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Health, safety and environmental risk management in laboratory fields

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Abstract
Background: Research project risks are uncertain contingent events or situations that, if transpire, will have positive or negative effects on objectives of a project. The Management of Health and Safety at Work (MHSW) Regulations 1999 require all employers and the self-employed persons to assess the risks from their work on anyone who may be affected by their activities. Risk assessment is the first step in risk-management procedure, and due to its importance, it has been deemed to be a vital process while having a unique place in the research-based management systems.

Methods: In this research, a two-pronged study was carried out. Firstly, health and safety issues were studied and analyzed by means of ISO 14121. Secondly, environmental issues were examined with the aid of Failure Mode and Effect Analysis. Both processes were utilized to determine the risk level independently for each research laboratory and corrective measure priorities in each field (laboratory).

Results: Data analysis showed that the total main and inherent risks in laboratory sites reduced by 38% to 86%. Upon comparing the average risk levels before and after implementing the control and protective actions utilizing risk management approaches which were separate from health, safety and environmental aspects, a highly effective significance (p<0.001) was obtained for inherent risk reduction. Analysis of health, safety and environmental control priorities with the purpose of comparing the ratio of the number of engineering measures to the amount of management ones showed a relatively significant increase.

Conclusion: The large number of engineering measures was attributed to the employment of a variety of time-worn machinery (old technologies) along with using devices without basic protection components.

Keywords: Total risk, Laboratory site, Risk management.

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Introduction

Quantitative risk analysis helps to lessen the likelihood of undesirable incidents and to minimize the possible adverse consequences. The use of Quantitative Risk Analysis (QRA) in process systems is a difficult task as component failures and incident consequences randomly vary from one process to another. Since each process system is made up of thousands of components and steps, it becomes very challenging to acquire the necessary quantitative information pertaining to all of them (1).

According to Olsson and Hillson, attempts to link risk with uncertainty based on the distinction between aleatory and epistemic uncertainty can be defined as: "risk is a measurable uncertainty and uncertainty is an immeasurable risk" (2,3). As stated previously, risk identification is the first step in risk management. The definition of each step is as follows:

1. Identification: Denotes the threats to a project.
2. Analysis: Recognizes the manner of such threats to the project.
3. Prioritization: Ranks the threats according to their impact.
4. Mitigation: Identifies possible preventive actions that reduce the effect of risk.

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5. Planning: Constructs a plan to be used for significant risks and is utilized prior to risks' occurrence (4).

6. Measuring and control: Manages, controls and traces the impact of risks to allow the goals of the project to be accomplished.

Risk ranking and filtering implements by breaking down the overall risk into risk components then evaluates them and their individual contributions to the overall risk (5).

Such a human risk reduction is the main issue of the health, safety and environmental management system (6). Danger exposure or, in other words, risk is a process that leads to ambiguous results in virtually all fields of research. However, risk or more appropriately termed 'process' always carries innovations that change the course of human history. The discoveries mankind has made in the field of science and technology are mainly a direct result of 'spirit of risk taking' (7) .The present study was conducted in an academic education center originally established to train postgraduate students in Tehran.

Risk assessment studies conducted by the US Environmental Protection Agency (EPA) and the Occupational Safety and Health Administration, have mainly used standard methods that focus on effective factors such as chemical exposure levels, type of exposure and duration of exposure to hazardous factors (8). Furthermore, in recent years, studies about the risks resulting from laboratory hazards have focused mainly on qualitative analysis of chemicals. Sayre conducted a study using a team with expertise in chemistry, engineering, toxicology, exposure assessment and risk assessment. Sayre's research focused on the behavior and probable risks of 100 different types of nonmaterial. Risk management exposure to such materials by employees working at the studied research center was of importance as it led to the control and modification of their workplace (9). In another study by Musee aiming at nanomaterial risk evaluation, challenges in both risk assessment and management were investigated using qualitative and semi-quantitative methods. The survey results showed the need for profile analysis of chemicals and nonmaterial within the risk assessment procedure. On the other hand, the conducted investigation focused on environmental aspects in addition to nonmaterial quality and safety supervision including control by senior manager of the organization (10). Another study conducted by Musee further elaborated on the studied methods in order to control the hazardous aspects of chemicals. Control priorities of potential causes of the studied chemicals as well as control and administrative strategies were identified and proposed in the mentioned study (11). The present study used the risk assessment method to investigate machinery, process, situations and dangers related to the working environment. The health and safety risk assessment method was used under the title of machinery risk. The employed technique was based on European standard requirements and approved as an international standard ISO14121 (12-14).

Nowadays, both education and research processes face greater complexity in addition to uncertainty. Rules and regulatory standards, in turn, impose stricter requirements (7).

Methods

We selected a technical faculty of a postgraduate university with 9 groups of research laboratories including electrical, mining, mechanical, hydraulic, nano, bio, chemistry, safety and computer labs.

Health, safety and environmental risks were first identified and studied independently for each research facility (laboratory) using the hazard identification (HAZID). The adopted method by the US EPA was limited in terms of complexity, effects, consequences and result formulation points of view (15,16).

More complex processes such as laboratory and research fields where there is a combination of chemical, physical, magnetic, unsafe behaviors, fire hazards as well as unsafe behaviors from the students; suffer from some limitations in choosing the mentioned methods (17-19). This method can help to inform the personnel about the risk of exposure that can be made to prevent possible hazardous situations and health-promoting behaviors to protect and control a health leading health-promoting lifestyle (HPL) (20). Structure of the method is based on HSE requirements. European standards EN (PILZ) 1050 is considered to be a new technology using an approach for the protection of humans, machines and the environment.

Hazard Rating Number (HRN) calculation

The HRN results for the assessment of risk levels in addition to risk mitigation effort prior to and post corrective actions were calculated in two separate steps using the following formula:

$$HRN= LO \times FE \times DPH \times NP \qquad (1)$$

Environmental hazard assessment was performed during the study using an inductive method (from specific to general) called environmental failure mode and effect analysis (EFMEA). In the fields where risk assessment is performed, the method seeks to identify and score, as far as possible, the potential risks in addition to their related causes and effects. This method is used to prevent failure prior to occurring. Unlike many other quality optimization methods, performing an FMEA does not require complex statistics (16,17)

Risk priority number (RPN) is the product of three numeric scores: severity (S), occurrence (O) and detection (D). In calculations, the priority number is given as a number between 1 and 125.

Environmental degradation rate calculation

Risk identification and reduction are critical stages in successful project management. EFMEA was used to evaluate the identified environmental aspects. This allowed the evaluation to take place in a timely manner. To perform EFMEA, the identified factors are divided into two groups:

A. Environmental aspects that led to the emission or production of various types of contaminants, waste and sewage into the environment, which is yielded according to the following relation:

Environmental degradation rate= severity × probability of occurrence × contamination range (2)

B. Environmental aspects that led to the reduction or loss of natural resources as a result of using those resources, which is yielded according to the following relation:

Environmental degradation rate= severity × probability of occurrence × recycling possibility

Making a decision when facing assessed risks

In this study, TLB method was used due to having access to PRN before and after control proposals, the simplicity of the calculation method as well as having the required accuracy (Eq. 4) (21).

$$TLB=\frac{\text{RPN Before} - \text{RPN After}}{Fi}=\frac{\Delta RPN}{Fi} \qquad (4)$$

Where RPN Before= Risk priority number pre-corrective measures

RPN After= Risk priority number post-corrective measures

ΔRPN= Risk difference prior to and following corrective control measures

Fi= Feasibility of corrective measures, a variable in the range of 1-10.

Total Risk Estimation (TRE) within laboratory fields

By using this index, besides estimating relative risk in each laboratory, we can also compare the risk potentials resulting from identified hazards across the tested laboratories (Eq. 5) (22).

$$\text{Total Risk Estimation}^5 = \frac{\sum_{i=1}^{n} \text{RPNi}}{n \times MRN} = \times 100\% \quad (5)$$

Where RPNi= Risk priority number for each possible hazard (cause)

N= Number of hazards (causes) in each project or laboratory

MRN= Maximum risk number upon calculating risk.

A paired-samples t test was conducted to evaluate the impact of the intervention on laboratories' risk priority numbers. The test was conducted using SPSS v. 18, as before and after performing the control measures independently for health, safety and environmental criteria at 9 laboratory sites with a 95% confidence level. Powers are given for alpha values of 0.05.

Results

The results are shown in Tables 1, 2, 34 and Figures 1, 2, and 3. Table 1 shows the results of risk situation, considering 5different levels separately as well as two situations before and after making an effort to reduce risk in 9 laboratory fields. The results from Table 2 shows that before and after performing the control measures independently for health, safety and environmental criteria at 9 laboratory sites with a 95% confidence level, there was a significant difference among the average levels of risk (p=0.0001). The highest health and safety residual risk of 4.7 (Figs. 1-3) was related to research site 7, which was due to the usage in different projects of various types of nonmaterial and carcinogenic substances which included A1 as well as A2.

This was due to the discharge of a wide range of chemical and oil materials into the environment on top of the lack of performance monitoring and waste control sys-

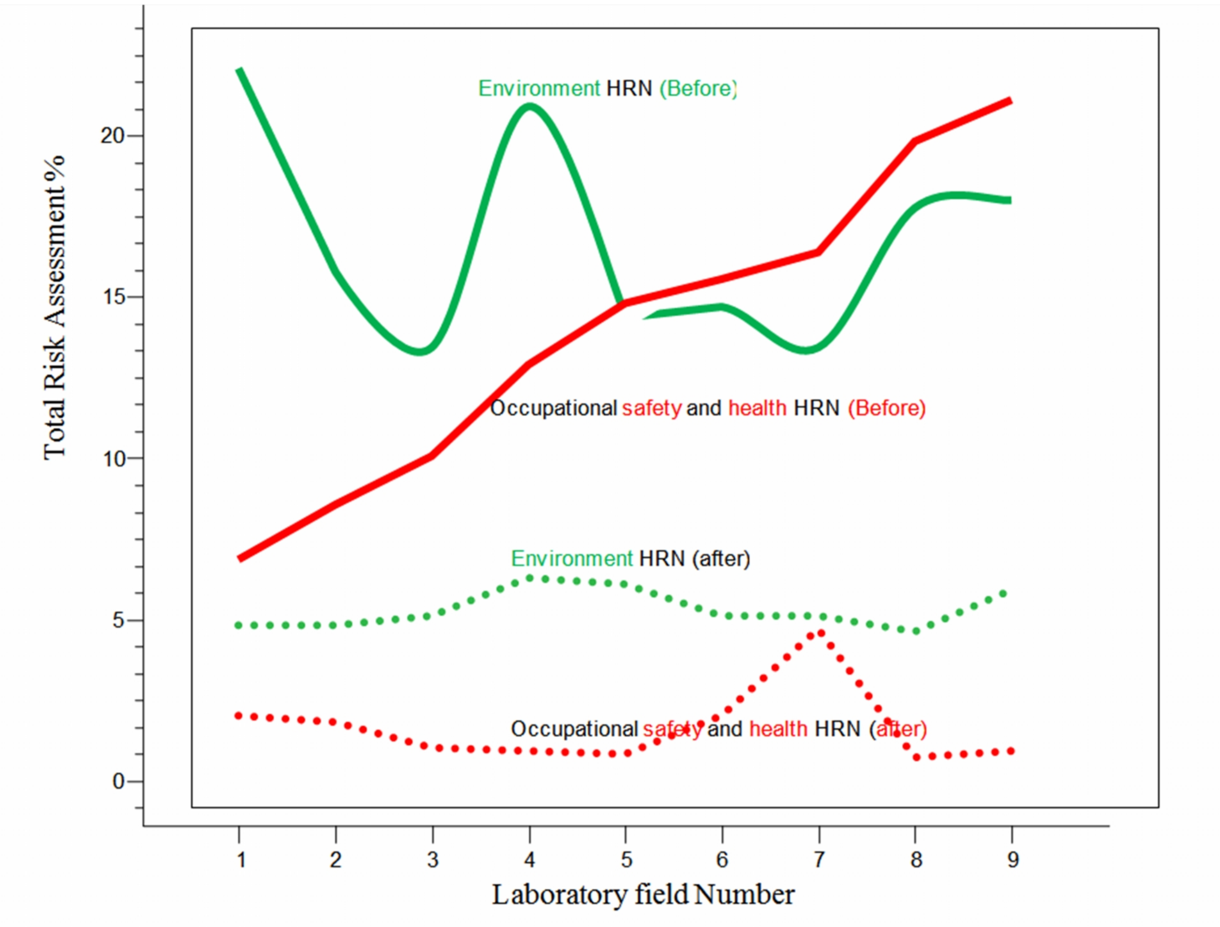

Fig. 1. Comparison of the total risk levels from different aspects of health, safety and environment before and after control measures

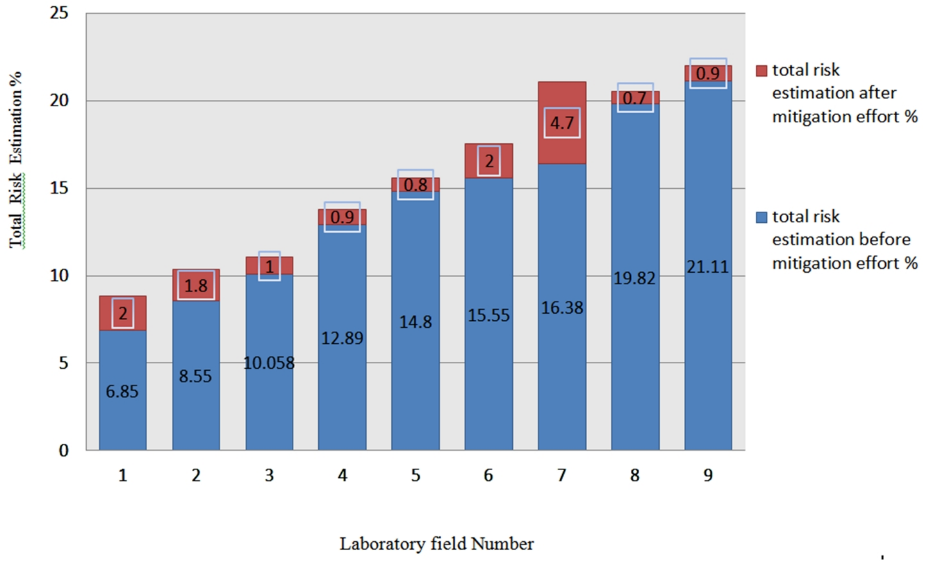

Fig. 2. Comparison of occupational safety and total health risk estimation, before and after mitigation effort

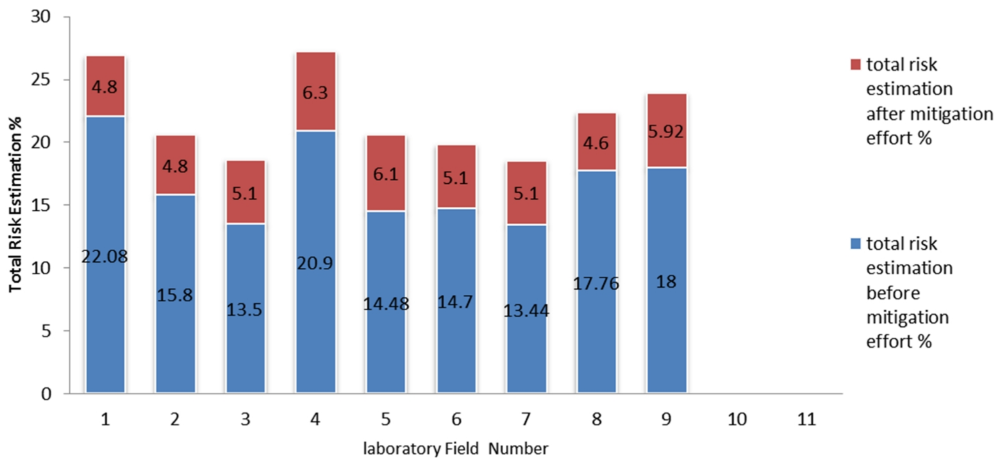

Fig. 3. Comparison of environmental overall risk estimation, prior to and following mitigation efforts (This figure shows the comparison of total risk levels associated with hazard and environmental aspects in each laboratory field before and after control measures.)

tems in the site outlet.

Discussion

Study of risk factors, hazard identification and accident-prone areas in an organization is of particular importance in preventing accidents. Laboratory project risks are uncertain contingent events or situations that, if occur, can have positive or negative effects on objectives of a given project. Table 1 shows the results of risk situation that after carrying out corrective actions at three levels of high, very high and unacceptable, HSE hazard potentials were reduced to substantial and lower levels.

The results of risk analysis showed the maximum risk reduction within laboratory field 8 (86%) and the minimum risk reduction in research field 2 (38%). In laboratory 2, due to the type of hazard potentials, the minimum risk rate reduction was 38% and 62% of the initial risk remained at this site. Hazard potentials leading to poor reduction in risk rate were mainly as a result of unsafe designs pertaining to test devices, unsafe process, elevators and lack of protection related to technical and engineering controls, complexity and high costs of carrying out corrective actions and modifications by accessible facilities.

Table 1. Comparison of risk levels (before and after effort) with residual and mitigated risk in 9 groups laboratory field

Laboratory field	Mitigation effort	Risk levels (%)							Initial risk	Residual risk	Mitigated risk %
		Negligible	Low	Moderate	Substantial	High	Very High	Unacceptable			
1	Before	8	11	17	47	15	0	2	92	---	69
	After	77	15	0	6	0	2	0	---	23	
2	Before	0	3	32	58	7	0	0	100	---	38
	After	38	16	32	14	0	0	0	---	62	
3	Before	1	5	30	37	26	1	0	99	---	83
	After 1	84	6	1	9	0	0	0	---	16	
4	Before	2	9	8	44	27	8	2	98	---	57
	After	59	33	2	0	6	0	0	---	41	
5	Before	2	10	2	42	42	2	0	98	---	54
	After	56	25	12	0	0	7	0	---	44	
6	Before	6	12	24	45	10	3	0	94	---	44
	After	50	14	19	17	0	0	0	---	50	
7	Before	3	12	16	37	30	2	0	97	---	75
	After	78	14	2	6	0	0	0	---	22	
8	Before	1	10	12	39	30	5	0	99	---	86
	After	87	7	2	3	1	0	0	---	13	
9	Before	2	10	9	33	36	8	2	98	---	81
	After	83	10	2	4	1	0	0	---	17	

The evaluation and comparison of residual and initial risks among the total health, safety and environmental hazards revealed that the mitigated risk was equal to 65% of the total risk post-intervention. Additionally, the residual risks associated with health, safety and environmental issues were averagely equal to 32% of the total initial and

Table 2. Comparison of statistical parameters (mean, SD, t test) in 9 groups laboratory fields (as total risk estimation) before and after mitigation efforts with occupational health, safety and environmental approach

Laboratory field	Total Risk Estimation			
	Occupational safety and health aspects		Environment aspects	
	Before mitigation effort	After mitigation effort	Before mitigation effort	After mitigation effort
1	6.85	2.00	22.08	4.80
2	8.55	1.80	15.80	4.80
3	10.06	1.00	13.44	5.10
4	12.89	0.90	20.90	6.30
5	14.80	0.80	14.48	6.10
6	15.55	2.00	14.7	5.10
7	16.38	4.70	13.44	5.10
8	19.82	0.70	17.76	4.60
9	21.11	0.90	18	5.92
Mean	14	1.64	16.73	5.31
SD	4.8	1.26	3.1	0.62
Paired –t test	p<0.0001		p<0.0001	

Table 5. Weight distribution of control priorities, independent engineering and management measures at laboratory sites, by focusing on health-safety and the environment

Laboratory field	Priority of act					
	Occupational safety and health			Environment		
	Risk priority numerals	Administrative methods numbers	Engineering methods numbers	Risk priority numerals	Administrative methods numbers	Engineering methods numbers
1	85	19	66	5	1	4
2	101	26	75	5	1	4
3	41	11	30	5	2	3
4	66	16	50	11	4	7
5	130	50	80	27	0	27
6	47	22	25	6	2	4
7	40	10	30	5	4	1
8	97	40	57	13	1	12
9	92	32	60	9	1	8
sum	699	226	473	86	16	70
Ratio (%)	100	32.3	67.7	100	18.6	81.4

inherent risks (in addition to 3% risk which was deemed to be negligible) at the tested research complexes.

The results of the risk levels for health, safety and environmental issues (Table 2), in both columns of "after mitigation effort" were in an acceptable range. It can also be mentioned that in addition to the components of process and the environmental damage and degradation, the possible causes of human injuries were controlled in addition to being reduced. Conversely, the low mean and dispersion levels pertaining to the residual risk following control measures can confirm the effective convergence and concentration of control measures in this project. Figure 1 compares risk levels before and after the use of corrective control measures independently for each tested laboratory site.

The results from the risk levels prior to the implementation of corrective measures showed that the most and least human injuries as well as process damage (health and safety) occurred at locations 1 and 9, respectively. Environmental degradation was observed to be most common at locations 1 and 4 (maximum risk level). On the other hand, facilities 3 and 7 (minimum risk level) exhibited the lowest amount of environmental degradation among the sites examined. Location 9 was found to possess major factors that could lead to a high rate of injuries and damages including those concerning humans as well as processes. Some of the issues found to be the leading cause of such injuries were abundance of research devices, variety plus variability in research tests and large number of researchers working during the shift work. Moreover, long term period tests and limited number of tests per season can be considered as effective solutions when seeking to lower the rate of damage at any particular health and safety site.

The highest health and safety residual risk of 4.7 (Figs. 1 and 2) was related to research site 7, which was due to the usage in different projects of various types of nonmaterial and carcinogenic substances which included A1 as well as A2. Verification of the findings of the present study was done by analyzing the results from a research conducted by Sayre, et al., (2001) in which the persistent risks of toxicity and extreme increases in levels of nonmaterial particles were found to be the main factors involved in relative health risks (8).

This was due to the discharge of a wide range of chemical and oil materials into the environment on top of the lack of performance monitoring and waste control systems in the site outlet (Figs. 1 and 3).

The results of the latest studies by researchers regarding the poor ability of waste management systems found that isolation, transportation, treatment and disposal were the main areas of concern. These findings confirm the fact that high residual risks at research sites are cause of the use of complex chemical substances and uncontrolled waste discharge into the environment (22).

Study of corrective control measures independently using management and engineering methods explained in Table 3, shows that the sites with complex process systems and equipments including hazardous and toxic substances are associated with much more severe risk factors (such as facilities 2, 5, 8 and 9). Accordingly, by using TLB method, more control and protective actions have been ranked and used within risk management programs. Moreover, the increase in the amount of health and safety measures (699 actions) as compared to the environmental measures (86 actions) at the studied research sites was found to be due to risk identification as well as an increase in concentration of health, safety and process risk causes and factors in comparison to the environmental aspects. On the other hand, the study of health, safety and environmental control priorities based on engineering measures shows a relatively significant increase in comparison to management measures. In the two cases pertaining to health, safety and environmental measures, the reason for the large number of engineering measures can be rooted in the large number and variety of machinery with a long working life (press machine and elevators). Using the devices without basic protection components also further contributes to this problem as well (saw without guard, defects in the earth system, etc.). In the present study, however, while evaluating the total health, safety and environmental risk, "not just health-risk factors", control measure priorities were determined using the TLB method. Though, it should be mentioned that both of the studies emphasized the control of risk factors including source, receiver, risk factor and work site, respectively.

Conclusion

The first major practicable result of a risk assessment program is "risk rating". This was carried out independently for the hidden and evident causes of risk potentials within processes in addition to working situations and conditions. In each laboratory field, following the identification of hazards and their related causes, RPN methodical calculation was performed. Control measure priorities were calculated separately for health, safety and environmental factors. This was considered to be a primary criterion for judgment.

In the HSE management system, allocation of funds to study risk assessment has brought significant benefits to many organizations. The results from risk assessments can help in selecting appropriate solutions, which is certainly the removal of main threats. Furthermore, risk assessments can also be used to prepare and improve HSE policies.

In this study, estimation of the rate of degradation, damage and injury to human and environment was carried out separately for each laboratory and provided as a coefficient of risk score arithmetic mean. This coefficient was used as the total risk estimation in comparing risk levels before and after the implementation of corrective measures.

It was also revealed that ISO 14121 can be used as a useful research and administrative tool in management projects to prevent probable events and damages, particularly those occurring in research and laboratory sites.

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References

1. Ferdous R, Khan F, Sadiq R, Amyotte P, Veitch B. Fault and event tree analyses for process systems risk analysis: uncertainty handling formulations. Risk Analysis 2011;31(1):86-107.
2. Olsson R. In search of opportunity management: Is the risk management process enough? IJPM 2007;25(8):745–752.
3. Hillson D. Effective opportunity management for projects – exploiting positive risk. New York, Marcel Dekker 2004;pp.51-61.
4. Sotoudeh GA, Khanzadi M, Jalal M, Parchami A. Fuzzy MCDM for evaluating risk of construction projects. AJBAS 2011;5(12):162-171.
5. http://www.directives.doe.gov,Office of Health, Safety and Security, DOE G 414.1-1C.
6. http://www.epa.gov/oppfead1/trac/science/cumulative_guidance.pdf, 2002.
7. http://www.hc-sc.gc.ca/ewh-semt/air/out-ext/research-recherche-eng.php. 2012,
8. Goyal RK. FMEA, the Alternative Process Hazard Method". Hydrocarbon Processing, 1993; 72(5):95-99.
9. Sayre P, Prothero S, Alwood J. Nanomaterial risk assessment and management experiences related to worker health under the toxic substances control act, Journal of Occupational and Environmental Medicine 2011;53(6):98-102.
10. U.S. EPA. Exposure Factors Handbook (1997 Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/P-95/002F a-c, 1997.
11. Musee N. Nanotechnology risk assessment from a waste management perspective: Are the current tools adequate? Hum Exp Toxicol 2011;30: 820-835.
12. Yousuf M. Risk assessment of hazardous chemicals case study chemistry research laboratory of USM, Thesis submitted in fulfillment of the requirements for the degree of Master of Science, school of chemical engineering, University of Science Malaysia 2008.
13. Moran L, Masciangioli T. Chemical Laboratory Safety and Security, A Guide to Prudent Chemical Management, The National Academies Press

2010:215-225.

14. Guide to the New Machinery Directive 2006/42/EC, 6th. edition (http://www.machine building. net/n/n2306.htm)

15. U.S. Environmental Protection Agency Washington, Guidance on Cumulative Risk Assessment. Part 1. Planning and Scoping. Science Policy Council, 20460 July 3, 1997. http://www.epa.gov/sites/production/files/2014- 11/documents/frmwrk_cum_risk_assmnt.pdf.

16. Michael A, Callahan KS. Cumulative risk assessment is the answer, what is the question? U.S. Environmental Protection Agency, Region 6, Dallas, Texas, USA; University of Texas School of Public Health, Environmental Health Perspectives 2007; 115:5.

17. Thomas AT, Donald D. Project risk management using the project risk FMEA, Engineering Management Journal 2004;16:4.28-35.

18. Jozi SA, Saffarian S, Shafie M. Environmental risk assessment of a gas power plant exploitation unit using integrated top-eFMEA method. Pol. J. Environ. Stud 2012;21(1):95.

19. Mahdinia M, Yarahmadi R, Jafari MJ, Koohpaei AR. Presentation of a software method for use of Risk assessment in Building Fire Safety Measure Optimization. Iran Occupational Health, Spring 2012;9(1):9-16. (Persian)

20. Rezazadeh A, Solhi M, Azam K. Determinants of responsibility for health, spiritual health and interpersonal relationship based on theory of planned behavior in high school girl students. Med J Islam Repub Iran 2015 (21 April);29:204.

21. PFMEA, RAM Commander RAMC 7.2 New Features, ALD WEB Site, www.aldservice.com Download the latest version of RAM Commander V8.5 (February 2015).

22. Bluvband Z, Grabov P. Failure analysis of FMEA, Reliability and Maintainability Symposium, 2009:344-347.