Original Article

Identification of Health, Safety and Environment Aspects in Cement Factory using AHP and FMEA Techniques

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Abstract

Background and Purpose: Cement production processes are associated with different hazards, such as health and safety hazards and environmental pollution. The current study was conducted to evaluate and determine the safety, health, and environmental risks of using FMEA and AHP techniques in the cement factories while providing certain suggestions for controlling them.

Materials and Methods**:** The study was conducted as a case in one cement factory in 2019. The checklists for FMEA and AHP techniques were filled out by the evaluation team. The risks were identified and prioritized. Controlled approaches were suggested for the identified risks.

Results**:** In this study, 101 risk cases were evaluated and categorized in various units of the factory, such as manufacturing and service units. The results of FMEA technique showed that crushing, crushing monitoring, milling, filtration, and pre-heater sections had the highest degree of health and safety risks. The results of AHP technique also showed that the environmental pollution caused by the removal of electro filter from the circuit, electro fan burning caused by over current, the failure of the equipment and process, and the defect in the filtration system were all prioritized.

Conclusion**:** Through taking technical-engineering measures, adopting comprehensive HSE management solutions, such as changes in the work process, making replacements in parts and used machinery, installing recyclable systems, repairing and maintaining the system of air pollution protection, installing a warning and responsive system, mechanizing activities, shielding, implementing instructions and regular curriculum can greatly reduce the risk level.

Keywords**:** Health; Safety; Environment; FMEA; AHP

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1. Introduction

Given its nature and type of activity, cement factory has a variety of safety, health, and environmental issues. Thus, there is the potential of damage to worker, equipment and environment in case of an accident (1-2). In the cement production process, most of the accidents are related to explosions, fire, and equipment breakdown, while in case of damage, they are related to employees due to glide, slip, object fall, hitting the objects, lifting, and carrying loads. Studies in the Bangladesh cement industry indicate that 76% of the accidents and injuries are related to lifts, conveyor belts, welding, and lifting cement bags (3-4). Examining the accident in the Egyptian cement industry showed that 155 cases of the incident occurred in a population of 3,200 workers, resulting in 4776 work days to be lost (5-6). The cement industry was ranked second among the most Polluting industries given its use of fossil fuels. Thus, considering the Co_2 produced, and calculating and justifying the cost in the process of this industry are of great importance. The pollutant gases that come out of the cement factories chimneys include SH_2 NO, CO_2, SO_2 and particles (7-8). The entry of the particles into the atmosphere and the accumulation of dust collected by deduster in the factory environment are among the important environmental problems of the cement plant. Overall, the main sources of pollution in the cement industry are physical pollutions, like noise and vibration, chemical pollution, such as dust, especially silica, co_2, and heavy metals present in the gases of cement furnaces, which would lead to side effects in the workers in the industry, the environment, and possible inhabitants around the factory (9-10). The significance of this study was that in developed economies, the role of risk assessment and management in achieving organizational goals is well recognized and properly utilized. Significant losses have been incurred in developing countries due to the lack of risk assessment and risk management systems on property, assets and employees. It can be said that there has been no significant effort to reduce the damage in developing countries (6-7). On the other hand, rising labor costs and its irrational upward trend in developing countries indicates that production in these countries is very costly. If the risk assessment and safety assessment is done in the industry, it can reduce costs by protecting human and physical resources (8-9). In general, the major sources of contamination in the cement plant can be physical contaminants, such as noise and pollution, as well as chemical contaminants, such as dust, especially silica, CO2 gas, and heavy metals in the cement kiln's exhaust gases. These contaminants cause disease in factory workers (10). FMEA is a survey technique used to identify and eliminate errors, potential problems and errors in the process of production and delivery of service before occurrence in customer. Since 2000, this method has been one of the most widely used ones in risk assessment methods in all industries. FMEA is one of the most experienced and useful methods for identifying, classifying, analyzing, and assessing failures and risks associated with them. With the help of this method, one can root out the failures and prevent them (11-12). AHP is one of the most efficient Multi Attribute Decision Methods (MADM) techniques first proposed by the Iraqi Thomas L. Saaty in 1980, based on a pairwise comparison allowing the managers to examine various scenarios. Given the rational constraint that each individual has, perhaps a collaborative effort was the only way to reach a rational, disciplined, and comprehensive decision (13-14). Before any event using existing techniques and methods, such as FMFA, AHP, which provide an acceptable level of safety, can be used to examine the safety of systems. Failure to identify the process errors could have irreversible consequences; hence, in spite of spending a lot of money and devoting a lot of time, it may not be successful in achieving predetermined goals. Thus, the current study attempted to use FMFA and AHP techniques to evaluate safety, health, and environmental risks in cement plants.

2. Materials and Methods

The study was conducted as a case in one of the cement factories in 2019. The studied population was the units of crushing, inspection, milling, filtration, preheater, furnace, material mill repair, packing and loading, operator rooms, central control, telecommunications, and HSE unit of Ardabil Cement Plant. Data collection was performed using FMEA and AHP work paper by a team of evaluators consisting of the researcher, factory health professional, and the supervisor of the 12 units.

2.1. FMEA Method:

One of the most well known risk identification methods is FMEA with a significant role in industry. This technique is a preventive and systematic approach whose purpose is to identify the points and paths where the process or design of a system can be problematic and block the entire system.

Ten basic steps of conducting FMEA

Step 1: process / product revision

Step 2: brainstorming

Step 3: listing the potential effects of each failure mode

Step 4: determining the severity rating

Step 5: determining the probability rating

Step 6: determining the rating of discovery/diagnosis

Step 7: calculating the preliminary grade of risk. Risk priority number (RPN)

Step 8: prioritizing failure modes for action (Table 1)

Step 9: taking executive measures to eliminate or reduce potentially hazardous situations

Step 10: Re-calculating the initial risk score (9-12).

Table 1. Prioritizing failure modes for action

RPN	Risk level	Necessary actions
340-1000	Unacceptable	Process or operation to ensure that the failure mode has stopped and while insuring, if needed, there is a reaction according to the program in emergency case. Advanced failure mode analysis is also done to perform corrective and preventive action in the process. Change in the procedure or process is performed, followed by the relevant change management.
126-340	High	Process or operation until ensuring that the state of failure is not stopped. Otherwise, the start of the process or operation will be with the use of special controls and by obtaining permission from the HSE manager and the head of the unit. Examining the safety of the process, identifying and implementing control measures necessary to reduce the failure and risk of individuals exposed to lower levels of risk and remaining risks to the insurance industry with regard to facilities and study cost benefits.
100 - 126	Average	Process or operation is done according with observing the safety regulations, procedures, and instructions in coordination with relevant authorities and safety. Implementing corrective actions to reduce failure mode and the risk of persons exposed to lower levels in accordance with the principle of ALARA.
40- 100	Bearable	Corrective measures are not required to reduce the failure mode, but to ensure that controls are in place, there is a need for routine process monitoring.
1- 40	Acceptable	Needless of checking safety or control measures

***2.2.AHP method*:**

One of the first MADMs is AHP Method, used more than many methods in management science. AHP is one of the most popular MDAM techniques that show the natural behavior and human thinking. Finally, AHP logic integrates the matrices derived from the pairwise comparisons to obtain the optimal decision.

Using this method needs four steps:

Step 1: Modeling: in this step, the problem and purpose of decision-making are hierarchically derived from the decision elements that are related.

Step 2: Preferential judgment (pairwise comparisons): this includes comparisons between different decision options, based on each index, and judging the importance of the decision index by conducting pairwise comparisons.

Step 3: Calculating relative weights

Step 4: integrating relative weights: to determine the decision options, at this stage, one must multiply the relative weights of each element in the weight of the higher elements to obtain the final weight. By doing so for each option, the value of the final weight is obtained. Inconsistency Ratio (IR) shows how much the specified priorities can be trusted. Experience has shown that if IR is less than 10%, consistency of the comparisons is acceptable, and otherwise the comparisons should be revised (13-14).

3. Results

In this study, 101 risk factors were evaluated and categorized in various units of Ardabil Cement Plant, including production and services. Excel Software was used for calculations. Major identified risks were noise, lighting, vibration, magnetic field, and electrical hazards, dust especially silica, the presence of toxic gases, and heavy metals, such as chromium, ergonomic problems, psychological stress, cold stress due to mountainous region, thermal stress due to the process of work, and eventually mechanical factors.

Of the identified risks, 38 cases were in an acceptable range without revision, 21 items were acceptable but with revision, 42 cases were identified to be in an undesirable risk area, and risk was not acceptable in the area. In Table 2, the Risk Priority Numbers (RPNs) extracted from the various units of the plant evaluated are presented separately.

Table 2. Ranking health and safety risks using FMEA Method

Row	Unit name	The number of errors with RPN below 100	The number of errors with RPN from 100 to 126	The number of errors with RPN from 126 to 340	The number of errors with RPN from 340 to 1000
1	Crusher	6	3	16	-
2	Crusher inspection	4	1	-	-
3	Material mill	2	2	1	
4	Filtration	-	1	4	-
5	Preheater	-	1	4	-
6	Furnace	-	-	5	-
7	Repairs	4	1	-	-
8	Package and loading	10	4	6	-
9	Operator rooms	4	2	4	-
10	Central control	1	3	1	-
11	Telecommunications	3	2	-	-
12	HSE unit	4	1	1	-
	Total	38	21	42	-

In Crusher unit due to the lack of direct human intervention, there was a major risk associated with equipment that could occur in the event of a financial loss, a defect in the production process, the stop of the production process, and air pollution. The highest RPN number for this section was related to stopping the production process. The production process could also be stopped due to various reasons, such as conveyer belt rupture. Purchasing engineering and using quality parts as well as periodic services could then reduce existing risks.

Identified potential hazards were high noise levels and hearing loss, defects in lighting systems, occupational accidents, and mechanical factors. The highest RPN number in Crusher inspection was attributed to hearing loss due to a noise level higher than 85 dB, which can be reduced by technical-engineering, management, such as reduced exposure time and the use of personal protective equipment (PPE) to acceptable level.

The identified potential hazards were particles, sound, and vibration. Air pollution and pulmonary complications caused by it, and hearing loss were among the consequences of this section. In Material mill, the highest RPN number was assigned to abnormal sounds due to rocks crushing, which can be attributed to the work process, and this problem can be reduced to some extent by technical-engineering and management controls, but it cannot be reduced to acceptable levels using the current devices.

The most important potential hazard to this part (Filtration) was the cement dust caused by the removal of the electro-filter from the circuit, which may lead to air and soil contamination. Inspections, especially in its neighboring village, showed that agriculture and horticulture were affected and may undermine the ecosystem of the region and lead to a reduction in resources and loss of resources.

The main potential hazards of Pre-heater, responsible for heating and removing the moisture content of the milled material, according to its department include the level of insecure work, lack of protection or high protection systems, which, in the absence of a person's mental and physical health, can have irreparable consequences. By installing security fences, creating channels for people to travel, using personal protective equipment, periodic training and job tests, one can greatly reduce the risks of this unit.

Due to the high temperature of the furnace, and lack of the necessary protections, the non-systematic disposal of chromite bricks can result in very severe consequences for the death penalty. Thermal stress, the risk of coating fall, or even the people falling into the grate and the environmental pollution caused by the disposal of Cr (VI), including the potential risks of this sector were all evaluated.

The identified potential hazards in Material mill repair were related to mechanical factors that lead to waste generation and air and soil contamination. The obtained RPN showed that current controls were generally optimal, keeping the risk to an acceptable level, so no specific corrective action was needed except in the filtration section in other sectors.

The identified potential hazards included hitting the equipment, cement dust, psychological stress, ergonomic problems and musculoskeletal disorders, cold stress, and high levels of noise. Among the consequences of these risks were the damage to the operator and damage to the equipment, air pollution and its resulting lung problems, musculoskeletal disorders and hearing loss. The highest RPN of Package loading section was related to this risk due to the possibility of developing pulmonary diseases because of the presence of dust from cement, which could be due to defects in equipment and work processes. Examining the spirometer results of the periodic examinations of workers in this department also indicated that pulmonary function decreased the presence of shortness of breath, which can be reduced to risk level by controlling and reducing preventive measures.

The major potential hazards identified in Local operator rooms were the probability of carbon monoxide, cold stress, musculoskeletal disorders, electrical hazards, and vibration. The highest RPN in this section was causing death due to inhalation of carbon monoxide. This problem can be reduced to some extent by general effective ventilation, using personal protective equipment, training on primary aids, and continuous measurement of gases.

Table 3 shows the result of AHP based on pairwise comparison of the options. As can be seen, the “air pollution caused by the removal of the electro-filter from the circuit”, “the destruction of trees due to the removal of electro-filter from the circuit and the release of cement dust,” “air pollution due to over current and burning of the electro-fan”, “air pollution due to equipment and work process failure,” “air pollution due to defective filtration system,” air pollution due to tear in the packets and bags,” “soil contamination caused by the removal of electro-filter from circuit,” “pollution of underground waters due to non-regular disposal of chromite bricks,” “soil contamination due to oil leakage during replacement and repair of parts” and finally,” soil contamination caused by infectious waste” have the priority.

Table 3. Ranking of environmental risks by AHP approach

Row	Option name	Weight
1	Air pollution caused by the removal of the electro-filter unit from the circuit	0.15418
2	The destruction of trees caused by the removal of electro-filter from the circuit	0.135068
3	Air pollution caused by over current and burning of the electro-filter	0.118077
4	Air pollution caused by a failure in the equipment and process	0.09641
5	Air pollution due to defect in the filtration system (electro-filter)	0.093236
6	Air pollution due to tear in packets and bags	0.088286
7	Soil contamination caused by the removal of electro-filter from the circuit	0.08269
8	Pollution of underground waters due to non-regular disposal of chromite bricks	0.078919
9	Soil contamination due to oil leakage during replacement and repair of parts	0.052423
10	Soil contamination caused by infectious waste	0.052063

Electro-filter out of circuit

Changes in the production process or working conditions, using the particle system, and the creation of a high-performance, high efficiency electro-filter system, periodic auditing, and the formation of a reaction team in an emergency

Over current and burning of electro-fan

Daily control by the operator, checklist modification, Preventive Maintenance (PM), implementation concerning the equipment, prevention of resource degradation, and spread of contaminants

Fault in the filtration system

Air humidity control, observing the specific maintenance conditions of each item, the formulation of the instructions and the relevant checklist, the implementation of equipment PM

Tear in packets and bags

Enhancing the quality of the bags used by changing their material, training the operator for preventive measures against the secondary pollution and reducing the consequences of dusts in the environment

Underground water pollution with non-systematic disposal of chromite bricks

The plan for selling bricks used in non-burning bricks factories, maintenance of waste in special circumstances and preventing its re-use in the production line, and self-declaration to the environmental organization on an annual basis

4. *Discussion*

Noise control can be achieved by purchasing equipment that is inherently quiet or by changing the process or operating procedures. It can be reduced or controlled by sound control techniques, such as using sound barriers or mufflers along the sound path. Standard personal protective equipment should also be used if noise is not controlled by engineering methods. Dust produced in various parts of this industrial unit, including milling unit, packing, and loading of envelopes exposes workers in this sector to complications of respiratory system (sensitivity, shortness of breath) and reduced spirometric indices. It also shows the medical records of the employees (periodic examinations) of those cases.

Implementation of strategies to improve the health of workers in this industry is an important issue. Implementation of risk control guidelines, continuous inspections, use of personal protective equipment, and training of first aid in controlling these complications will be helpful.

Due to the nature of its activities, the cement factory is one of the most influential factories affecting the environment.

In addition to the emission of dust, noise, vibration, and exhaust gases from cement kilns, such factories can also have detrimental effects on the environment. Studies show that only the grinding unit, which is one of the essential steps in production line, can be crushed by dust and noise, causing environmental pollution. Implementation of equipment maintenance, filtration, and use of high quality components and continuous monitoring will be effective in controlling these pollutants and preventing environmental contamination. Due to the potential effect of environmental pollution, a cement plant requires more careful observation and continuous monitoring of environmental factors. As mentioned above, these types of pollution include air, water, sewage, and noise pollution, as well as toxic gases, etc.

At the same time, applying FMEA technique showed that crushing, crushing inspection, material milling, filtration and pre-heater sections have the highest safety and health risks. The results of AHP technique showed that the environmental pollution caused by the removal of electro-filter from the circuit, burning of the electro-fan due to over current, failure in the equipment and work process, and the defect in the filtration system are prioritized. To control the existing risks by performing purchase engineering, using quality components, periodic services, PM, technical-engineering controls, management controls, such as reducing the duration of exposure, installing protective fences, creating channels for the people to move, and using personal protective equipment (PPE), periodic training, and job examinations can greatly reduce the high risks of this unit. The study of Khanijazani et al. (2016) entitled "The relationship between occupational stress and harmful factors in cement industry" showed that noise and dust in the workplace are the factors affecting occupational stress of the workers in the cement industry (15). The study by Mr. Aghamolaie et al. (2015) entitled "Evaluation of air pollution from the cement industry," showed that exhaust from chimney and environmental dust, and dust concentrations were more than the standard, which confirmed the results of the present study regarding environmental hazards (16). Vazdani et al. (2018) showed that the highest risk is the environmental risk. In the safety and health sections, the highest risk was for inhalation of vapors during repairs due to non-observance of safety precautions and non-use of personal protective equipment (17). Golbabaei et al. (2012) showed that the highest exposure to respirable fraction of cement dust was observed in cement mill and in silica crystals in milling units, crusher and furnace. Thus, these units should prioritize the use of control measures (18). The study of Jozi et al. (2014), in line with the present study, showed that control measures were suggested to reduce the level of risk based on expert opinions in equipment safety departments, operators training, and regulatory measures (19). By taking corrective action and considering the principle of "As Low as Reasonably Achievable" (ALARA), one can take measures to take the risk with high priority to acceptable or tolerable risks. By technical-engineering measures, adopting comprehensive HSE management solutions, such as changes in the process of work in Crusher unit, replacement of used parts and machinery in Material mill unit, installation of recyclable systems in Crusher, Package and loading unit, repairing and maintenance of air pollution protection system, installing warning and responsive systems, mechanizing activities in Package and loading unit, safeguarding in Filtration, Preheater and Furnace units, implementing instructions and regular plans in Central control unit, one can drastically reduce the risk level.

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Conflict of interests

None.

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