Implementing the Analytical Network Process (ANP) in Ranking the Safety and Occupational Health Risks of Cement Plants according to the Combination of the FMEA and William and Fine Methods.

Abstract

Risk assessment is a logical method to determine the quality and quantity of risks and investigate the potential consequences of probable accidents on people, materials, equipment, and environments. Indeed, the process provides valuable data to make decisions concerning the reduction of risks and threats, the optimization of control systems, and the planning to respond to them. Thus, the present study aimed to determine and estimate, control, and reduce the rates of risks by evaluating and managing the safety and health risks of cement plants using the analytical network process (ANP). The present study used 2 ANP models, and the pairwise comparisons of the risks were created in each set using the ANP process. Then, the results of the comparisons were handed to a panel of experts that consisted of 10 people. After the matrices of pairwise comparisons were completed, the incompatibility rates were calculated. As the obtained values were all below 0.1, the stability and compatibility of the matrices were confirmed. Then, the pairwise comparisons of the experts were combined using the geometric mean technique, and finally, they were entered into SuperDecision so that their weights could be determined.

The present study found a total of 1184 risks that threatened the safety of the plants and the employees' health. Evaluating the health risks led to the detection of 352 risks, and the most significant risks were the noise produced by grinding the cement (0.0607), the dust produced by the grinding process (0.0597), and the thermal stress of the baking department (0.0596), respectively. Moreover, evaluating the safety risks resulted in the detection of 529 risks, and the most significant ones were related to falling from the cement mill (0.0601), the fall of items from the packing plant (0.056), and explosions in the baking department (0.0549), respectively. The proposed method in the present study could both distinguish risks more accurately and determine the degree of their relative importance according to their risks degrees.

Keywords: *Risks assessment, Occupational Health, Safety, Analytical network analysis (ANP)*

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1. Introduction

In the Occupational Health and Safety (OH&S) management systems, risk assessment is defined as the process of evaluating the risks originating from the work environment by considering the existing control measures and deciding on the degree of their acceptability (1).

Risk assessment is a logical method to determine the quality and quantity of risks and investigate the potential consequences of probable accidents on people, materials, equipment, and environments. Indeed, the process provides valuable data to make decisions concerning the reduction of risks and threats, the optimization of control systems, and the planning to respond to them (2). The majority of the existing methods of risk assessment are convenient, and their results can be implemented to manage and conduct follow-up actions concerning the control of the risks and the reduction of their consequences. Various organizations and industries need systems to evaluate their activities and processes as well as guide them in terms of their risk conditions, determine the criteria related to the tolerable risks, and meticulously specify the risks of their processes. The prevalence of such systems depends on the complexity of the activities that are required to fulfill the goals of the companies (3).

One of the most remarkable problems in the process of risk assessment is the existence of multiple parameters that influence the rates of the risks by varying degrees. This can make analysts bewildered and unable to make accurate judgments concerning the rates of the risks. Thus, the Multiple-criteria Decision-making (MCDM) techniques need to be implemented to eliminate the effects of the analysts' subjective judgments (4).

The MCDM techniques can determine the factors that influence each parameter, specify the risks concerning the importance degrees of each item, and quantify each risk parameter. This will minimize the analysts' judgments (5).

The ANP technique is an extension of the Analytical Hierarchy Process (AHP) that can model the correlations and feedback existing between the effective elements of a decision-making process and consider and calculate all internal influences that affect the process. In many instances, the decision elements cannot be modeled hierarchically and independently. Thus, the elements become dependent on one another, and it is recommended to implement the ANP technique in such instances (6).

2. Background

In 2013, Sana et al. investigated three cement plants to investigate the health risks posed by such factories to the workers of cement plants in Kashmir, India. The findings indicated the significant influence of the plants on the workers' health, and it was shown that the issues were exacerbated during the summer. In other words, 89-93% of the workers had respiratory problems, while 89-01% of them suffered from skin allergies. The irregular heartbeat was a common issue among 91-92% of the workers, 87-91% coughed, and 50-59% complained about pains in their chests (7).

In 2017, Rampuri et al. studied and analyzed work occupational health and safety in cement plants and indicated that the workers in such places were exposed to many health issues like (among others) chronic coughs, respiratory problems, the irregular function of the lungs, the tightness of the ribcage, skin irritation, conjunctivitis, stomachache, headache, exhaustion, larynx carcinoma, colon disorders, being exposed to the noises made by the machinery and equipment, dust, gases, and other dangers in cement plants like the mechanical threats, sharp edges, electricity (the risks of electroshocks, electrocution, fire), falling, mechanical vehicles, physical factors (temperature, insufficient light), chemical risks, and fire (flames and hot materials). Thus, it was shown that safe workplaces could reduce the frequency of injuries and increase organizational productivity (8).

In 2013, Aminbakhsh et al. implemented the AHP technique to make planning and budgeting for the evaluation of the risks of construction projects. They stated that the analysis of safety risks is the most remarkable step in detecting the potential risks and reducing their consequences. Thus, the main factors that influenced the risks were detected using the above technique, and a convenient budget was allocated to eliminate them by considering the capital-based limitations (9).

In 2013, Saharghaleh et al. investigated the process of producing cement in the Faraz Firouzkouh Cement Plant and detected 176 health risks in three areas (mechanical, production, and administrative) and 45 environmental risks by studying the available documents and interviewing the relevant officials. The risks were determined by the PHA method, and their analysis was conducted according to William Fine's technique. The researchers offered some recommendations and corrective procedures to reduce the high-level risks into medium-level and, then, lower-level ones (10).

Pordel et al. (2014) investigated the environmental risks of the 2nd and 3rd phases of the Pataveh Gas Compression Station using the AHP technique. The risks were ranked based on the scores obtained in various environments, and the top ranks were assigned to noise pollution (192.4), threatening public health (4.004), fluid contaminants and sewage (2.24), and the reduced security of Dena Protected Area (2.107). The researchers offered some solutions to control and eliminate the most remarkable reasons for the emergence of the risks (11).

Ashna et al. (2014) investigated the environmental risks imposed by the Larestan Cement Plant using the William & Fine (as an organized and systematic way to evaluate risks, detect potential risks, and estimate the level of risks) and TOPSIS techniques to manage and reduce them to acceptable levels. Moreover, 60 criteria that matched the common methods were specified. Finally, the TOPSIS technique was implemented to compare the criteria using control methods and assign weights to them by Shanon's Entropy technique (12).

3. Materials and methods

3.1. Risk Assessment

The present study aimed to assess the safety and health risks and reduce their consequences in Cement Plant. The FMEA, William & Fine, and EFMEA were implemented to achieve the above goals. The methods required investigating the safety, health, and environmental risks of industrial plants. Thus, first, the methods of detecting the parameters and the environmental aspects were investigated; then, a brief definition of the analysis techniques was given, and, finally, the study was conducted. The stages of the study are illustrated in Figure 1.

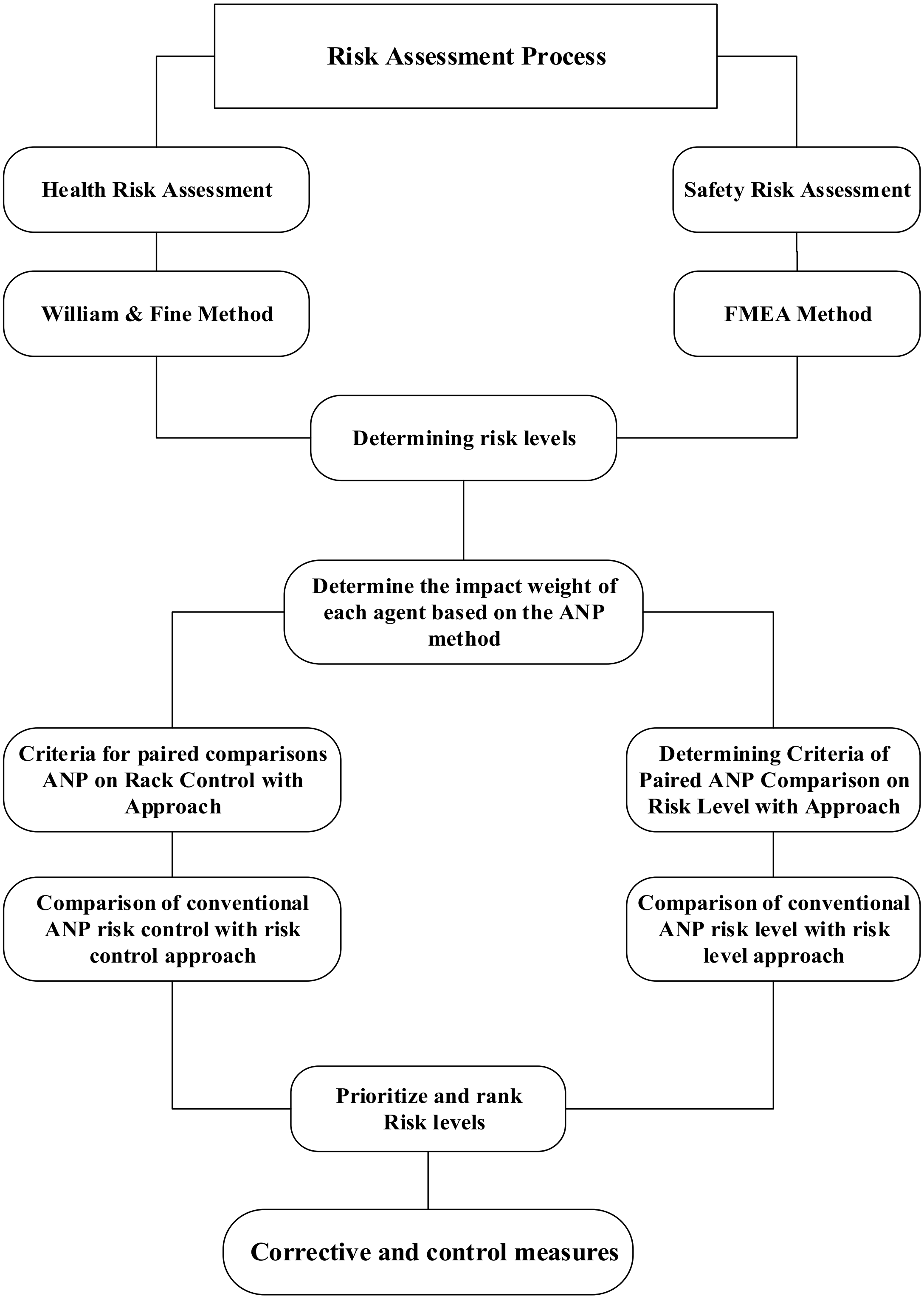

Figure 1. The stages of the study

After conducting the library studies and investigating articles, the cement plant was visited to collect the preliminary data and get familiar with the process of cement production. The processes in the plant were detected, its authorities and employees were interviewed, and the records and documents concerning accidents and the measures envisaged to prevent them were investigated.

The first stage consisted of making a preliminary investigation of the documents and processes, performing field observations, collecting data and analyzing them and comparing them with standard sources, getting familiar with standardized methods, and filling out the checklists (the checklists were developed by a group of occupational health, HSE, and environmental specialists in the plant) to investigate the safety and health conditions of each unit in terms of pollution and accidents and their causes. Then, the FMEA and William & Fine techniques were implemented to evaluate the health and safety risks of the plant. Finally, some managerial and corrective solutions were proposed to optimally manage the above risks.

First, the risk indicators were found using the confidence interval, and the risk levels of each unit were determined. To determine the confidence interval, the mean priority figures of the risks and their SD were calculated in SPSS> the following formulae were implemented to calculate the mean and SD values.

(1)

$$\mu_x = \frac{\sum_{i=1}^{n} X_i}{N}$$

In the above equation, μ is the mean, $_i\chi$ is the priorities of the risks, and N is the number of priorities.

(2)

$$\sigma = \sqrt{\frac{\sum (X_i - \mu_x)^2}{N}}$$

In the above equation, σ is the SD, $_i\chi$ is the priorities of the risks, N is the number of priorities, and μ is the mean.

In each unit, the mean values were calculated as the risk indicators, then, statistical calculations were performed to determine confidence intervals for the units using the following formula:

(3)

$$\mu - \frac{\sigma}{\sqrt{n}} \leqslant \text{Index} \leqslant \mu + \frac{\sigma}{\sqrt{n}}$$

Finally, the risks above ($\mu + \frac{\sigma}{\sqrt{n}}$) were labeled as the high risks, the ones below ($\mu - \frac{\sigma}{\sqrt{n}}$) were considered low risks, and the risks falling between them were labeled as the average risks. Based on the levels of the risks, some corrective and control actions were offered, first, for the high (H) risks and, then, for the average ones so that they may be promoted to the low (L) risks by adopting control methods and constant monitoring (13).

3.2. The analytical network process (ANP)

In the present study, the analytical network process was implemented to model the problem of decision-making concerning the prioritization of the detected risks. An ANP model consists of “options”, “the network of criteria and sub-criteria”, and “the goal”, and the “pairwise comparisons between the elements” and the “relationships between the elements” are illustrated in Figure … . To model the problem, first, the goal, the overall structure of the model, and the relationships between the elements were identified, and every pair of elements was compared pairwise with a third element to which both members of the pair were related. Then, the ranking model was created to rank the options, and the options were introduced into it. The stages of the process are explained in more detail below.

3.2.1. The ANP modeling

After detecting the risks of the present study, their importance and weights were determined using the hierarchical ANP technique. In the present study, three ANP models were created for the safety, health, and environmental risks. Then, the pairwise comparisons of the risks were performed after forming the model in Super Decision.

3.2.2. The ANP questionnaire

The questionnaires of the pairwise comparisons of the sets (based on Table 3) were created, and they were handed to a panel of experts consisting of 10 specialists. After the matrices of pairwise comparisons were filled out, the incapability rates were calculated. As all rates were below 0.1, the stability and compatibility of the matrices were confirmed. Then, the pairwise comparisons of the experts were combined using the geometric mean technique, and their weights were determined in Super Decision. Finally, the calculated weights were used to obtain the weights of the risks in each set.

Numerical value	The degree of importance in pairwise comparisons
1	Similar preference
2	A similar or rather similar preference
3	Relative preference
4	Relative to a strong preference
5	Strong preference
6	Strong to a very strong preference
7	Very strong preference
8	Very strong to an infinitely strong preference
9	Infinitely strong preference

4. Results

4.1. Introducing the risks of the study to the ANP technique

In this section, the risks of the study (identified using FMEA, Willian, & Fine methods) were prioritized by implementing the ANP technique. The risks obtained based on the data and the frequency of the criteria and the results of risk analysis, risk priority numbers, and risk levels in 9 departments are given in Tables 1, 2, and 3 below.

Table 1. The risks obtained by the William & Fine method

Support	Quality control	Material milling	Packing plant	Baking department	Crushing plant	Production workshop	Mine	Cement mill
Light and brightness	Chemicals	Noise	Ergonomic (carrying heavy loads)	Thermal stress	Noise	Fume (gases and vapors)	Noise	Dust
Ergonomic factors (carrying heavy loads, inconvenient working stations	Ionizing-radiation	Dust	Dust	Noise	Dust	Non-ionizing radiation	Thermal stress (coldness and heat)	Noise
Magnetic fields (electrical substations)	Ergonomic (excessive pressure on a muscle, inconvenient working stations)	Thermal stress (coldness and heat)	Chemicals	Dust	Mental factors (shifts, occupational stress)	Noise	Dust	Thermal stress (coldness and heat)
Mental factors (occupational stress)	Mental factors (occupational stress)	Ergonomic (inconvenient working stations, inconvenient tools)	Noise	Ergonomic (inconvenient working station)	Ergonomic (carrying heavy loads)	Chemicals	Non-ionizing radiation	Ergonomic (excessive pressure on a muscle, inconvenient working stations)

Table 2. The risks obtained by the FMEA method

Mine	Cement mill	Production workshop	Crushing plant	Baking department	Packing plant	Material milling	Quality control	Support
Explosion	Falling items	Falling metal objects and particles	Falling people	Explosions	Falling items	Being stuck in the moving parts of the vehicles	Electrocution	Electrocution
Crashes with vehicles	Splashing hot materials	Contact with sharp objects	Falling items	Fire	Being stuck in the moving parts of the vehicles	Fire	Splashing hot materials	Fire
The overturning of vehicles	Electrocution	Being stuck in the moving	Electrocution	Falling people	Fire	Falling people	The slippery and uneven	Falling items

		parts of the vehicles					floor of the workshop	
Falling items	Falling people	The slippery and uneven floor of the workshop	Being stuck in the moving parts of the vehicles	Contact with flames	Splashing hot materials	Falling items	Contact with sharp objects	Falling people

Table 3. ……………………………………

4.3. The findings of the ANP method

After the risks were identified, the hierarchical ANP method was implemented to determine their importance and weights. In the present study, three ANP models were formed for the safety, health, and environmental risks. Then, the matrices of pairwise comparisons were created for the sets, and they were handed to a panel of experts consisting of 10 participants. After the matrices were filled in, their incompatibility rates were calculated. As the obtained rates were all below 0.1, the stability and compatibility of the matrices were confirmed. Then, the experts' pairwise comparisons were combined using the geometric mean technique, and their weights were determined in Super Decision. The results of the pairwise comparisons and the obtained weights are given in the following section.

4.3.1. The results of the ANP technique for the risks detected by the William & Fine method

A schematic representation of the implementation of the William & Fine model in Super Decision is given in Figure 2.

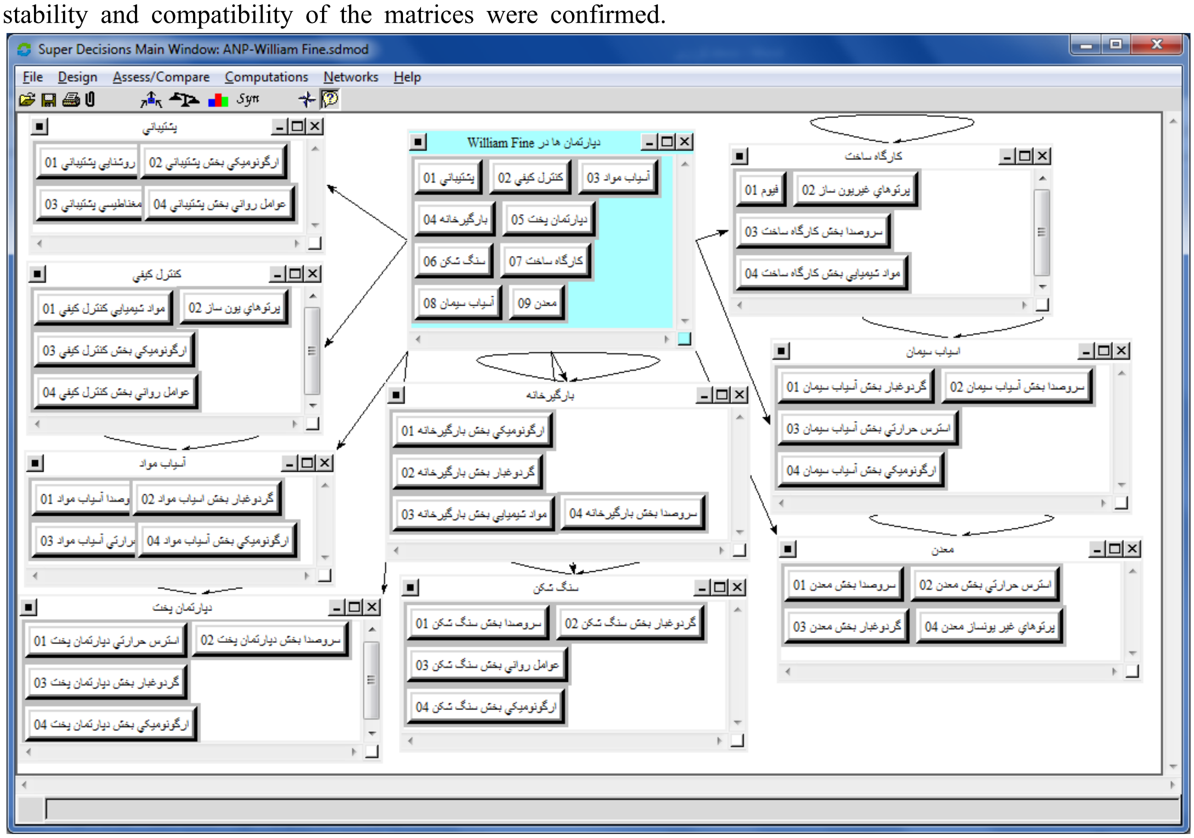

Figure 2. The research model in Super Decision

After the model was created in Super Decision, the pairwise comparisons of each set were formed and completed by a panel of 10 experts. Then, they were introduced into the software to determine their weights.

4.3.1.1. The pairwise comparison of the risks in the department of metrical milling

Table 4. The weights assigned to the risks of the department of material milling

Risk	Rank	Weight in the set	Weight obtained from the super-matrix
Noise	1	0/506	0/0562
Dust	2	0/242	0/0269
Thermal stress (coldness and heat)	3	0/133	0/0148
Ergonomic (inconvenient working station, inconvenient tools)	4	0/119	0/0132

1-

Based on Table 4, noise ranked first (0.506) among the risks of the department of material milling, while ergonomic risks including inconvenient working stations and inconvenient tools (0.119) ranked fourth.

4.3.1.10. Forming the super-matrices of ANP

In the ANP technique, three super-matrices (preliminary, weighted, and limited) needed to be formed to calculate the ultimate weights. This was performed automatically in Super Decision. The ultimate weights are given in Figure 4.

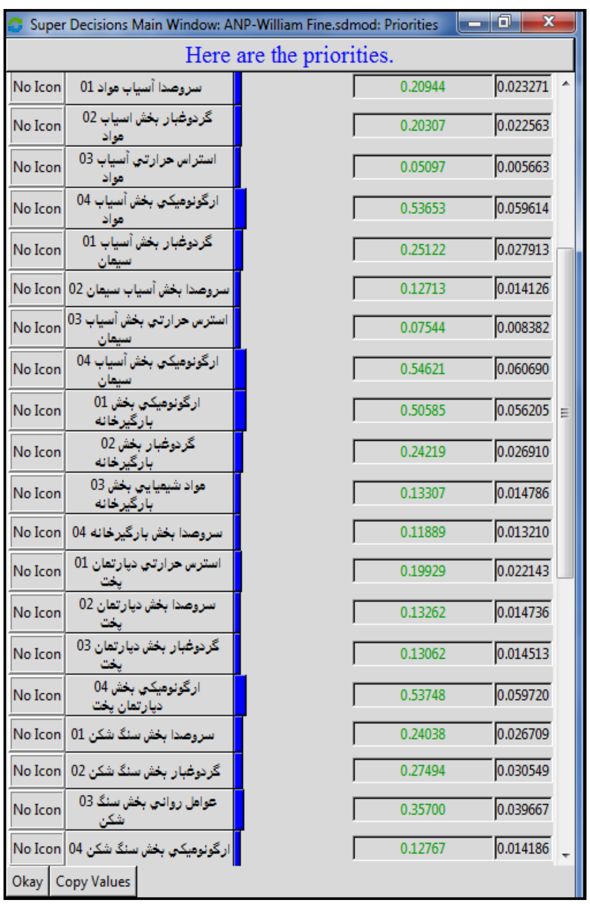

Figure4. The ultimate weights of the risks according to the William & Fine method

The weights calculated in Figure 4 could be used to obtain the weights of the risks. This could be performed by normalizing the ultimate weights of each set (dividing each weight by the total weights). The results are given below. Moreover, the ranking of all risks is given in Figure 5.

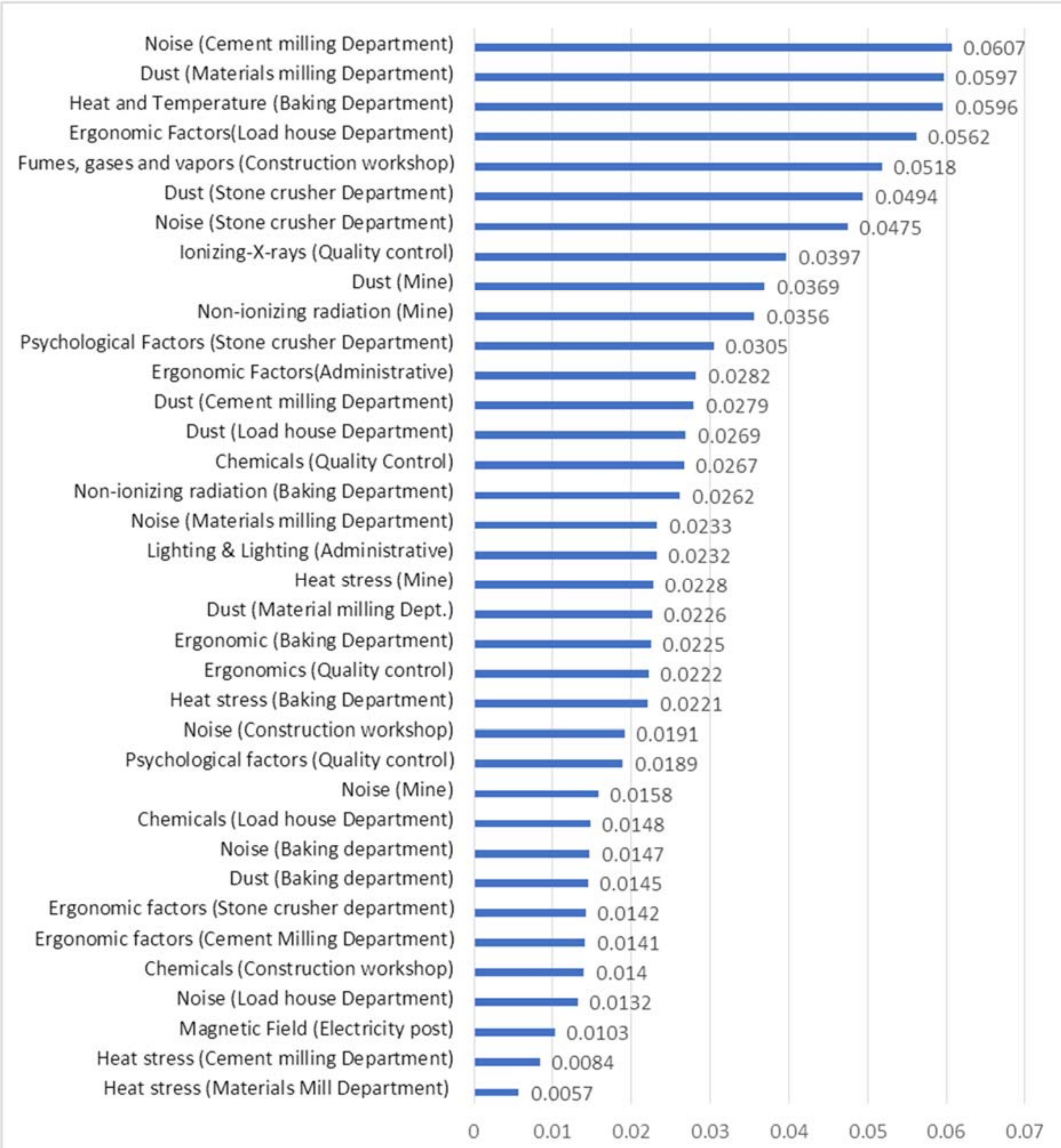

Figure 5. Ranking the risks obtained by the William and Fine method

4.3.2. The results of the ANP technique for the FMEA risks

A schematic representation of the implementation of the FMEA model in Super Decision is given in Figure 6.

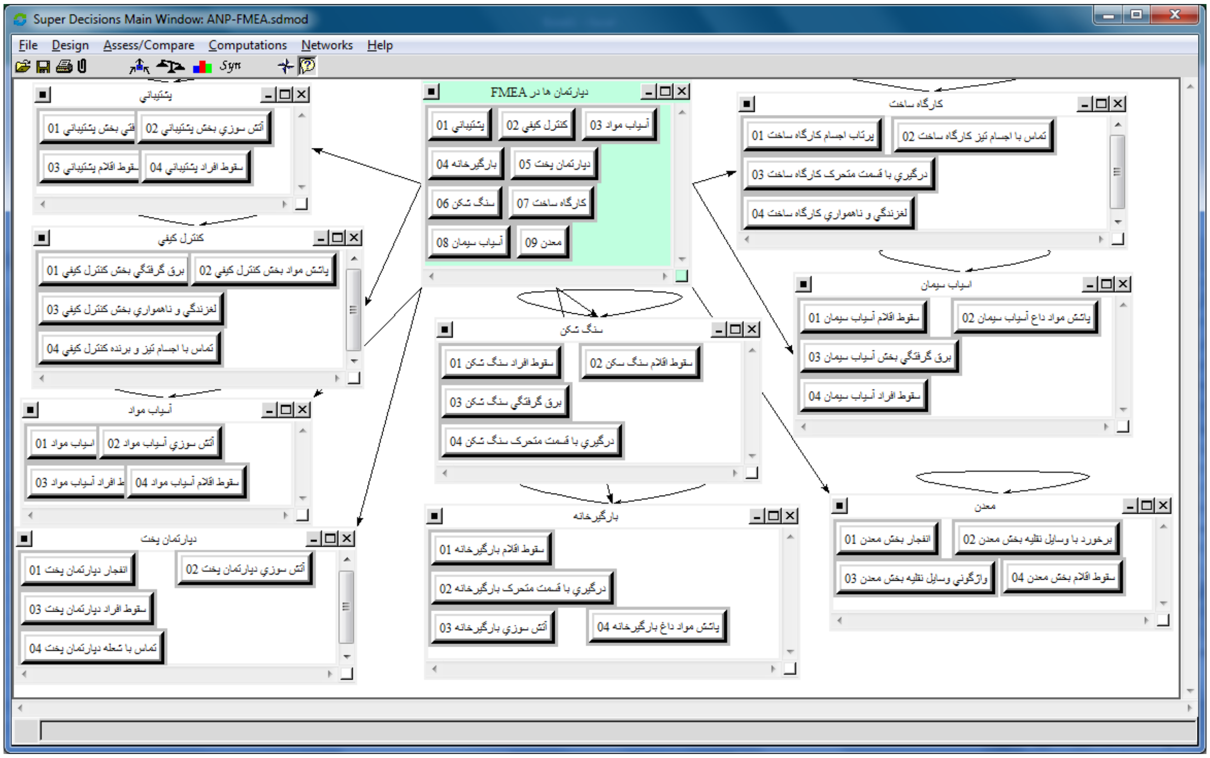

Figure 6. The research model in Super Decision

Similar to the procedure performed for the FMEA risks, the pairwise comparisons were performed and introduced to Super Decision to calculate the weights. Figure 7 illustrates the ranking of all risks. As it can be observed, workers falling from the cement mill ranked first among all risks.

Figure 7. Ranking all risks obtained by the FMEA technique

4. Discussion and conclusion

The William & Fine and FMEA techniques are among the most advanced, significant, and widely-used methods of risk detection and prioritization in process industries. The methods can quantitatively detect any risk related to a certain activity. The preliminary analysis of harmful factors in workplaces was carried out at the beginning of the study to detect the sources of risks. Moreover, the forms of detecting the harmful factors were filled in concerning all departments and sections of the plant. Then, the analytical methods were implemented to distinguish the safety and health risks in various stages of production. After detecting the risks of the study based on the above two methods and the tables of risk analysis (risk priority numbers), the risks levels, and the frequency of the criteria, the ultimate importance and weights of the health and safety risks were prioritized and ranked using the ANP technique.

Super Decision (as a specialized software based on mathematical equations) was implemented to calculate the ultimate weights of the obtained risks and investigate the effects of the internal relationships of the risks on one another. Overall, five main departments (material mill, cement mill, crushing department, baking department, and packing plant) and seven main sections (administrative and support bureau, quality control, HSE, production workshop, electricity, warehouse, mine, and construction) were investigated in the present study, and 1184 risks that threatened the safety of the plant and the employees' health and could result in probable accidents for people, material, equipment, and environment were identified.

Analyzing the health risks by the William & Fine method resulted in the detection of 352 risks where the highest weights were found for the noise of the cement milling department (0.0607), the dust resulting from milling the materials (0.0597), thermal stress (heat), the baking department (0.0596), the ergonomic factors of the packing plant (0.0562), and the fumes, gases, and vapors of the production workshop (0.0518).

Table 5. The total results of the risk assessment in different sections of the cement plant

	William & Fine	**The number of health risks**	**FMEA**	**The number of health risks**
1	HSE	13	HSE	26
2	Administrative bureau	23	Administrative bureau	31
3	Cement mill	41	Cement mill	51
4	Material mill	19	Material mill	40
5	Packing plant	19	Packing plant	27
6	Baking department	66	Baking department	85
7	Crushing department	35	Crushing department	64
8	Production workshop	45	Production workshop	89
9	Quality control	26	Quality control	39
10	Mine	33	Mine	23
11	Warehouse	10	Warehouse	25
12	Electricity	22	Electricity	30
13	The sum of risks in each method	352	The sum of risks in each method	529

Moreover, analyzing the safety risks using the FMEA technique resulted in the detection of 529 risks in various operational sections, and the highest weights were given to the fall of the employees from the cement mill (0.0601), the fall of items from the packing plant (0.056), explosions in the baking department (0.0549), the slipperiness and unevenness of the floor of the crushing department (0.0476), and the splashing hot materials in the department of baking (0.043).

Kenarroudi and Bahadori conducted a study in 2012 titled "An investigation of the safety and health risks in Shargh Cement Plant according to William & Fine method" and analyzed the safety and health risks of the workplace. They found out that the risks of welding and cutting activities (electrocution, welding fumes, excessive pressure on muscles, and noise), the inspection and service of electrical equipment (electrocution), and the storage of gas and air capsules inside the workshop (explosion and inflammation) were more serious than other activities. Though the study did not perform a comprehensive investigation of the whole plant, its results – particularly the ones concerning the safety risks of the workshop – were conveniently in line with the analyses of risks by the FMEA and ANP techniques in the present study.

The study conducted by Rezaeian and Mahmoudi in 2014 titled "An investigation of the safety, health, and environmental risks of Sefid Saveh Cement Plant according to the William & Fine and EFMEA techniques" was somehow similar to the present study in terms of the methods of performing risk analyses (William & Fine, EFMEA). The only difference was the study made no distinction between the safety and health risks, and the ranking was performed only according to the risk priority numbers in some of the main departments (the crushing department, material mill, the baking department, and cement mill), and a total of 177 health and safety risks were detected in them.

On the other hand, the statistical report of the Social Security Organization of Iran concerning the work-related accidents during 2008-08 according to the geographical distribution and the types of the accidents showed that falling and slipping, the fall of objects, and being stuck between objects were the most prevalent accidents, and this was in line with the findings of the present study (15).

Moreover, the findings of the present study concerning the risks and the reasons for their occurrence were in line with the findings of Donghi et al. (2011), Sana et al. (2013), and Rampuri et al. (2017) where the main causes of accidents in cement plants were attributed to being exposed to the noise of machinery, unsafe equipment, dust, gases, vapors, mechanical risks, contacts with sharp edges, electricity (electrocution, shocks, fire), falling, being crushed by vehicles, physical factors (heat, insufficient light), chemical hazards, and fire (flames, hot materials),

Based on the results of the risk analysis according to the FMEA and William & Fine methods and the ranking of the ultimate weights obtained using the ANP technique, the most significant control measures concerning the safety and health risks were the following ones. In the crushing department (consisting of the crushing equipment, the mixing salon, hopper silicon, and the sampling chamber of the quality control department), the convenient protection of all rotating parts, covering three sides of the salon up to the ceiling with plate sheets, moisturizing and granulating the incoming silicon to prevent the emergence of dust and its inhalation by the workers, and installing emergency switches on both sides of the conveyor below (so that the employees could stop the belts in the case of mechanical issues and probable accidents) were proposed.

In the department of the raw material mill (triple silos, the raw material mill, and the baghouse), the proposed solutions included installing covers on the conveyor belts, covering both sides of the departments with plate sheets (to prevent the effect of wind0, installing handrails on the tripe silos, enclosing and isolating the operation room of the personnel, and implementing two metal doors and a two-layered wall coverage to reduce noise.

In the department of the cement mill (the open-circuit mill, the closed-circuit mill, the hopper of plaster and silicon), discharging and changing the pellets inside the mill and installing a cover on the conveyor belts were proposed, while the suggestions in the baking department (the furnace feeder, preheater, furnace, grate coolers, electro-filters, clinker silos, reject silos) included using air-shocks installed on the body of the silicon or their inspection valves and milpipes using compressed air to eliminate obstructions, using lifts and convenient handrails in the pre-heater section, reducing the tonnage, decreasing the flame intensity of the furnace, wearing fireproof clothes, boots, face masks, and flameproof gloves, increasing the distance of the operation room, building a room with quality materials, and installing double-glazed windows (16).

Observing the safety measures of work like implementing reliable and convenient scaffolds, anchoring the scaffolds, installing protective fences in precipices, wearing safety belts, using warning signs and equipment, fire alarm systems, specifying the employees' training needs, and holding safety and health courses for them concerning the risks of hazardous factors in their occupations, making coordination and discussions in group activities, observing safety actions before the work, providing protective clothing and equipment for the employees according to the types of the occupations and the related threats, monitoring the employees' behavior, particularly during the fixing activities, and providing technical training courses for the newly-employed people are some other control measures concerning safety and health risks (17).

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