inhalation of toxic gases due to leaks in the system
	Δ Health diseases by solvents, chemotherapic agents (Ozvaris, 1999)
	ΔCell damage by harmaceutical material, gluteraldehid, latex (Parlar, 2008)
Allergy	Skin energy due to allergen use (latex gloves, etc.)
	Skin allergy due to hand sanitizer / disinfectant use
	Drug reaction due to drug splashes
Ergonomic	Employee injuries caused by falling or rolling over of items that are not fixed to the wall, floor, or falling / rolling goods or materials that cannot be fixed
	Crash, squeeze, fall and injury due to the irregular placement of items in the work environment
	Musculoskeletal / vascular diseases caused by prolonged standing
	Body injuries occurring patient handling and turning, pulling, moving
	Wrist / neck disorders due to long term computer use
	Sprain and injury due to wet / slippery ground by sliding, stumbling, falling and compression
	ΔHealth problems due to physical factors, lighting, temperature, noise (Ozdener et al., 2004)
	ΔMovement restriction and disability due to physical and psychosocial risks during the study (Ozcan and Kesiktas, 2007)
Communication	Anger, stress development related to communication with patients / patient relatives
	Being sued
Violence	Physical violence (assault, assault, etc.)
	Verbal violence (insults, threats, slander, etc.)
	Sexual harassment (verbal or physical)
	Δ Overload, monotone working conditions (Tayran and Talas, 2001)
	Δwork stress due to feeling under pressure due to low wages, shift work, etc. (Ozkaya et al., 2008).
Electric shock	Distortions due to electrical leakage in devices
	Electrical burn due to defibrillator use

All risks and sub risks obtained from the biochemistry laboratory in this paper are demonstrated as above. Those risks are organized based on historical data of accidents. Some risks are not considered since their low risk scores can be neglected. Risks and current measures by the hospital administration are provided in Table 2.

Table 2. Safety Measures Implemented by the Biochemistry Experts

Risk	Safety measures
Infection	Personal protective equipment is used, hand hygiene is checked, employees are informed and department training is carried out. Based on the contamination after injury, comprehensive control is carried out. Health screening plan is controlled by the department manager. Proper ventilation / air conditioning is provided.
Radiation	Scopy device is not used in the laboratory.
Noise	Devices that cause noise are maintained immediately.
Dangerousterial	Personal protective equipment is used, controls are carried out with the health screening plan and checked by the department manager.
Allergy	Alternative gloves are available in the department, hand protective cream is used. Disinfectant storage boxes are used in a controlled manner.
Ergonomic	Employees are trained on occupational safety and employee health (ergonomic hazards and risks). The working environment is arranged ergonomically such as fixings of items, cabinets, etc. More employees are assigned to patient transportation and translating. Used equipment is eliminated or sent for maintenance and repair. Warning signs are used for slippery floor in the required areas.
Communication	Employees are trained to increase their professional knowledge and skills through communication, stress management and anger control. Security personnel are available for 24 hours. Areas of the hospital are monitored by security camera. White code call and violence notification is conducted.
Violence	Employees are trained to increase their professional knowledge and skills through communication, stress management and anger control. Security personnel are available for 24 hours. Areas of the hospital are monitored by security camera. White code call and violence notification is conducted.
Electric shock	Electrical tools and equipment are kept away from potential water (dirty-clean) flooding areas. Training on electrical safety is provided. Damaged equipment is eliminated, maintenance and repair is provided. Technical service is informed for damaged electrical devices. Defective equipment is sent for maintenance and repair, and it is identified with the warning letter "do not use". Electrical safety measures are followed.

In the Table above, the risks that could occur in biochemistry laboratories have been provided. Experts present their assessments considering the current risk situation of the hospital. Many workplaces may have different hazards for employees, and different risk analysis methods can be used to identify and evaluate them.

Risk score value is calculated to determine the class between A-E in the 5x5 matrix method. Occurrence and severity are used as risk factors in the 5x5 matrix method. The risk score is obtained by probability * severity. If risk score is 1,2; the situation is reported and named acceptable risk group. Trainings are increased and named low risk group if the number is 3,4; while to follow the available controls is required if the number is 5,6,8,9,10,12. If risk score is 15,16,20; high priority risks are determined and named high risk group. Stopping the work and taking measures immediately are important if the number is 25.

FMEA is developed by the U.S military and they publish a safety standard named ‘MIL–P–1629” (US Department of Defence, 1980). Occurrence, severity, detectability are used as risk factors in this method. The risk score is obtained by occurrence * severity * detectability. Then, classes between A-E are decided. If risk priority number is under 20, the situation is reported. Controls and trainings are increased if the number is between 20 and 40 while to review and train is required if the number is between 40 and 100. Measures of the high priority risks are planned if the number is between 100 and 250. Stopping the work and taking measures immediately are important if the number is over 250.

FMEA and 5x5 matrix methods have been applied by the authors since quantitative proactive methods can include subjectivity. Different risk class results can be obtained even in the same method performed by different experts. Therefore, these two methods are repeated with the same team including biochemistry laboratory staff. The risk scores are calculated according to both methods and the classes are compared.

3.2. AHP Method

One of the most important and widely used MCDM tools is AHP. Saaty (1980) developed this method. AHP transforms the problem into a hierarchical structure, making it simpler, useful and understandable. Defining the problem in the AHP method is the first step. Following the definition of the problem, the problem is transformed into a hierarchical structure, each level consisting of certain criteria. These criteria are divided into sub-criteria. In order to develop a hierarchical structure and decide the necessary criteria, the whole system, its elements and their relations should be observed comprehensively.

The AHP is conducted by comparing the evaluation criteria in the risk assessment regard to their importance. The AHP method has been applied to identify the highest priority hazards. Unlike the prior studies, to priority measures have been conducted. Also, a mathematical model has been developed taking into consideration the weight values of these measures, cost of measures. The mathematical model is solved using the GAMS program.

3.3. Mathematical Programming Model

One of the optimization methods used to solve multi objective problems is the goal programming method. In this paper, a goal programming method is used since the presented study deals with the two different objectives, index, decision variables, parameters, objective function and constraints are discussed in the following:

Sets

i evaluation criteria index $i = 1, \ldots, I$

Decision variables

$$x_i = \begin{cases} 1, & if\ i.evaluation\ criteria\ is\ selected \\ 0, & otherwise \end{cases}$$

$$y1_i = \begin{cases} 1, & if\ 5\text{x}5\ matrix\ evaluation\ criteria\ is\ considered \\ 0, & otherwise \end{cases}$$

$$y2_i = \begin{cases} 1, & if\ FMEA\ evaluation\ criteria\ is\ considered \\ 0, & otherwise \end{cases}$$

d_j^+ positive value of deviating from target for target i equation $\mathrm{j} = 1, \ldots, 4$

d_j^- negative value of deviating from target for target i equation $\mathrm{j} = 1, \ldots, 4$

Parameters

$ahp(i)$ $ahp\ scores\ for\ i.evaluation\ criteria$
$c(i)$ $measure\ cost\ for\ i.evaluation\ criteria$
$fmea(i)$ $FMEA\ score\ for\ i.evaluation\ criteria$
$fxf(i)$ 5x5 $score\ for\ i.evaluation\ criteria$
$lowbudget\ minimum\ hospital\ budget$
$highbudget$ $maximum\ hospital\ budget$
$s1$ $working\ stop\ limit\ for$ 5x5
$s2$ $taking\ measure\ limit\ for$ 5x5
$s3$ $no\ measure\ limit\ for$ 5x5
$a1$ $working\ stop\ limit\ for\ FMEA$
$a2$ $taking\ measure\ limit\ for\ FMEA$
$a3$ $no\ measure\ limit\ for\ FMEA$
M $larger\ number$

Objective Function

z objective function value

$$Z = \mathrm{d}_1^+ + \mathrm{d}_1^- + \mathrm{d}_2^+ + \mathrm{d}_3^+ + \mathrm{d}_3^- + \mathrm{d}_4^+ + \mathrm{d}_4^- \qquad (1)$$

Constraints

Goal1

$$\sum_{\mathrm{i}}^{\mathrm{I}} \mathrm{ahp_i} * x_\mathrm{i} + \mathrm{d}_1^+ - \mathrm{d}_1^- = 0 \qquad (2)$$

Goal2

$$\sum_{\mathrm{i}}^{\mathrm{I}} \mathrm{c_i} * x_\mathrm{i} + \mathrm{d}_2^+ - \mathrm{d}_2^- = 0 \qquad (3)$$

Goal3

$$\sum_{\mathrm{i}}^{\mathrm{I}} \mathrm{fmea_i} * x_\mathrm{i} + \mathrm{d}_3^+ - \mathrm{d}_3^- = 0 \qquad (4)$$

Goal 4

$$\sum_{\mathrm{i}}^{\mathrm{I}} \mathrm{fxf_i} * x_\mathrm{i} + \mathrm{d}_4^+ - \mathrm{d}_4^- = 0 \qquad (5)$$

$$lowbudget \le \sum_{\mathrm{i}}^{\mathrm{I}} \mathrm{c_i} * x_\mathrm{i} \le highbudget \qquad (6)$$

$\mathrm{M} * y1_\mathrm{i} + (\mathrm{s} - \mathrm{fxf(i)}) \ge 0 \quad , \forall \mathrm{i}, s = s1, s2$ (7)
$\mathrm{M} * (1 - y1_\mathrm{i}) + (\mathrm{fxf(i)} - \mathrm{s}) \ge 0 \quad , \forall \mathrm{i}, \mathrm{s=s1, s2}$ (8)
$\mathrm{M} * y2_\mathrm{i} + (\mathrm{a} - \mathrm{fmea(i)}) \ge 0 \quad , \forall \mathrm{i}, \mathrm{a} = \mathrm{a1}, \mathrm{a2}$ (9)
$\mathrm{M} * (1 - y2_\mathrm{i}) + (\mathrm{fmea(i)} - \mathrm{a}) \ge 0 \quad , \forall \mathrm{i}, \mathrm{a} = \mathrm{a1}, \mathrm{a2}$ (10)
$y1_\mathrm{i} \le x_\mathrm{i} \quad , \forall \mathrm{i}$ (11)
$y2_\mathrm{i} \le x_\mathrm{i} \quad , \forall \mathrm{i}$ (12)

If (fxf(i) ≤ s3) , ∀i
{no measure is taken} (13)

If (fmea(i) ≤ a3) , ∀ i
{no measure is taken } (14)
dj^- , dj^+ ≥ 0 , $j = 1,2,3,4$ (15)
$y1_i, y2_i, x_i = (0, 1)$ (16)

Constraint (1) defines the goal function, in which to reach the most appropriate result with positive and negative deviating values is aimed. The negative and positive sling values related to d1, d3, d4 provide maximization while the sling value related to d2 aims to provide minimization. Constraint (2) defines to choose the maximum outcome of the AHP results, while choosing the minimum of the prevention costs in constraint (3) is aimed, selecting the ones with the maximum value by the FMEA method in constraint (4), constraint (5) is to select the ones with the maximum value by the 5x5 matrix. The value in constraint (6) indicates the lower and upper budget allocated by the hospital. Constraint (7) and constraint (8) are used to stop work or take precautionary measures for variables s1 and s2 according to the 5x5 matrix. Constraint (9) and constraint (10) are used to stop work or take precautionary measures for variables a1 and a2 according to the FMEA method. Constraint (11) and constraint (12) indicate to choose the risks of stopping work or taking precautionary measures by 5x5 matrix and FMEA method, respectively. Constraint (13) ensures to not taking measures for values below s3 for the 5x5 matrix, constraint (14) ensures to not taking measures for values below a3 for the FMEA method. Constraint (15) ensures that positive and negative sling values are positive. Constraint (16) defines that the variables y1i, y2i, xi are binary.

IV. RESULTS AND DISCUSSION

4.1. Results Related with the Risk Analysis

Risks obtained by the biochemistry laboratory and prior studies have been organized and proposed methods have been applied for these risk groups. Risk scores are obtained using FMEA and 5x5 matrix. Regarding risk scores, classes of each failures are revealed. Table 3 demonstrates the risk scores and classes obtained by both FMEA and 5x5 matrix. Total 23 number of risks are scored and assigned to the classes.

Table 3. **Evaluation of the Risks by FMEA and 5x5 Matrix**

Risk	Order no	Sub-risks	FMEA					5x5			
			O	S	D	Risk Score	Class	O	S	Risk Score	Class
Infection risk	1	Contamination of blood and body fluids through contact with skin	5	4	3	60	C	3	4	12	C
	2	Contamination of blood and body fluids through contact with eye	4	4	3	48	C	2	3	6	C
	3	Transmission of infection-induced physical environment	3	3	5	45	C	2	2	4	D
	4	Injury with a cutting tool	5	4	3	60	C	3	3	9	C
	5	Respiratory diseases transmitted through inhalation from patients	4	3	4	48	C	2	1	2	E
	6	Infection due to medical / chemical waste / cutting-piercing tool boxes accidents	4	4	6	96	C	2	3	6	C
Noise	7	Exposure to noise	6	3	1	18	D	3	3	9	C
Dangerous materials	8	Chemical spillage-splash accident injuries, burns, allergic reactions	3	5	5	75	C	2	2	4	D
	9	Injuries and burns due to use of pressurized oxygen cylinders	8	1	7	56	C	2	5	10	C
Allergen	10	Skin energy due to allergen use (latex gloves, etc.)	5	3	2	30	D	3	2	6	C
	11	Skin allergy due to hand sanitizer / disinfectant use	6	3	2	36	D	3	2	6	C
Ergonomic	12	Employee injuries caused by falling or rolling over of items that are not fixed to the wall, floor, or falling / rolling goods or materials that cannot be fixed.	1	5	2	10	E	3	2	6	C
	13	Musculoskeletal / vascular diseases caused by prolonged standing	6	3	3	54	C	3	3	9	C
	14	Body injuries occurring patient handling and turning, pulling, moving	2	3	5	30	D	2	2	4	D
	15	Wrist / neck disorders due to long term computer use	6	3	5	90	C	4	3	12	C
	16	Sprain and injury due to wet / slippery ground by sliding, stumbling, falling and compression	3	5	2	30	D	2	2	4	D
	17	Movement restriction and disability due to physical and psychosocial risks during the study	5	3	3	45	C	3	2	6	C
Communication	18	Anger, stress development related to communication with patients / patient relatives	3	2	10	60	C	3	2	6	C
Violence	19	Physical violence (assault, assault, etc.)	3	4	7	84	C	2	3	6	C
	20	Verbal violence (insults, threats, slander, etc.)	6	2	2	24	D	2	2	4	D
	21	Sexual harassment (verbal or physical)	7	2	2	28	D	4	3	12	C
	22	Work stress due to feeling under pressure due to low wages, shift work, etc.	9	2	2	36	D	4	3	12	C
Electric Shock	23	Distortions due to electrical leakage in devices	2	7	7	98	C	2	4	8	C

In the Table above, risks are scored by FMEA and 5x5 matrix risk assessment methods. Risk scores and risk classes were determined by using FMEA and 5x5 methods based on the risk situations. Risk situations are named from 1 to 23 in the table. These sequence numbers will be used instead of names in the next steps. There are five class ranges in which the risk score results of the FMEA, RPN score and the 5x5 matrix are evaluated. The risk scores found by these two methods and the corresponding risk classes were determined. When the results obtained with the two methods were compared, it was determined that there were different risk classes. Considering the results obtained with the two methods, it was decided to take precautions for all hazards with high risk scores obtained by the two methods in order to completely eliminate the risk factor and bring it to an acceptable level.

In the study, according to FMEA and 5x5 risk scores, C and D classes are determined that should be taken precautions. According to these results, 9 of the 35 hazards identified are in different precaution groups. These hazards are contamination from the physical environment, respiratory diseases transmitted from patients by inhalation, exposure to noise, accident injuries due to chemical spills and splashes, skin allergy due to the use of allergen materials (latex gloves, etc.), skin allergy due to the use of hand antiseptic / disinfectant, wall It is the work stress caused by feeling under pressure due to the falling or overturning of unfixed items, falling or rolling of unfixed items/materials, excessive workload and uniform working conditions, low wages, and shift work. Risk scores obtained according to FMEA and 5x5 method may contain similarities and differences as seen in Table 3. The ranking of the 23 risks addressed may differ when prioritized by the AHP method and prioritized by the integrated mathematical model. This shows that cost is an important parameter.

4.2. Results regarding MCDM

In the risk analysis method, failure modes with higher risk scores are decided and they require more immediate measures. AHP method is applied to calculate the weight of each measures. Accordingly, hospital should organize proper corrective activities regarding resource constraints such as time, cost, etc.

In the Table 4 below, FMEA and 5x5 matrices are compared. The FMEA criterion is weighted as 0.6 and the 5x5 matrix as 0.4. While the number of evaluation variables in FMEA is 3 as occurrence, severity and detectability, and in 5x5, the number of variables is 2 as probability and severity.

Table 4. **Obtained results by the AHP**

Order number of Criteria	**AHP Score**	**Ordering by AHP comparing**	**Order number of Criteria**	**AHP Score**	**Ordering by AHP comparing**
1	0.060455605	4	13	0.049992866	8
2	0.039530128	13	14	0.025319827	20-21
3	0.033071765	16	15	0.075959481	1
4	0.053093642	7	16	0,025319827	20-21
5	0.029714177	19	17	0.03797974	14
6	0.064336329	3	18	0.045731678	11
7	0.031388215	17	19	0.058134779	5
8	0.048575641	9	20	0.022219052	22
9	0.053480446	6	21	0.043918137	12
10	0.030227802	18	22	0.048052504	10
11	0.033328578	15	23	0.070277897	2
12	0.019891885	23	Total	1	

As a result of the AHP comparisons, the ranking of the criteria has changed and as seen in the table, the 15th criterion named “wrist / neck disorders due to long term computer use” has become the most important risk to take measures.

4.3. Results related to Mathematical Programming Model

In this step, a goal programming is applied to choose the maximum outcome of the AHP results, while choosing the minimum of the prevention costs. The model considers not only risk results but also risk budget values. Table 5 demonstrates the measures for assigned budget.

Table 5. Measures based on the Results of Proposed Methods

Risk	Measures
Infection	Employees should attend to trainings, personal protective use, hand hygiene audits should be conducted carefully.
Noise	The sound levels specified in the user manual of the devices should be checked and headphones should be kept if the noise is exceed 80 dB (a).
Dangerous material	Employee participation should be ensured to the training. Personal protective equipment should be provided.
Allergy	Personal protective equipment should be provided. Employee participation should be ensured to the training.
Ergonomic	Employees should participate in occupational health and safety (ergonomic hazards and risks) training,
Communication	Employees should participate to trainings about communication, stress management and anger control trainings regularly, social organizations should be organized, psychological support should be provided to employees, An exercise should be applied to go to the white code call as soon as possible.
Violence	
Electric shock	Maintenance and calibration of electrical appliances should be conducted regularly. Faulty leakage relays should be changed.

In the study, the evaluation criterion index defined as 'i' is taken as 23 since number of risks is 23. Table 6 ensures to mathematical model parameters provided in the paper. The parameters discussed in the study are provided with the descriptions in the table.

Table 6. Mathematical Model Parameters

Parameter	Definition
ahp(i)	Results from AHP
c(i)	Prevention costs for risks
fmea(i)	Results from FMEA
fxf(i)	Results from 5x5
s1, s2, s3	Prevention levels for 5x5 matrix
a1, a2, a3	Prevention levels for FMEA
M	Large number

According to the 5 * 5 matrix, s1 is defined as 25 for variable criteria that need to be stopped. S2 is defined as 15 and above. Since the study does not include 15 and above, the initial value of $y1_i$ is 0. According to the FMEA matrix, 250 is defined as a1 for variable criteria that must be stopped. For a2, 100 and above are defined. Since the study does not include 100 and above, the initial value of $y2_i$ is 0. The minimum budget limit is identified in the hospital is 50000, and the maximum budget limit is 150000. Table 7 provides the criteria situations and the criteria that are important to take measures.

Table 7. Criteria Situations

Selection/ Not Selection of evaluation criteria	**Criteria that are firstly important to take measure**
x_i	**1** Contamination of blood and body fluids through contact with skin
	6 Infection due to medical / chemical waste / cutting-piercing tool boxes accidents
	15 wrist / neck disorders due to long term computer use
	17 movement restriction and disability due to physical and psychosocial risks during the study
	19 physical violence (assault, assault, etc.)
	21 sexual harassment (verbal or physical)
	22 work stress due to feeling under pressure due to low wages, shift work, etc.
	23 distortions due to electrical leakage in devices

According to the results obtained from the mathematical model established, the first risk type to be taken are 1 (Contamination of blood and body fluids through contact with skin), 6 (infection due to medical / chemical waste / cutting-piercing tool boxes accidents), 15 (wrist / neck disorders due to long term computer use), 17 (movement restriction and injury due to physical and psychosocial risks during work), 19 (physical violence (assault, assault, etc.), 21 (sexual harassment (verbal or physical), 22 (work stress due to feeling under pressure due to low wages, shift work, etc.), 23 (distortions due to electrical leakage in devices).

4.4. Sensitivity Analysis

Sensitivity analysis examines the results by changing the parameters in the mathematical programming model. Table 8 provides that sensitivity analysis conducted reveals that which risks need precautions as a result of changing 50000, which is the lower limit set by the hospital.

Table 8. Changing of the Risk Values by Budget Value

Budget low level	**Risks**
50000	1,6,15,17,19,21,22,23
55000	1,**5**,6,**12,13**,15,21,22,23
60000	1,**5**,6,**8,12,13**,15,21,22,23
65000	1,**2,3**,6,**9**,15,17,19,21,22,23

As a result of the increase in the low level of budget as 55000, 5th risk (respiratory diseases transmitted through inhalation from patients), 12 (injuries caused by falling or rolling over of items that are not fixed to the wall, floor, or falling or rolling of items / materials that cannot be fixed), 13 (musculoskeletal / vascular diseases caused by prolonged standing) are added. As 60000 budget, 8th risk (chemical spillage-splash accident injuries, burns, allergic reactions) are added. As 65000, 2 (Contamination of blood and body fluids through contact with eye), 3 (Transmission of infection-induced physical environment) and 9 (Injuries and burns due to use of pressurized oxygen cylinders) are added.

V. CONCLUSION

Risk management tools ensure to reduce or eliminate the risk types and investigate the consequences on personal, systems, etc. One of the most widely used risk management tools are FMEA and 5x5 matrix and AHP method. In this paper, an integrated method including FMEA method, 5x5 matrix method, a mathematical model and AHP is discussed and prevention costs are incorporated into the study for the risk measures. Obtained results from the mathematical model propose that the most important risks to take measures are contamination of blood and body fluids through contact with skin, infection due to medical / chemical waste / cutting-piercing tool boxes accidents, wrist / neck disorders due to long term computer use, movement restriction and injury due to physical and psychosocial risks during work, physical violence (assault, assault, etc., sexual harassment, verbal or physical, work stress due to feeling under pressure due to low wages, shift work, etc., distortions due to electrical leakage in devices, respectively.

Comprehensive risk management is conducted to prioritize the risk types and prevent of potential results of hazards by the decision makers in the various sectors. Healthcare sector is one of these risky sectors in terms of human living. The effective management of the hospitals ensures to improve the system safety and reduces the risks to an acceptable level or eliminates them. Proactive methods should be applied to prevent these hazards in the critical units of the hospitals. The integrated approach could be useful tool for the decision makers to prioritize the risks to take measures and use budget efficiently. For future works, the proposed method can be used in other sectors to validate the reliability. New MCDM methods could be used under fuzzy environment.

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