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## Analysis of the recent occupational accidents occurred at Western Lignite Corporation (Turkey) by data envelopment analysis

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### Abstract

Background: Developments of countries are interpreted through many parameters. One of the most important parameters is, perhaps, the number and severity of occupational accidents. Especially, work related accidents occurred at different sectors did not decrease recently; they even increased despite the developments in the technology and emphasis made on regulations. This situation can be explained as an open debate in which the employees still do not internalize the work they do. When the mining sector is considered, this problem becomes even clearer. Among many reasons for this problem, it can firstly be mentioned about the difficulty of employing qualified personnel. Since the enterprises do not have many options for solving this problem, their approach to work accidents should be institutionally a highest priority. Objective: The aim of the present work is to analyze the work accidents took place in both underground and surface facilities at Western Lignite Corporation in Turkey between 2014 and 2018. Methodology: The types of accidents were examined and interpreted using information obtained from calculation of accident frequency, weight and probability rates. The relationship between these parameters and number of accidents occurred was investigated with Data Envelopment Analysis which is one of non-parametric efficiency analysis methods. Results and Conclusions: As a result, a full effectiveness was found in 2015 and ineffectiveness in other years. With the sensitivity analysis, it was concluded that the total number of accidents, total workday loss should be reduced and the total hours worked should be increased.

## 1. INTRODUCTION

### 1.1 Background

All kinds of laws, directives and regulations which place the human being to the center implement priority to respect the right to life of mankind. This is not particularly important in terms of occupational health and safety, but also imposes significant responsibilities onto enterprises as well as individuals. The complexity of the production processes, the equipment and the chemicals involved in the processes used has both increased the number of occupational accidents and occupational diseases and caused them to diversify. Today's understanding of occupational health and safety, beyond the surveillance of the working environment and conditions, is designed to ensure the sustainable goodness of the production process from beginning to end including the employees (Sanmiquel *et al.*, 2018).

With the developing technology, employees face new risks and dangers that they have not encountered before. As these problems endanger the work of enterprises, affect labor productivity negatively, and material and moral losses reach to great dimensions, health and safety measures have been taken into consideration. Protecting and avoiding them is only possible by taking necessary "Occupational Health and Safety" measures.

In recent years, Turkey has made a great development in the mining sector exports. Both underground and surface mining is one of the most demanding sectors in the world due to the

inherent risks. It requires equipment, knowledge, experience, expertise and continuous supervision from planning to production and even to marketing. Furthermore, considering that most of the mining activities are based on manpower, the necessity of making this area safer in terms of occupational health and safety comes to the fore. Risk analysis without accidents is of great importance for both employee health and employers. In the light of risk analysis studies, the production processes are determined and the risks that may arise are determined and eliminated beforehand. For this purpose, a few studies in the literature can be listed as follows;

In their studies, [Kasap and Subaşı \(2017\)](#) conducted risk analyzes in open pit mining and tried to draw attention to the fact that it is possible to eliminate problems such as death, injury and material damage that may occur as a result of work accidents. In this context, occupational accidents took place between 2005 and 2010 during open pit coal production in Western Lignite Corporation (WLC) were evaluated and risk auditing was carried out by using Analytical Hierarchy Process (AHP) method.

In their study, [Knights and Scanlan \(2019\)](#) analyzed the mortal cases recorded in coal mines in Queensland during the period 1985-2016 as a function of the change in coal prices. In difficult economic conditions, it was tried to analyze whether the mining companies protected the employees. As a result, the relationship between the mortality and coal prices was not linear.

[Lööv and Nygren \(2019\)](#) examined the developments in occupational health and safety in the Swedish mining industry between 1980 and 2010. They investigated factors that could contribute to reducing accident frequency rates in the sector and improving safety further. The results showed that there were low accident frequency rates and overall security improvements after the technology development in the 1980s and beyond.

[Dominguez et al. \(2019\)](#), in their study, aimed to draw attention to the relationship between the working conditions of underground mining and occupational accidents worldwide, in the State of Mexico and the State of Guanajuato. In order to improve working conditions, they applied the decision matrix risk-assessment (DMRA) technique, which is classified according to the severity and likelihood of accidents in order to assess risks and to identify activities that should continue. As a result, corrective actions have been proposed to help in preventing the occurrence of occupational accidents.

[Sanmiquel et al. \(2018\)](#) attempted to analyze the main causes of work accidents in the Spanish mining sector using a database of approximately 70,000 occupational accidents and death reports corresponding to 2003-2012. In addition to data mining techniques, their analysis using statistical tools has produced some conclusions that can help to develop appropriate prevention policies to reduce injuries and deaths.

Although the data envelopment analysis (DEA) used in the analysis dates back to 1957 and has a widespread use in other sectors, it has recently begun to find new uses in the mining sector. Unfortunately, the number of studies related to the use of DEA in the assessment of occupational accidents in the mining sector is very few.

In 2008, [Tong and Ding](#) tried to analyze the safety measures taken against occupational accidents in China's coal mines by using DEA method.

In a study carried out in 2011 by [Kasap](#), Turkish Hard Coal Corporation (THCC) between the years 1987-2006 were analyzed with the effectiveness of occupational accidents on the production by non-parametric linear programming method. As a result of the study, total sources of technical ineffectiveness in the years examined were determined and a general increase in efficiency values was determined since 1993 due to the importance given by the THCC to occupational health and safety.

In his study in 2011, [Wang](#) attempted to analyze the annual safety parameters of the Jiahe coal mine in Xuzhou between 1996 and 2005 by non-parametric linear programming method. As a result, it has been shown that a decrease in the accident rate and an increase in coal production may occur by the help of security measures and investments realized.

## 1.2 Objective

The main objective of this work is to carry out a research at Western Lignite Corporation by associating the work accidents that took place between the years 2014 and 2018 with the production in a statistical manner together with the use of DEA and to identify the measures to be taken.

## 2. METHODOLOGY

### 2.1 Western Lignite Corporation

Western Lignite Corporation (Tavsanlı/Kütahya) hosts within about 4.6% of lignite reserves license area of Turkey (Figure 1) and carries approximately 7.5% of the country lignite production. Approximately 5-6% of the 4.300.000 tons of coal produced annually is obtained from underground operations while the rest are from open pit mines. The production of lignite coal from underground is provided by a mechanized block caving system. In the open pit workings, the excavation of overburden is realized by using dragline with shovel + truck preparation and the coal production is carried out by shovel + truck system. Lignite coal produced from both open pit and underground operations is enriched and got ready for use in Tuncbilek and Omerler coal washing plants.



Figure 1. Map of Western Lignite Corporation Region

### 2.2 Information sources

Salable lignite production realized at the WLC between 2014 and 2018 is given in Table 1 (Western Lignite Corporation, 2019; Turkish Coal Board, 2014; 2015; 2016; 2017; 2018). The production of coal is solely important as 34% of electric production in Turkey is compensated from coal in 2017. All the data used during the present work has been obtained from the records of WLC.

Table 1. Salable Lignite Production of WLC for the Years 2014 and 2018

	2014	2015	2016	2017	2018
<b>Open pits (ton)</b>	3.219.866	2.661.946	2.052.068	2.359.317	4.035.382
<b>Underground (ton)</b>	170.842	134.228	155.607	44.023	246.573
<b>Total (ton)</b>	3.390.708	2.759.174	2.207.675	2.403.340	4.281.955

### 2.3 Ratios for Occupational Accidents

Accident frequency ratio, accident weight ratio and accident probability ratio were used in the analysis of the accidents that occurred between 2014 and 2018 at WLC. The equations used in the definition and calculations of these ratios are given below.

#### *Accident Frequency Ratio*

It is obtained by dividing the total number of mortal and non mortal injuries incurred in work accidents during the year of work by the total work hours of the same year, multiplied by the coefficient of  $1.10^6$  (Equation 1) (Balci *et al.*, 2013; Aritan *et al.*, 2017; Erginel *et al.*, 2017; Bayraktar *et al.*, 2017). Figure 2 shows the frequency of accidents for the years in concern.

$$\text{Accident Frequency Ratio} = \text{Number of Total Accident} \times 10^6 / (\text{Total Work Hours}) \quad (1)$$

### Accident Weight Ratio

It is obtained by dividing the total number of days lost due to mortal and non mortal injuries occurring during a one-year work period by the total work hours of the same year, multiplied by the coefficient of  $1.10^3$  (Equation 2) (Balci et al., 2013; Aritan et al., 2017; Erginel et al., 2017; Bayraktar et al., 2017).

$$\text{Accident Weight Ratio} = \text{Number of Lost Days} \times 10^3 / (\text{Total Work Hours}) \quad (2)$$

### Accident Probability Ratio

It is obtained by dividing the total number of mortal and non mortal injuries incurred in work accidents during the year of work by the total number of workers of the same year, multiplied by the coefficient of  $1.10^5$  (Equation 3) (Balci et al., 2013; Aritan et al., 2017; Erginel et al., 2017; Bayraktar et al., 2017).

$$\text{Accident Probability Ratio} = \text{Total Number of Accident} \times 10^5 / \text{Total Number of Workers} \quad (3)$$

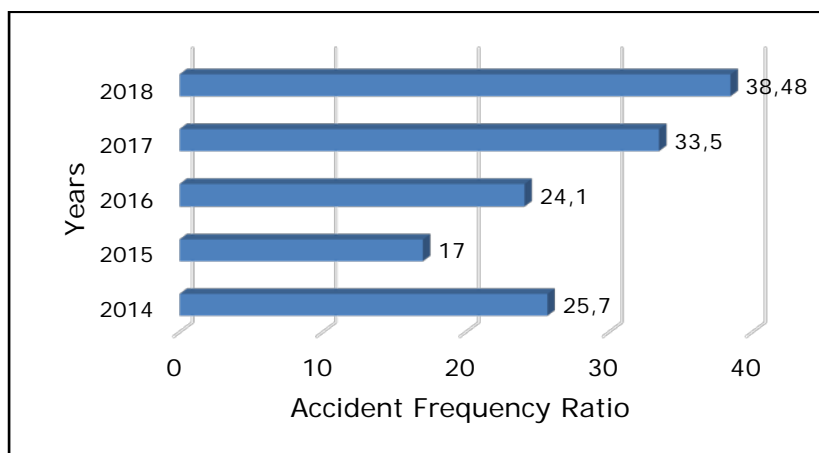


Figure 2. Accident Frequency Ratio for the Years 2014 and 2018

## 2.4 Data Envelopment Analysis

The basis of the DEA used in the analysis dates back to 1957. Although it has been extensively used in other sectors since then, it has started to find application in the mining sector in recent years. Unfortunately, the number of studies on the use of DEA in the evaluation of work accidents in the mining sector is very small. In 2008, Tong and Ding analyzed the safety measures at work taken to prevent accidents at coal mines in China. Kasap (2013) investigated the effect of occupational accidents occurred in Turkish Bituminous Coal Corporation (TBCC) between the years 1987 and 2006 on the production. Wang (2011) also tried to interpret the annual occupational safety parameters of Jiahe coal mine in Xuzhou (China) in 1996-2005 by DEA (Tong and Ding, 2008; Kasap, 2011; Wang, 2011).

DEA was used to investigate the occupational accidents occurred in WLC. DEA is a linear programming-based technique to measure the relative effectiveness of decision-making units where inputs and outputs are measured at multiple and different scales, or where inputs and outputs with different measurement units make comparison difficult. Besides, it does not need a functional form as in parametric methods and it performs comparison according to the best technological application rather than average technological application (Kasap, 2008; Grosskopf, 1986; Seiford, 1996). In this study, the CCR model which forms the base for DEA developed by Charnes et al. (1978) was used. The CCR model is developed under the assumption of constant return to scale and is used to determine the Overall Technical Efficiency scores, which include both Pure Technical Efficiency and Scale Efficiency.

The CCR model of the problem where input minimization is determined as the purpose is as follows.

*Objective function*

$$\min \theta_k \tag{4}$$

2.4.1.1.1 Subject to;

$$\sum_{j=1}^n \lambda_{jk} \cdot Y_{rj} - s_{rk}^- = Y_{rk} \quad ; \quad r = 1, 2, \dots, s \tag{5}$$

$$\sum_{j=1}^n \lambda_{jk} \cdot X_{ij} + s_{ik}^+ = \theta_k \cdot X_{ik} \quad ; \quad i = 1, 2, \dots, m \tag{6}$$

$$\lambda_{jk}, s_{ik}^+, s_{rk}^- \geq 0 \quad ; \quad \forall i, r, j \tag{7}$$

In order to make a decision making units (DMU) effective as a result of the analyzes made by using the constraints of Equations 4-7;

- Optimum  $\theta_k$  (efficiency) value is equal to 1,
- All slack variable values need to be zero ( $s_{ik}^+, s_{rk}^- = 0$ ).

An evaluation was made by using the calculated accident rates (Table 2) between the years of 2014-2018 (DMU). As input; Accident Frequency Ratio ( $X_1$ ), Accident Weight Ratio ( $X_2$ ) and Accident Probability Ratio ( $X_3$ ) are taken into account because they reflect other parameters given in Table 2. The purpose function of DEA; is to increase outputs or reduce inputs. It has been found appropriate to normalize the Total Number of Accident ( $Y$ ) which is considered as output for this reason. As output; 1/Total Number of Accident values are taken into consideration.  $\lambda$  is the vector of the intensity variables giving the weight averages of the input and output. DEAP 2.1 package program was used in the solution of models (Coelli, 1996).

The values obtained by using Equations 1-3 are also listed in Table 2.

**Table 2.** Calculated Accident Ratios for the Years 2014 and 2018

	2014	2015	2016	2017	2018
<b>Total Number of Accident</b>	76	66	91	97	109
<b>Working Hours</b>	2955152	3867904	3779648	2897864	2832720
<b>Number of Workers</b>	1580	2061	1893	1483	1471
<b>Lost Working Day Due to Accident</b>	1001	809	1076	1377	8762
<b>Accident Frequency Ratio</b>	25,7	17	24,1	33,5	38,5
<b>Accident Weight Ratio</b>	0,34	0,21	0,28	0,48	3,09
<b>Accident Probability Ratio</b>	4810	3202	4807	6541	7410

### 2.5 Sensitivity Analysis of DEA

One of the most important advantages of DEA is the possibility to make recommendations to the management through sensitivity analyses. Sensitivity analysis was conducted in order to eliminate the ineffectiveness of the 2014, 2016, 2017 and 2018 years, which are considered as ineffective by using the formulas given in Equation 8 and Equation 9, and to guide for the measures that may be taken in the next years in terms of occupational accidents.

$$X_{ik}^* = \theta_k \cdot X_{ik} - s_{ik}^+ \tag{8}$$

$$Y_{ik}^* = Y_{ik} + s_{rk}^- \tag{9}$$

## 3. RESULTS AND DISCUSSIONS

### 3.1 Analysis of Work Accidents occurred between 2014-2018

A total of 439 work-related accidents took place between the years in concern and 308 of them (70.2%) occurred in underground working places while 131 of them (29.8%) were at surface working places (Figure 3). The largest number of accidents in the underground scene occurred in 2018.

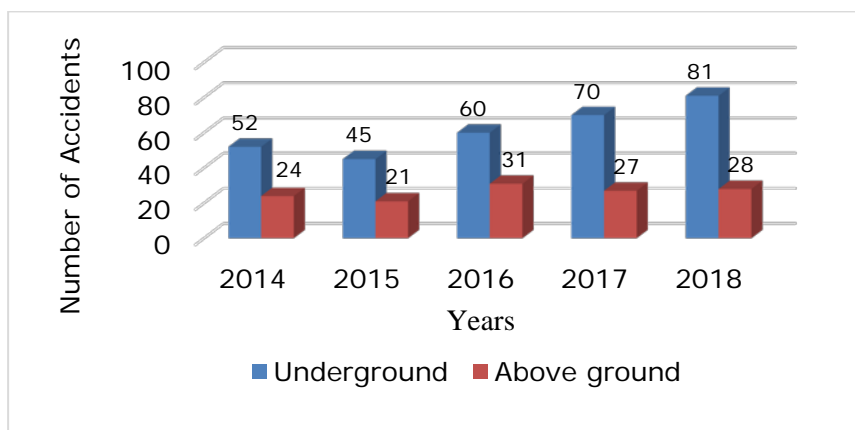


Figure 3. Underground and Aboveground Distribution of Accidents Arising from 2014 to 2018

Types of accidents that took place between 2014 and 2018 are classified as suffocation and poisoning from gas, collapsing of rocks and coal, falling of material, material stroke, hand transportation, mechanical transportation, road transportation, electricity, machinery, working machines, hand tools and other subheadings. It is very much fortunate to see that all these accidents have not caused any loss of lives between 2014 and 2017 except in 2018. The cause of the only death in 2018 was hearth attack. Among these years, accidents occurred mainly due to rocks and coal falling (39), material stroke (59), hand transportation (79) and other (162) reasons (Figure 4). Figure 5 shows the weight of accidents for the years in concern and Figure 6 shows the probability of accidents for the same period.

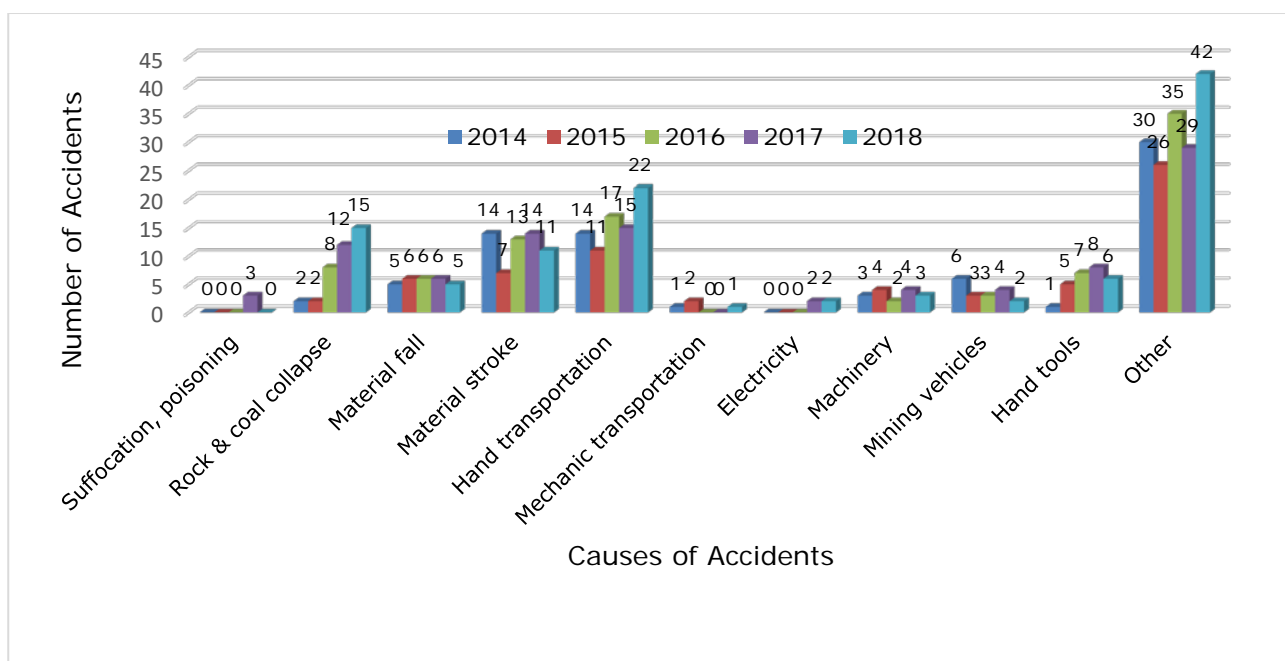


Figure 4. Number of Accidents between 2014 and 2018 by Causes of Occurrence

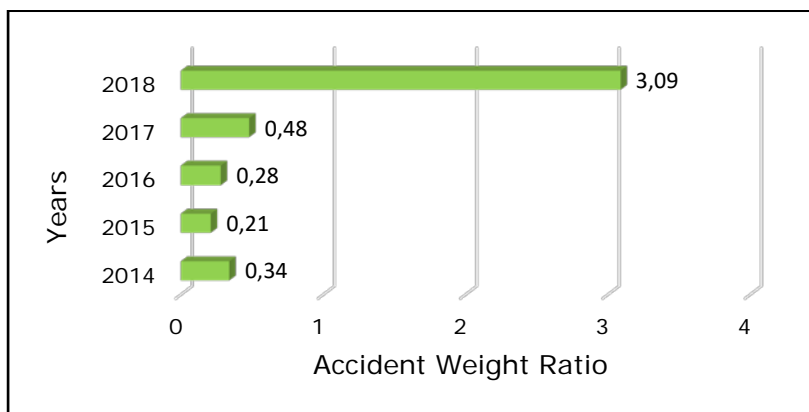


Figure 5. Accident Weight Ratio for the Years 2014 and 2018

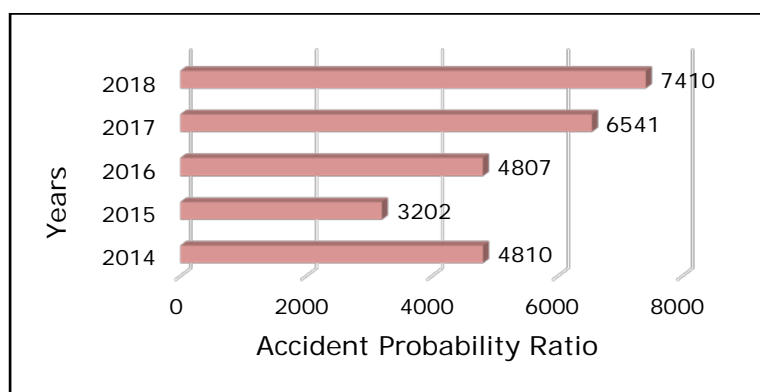


Figure 6. Accident Probability Ratio for the Years 2014 and 2018

### 3.2 Results of DEA

The results of the analysis made according to the DEA model, which aims to reduce the inputs by keeping the outputs constant, is given in Table 3. The results obtained in 2015 were consistent with Table 3 showing complete effectiveness. 57.8% effectiveness was determined in 2014. The reasons for inefficiency here are due to Accident Frequency Ratio ( $s_1^+ = 0.094$ ) and Accident Weight Ratio ( $s_2^+ = 0.014$ ) being high. Accident Frequency Ratio is high due to the fact that the total number of hours worked is less than the effective limit of 2015. The reason for the high Accident Weight Ratio is that the total working day loss is high and the total number of hours worked is low.

Table 3. Results of DEA model

DMU	$\theta_k$	$s_1^+$	$s_2^+$	$s_3^+$	$s_1^-$
2014	0.578	0.094	0.014	0	0
2015	1.000	0	0	0	0
2016	0.544	0.780	0	292.467	0
2017	0.345	0	0.023	79.822	0
2018	0.267	0	0.699	42.354	0

54.4% effectiveness was determined in 2016. The reasons for inefficiency here are that Accident Frequency Ratio ( $s_1^+ = 0.780$ ) and Accident Probability Ratio ( $s_3^+ = 292.467$ ) are high. The high Accident Frequency Ratio (AFR) is due to the low working hours. The reason for the high Accident Probability Ratio (APR) is that the number of accidents occurred compared to the number of workers are also high.

The reasons for inefficiency during 2017 ( $\theta_k = 0.345$ ) and 2018 ( $\theta_k = 0.267$ ) are high Accident Weight Ratio (AWR) and Accident Probability Ratio. The reason for the high AWR is that both the

total working day loss is high and the total number of hours worked is low. On the other hand, the high APR is due to the high number of accidents occurred compared to the number of workers in WLC.

In the last months of 2016 and in 2017, AFR and APR were determined to increase due to the flooding in the underground. The fatal accident that occurred in 2018 led to the greatest inefficiency achieved in this year.

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### 3.3 Results of Sensitivity Analysis

When Table 4 is examined, AFR, AWR and APR should be decreased in order to make ineffective years effective. To reduce these rates to the values given in Table 4, the total number of accidents, total working days' loss should be decreased and the total number of hours worked should be increased. The results obtained here are important in order to draw attention to the occupational safety measures to be taken in the coming years.

Table 4. Adjustment of DMU of inefficiency

	2014		2016		2017		2018	
	Real data	Comparative data	Real data	Comparative data	Real data	Comparative data	Real data	Comparative data
<b>AFR</b>	25.7	14.8	24.1	12.3	33.5	11.6	38.5	10.3
<b>AWR</b>	0.34	0.18	0.28	0.15	0.48	0.14	3.09	0.13
<b>APR</b>	4810	2781	4807	2322	6541	2179	7410	1939

## 4. CONCLUSIONS

Within the scope of the present study, the results of work accidents from the surface and subsurface facilities between 2014 and 2018 belonging to WLC were analysed and the following results were obtained:

- 439 occupational accidents were recorded at WLC between the years in concern, however, none of the employees lost their lives, except one occupant who lost his life due to heart attack in 2018,
- 70.2% of the incidents occurred in the underground workings and 29.8% in the open pits and at surface facilities. Although the amount of underground production is much smaller than that of open pit production, most of the accidents took place in underground,
- The number of accidents has reached a peak in 2018,
- Additionally, AFR, AWR and APR values in 2018, were also the highest and the greatest inefficiency has been identified in this year.



- When the accidents were examined cumulatively, it was understood that most of the accidents had resulted from personal negligence of the workers.
- As a result of the analysis based on the data taken into account, a full efficiency was determined in 2015.
- In the last months of 2016 and in 2017, AFR and APR were determined to increase due to the flooding in the underground.

Given the consequences of the work presented, it is important to note that employees should be well trained to become more aware of occupational health and safety as well as creating an effective safety culture.

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