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ORIGINAL ARTICLE

Fire and Spillage Risk Assessment Pattern in Scientific Laboratories

MANOUCHEHR OMIDVARI[1*], N MANSOURI[2]

[1]*Industrial and Mechanical Engineering Faculty, Islamic Azad University, Qazvin Branch, Qazvin, Iran;* [2]*Graduate School of the Environment and Energy, Science and Research Branch, Islamic Azad University, Tehran, Iran.*

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ABSTRACT

Material hazards are the most important risk in scientific laboratories. In risk assessment processing, the potential impact of assessor personal judgment is the most important issue. This study tried to develop a risk assessment pattern based on Failure Mode and Effect Analysis (FMEA) and Analytical Hierarchy Process (AHP) logics and empirical data in scientific laboratories. The most important issues were high pressure reservoirs and hardware failure fuel. The other type of data about building plan, evacuation procedure and ability of hazard detection were also collected. Both groups of data were used as input to construct the model. Information integration plays a key role in the performance of fire and spillage risk assessment. For this purpose, a method based on analytical hierarchy process theories was applied to investigate the multi-hierarchy and multi-factor assessment problems. Testing the conceptual model for material risk assessment was performed in the proposed site. The results showed that the Laboratories of Sciences and Research Campus of Azad University were not suitably safe according to the fire and spillage risk assessment model. To reduce the risk probability, all of occupants in the buildings were required to be trained and automatic fire fighting and spillage detection system and adjustable fire exit and emergency stairs should be installed.

Keywords: *Fire, Spillage, AHP, FMEA, Scientific laboratories*

INTRODUCTION

Educational centers were the most important society centers in crisis management. Although there were a lot of installed safeties systems in the educational center units such as: laboratories, libraries and warehouses but still many accidents have been frequently reported from them. They have potential to cause serious injury to personnel, major damage to equipment, structure, scientific and invaluable documents and disruption of educational operation. The past few decades had seen a wide range of major accidents with a number of fatalities, economic losses and damage to the invaluable documents in educational center. Fire in the library of Faculty of Law in University of Tehran in 1995 burned the invaluable historical documents. Explosion in biochemistry laboratory in Tarbiat Modarres University, Tehran Iran, resulted in death of a person and loss of many laboratory equipments in 1996. In fire risk assessment of a building, occupants evacuating was a most crucial parameter which needs emergency exit and necessary tools in advance.

Historically, Iran has suffered from many damages emanating from fire and material spillage.

Risk management system presentation in high risk centers is one of the requirements which has recommended by many standard organizations and centers. The loss for an organization with a strong emergency response system could be reduced to 6% of

*** Corresponding author:** Manouchehr Omidvari, E-mail: omidvari88@yahoo.com

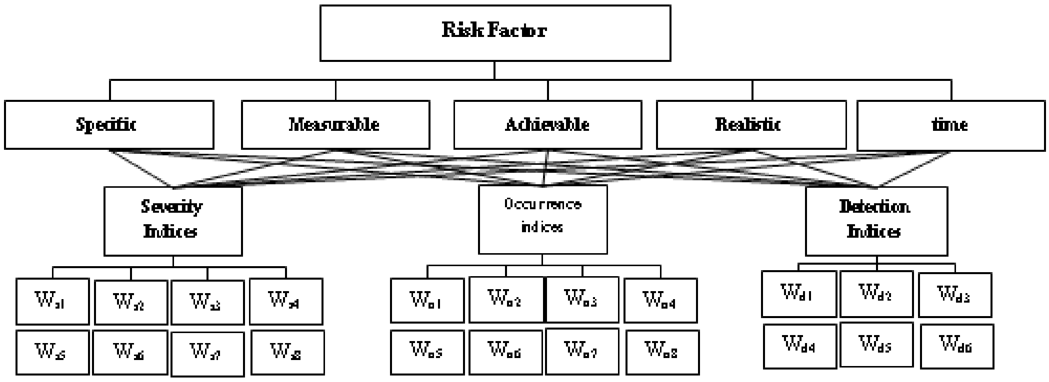

Fig 1. Hierarchical structure for Fire and Spillage Risk

the loss for the same organization with poor emergency system [1, 2]. Kobes and colleagues had summarized the factors contributing to the building safety and people behaviors at the time of fire break-out into 3 categories:

1. Types of building
2. The people characteristics
3. The type of fire

They demonstrated that the factors and conditions created these categories influence the evacuation time, building vulnerability and finally the fire break-out risk buildings face [3]. Discussing the risk management in scientific laboratories, it was concluded that factors are such as the exit doors location, the aisles width and number of occupant in the scientific laboratories influence the risk number [4]. Due to large number of occupants and complexity of the buildings in scientific laboratories of educational centers, once fire occurs, the evacuation was a major problem and might be resulted in many people casualty [5]. It was difficult to make a precise assessment on probability and consequence of every fire and spillage scenario, but their lower bound and upper bound could be achieved based on statistical data [1, 6].

An issue of great concern in risk assessment is potential impact of personal judgment and assessor's attitudes which may result various evaluations of a single risk [7]. Personal judgments impact in risk assessment is one of the most important disadvantages of Failure Mode and Effect Analysis (FMEA) method. In this regard, Analytical Hierarchy Process (AHP) method has been used to solve the problem. Therefore, materials spillage and fire risks can be assessed precisely by determining effective factors weights in each one of these three ones (Detection, Severity and Occurrence) [7]. Fire and material spillage risk assessment was a multi-hierarchy and multi-factor document system. AHP which has been used in many fields is an applicable method to deal with multi-factor and multi-hierarchy assessment problems [8, 9]. Rehan constructed three-level hierarchy system to asses environmental and the aggregative risk for different discharge scenarios that were calculated layer-by-layer [10]. In recent decades, education population has increased very quickly in Iran. However, providing many large scale educational buildings, high-rise buildings, and large number of people in them made risk number very high and may induce many people casualty in the case of fire and toxic material spillage occurring. Hence it was necessary to perform a fire and material spillage risk assessment as a basic tool for the implementation of appropriated mitigation measures and emergency response plans to promote personnel safety as well as equipment. In order to provide a pattern fire and material spillage risk assessment in scientific laboratories and help it, a suitable method for inspection, assessment and mitigation is required.

The object of this study was to present a pattern for material spillage and fire risk assessment in scientific laboratories.

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MATERIALS AND METHODS

FMEA was as an appropriate method to assess material spillage and fire risks in laboratory. We used a questionnaire to collect data on the factors influencing the level of fire and material spillage risk and the degree to which scientific laboratories are well-prepared to cope with disasters. The risk assessment method used in this study was FMEA. RPN (Risk Priority Number) has been defined in FMEA method. The RPN is defined in equation 1[11].

Eq. (1) = $RPN = O \times S \times D$ (1)

O: Occurrence of risk
S: Severity of risk
D: Detection of risk

The factors influencing fire and material spillage risk were divided into 3 categories:

1) Occurrence of fire and material spillage risk,
2) Severity of fire and material spillage risk,
3) Detection of fire and material spillage risk.

Then, the experts have consulted to derive the factors influencing each parameter. In this study expert is the one who has adequate information about evaluating fire and spillage risk in scientific laboratories and who is familiar to AHP. In this study, number of expert is 5.

Number of expert was calculated according to Cochran formula [12, 13].

The reliability of questionary was estimated via Cronbach's alpha (perceptions 92% and expectations 90%) by SPSS software. The Cronbach's Alpha was 0.86.To better understand the conditions of indices and their grouping method, a schematic plan of the hierarchy structure is shown in Fig 1.

According to opinion experts; none of criteria's and indices do not depended together. The resulting factors were weighted against the questionnaire and the data given by the experts.

In the next step, it was needed to determine the level of severity, occurrence and to detection factor of hazards. Information integration was one of the cores in the performance of fire and material spillage risk assessment. In order to integrate the information from questionnaires, a method based on AHP theory could put forward to solve the multi-hierarchy and multi-factor assessment problem [13-15]. The effective factors of severity, occurrence and detection fire and material spillage risk that calculated by AHP, are showed in Table 1. It shows the influential factors and their estimations in these parameters. The weight of each factor influencing the fire and material spillage risk was estimated using AHP. The weights of effective parameters were determined by AHP method. Matrix Eq. (2) was the pair wise matrix of effective elements. The inconsistency index was defined as Eq. (3) [12, 13].

$$w_{(O,S,D)} = \begin{bmatrix} 1 & a_i & . & . & . & . & . & a_n \\ \frac{1}{a_i} & 1 & & & & & & . \\ . & & 1 & & & & & . \\ . & & & 1 & & & & . \\ . & & & & 1 & & & . \\ . & & & & & 1 & & . \\ . & & & & & & 1 & . \\ \frac{1}{a_n} & . & . & . & . & . & . & 1 \end{bmatrix} \rightarrow w_{(O,S,D)i} = \begin{matrix} w_{(O,S,D)1} \\ . \\ . \\ . \\ . \\ . \\ . \\ w_{(O,S,D)n} \end{matrix} \rightarrow W_{(O,S,D)} = \sum_{i=1}^{n} w_i = 1 \quad (2)$$

$$Eq.(3) = I.I. = \frac{\lambda_{\max} - n}{n-1} \rightarrow I.R. \prec 0.1 \quad (3)$$

The occurrence, severity and detection effective parameters of fire and material spillage in scientific laboratories are showed in Table 1.

In the next step, the score of Occurrence, Severity and Detection should be calculated. The following procedures were used to calculate the score:

$$Eq.(4) = O = 10W_O \quad (4)$$

$$Eq(5) = S = 10W_S \quad (5)$$

$$Eq.(6) = D = 10W_D \quad (6)$$

Drawing on the resulting weights, risk priority number (RPN) is calculated as in Eq. (1).

The RPN, which is computed as the product of the occurrence, the severity and the detect ability of the considered failure mode, is shown in Table 2.

Aiming at improving material safety management through material spillage risk assessment in scientific laboratories, six emergency management goals including initiate rapid response, control incident and prevent escalation, evacuated, escape and rescue, protect lives, protect environment and protect assets were established in scientific laboratories. The frame diagram of fire and material spillage risk assessment method is shown in Fig 2.

Effective factors for material spillage and fire Risk include; occupant characteristics (such as age, experience, seeking information, informing others, collecting belongings, and choosing an exit) and building characteristics or building layout (such as corridor width, exit numbers and widths), etc. Another effective factor in fire and material spillage risk is onset time. If onset time to untenable condition is smaller than evacuation time, casualties may occur. Number of people remaining in building is related to probability density distribution of onset time to untenable condition. All of these parameters in fire and material spillage risk assessment should be directly or indirectly assessed. Base on the results of this research stage, an assessing checklist is designed.

Fire and material spillage risk assessment process was started with hazard identification. This task is usually accomplished using suitable formal techniques of hazard identification, and expert's assessment with support of the historical data results on accidents that occurred in the past. In practice, it is done by working systematically with a check list, as it was done in this work. The most important parameters in the check list were type and measure of used material, building layout, evacuation time, number of persons who work in laboratory building, ability of hazard detection or detection probability (safety measure) and frequency of fire and spillage accident. To determined the validity of proposed method. The RPN were determined by 4 assessors. The result of this stage was compared by *t*-test.

RESULTS

With the most score of 0.16 "usage material flammable", 0.15 score" usage material toxic" and 0.1 score "keeping of material state" was considered as the most important alternative in occurrence risk category for fire and spillage risk assessment. The most score of 0.260 score "pressure thank in laboratories" and 0.101 score "Automatic firefighting equipment" in severity category for fire and spillage risk assessment. The most score of 0.241 "fire and spillage detection equipment" 0.172 score "thermal control devices" in detection category for fire and spillage risk assessment (Table 1).

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Table 1. Factors influencing the vulnerability parameters and their weight

Parameter	**Influential factors**		**Indices weight (w_i) AHP**	**Indices weight FMEA**
Occurrence of fire and material spillage risk (O)	Kind of Material (W_{o1})	Is usage material flammable	0.15	1.5
		Is usage material toxic	0.16	1.6
	keeping of Material state(W_{o2})		0.101	1.01
	Explosion state (W_{o3})	Is there any pressure tank in laboratory	0.013	0.13
		Is there any explosive examination in laboratory	0.1	1
	Is electrical system standard (W_{o4})		0.091	0.91
	Transportation of material (W_{o5})		0.046	0.46
	Occupant characteristics (W_{o6})	Trained	0.025	0.25
		Experienced	0.045	0.45
	Is there any ignition source in laboratory (W_{o7})		0.076	0.76
	Heating and cooling system (W_{o8})	Central system	0.043	0.43
		Electrical heater	0.06	0.6
		Gas heater	0.09	0.9
Total			1	10
Severity of fire and material spillage risk (S)	Material state (W_{s1})	Using Explosive material	0.07	0.7
		keeping Toxic and Explosive material	0.04	0.4
		Is there any flammable and Toxic material in neighboring place?	0.05	0.5
	Physical state of material (W_{s2})	Vapor	0.018	0.18
		Liquid	0.014	0.14
		Powder	0.01	0.1
	Number of person (W_{s3})	More than 10	0.09	0.9
		Less than 10	0.012	0.12
	Is there any famous person in laboratory (W_{s4})		0.04	0.4
	Utilization of neighboring place (W_{s5})	Conference salon	0.05	0.5
		Ware house	0.02	0.2
	Firefighting equipment (W_{s6})	Manual firefighting equipment	0.061	0.61
		Automatic firefighting equipment	0.101	1.01
	Is there any pressure tank in laboratory (W_{s7})		0.260	2.6
	Exit line (W_{s8})	Location of door	0.05	0.5
		Type of door lock	0.03	0.3
		Width of corridor	0.044	0.44
		Is there suitable Emergency stair in building	0.04	0.4
Total			1	10
Detection of fire and material spillage risk (D)	Is there CCTVs (W_{D1})		0.17	1.7
	Is there fire and material spillage detection (W_{D2})		0.241	2.41
	Is there any Auto fire fighting ,Sprinkler (W_{D3})		0.201	2.01
	Is there any Fire extinguisher (W_{D4})		0.136	1.36
	Is there any Environmental Thermal control devices (W_{D5})		0.172	1.72
	Is there any routine inspection system (W_{D6})		0.080	0.8
Total			1	10

The mentioned method for fire and spillage risk assessment was studied in Scientific Laboratories of Sciences and Research Campus of Islamic Azad University, one of the greatest universities in Tehran, Iran. Totally 8 buildings were included in this study that three of them were educational and the rest were related to the laboratories. All of the laboratories gain the central heating and cooling system but due to inefficiency of the system, many personnel used their own electrical heaters. There was no emergency planning in these scientific laboratories. Exit door and emergency stair was not suitable. All of exit doors were opened toward in. Number and width of fire exit doors were not well proportioned with the number of occupants. These exit doors caused confusion in evacuation. Manner of flammable and toxic material keeping is not suitable. For example, the place of keeping flammable and toxic material is hot and uncontrolled. The other characteristic of laboratories are shown in Table 3.

Risk calculation based on suggested method has been calculated. The RPN score of fire and spillage risk in each scientific laboratory building has been shown in Fig 3.

Laboratories building were assessed laboratories building by all assessors' similarity. The RPN of risk was assessed by assessors were equal (P_{value}<0.05). Most of laboratories in Science and Research Branch of Azad University are not capable of an appropriate response in the case of fire and material spillage. Therefore their fire and material spillage risk levels were high.

Table 2. Decision-making for risk level estimation

Rank (RPN)	Description of probability of danger accordance	Degree
>201	Urgent measures are required, corrective measures should be taken quickly	High
200-101	Corrections should be carried out (un acceptable risk or tolerable risk)	Moderate
<100	Monitoring and control are required (acceptable risk)	Low

Among the reasons of higher fire risk, unsafe ignition sources, untrained personnel, materials control, lack of regular maintenance for fire detection system, pressure tank stabilization of the buildings, uninstall CCTVs inside the labs, manner of material keeping and uninstall auto fire extinction systems are more important.

DISCUSSION

The results pointed out that safety management in universities is an important issue which must be considered precisely. The existence of risk and inappropriate control over them and also the existence of valuable equipments, scientific and social human resources compel us to have adequate preparedness rate [7]. An issue of great concern in risk assessment is the potential impact of the personal judgment and attitudes of the assessor which may result in various assessments of a single risk [16]. In this article, attempts are made to determine the potential degree of influence of each parameter underlying the fire and spillage risk utilizing the AHP method as an original and pioneering application at this stage of the study of risk assessment. Besides, the proposed model may pave the way for reducing the contaminating effect of assessor's personal judgments and enhance consistency of assessment of the factors influencing safety in scientific laboratories by various individuals.

Various parameters were effective in toxic materials

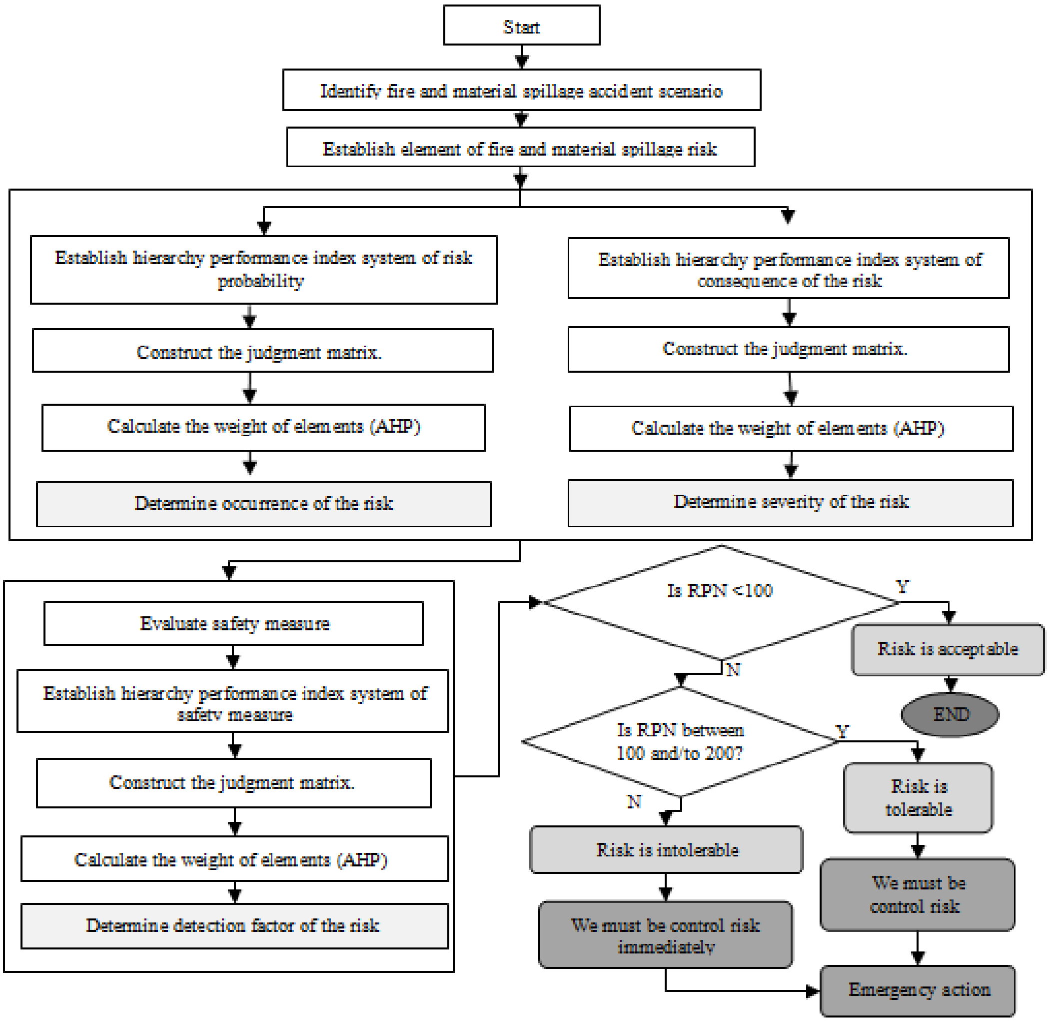

Fig 2. Frame diagram of fire and spillage risk management

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Table 3. Investigation the laboratory characteristics for fire risk assessment

Laboratory building name	Number of laboratory in each building	Average of occupant in each laboratory	experience & age of occupants	fire fighting	Emergency exit & stairway	Manner of material keeping	Is there any flammable material
Laboratory 1	6	18	N	Y	Unsuitable	-	N
Laboratory complex	45	20	N	Y	Unsuitable	Unsuitable	Y
Physics plasma	8	5	Y	Y	Unsuitable	Suitable	Y
Old Physics building	10	5	Y	Y	Unsuitable	Unsuitable	Y
Metal logical laboratory	9	15	N	Y	Unsuitable	-	N

laboratory Building name	Natural gas	Pressure tanks	Transporting material	Neighbors	Fire detection	Electrical devices
Laboratory 1	Y	Y	Suitable	Uncritical	Y	Unsuitable
Laboratory complex	Y	Y	Suitable	Critical	Y	Unsuitable
Physics plasma	Y	Y	Suitable	Critical	Y	Suitable
Old Physics building	Y	Y	Suitable	Critical	Y	Suitable
Metal logical laboratory	Y	Y	Suitable	Critical	Y	Unsuitable

Laboratory building name	thermal control devices	Sprinkler	$CCTV_s$	training	Quantity of Flammable material	Electrical system
Laboratory 1	N	N	N	N	Low	Suitable
Laboratory complex	N	N	N	N	High	Suitable
Physics plasma	N	N	N	N	Low	Suitable
Old Physics building	N	N	N	N	High	Suitable
Metal logical laboratory	N	N	N	N	Low	Unsuitable

spillage and fire risk assessment. This parameter was influenced by different factors; the most important parameters were the number and characteristics of occupants [3]. One of the parameters influencing severity of material spillage and fire risk was people and their characteristics. The weight of occupant characterizes is

0.07. The present study has also taken into account same parameter namely number and characteristics of occupants as an important factor influencing fire & material spillage risk of scientific laboratories.

The other influenced factors in fire and spillage risk are layout and structure of the building. The weight of layout and structure is 0.164. If structure and layout of building is good, the level of risk has significantly decreased. We have offered a model base on a set of factors influencing the layout and structure of buildings. This model had been included in the present study, many researchers estimated fire on the basis of structure and layout problems in a building field whereas the present study maintains the fire was influenced by factors beyond building domain, dealing with other factors as well [17, 18]. Chow proposed that the new buildings layout needs to be designed in such a way that the time needed for evacuation buildings and severity of risk is reduced. This, in turn, reduces the fire and spillage material risk [19]. Present study has also taken into account the same parameter namely volume of properties and assets as an important factor influencing fire & material spillage risk of educational centers. Offering a model on the basis of a set of factors influencing the layout and structure of buildings

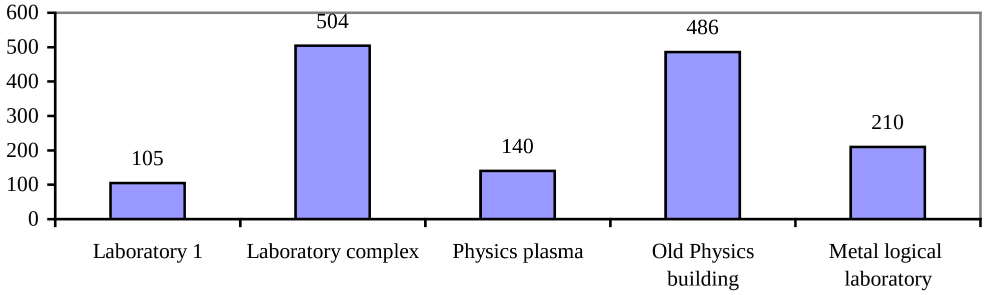

Fig 3. RPN of material spillage and fire risk in each laboratory building

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included in the present study, Martinelli et al., (2008) as well as Sconwiese et al., (2003) and Emanual (2005) estimated severity of risk on the basis of economic problems in a society whereas the present study maintains that severity of risk is influenced by factors beyond the economic domain, dealing with other factors as well [15, 20, 21].

CONCLUSION

With this method, just the worse indices and suggestions are provided for improving the emergency planning definitely. The originality of the method lies, among other things, in its capability to gear the control activities to the three aforementioned levels and, hence, to help agents and managers take the right measures in order to minimize the impact of the factor underlying the corresponding risk. The findings indicate that many parameters, including building structure, people and detection and control devices influence the fire and material spillage risk. The building where expensive hazardous materials and equipment are kept can have greater safety value. Building used for learning objectives, with no hazardous material, is subject to less risk. So, rules related with the fire and material spillage should be studied in order to eliminate its deficiencies and to increase safety systems efficiency. Judgment about severity rate determination and risk probability based on effective events could increase evaluation accuracy in this method than others. Also, the proposed model may pave the way for reducing the contamination effect of assessor's personal judgments and enhancing consistency of the factors assessment which influence fire and material spillage risk by various individuals in higher education centers.

In this article the weight of risk parameters (S, O & D) were supposed equal but in actual state the weight of FMEA parameters (S, O & D) are not equal and their variable should be calculated by MCDM Method.

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