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Research paper

Risk assessment of occupational groups working in open pit mining: Analytic Hierarchy Process

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ABSTRACT

In open pit mining it is possible to prevent industrial accidents and the results of industrial accidents such as deaths, physical disabilities and financial loss by implementing risk analyses in advance. If the probabilities of different occupational groups encountering various hazards are determined, workers' risk of having industrial accidents and catching occupational illnesses can be controlled. In this sense, the aim of this study was to assess the industrial accidents which occurred during open pit coal production in the Turkish Coal Enterprises (TCE) Garp Lignite unit between 2005 and 2010 and to analyze the risks using the Analytic Hierarchy Process (AHP). The analyses conducted with AHP revealed that the greatest risk in open pit mining is landslides, the most risky occupational group is unskilled labourers and the most common hazards are caused by landslides and transportation/hand tools/falling.

1. Introduction

Mining is a sector which is distinguished from other fields by its basic structure. It requires production in continuously changing environmental conditions due to the diversity of natural conditions and therefore contains multiple risks from the production phase to final shipment. These risks might lead to undesirable situations and the amount of workplace accidents can increase. Therefore, the accurate identification and assessment of risks is becoming increasingly important in the mining sector.

Open pit mining, as one of the two methods of production in the mining sector, seems to have a relatively more reliable operating environment, however, it also contains a number of hazards within itself. The hazards that must be considered in this production method are those caused by slopes, water income, machinery, falls, hand tools and dust.

In open-pit mining, there is a wide range of possibilities of encountering hazardous situations due to differences among various occupational groups in terms of working conditions. The aim of this study was to assess the industrial accidents which happened in TCE Garp Lignite Company between 2005 and 2010 and to analyze the risks using the Analytic Hierarchy Process (AHP).

The AHP model is commonly used in decision theory and takes into consideration conflicting, measurable and/or abstract criteria. By means of pairwise comparisons, these criteria are analyzed by using their weights and priorities. The method is successful in that it.

- ensures accurate decisions are made by ensuring the decision making process is formal and systematic,
- allows for carrying out sensitivity analyses of the results,
- is a practical method which makes it possible for the decision-maker to appropriately determine the choices regarding the objective,
- has a design that simplifies complicated problems,
- allows for involving both quantitative and qualitative data in the decision making process for a decision problem,
- allows for measuring the consistency level of the decision maker's judgments,
- is suitable for use in group decisions.

Although there are several studies about the risk analysis of mining companies such as the studies by Komljenovic, Groves, and Kecojevic (2008), Marhavilas and Koulouriotis (2008) and Öztaş (2007), these studies do not adopt AHP method in their analyses. However, there are examples of risk analyses through this method

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in various sectors (Fang, Shen, Wu, & Liu, 2003; Dağdeviren & Yüksel, 2008; Ouédraogo, Groso, & Meyer, 2011).

By using data from the TCE Garp Lignite unit, this study demonstrated, in practice, that the AHP method could be used to determine the types of hazards which workers in different occupational groups in open pit mining are more likely to encounter and to assess their risk of having industrial accidents and catching occupational diseases due to these hazards.

2. Materials and methods

AHP was first introduced by Myers and Alpert in 1968 and later developed by Saaty (1977). AHP is a decision making process which is based on using a managerial decision mechanism by assigning importance according to decision options and criteria. Decision making with AHP might involve taking qualitative values into account as well as quantitative ones. AHP is based on the principle that knowledge and experiences that are as valuable as data are taken into consideration in decision making.

The stages which are required to analyze a decision making problem with AHP are described below.

Stage 1: The decision making problem is defined and divided into sub-problems in a hierarchical order. In other words, a model which shows the fundamental criteria of the problem and the relationships among these criteria is formed.

Stage 2: A comparison matrix is formed by making a pairwise comparison between the factors.

At this stage, two factors are compared with each other according to their relative importance based on the decision maker's judgment (pairwise comparison). The relative importance values are determined by using the 1–9 point scale developed by Saaty (Table 1). In the comparison matrix (**A**), n represents the number of criteria to be compared and a_{ij} shows the importance of i property in comparison with j property.

$$\mathbf{A} = (a_{ij})_{n \times n} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}$$

When $a_{ii} > 0$, there are $a_{ij} = 1/a_{ji}$ and $a_{ii} = 1$ relationships between the matrix elements. For example, if the first factor is seen as more important than the third factor, by the person making the comparison, the first row third column component ($i = 1, j = 3$) of the comparison matrix is scored as 3. In the opposite case, when the third factor is favored over the first one in terms of importance, the first row third column component of the comparison matrix receives the score 1/3. On the other hand, if the first and third factors are regarded to be equally important, then the component will receive the score of 1.

Comparisons are made for the values remaining above the diagonal of the matrix, all values of which are 1. For the components remaining below the diagonal, however, Equation (1) below is used.

$$\mathbf{a_{ji}} = \frac{1}{a_{ij}} \tag{1}$$

Stage 3: Percentual distribution of the importance of factors is determined.

The comparison matrix displays the relative importance of factors over each other with certain logic. However, in order to determine the individual weights of these factors of the whole, that is in other words the percentual distribution of importance, the n B column vector with the n-element is formed by using the column vectors constituting the comparison matrix.

$$\mathbf{B_i} = \begin{bmatrix} b_{11} \\ b_{21} \\ \cdot \\ \cdot \\ \cdot \\ b_{n1} \end{bmatrix}$$

Equation (2) is used to calculate **B** column vectors.

$$\mathbf{b_{ij}} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{2}$$

The weights of all the assessment factors within the whole, i.e. the **B** column vectors, are generated. When the n **B** column vector is gathered in the form of a matrix, the **C** matrix below is formed.

$$\mathbf{C} = \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1n} \\ c_{21} & c_{22} & \cdots & c_{2n} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ c_{n1} & c_{n2} & \cdots & c_{nn} \end{bmatrix}$$

The percentual distribution of importance, which shows the importance values of factors, can be obtained by using the **C** matrix. For this purpose, as shown in Equation (3), the arithmetic mean of the row elements that make up the **C** matrix is calculated and the **W** column vector, called the priority vector, is obtained.

$$\mathbf{w_i} = \frac{\sum_{j=1}^{n} c_{ij}}{n} \tag{3}$$

The **W** vector is shown below.

Table 1
The pair-wise comparison scale.

Intensity of importance	Definition	Explanation
1	Equal importance of both elements	Two elements contribute equally to the property
3	Moderate importance of one over the other	Experience and judgment slightly favor one element over the other
5	Strong importance of one element over the other	Experience and judgment strongly favors one element over the other
7	Very strong importance of one element over the other	An element is strongly favored and its dominance is demonstrated in practice
9	Extreme importance of one element over the other	The evidence favoring one element over the other is of the highest possible order of affirmation
2,4,6,8	Intermediate values	When compromise is needed

$$\mathbf{W} = \begin{bmatrix} w_1 \\ w_2 \\ \cdot \\ \cdot \\ \cdot \\ w_n \end{bmatrix}$$

The relative importance of each factor is determined when each factor is assessed together.

Stage 4: The consistency of factor comparisons is measured.

Although AHP has an internally consistent system, the authenticity of results depends on the consistency of the one-to-one comparison among factors made by the decision-maker. AHP suggests a process to measure the consistency of these comparisons. It provides an opportunity to test the consistency of the priority vector and therefore one-to-one comparisons among the factors by means of the resulting Consistency Ratio (CR). In AHP, the CR calculation is based on the comparison of the number of factors and a coefficient called the Fundamental Value (λ). The **D** column vector is obtained by the matrix multiplication of comparison matrix **A** with priority vector **W**, in order to calculate λ.

$$\mathbf{D} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \text{x} \begin{bmatrix} w_1 \\ w_2 \\ \cdot \\ \cdot \\ \cdot \\ w_n \end{bmatrix} \tag{4}$$

As defined in Equation (4), the fundamental value of each assessment factor is obtained by dividing the corresponding elements of the resulting **D** column vector by the **W** column vector (**E** = equation (5)). Finally, the arithmetic mean of these values (Equation (6)) shows the fundamental value of comparison (λ).

$$E_i = \frac{d_i}{w_i} \quad (i = 1, 2, \ldots, n) \tag{5}$$

$$\lambda = \frac{\sum_{i=1}^{n} E_i}{n} \tag{6}$$

After λ is calculated, the Consistency Indicator (CI) can be generated through Equation (7).

$$\mathrm{CI} = \frac{\lambda - n}{n - 1} \tag{7}$$

In the final stage, CR is obtained by dividing CI by the standard correction value, which is also called the Random Indicator (RI) and shown in Table 2 (Equation (8)).

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{8}$$

The calculated value of CR of less than 0.10, indicates that comparisons made by the decision-maker are consistent. On the other hand, a CR value greater than 0.10 shows a calculation error in AHP or the inconsistency of the decision-maker in comparisons (Saaty, 1980).

Table 2
Average random consistency (RI) (Saaty, 1980).

Size of matrix	1	2	3	4	5	6	7	8	9	10
Random consistency	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

3. Result and discussion (risk assessment in open-pit mining)

Data about the industrial accidents which happened in the TCE Garp Lignite enterprise between 2005 and 2010 was analyzed (Table 3) (Subaşı, 2011), because determining the types of hazards which workers in different occupational groups in open pit mining are more likely to encounter could be helpful in assessing their risk of having industrial accidents and catching occupational diseases due to these hazards.

This study used general hazard categories based on the problems of mines mentioned in the Project Assessment Report of Surface and Underground Mines (2005) by the Ministry of Labor and Social Security. The hazards and occupational groups taken into account in the analysis were grouped in Tables 3 and 4, based on data about the industrial accidents in the mine examined. The hierarchical model of the decision making problem created in light of this data is shown in Fig. 1.

After the hierarchical model was formed, a pairwise matrix to determine the relative importance of the hazards in open-pit mining was formed and the weights of hazards causing industrial accidents and occupational diseases in the mine were determined (Fig. 2) (see Fig. 3).

Expert Choice, developed by Expert Choice, Inc., was used for all calculations. A consistency test was conducted by the formula developed by Saaty, as there may be inconsistencies since the comparisons made while establishing the matrix used in the calculations are assessed subjectively even though the calculations themselves are objective. The consistency ratio (CR) was found to be 0.02 (<0.10), which shows that the comparisons were consistent. Similarly, the consistency ratios calculated for the tables given in the appendices were also found to be lower than 0.10.

Data from the pairwise comparisons of the possible hazards revealed that landslides make up the greatest risk in open-pit mining, with a weight value of 24.7%. These are followed by noise + vibration and the hazards in “others” category, with a weight value of 15% each. Finally, the gases category was determined to have the lowest risk, with a weight value of 2%.

At this stage of the analysis, the hazards were assessed for each of the occupational groups by making pairwise comparisons for each hazard for the occupational groups in the mine (e.g. Fig. 4) and the graphics of the results were given in the appendices (Appendix A, B, C, D, E, F, G, H, I).

When each of the occupational groups was assessed in terms of gases, it was found that the powder makers were exposed to the greatest risk and they have a weight value of 31.2%. They were followed by the fuel oil service unit operators and then by workers. The group with the lowest risk was the technicians, with a weight value of 3.6% (Appendix A).

In general, the risk assessment (Fig. 5) revealed that the group with the greatest level of risk in terms of all the possible hazards in open-pit mining was workers, with a weight value of 25.3%. When the members of this group were analyzed for each of the hazards separately, it was found that the weight percentages varied between 17.8% and 31.2%. The most likely cause of accidents was Transportation + Hand tool + Fall followed by landslides. In order to minimize or completely eliminate these risks, the workers should be protected from adverse weather conditions and, where necessary, external influences such as falling objects, hazardous levels of noise, gas, steam and dust. They should be able to leave the workplace immediately and get help as soon as possible in case of any danger.

The group with the second highest level of risk in terms of the possible hazards in open-pit mining was the operators, with a weight value of 18.6%. They were most exposed to hazards classified as “other hazards”, such as road crash-tipping-burning,

Table 3
Hazard factors taken into account in analysis.

	Hazards	Explanation
1	Gases	Poisonous, choking, explosives gases
2	Dust	After explosion and dust generated during the production
3	Water + Fire	Water flushes, Coal or fire equipment
4	Explosives	Explosives
5	Transportation + Hand Tool + Fall	Accident causing by manual or mechanical transportation, Hand tool collision, fall, urge, Walking, or falling from height
6	Machinery + Materials	Machinery or materials, shock, drop, impingement, and back injury
7	Noise + Vibration	Noise, Vibration
8	Landslide	Landslide
9	Others	Electrical, chemical, Chip-nail penetration, Lighting, Road crash-tipping-burning, Heavy equipment drop-burning, Heavy equipment traffic collision-tipping-burning

Table 4
Occupational groups taken into account in analysis.

	Occupational groups	Explanation
1	Technicians	Operating Engineers Mining technicians
2	Operators	Truck drivers, heavy and tractor-trailer Excavating and loading machine and dragline operators Rotary drill operators
3	Powder maker	Power maker
4	Thresher	Thresher, Shunter
5	Wellhead pumpers	Wellhead pumpers
6	Fuel oil service unit operators	Fuel oil service unit operators
7	Workers	Helpers - Extraction workers

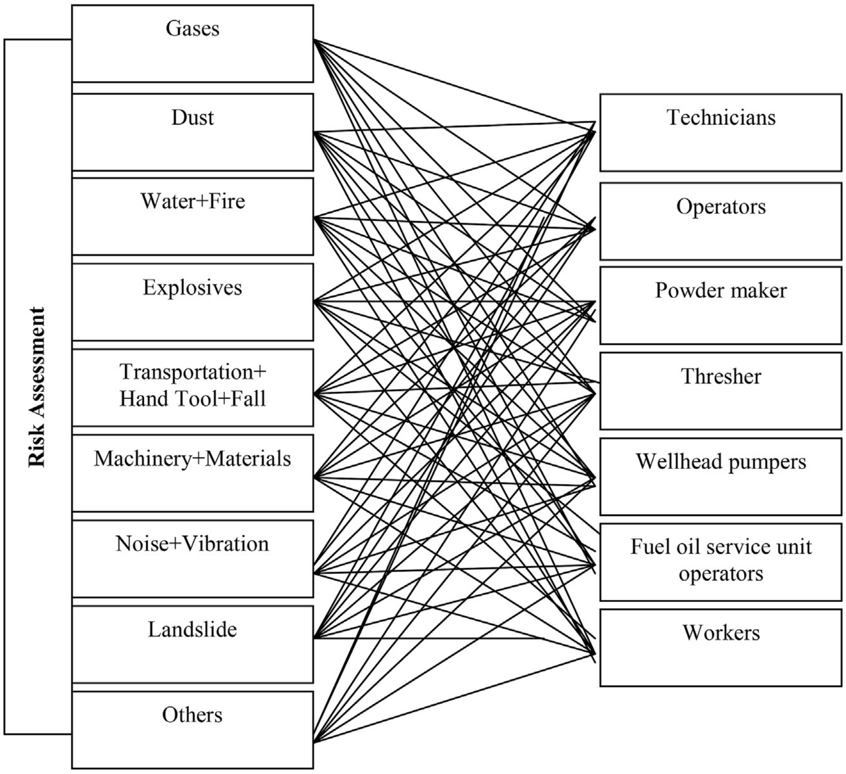
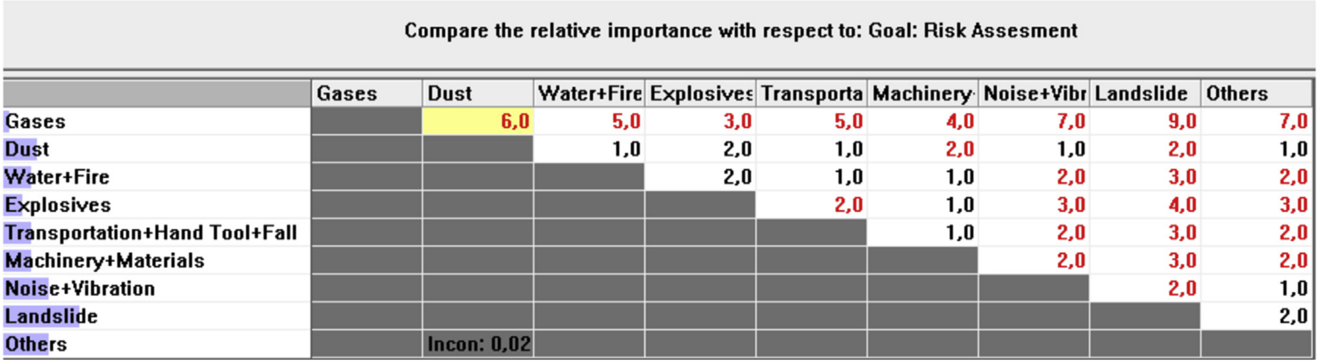


Fig. 1. The hierarchical structure of risk assessment.

dropping-burning of machinery and collision-tipping-burning of machinery (with a weight value of 30.1%). They should have safe access to working areas and these areas should be convenient enough to be evacuated quickly and safely in the case of an emergency. All transportation facilities including stairs, loading platforms and ramps should be designed, arranged and built in a way that offers easy, safe and convenient passing for pedestrians or vehicles and protects the nearby personnel from hazards. The

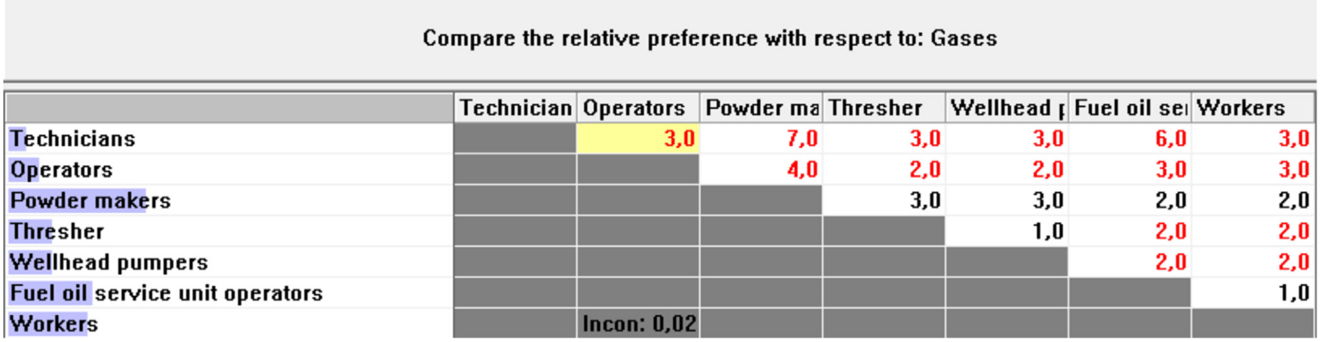


Compare the relative importance with respect to: Goal: Risk Assesment

	Gases	Dust	Water+Fire	Explosives	Transporta	Machinery	Noise+Vibr	Landslide	Others
Gases		6,0	5,0	3,0	5,0	4,0	7,0	9,0	7,0
Dust			1,0	2,0	1,0	2,0	1,0	2,0	1,0
Water+Fire				2,0	1,0	1,0	2,0	3,0	2,0
Explosives					2,0	1,0	3,0	4,0	3,0
Transportation+Hand Tool+Fall						1,0	2,0	3,0	2,0
Machinery+Materials							2,0	3,0	2,0
Noise+Vibration								2,0	1,0
Landslide									2,0
Others		Incon: 0,02							

Fig. 2. Pair-wise comparison matrix for criteria.

Fig. 3. Pair-wise comparisons of the hazards in open-pit mining.



Compare the relative preference with respect to: Gases

	Technician	Operators	Powder ma	Thresher	Wellhead	Fuel oil se	Workers
Technicians		3,0	7,0	3,0	3,0	6,0	3,0
Operators			4,0	2,0	2,0	3,0	3,0
Powder makers				3,0	3,0	2,0	2,0
Thresher					1,0	2,0	2,0
Wellhead pumpers						2,0	2,0
Fuel oil service unit operators							1,0
Workers		Incon: 0,02					

Fig. 4. Pair-wise comparison matrix for gases.

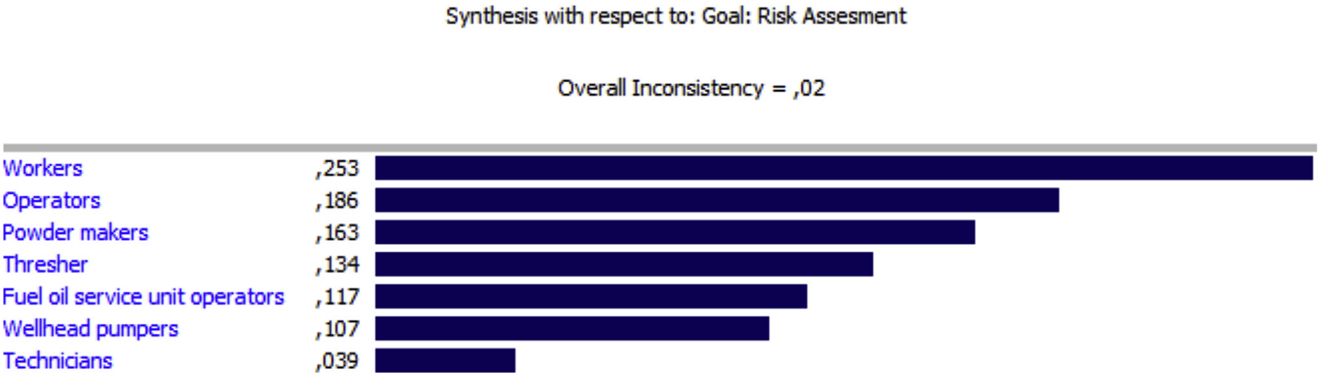


Fig. 5. Risk assessment of the occupational groups in terms of the hazards in open-pit mining.

tracks used by pedestrians and/or vehicles to transport material should be built with the appropriate dimensions for the number of users and nature of the work. There should be an adequate safety distance for pedestrians on those tracks used for material transportation. There should be an adequate sight distance between the tracks used for vehicular traffic and doors, pedestrian crossings, corridors and stairwells. Tracks and crossing points for vehicles should be clearly indicated to ensure personnel safety. Also, there should be appropriate traffic regulation when there are vehicles and machinery in the working area.

The group with the third highest level of risk was the powder makers, with a weight value of 16.3%. The powder makers were most exposed to hazards from explosive materials (a weight value of 36%). Storage, handling and use of explosive substances and burners should be performed only by experts and authorized personnel. These tasks should be organized and conducted in a way that does not pose a risk to workers. Also, the powder makers in this study were the occupational group that was influenced most by gases and noise + vibration.

The group with the fourth highest level of risk was the threshers, with 13.4%. It was found that the threshers were most exposed to noise + vibration and dust in comparison to the other hazard categories. The personnel in this group should be provided with personal safety equipment. Moreover, there should be sign agreement for shunters and threshers working in decoupling, coal production, soil moving, stocks and silos.

The fifth group was composed of the fuel oil service unit operators and the wellhead pumpers with 11.7% and of 10.7% respectively. The personnel in this group were most exposed to water + fire hazard. Water income analyses should be conducted before starting production and the necessary investments should be provided for proper drainage methods so that necessary tools and equipment are be available in mines to combat these hazards. Also, in this study, the wellhead pumpers were exposed to hazards caused by transportation and machinery + material while the fuel oil service unit operators were exposed to hazards caused by explosives, gases, and transportation + hand tool + fall.

It was finally determined that the technicians were the group least at risk with 3.9% and they were almost equally exposed to all of the hazards in the mine.

4. Conclusions

The data concerning industrial accidents over the last five years in the TCE Garp Lignites unit was analyzed and risk analysis of the various occupational groups in this open pit mine was carried out by means of AHP.

When the occupational groups working in the open pit mine in this study were analyzed in terms of all of the relevant hazards, it was found that the most at risk group was the workers (25.3%) while the least at risk group was the technicians (3.9%) in the mine. Each of the occupational groups in the study was examined separately in terms of all of the hazards in the mine and necessary precautions were taken.

The most likely hazard in open pit mining method is related to slopes because the production in open pits is conducted through slopes. Heavy machinery, workers, drillers operating on slopes, blasts, cracks, loose rocks and bad atmospheric conditions in mines cause slopes to move. Analyses also showed that the most likely hazard was landslides (24.7%).

In order to reduce this risk, the optimum slope angle, slope height, and slope width for the safety of machinery and personnel should be determined based on the site's geological, tectonic and physical properties.

Necessary precautions should be taken against hazards that may be caused by other machinery and equipment in upper slopes. Personnel should not be allowed to eat, rest or put explosives or cases for explosives on the slopes. After events like the loosening of a site's land due to blasts or cold weather conditions, cracks should be checked and at risk parts should be removed beginning from the upper parts to the lower slopes. In addition, operators using heavy machinery should keep clear of slope edges and wear safety belts at all times.

The second most likely hazard for all of the occupational groups in open pit mines is caused by the noise + vibration and others (road crash-tipping-burning, dropping-burning of machinery, crash-tipping-burning of machinery in traffic, lighting problems etc.) category. In order to minimize these risks, necessary safety precautions should be taken in operating conditions, maneuvering locations, loading, transporting and unloading tasks (e.g. spots for moving land, silos, etc.). Moreover, personnel should be equipped with personal protectors against possible noise hazards.

Another consideration is the conditions of working at night. Working at night requires extra attention and a safe working environment. Otherwise, it is harder to recognize hazards at night. Therefore, every part of the site should be properly illuminated.

Operators and drivers should move more slowly at night because it may take longer to slow down and stop due to limited field of view. Also, all vehicles should have their headlights on so that other vehicles and personnel can see them. However, their lights should not be too bright so as not to blind or dazzle others. Finally, all mud and dust should be removed from headlights for maximum illumination.

Portable lights can be used to see the condition of slopes. Also wearing clothes with light colors or with reflective bands would add visibility as a part of personal protective precautions.

The hazards that can cause industrial accidents and occupational diseases in open pit mines are dust, machinery + materials, transportation + hand tool + fall, water + fire, explosives and gases respectively (0.2%).

The risks of these hazards could be reduced by using protective safety equipment and determining the optimum values concerning the dimensions of blasting holes, the distance between blasting holes and the slope, and the amount of explosives accurately. Filling, stemming and detonating explosives should never be conducted without ensuring the safety of personnel and machinery first. In addition, explosives should be stored in a safe place and transported whilst taking all necessary precautions.

Another cause of hazards in open pit mining is water income. Rain water or water from melting ice can cause erosion and slippery slopes. Vehicle accidents and falls are more likely in slippery ground conditions. Most of the hardware in mines is supported by electrical cables and electric leakages cause serious injuries due to bare wire or faulty connections in water ponds. Mines should adopt a drainage method which is appropriate for their location and climatic conditions.

Finally, there should be sign agreement for the shunters and threshers and necessary measures should be taken against unauthorized access to working areas.

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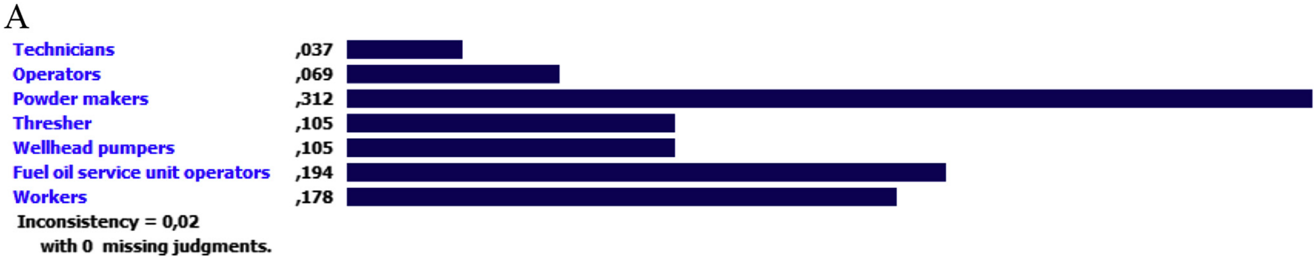
Conflict of interest

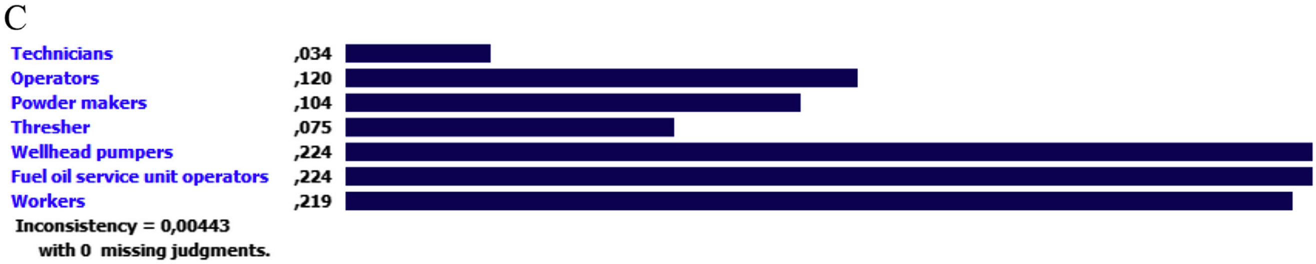
We declare and accept that there is no conflict of interest.

Appendix

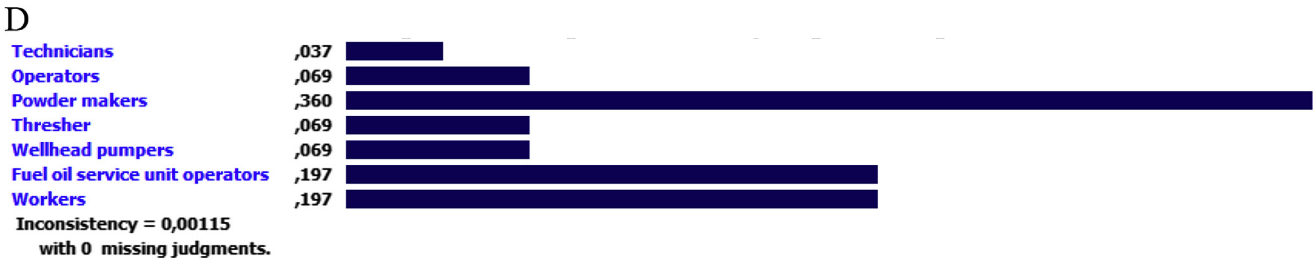


A: Pairwise comparisons of professional groups for gases.

B: Pairwise comparisons of professional groups for dust.

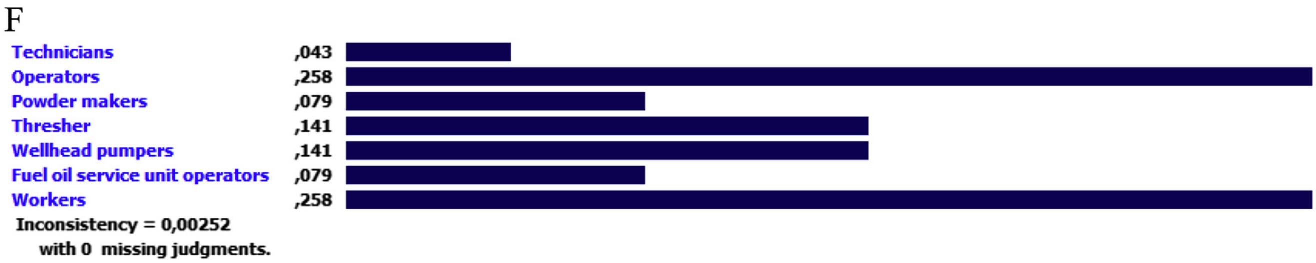


C: Pairwise comparisons of professional groups for water + fire.



D: Pairwise comparisons of professional groups for explosives.

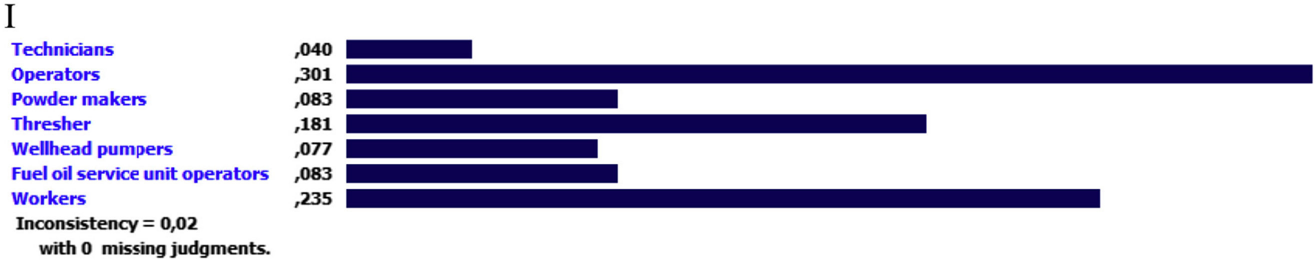
E: Pairwise comparisons of professional groups for transportation + hand tool + fall.



F: Pairwise comparisons of professional groups for machinery + materials.

G: Pairwise comparisons of professional groups for noise + vibration.

H: Pairwise comparisons of professional groups for landslide.



I: Pairwise comparisons of professional groups for others.

References

Dağdeviren, M., & Yüksel, İ. (2008). Developing a Fuzzy analytic Hierarchy process (AHP) model for behavior-based safety management. *Information Sciences, 178*(6), 1717–1733.

Expert choice software and manual. Pittsburgh, PA: Expert Choice, Inc.

Fang, D., Shen, Q., Wu, S., & Liu, G. (2003). A comprehensive framework for assessing and selecting appropriate scaffolding based on analytic Hierarchy process. *Journal of Safety Research, 34*(5), 589–596.

Komljenovic, D., Groves, W. A., & Kecojevic, V. J. (2008). Injuries in U.S. mining operations – a preliminary risk analysis. *Safety Science, 46*(5), 792–801.

Marhavilas, P. K., & Koulouriotis, D. E. (2008). A risk estimation methodological framework using quantitative assessment techniques and real accidents' Data: Application in an aluminum extrusion industry. *Journal of Loss Prevention in the Process Industries, 21*(6), 596–603.

Ouédraogo, A., Groso, A., & Meyer, T. (2001). Risk analysis in research environment – Part II: Weighting lab criticity index using the analytic hierarchy process. *Safety Science, 49*(6), 785–793.

Öztaş, S. (2007). Analysis and evaluation of risks different perspective. In *Mines Occupational Health and Safety Symposium. March 08-09 2007, UCTEA chamber of mining engineers*. Adana. Turkey.

Project Assessment Report of Surface and Underground Mines. (2005). *By republic of Turkey Ministry of labor and social security*. Ankara, Turkey.

Saaty, T. L. (1977). A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology, 15*(3), 234–281.

Saaty, T. L. (1980). *The Analytic Hierarchy Process*. New York: McGraw-Hill.

Subaşı, E. (2011). *Occupational health and safety-workplace accidents-risk analysis. Final Project*. Kütahya, Turkey: Dumlupınar University, Department of Mining Engineering.