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Risk Assessment of COVID-19 Precautions in Underground Mines Using FMEA: A Case Study of Soma-Eynez Region

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Abstract

The COVID-19 outbreak that started in December 2019 has taken hold of every aspect of life, and this global pandemic period has affected mining operations as in every field of the industry. If they have existed, mining activities have played a significant role in the economic development of countries. As a result of the extraction, processing, and supply of minerals for humanity, technological developments have increased. Almost all things that we use in our daily life is a product of a mining operation. Additionally, considering the supply and demand balance in the world, although nuclear, solar and wind energy is favorable, the production and necessity of coal-based energy production cannot be neglected as one-third of the world's energy production comes from coal. Due to these reasons, achieving the continuity of production in mining operations carries great importance. For the continuation of production and the timely supply of minerals for different sectors, companies have had to take additional precautions in this period to be protected from COVID-19. In this study, precautions taken for the uninterrupted continuation of production of underground minerals are investigated in detail based on a selected firm using the FMEA method, and cases before and after the precautions that are taken are comparatively presented.

Keywords: Coronavirus; FMEA; Precaution; Underground mines.

Abbreviations: WHO: World Health Organization; FMEA: Failure Mode and Effects Analysis; RPN: Risk Priority Number; PDCA: Plan-Do-Check-Apply Cycle

Introduction

With the World Health Organization (WHO) reporting an unknown respiratory disease in China in December 2019, the COVID-19 epidemic emerged and the world is alarmed. As the outbreak, which was first considered a regional 'epidemic' that affected China and its neighbors, started to cross the borders of Asia, and threaten global public health, the entire world has focused on developments related to the virus. On 7 January 2020, WHO reported that this disease spreading around the world is not the classic SARS virus and is caused by a new type of coronavirus. Following its origination in its epicenter, China, the outbreak moved first to the United States, then South America, Africa and eventually the entire world. It started to be seen in Turkey in March 2020.

Today, many sectors (e.g., construction, manufacturing, logistics) are completely dependent on raw materials and directly affected by price increases caused by the insufficiency of raw materials [1]. COVID-19 has the potential to destroy the food, production, and economic chain around the world. The mining industry is also significantly affected by these effects and there are significant disruptions in the raw material supply chain. Understanding these effects in detail and developing a plan for measures has become the main task of academic studies [2]. Researchers have investigated the effects of the COVID-19 pandemic on the supply-demand balance in different sectors and proposed solutions to problems that have emerged [3-14]. Considering mining, it is seen that studies in this period are limited to those focused on precautions taken against COVID-19. Skubacz et al. [15] conducted research to prevent the spread of the SARS-CoV-2 virus in underground mines and facilitate the continuation of production without interruptions. Our study focused on actual outcomes that emerged because of the precautions that are taken.

In this study, risk analysis is carried out for COVID-19 precautions in selected underground mine using FMEA. This is the first study that analyzed precautions taken against COVID-19 in underground mines using the FMEA method. RPN scores of Lack of social distance (F1) and Lack of using face mask (F2) are calculated as 400 and 320 respectively. After the precautions taken at the investigated mine, these values are reduced to 50 and 40, respectively. This way, with the control of these two parameters by using the FMEA method, both the management of the pandemic and the uninterrupted continuity of production are achieved thanks to the method that is used and the flowchart that is developed.

Failure Modes and Effects Analysis

Failure Mode and Effects Analysis (FMEA) is one of the most used techniques in risk assessment. The method considers the whole of a part of system. Then, analyze the results that may occur due to the failure of the system or its components [16]. The failure mode and effects analysis process are given in figure 1. Also, today, FMEA as become compulsory in quality management systems such as QS 9000, ISO/TS 16949, ISO 9001:2000, OHSAS 18001 and TS 18001 [17].

Figure 1: Failure mode and effects analysis process.

In the classical FMEA technique, the Risk Priority Number (RPN) value for each type of failure is evaluated with three parameters as severity (the degree of importance of a failure), probability (the probability of a failure to occur) and detectability (the difficulty of detecting a failure before its consequences occur). The values of these parameters are determined based on the field observations of experts, previous and recent projects, risk analyses and the assessment of statistical records. In the assessments, a customized ranking scale (e.g., very low, low, moderately high, very high) is used for each parameter [18].

FMEA should be considered as an essential part of safe engineering. This technique considers three parameters in the RPN value calculation. These parameters are probability (P), severity (S) and detectability (D). P is defined as the frequency of occurrence of the event. The severity (S) is the level of impact of the event that occurred. Detectable (D) is the degree to which a risk can be detected before it occurs. The RPN value is calculated by multiplying these three parameters (Equation 1).

$$RPN = P \times S \times D \quad (1)$$

FMEA tables given in figure 2 are used to determining P, S and D levels. The values of the P, S and D parameters are determined with the help of the tables given in figure 2 and the RPN values are calculated. If the calculated value is over 100, measures should be taken immediately to reduce the risk. If the RPN value is between 40-100, precautions can be taken. If this value is below 40, the risk is in the acceptable class. In order for a system to operate without a minimum degree of risk, some preventive actions must be put into use. These activities include practices and feedback mechanisms to correct the system. These applications are made with the help of the Plan-Do-Check-Apply Cycle (PDCA). The PDCA cycle is a tool used to optimize the quality of the system (figure 3).

The Plan-Do-Check-Apply Cycle consists of four stages.

- Plan: Planning the actions to be taken to reduce the risk level.
- Do: Test the plan made.
- Check: Checking the result of the measures taken.
- Act:
- If the plan yields positive results, apply it to the system.
- If the plan didn't work, start the cycle again.

Case Study

The coal reserves of the world, half of which consists of lignite and sub-bituminous coal, contain 891 trillion tons of coal including 297 trillion tons in Asia-Pacific countries (32%), 254

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trillion tons in North American Countries (28%) and 222 trillion tons in Russia and the Independent Republics. While more than half of the production, which is approximately 7.83 billion tons per year, is consumed in thermal power plants, about one-third of the total energy demand is met by using coal.

Lignite is a type of coal that is usually used as a fuel in thermal power plants due to its low calorific value and high ash and moisture contents. Despite this, it is a prevalently used raw material of energy production as it is found abundantly in the earth's crust. The region in Turkey with the richest lignite reserves is the Soma-Eynez region, where this study is carried out, the coal mining facilities in the region use the semi-mechanized and fully mechanized underground longwall mining methods. Figure 4 shows the area where this study is conducted, as well as the location of the examined facility. The approximately 30-35-million-ton production of lignite at the facilities in the region is made for supplying fuel to thermal power plants.

P

Failure	Degree (P)
Extremely high	10
Very high	9
Repeated failures	8
High	7
Moderately high	6
Moderate	5
Relatively low	4
Low	3
Remote possibility	2
Nearly impossible	1

S

Effect	Severity(S)
Hazardous	10
Serious	9
Extreme	8
Major	7
Significant	6
Moderate	5
Low	4
Minor	3
Very minor	2
No effect	1

D

Detection	Detection (D)
Absolute uncertainty	10
Very remote	9
Remote	8
Very low	7
Low	6
Moderate	5
Moderately high	4
High	3
Very high	2
Almost certain	1

$$RPN = P \times S \times D =$$

RPN Value	Precaution
[1,40]	Extra precautions are not necessary
[40-100]	Precautions may be taken
[100-1000]	Precautions must be taken urgently

Figure 2: FMEA Tables and quantitative analysis.

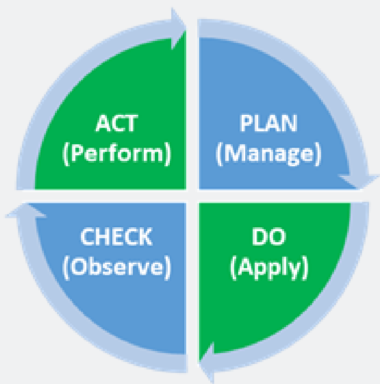

Figure 3: PDCA Cycle (ISO, 45001).

Approximately 1100 people work in the underground coal mine where the study is carried out. Precautions in the mine started to be taken when the COVID-19 in Turkey is noticed, especially in March 2020, and the data subject to the study is followed and reported for approximately 28 months. During the process, 99% of the employees are vaccinated and PCR tests are applied to the suspect employees in the whole mine. A minimum 5-day quarantine period has been applied to contacted workers. At the end of the quarantine, those whose PCR tests are negative continued to work.

Materials and Methods

Ten hazards that would trigger the fast spread of the SARS-CoV-2 virus in underground mine are determined in the first months of the onset of the pandemic, and the results of the risk assessments of these hazards are listed in table 1. These hazards are listed and coded as Lack of social distance (F1), Lack of using face mask (F2), Lack of quarantine (F3), Lack of routine health screening and measuring fever (F4), Lack of hand disinfectant (F5), Employee transport (F6), Underground refectory (F7), Lack

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of aerosol disinfectant in entrance or exit roadway (F8), Number of employees (F9) and Lack of COVID-19 education (F10).

It is seen that all the RPN values of the risks given in table 1 are above 100. After taking the preventive measures listed within the scope of the study and given in table 2, it is seen that the RPN values fell under 50. RPN levels directly help identify the riskiest areas. Corrective actions need to be taken quickly for high-scoring risks. The purpose of corrective actions is to reduce the probability of occurrence of the hazard and increase detectability. P, S and D values are recalculated after corrective measures are taken. The cycle should continue until all risks fall below tolerable limits. In tables 1&2, RPN values both for the current situation and after precautions are calculated. The decrease in RPN values can be seen in table 3 [19].

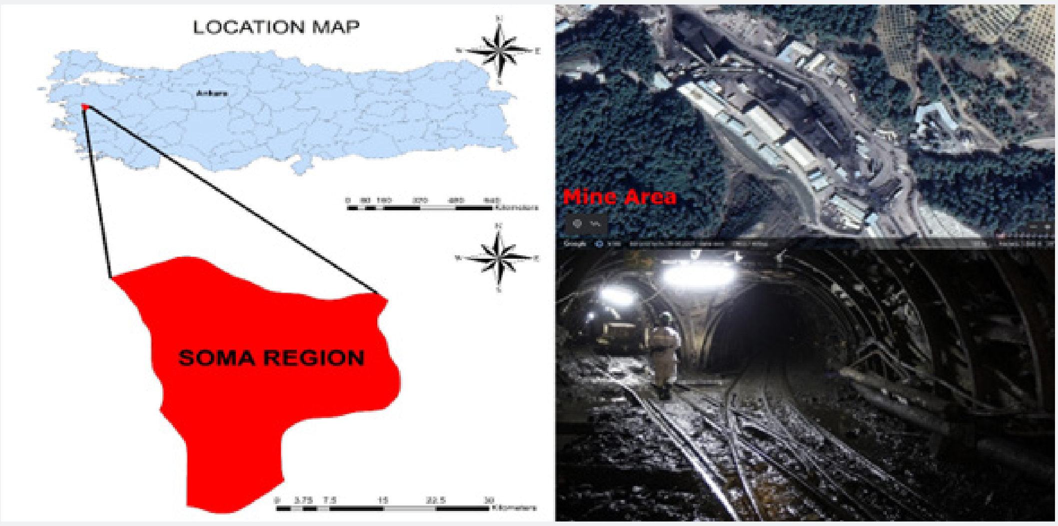

Figure 4: Location map of mine area.

Table 1: Risk evaluation COVID-19 of the current situation using FMEA.

Failure	Failure type	Risk	Current state			
			P	S	D	RPN
F1	Lack of social distance	Risk of infection and transmission, medical treatment process	8	10	5	400
F2	Lack of using face mask	Risk of infection and transmission, medical treatment process	8	10	4	320
F3	Lack of quarantine	Risk of infection and transmission, medical treatment process	6	9	4	216
F4	Lack of routine health screening and measuring fever	Risk of infection and transmission, medical treatment process	5	8	4	160
F5	Lack of hand disinfectant	Risk of infection and transmission, medical treatment process	6	8	3	144
F6	Employee transport	Risk of infection and transmission, medical treatment process	6	8	3	144
F7	Underground refectory	Risk of infection and transmission, medical treatment process	6	7	3	126
F8	Lack of aerosol disinfectant in entrance or exit roadway	Risk of infection and transmission, medical treatment process	5	8	3	120
F9	Number of employees	Risk of infection and transmission, medical treatment process	5	7	3	105
F10	Lack of COVID-19 education	Risk of infection and transmission, medical treatment process	5	7	3	105

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Table 2: Risk evaluation COVID-19 after corrective actions using FMEA.

Failure	Failure Type	Corrective Action	After Corrective Action			
			P	S	D	RPN
F1	Lack of social distance	Employees must comply with the rule of at least 2 m of social distance.	5	5	2	50
F2	Lack of using face mask	Employees must wear face masks. Employees without face masks must not be brought underground.	4	5	2	40
F3	Lack of hand disinfectant	Hand disinfectants must be placed visibly at certain locations. Employees must be given small bottles of hand disinfectant.	4	4	2	32
F4	Underground refectory	Tables and chairs in cafeterias must be organized in compliance with social distancing. The number of employees dining at the same time must be controlled by dividing the available lunch break times.	4	4	2	32
F5	Number of employees	The number of employees in shifts must be determined in a controlled manner.	4	4	2	32
F6	Lack of routine health screening and measuring fever	Routine health checks must be carried out, and the quarantine of those with symptoms must be ensured. Body temperature measurements must be taken at entry to the mine.	4	3	2	24
F7	Employee transport	Employee buses must transport employees in a controlled manner in compliance with social distancing.	4	3	2	24
F8	Lack of quarantine	Employees showing symptoms must be quarantined and immediately directed to referred institutions.	3	3	4	36
F9	Lack of aerosol disinfectant in entrance or exit roadway	Risk of crushing workers in reverse turning	3	4	2	24
F10	Lack of COVID-19 education	COVID-19 training must be provided to all employees regularly and by experts.	3	4	2	24

Table 3: Improvement rate of risks after corrective / preventive action.

Failure Type	Current Situation	After Corrective / Preventive Action	Improvement Rate %
	RPN Value	RPN Value	
F1	400	50	87.5
F2	320	40	87.5
F3	216	32	85.19
F4	160	32	80
F5	144	32	77.78
F6	144	24	83.33
F7	126	24	80.95
F8	120	36	70
F9	105	24	77.14
F10	105	24	77.14

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Results and Discussion

With the COVID-19-related implementations made at the mines, it was made possible to prevent the disease before it spread and ensure the uninterrupted continuation of production. FMEA is a numerical method among current risk analysis methods that prevents the onset of events proactively. Therefore, it is a useful analysis method in preventing infection and ensuring the continuation of production in a pandemic or epidemic period. The precautions that have been implemented and potential risks in the mining area are analyzed in this study by using the FMEA method for the period from the onset of the pandemic to the present on 1100 employees for 28 months. The analysis is carried out in two phases. In the first phase, the RPN values of potential risks at that moment are calculated, and how these risks could be managed is determined through the classification of the risks.

In the analysis, the hazards coded F1 and F2 provided the riskiest RPN values not only in terms of the pandemic but also in the analysis conducted for the mining area (F1=400>100, F2=320>100). In the second phase, by reviewing the analyses and taking preventive measures, making it compulsory to comply with at least 2 m of social distancing for F1 and making it compulsory to wear face masks and not allow employees who are not wearing face masks to go underground for F2 are calculated as the main corrective actions, and the results are given in tables 1&2.

As a result of the analyses that are carried out and precautions that are taken at the facility, improvements of 70% to 87.50% are determined in the RPN values of the occurring risks and unfavorable events encountered at the facility. These improvement values are shown in table 3. Graphical representation of improvement rate of risks after corrective/preventive action is given in figure 5. These improvements are achieved by implementing the flowchart given in figure 6 at the underground facility. Figure 7 shows examples of the implementations of the precautions taken underground.

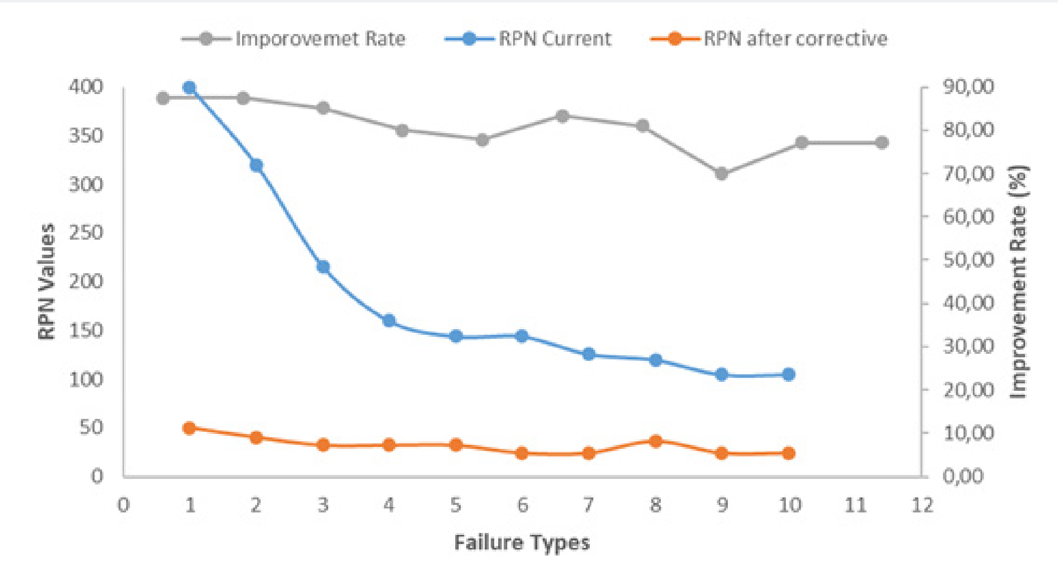

Figure 5: Graphical representation of improvement rate of risks after corrective/preventive action.

However, it should not be forgotten that, within the scope of the study, the effects of the precautions taken and controlled by the companies during the COVID-19 period are evaluated, not the general measures taken by the governments (obligations such as vaccines, tests, etc.) as is the case all over the world. For example, 99% of the employees in the mine under consideration are vaccinated. In addition, all those who are suspected of having a possible disease are working with a PCR test. In these conditions, the identified risks are evaluated with FMEA and it is observed that the measures taken by the mine reduced the risks to an acceptable level.

Conclusion

In this study, which investigated the process of reducing the effects of the global COVID-19 pandemic and the success of preventive-protective measures that are taken with a case study of a mining facility, it is ensured that the precautions that are taken are implemented in a complete and controlled manner as in the flowchart that is created. Considering the risk assessment and the effects of the precautions taken on the field, the rate of increase in cases was 3% compared to the number of employees before the risk assessment, while this rate approached zero after the precautions taken. This decrease is maintained for a long time in the mine and no increase in the number of cases is observed.

The FMEA method is an important method that is used in minimizing product defects, system failures and human errors at prominent establishments around the world. In the study, the risks that are found to have RPN values of higher than 100 at

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an underground coal mining facility are mitigated to have RPN values lower than 50 with the precautions that are taken and system improvements that are made. Using FMEA, by reducing the probability of errors in the assessments of workplace safety experts through RPN values found as the combinations of probability, severity and detectability values, a safer risk analysis and management process is achieved.

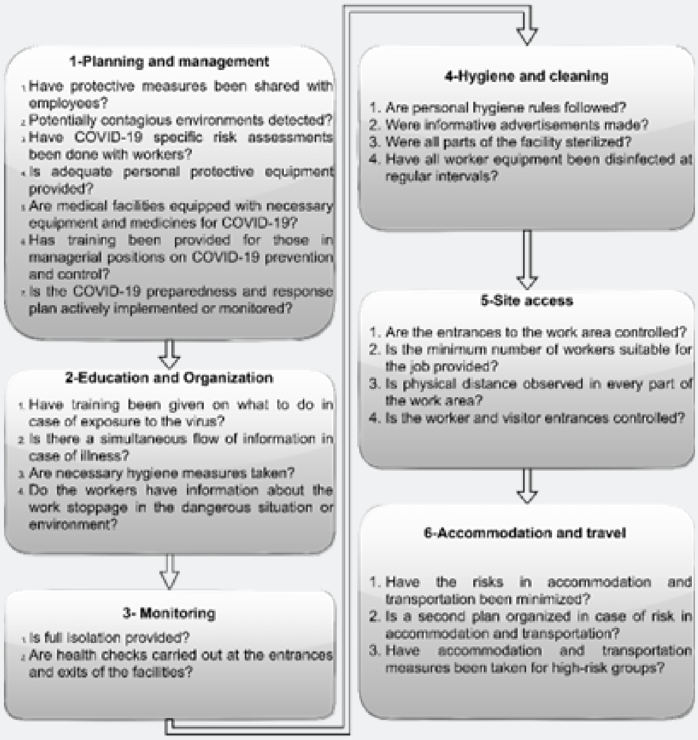

Figure 6: Developed and implemented COVID-19 prevention and control flowchart.

Figure 7: Precautions taken underground coal mine in Soma-Eynez ((a) and (b) inspection of work clothing, face masks, body temperature before going underground, (c) and (d) underground face mask usage, water and food given separately to employees, (e) and (f) disinfection procedures of vehicles going underground and transporting machinery-equipment and employees collectively).

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By using the FMEA method, the rate of spread of the epidemic is reduced in the underground mining operation, which is one of the sectors where the risk of COVID-19 spread is very high, and it is kept stable by decreasing it over time. The precautions taken to protect against this global epidemic that we are facing should continue without being reduced, and risk assessments should be renewed for changing conditions.

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