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Methodology for Analysing Risk Factor on Surface Top Hammer Drill Rig

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Abstract

Two-level risk mapping and assessment methodology was proposed with several criteria for risk prioritization (frequency of occurrence, downtime, level of danger, type of stoppage, cause of downtime, risk number). In a period of one year all stoppages, both planned and unplanned, were monitored and later on classified by type into: technological, mechanical, electrical, stoppages caused by the machine operator, external stoppages, which include stoppages of machine inactivity due to weather conditions and the like. The methodology proposed is oriented towards the calculation of risks to people, property, etc., which arise from various types of downtime. Then, based on the recording of data on stoppages of the observed machine, the structure of the share of individual stoppages was analyzed and appropriate measures to prevent incidents/accidents were recommended. The main causes of stoppages are isolated based on the frequency of occurrence, the percentage of the downtime duration in the total time spent and the level of danger. The primary cause of stoppages according to the mentioned criteria is the rupture of the hose in the observed machine with percentage participation in the duration of mechanical stoppages of 25.17%, with a frequency of 25% and a degree of danger of 6, while repairing the rod clamp is the second causal factor singled out as important from the risk aspect. Thanks to this, it is possible to plan maintenance activities and manage risks in an adequate way. The proposal for further research is further performance prediction and the determination of optimum operating parameters for different working conditions.

Keywords: surface top hammer driill rig; risk map.

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1. Introduction

Opencast mines are known for their high level of mechanization, which involves the use of large earth moving equipment for primary and secondary operations (Chaudhary et al., 2015). Surface mining is the primary method of producing raw materials in modern mining, and it has been progressively updated over the past several decades by the introduction of extremely huge gear and highly automated equipment, such as surface top hammer drill rig (Morad et al., 2014).

The surface top hammer drill rig is a crucial tool in many industries that require drilling in hard rock formations. Those mining machines arise from hand handled pneumatic drills to ultramodern remotely operated electrohydraulic drill rigs. A surface top hammer drill rig is used in mining, quarrying, construction, and other drilling applications, according to Song (2013). It is designed to drill holes in hard rock formations with a diameter ranging from a few centimeters to several meters (Oh et al., 2012). The rig is operated from the surface and is equipped with a hammer that is mounted on top of the drill string (Senjoba et al., 2021). The hammer strikes the drill bit, which then rotates and cuts through the rock. The rig is typically mounted on a crawler or a truck for mobility and stability during drilling (Senjoba et al., 2021).

Problem of mining machinery, such as surface top hammer drill rig, efficiency should be considered through impact of different types of downtimes (Misita et al., 2021). The least downtime drill rigs are still the most beneficial to customers, highlighting the need of appropriate maintenance and lowest possible risks (Hosseini et al., 2014). Accidents/incidents while operative work of surface top hammer drill rig can occur due to various reasons, including operator error, equipment failure, and environmental factors, according to Albdiry et al. (2016) and Oparin et al. (2022). Risk prioritization there is very important (Misita et al., 2021). Accordingly, it's important for companies and operators to follow safety protocols, provide proper training, and perform regular maintenance to minimize the risk of incidents (Sebor et al., 2019; Rahimdel et al., 2013; Leonida, 2019; Rahimdel et al., 2014). On other side, numerous mining corporations have been compelled to investigate novel tactics to reduce operational expenses as a result of low commodity prices in manner such as improving drilling performance and efficiency is one way to reduce costs, since drilling activities are costly and have a direct or indirect impact on most components of the mining process, according to Ugurlu et al. (2020). The drilling operation is one component that can be the focus of cost reduction efforts because it affects all phases of mineral production- from exploration to extraction and mineral processing. Therefore, an efficient drilling operation can help to achieve the desired economic production cycle, but it must be optimized to balance operating performance. Unexpected failures severely affect the production schedule and poses different kind of risks, thus, equipment reliability is required for satisfactory performance. Even more, certain authors point out that drilling jobs count on 12.8% of all injuries in mining processes, according to Stemn (2019).

In total, recent years have seen a number of difficulties for mining businesses, such as increased environmental pressure, high operating expenses, and low commodity prices. They have been compelled to research efficient cost management solutions to streamline and optimize operations and increase the viability of the mining operation in order to stay in business in this environment (Hrehová et al., 2012; Al-Chalabi et al., 2015). Since the drilling operation influences the amount of material blasted, the particle size distribution of fragmented material, the fill factor of shovels and trucks, and the input size of crushers, increasing bench drilling efficiency and performance in open-pit mines must be a top concern.

Research in the field are rare and only tangentially related to that topic. Using reliability analysis of field datasets, Barabadi et al. (2014) calculated the amount of spare components needed to prevent unexpected stops for a drilling machine. Based on environmental variables, Ghodrati and Kumar (2005) anticipate the necessary non-repairable inventory. In order to improve machine reliability through reliability-centered maintenance and develop a plan to optimize preventive maintenance based on safety, operational, and financial factors, Ataei et al. et (2015) have modelled the dependability of four rotary drilling machines. Accordingly, any contribution to the given topic is significant.

2. Methodology

The research methodology was designed to record the operation of the machine in the period January 2019 - August 2020 with the aim of determining the structure and frequency of stoppages in the operation of the machine. The purpose of this research is to increase safety and health at work and the prevention of incidents and/or accidents. Given that it is necessary to determine the source or cause of the stoppage in order to analyse the structure of the stoppages later, before recording the operation of the observed machine, a classification of stoppages was made into the following types: technological stoppages, mechanical stoppages, electrical and all stoppages related to electricity, stoppages caused by machine operator, which in the further research we named misuse when operating the machine, external stoppages, which included stoppages of the machine due to weather conditions and the like.

After the recording of work had been done and data processed, the research plan was to:

- form a structure of stoppages according to defined types of stoppages,
- calculate the frequency of stoppages according to the defined types of stoppages,
- calculates the total downtime and estimated share of downtime under defined types of stoppages.

Given that the aim of the research is to calculate the risk resulting from stoppages on the observed machine, the next planned step in the research was related to the assessment of level of danger of each stoppage by an expert. A scale of 1 to 10 was adopted to assess level of danger of a stoppage, whereby the observed score indicated moslty the seriousness of the incident or accident to people and property (somewhat less impact these stoppages have on the environment and reputation of the company).

After assessing the level of danger of the stoppages, the following steps are taken:

- the formation of a structure of stoppages according to different levels of danger
- calculation of stoppage frequencies according to defined types of stoppages and levels of danger
- calculation of the total downtime and estimated share of downtime by types of stoppages and level of danger,
- risk calculation as a product of the frequency of stoppages by types of stoppages and the corresponding levels of danger,
- risk calculation as a product of the estimated share of downtime and the corresponding levels of danger,
- forming a risk map,
- risk ranking according to different criteria and analysis of the obtained results.

3. Results

In the observed time interval (January 2019 to August 2020), a total of 48 stoppages were recorded, the total downtime of which was 2860 minutes. The machine's available time is calculated for working in one shift minus non-working days, holidays, vacations, breaks and time for repair. In the further analysis, only the structure of downtime was considered.

Figure 1 shows the recorded working hours and the corresponding amount of fuel used, monthly in the period from January 2019 to August 2020. The average working time per month was 86.4 hours, i.e. 5184 minutes. Average fuel consumption per month was 1974.5 l.

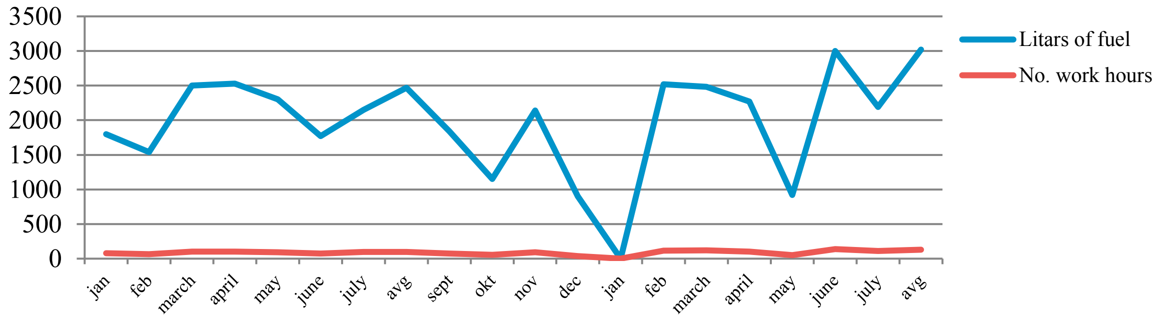

Fig. 1. Recorded working hours and the corresponding amount of fuel used

Table 1 shows the frequency of stoppages by type. The largest share was mechanical stoppages (70.8%) followed by technological stoppages with 27.1%, while misuse, organizational and external stoppages were not recorded.

Table 1. Stoppage frequencies, Percentage share of downtime by types of stoppages and level of danger

TYPE OF STOPPAGE	**Stoppage frequencies**		**Danger level**				TOTAL
	Frequency	Percentage	Danger level 6	Danger level 7	Danger level 8	Danger level 9	
Technological	13	0.271	11.99%	1.98%	0.00%	0.00%	13.28%
Electrical	1	0.021	0.00%	2.57%	0.00%	0.00%	2.57%
Mechanical	34	0.708	**51.61%**	**13.70%**	7.71%	11.13%	**84.15%**
Misuse	0	0.000	0.00%	0.00%	0.00%	0.00%	0.00%
Organizational	0	0.000	0.00%	0.00%	0.00%	0.00%	0.00%
External	0	0.000	0.00%	0.00%	0.00%	0.00%	13.28%
TOTAL	48	1.000	11.99%	1.98%	0.00%	0.00%	**100.00%**

The chronological presentation of all stoppages by types and downtimes (in minutes) is given in the following graph, Figure 2.

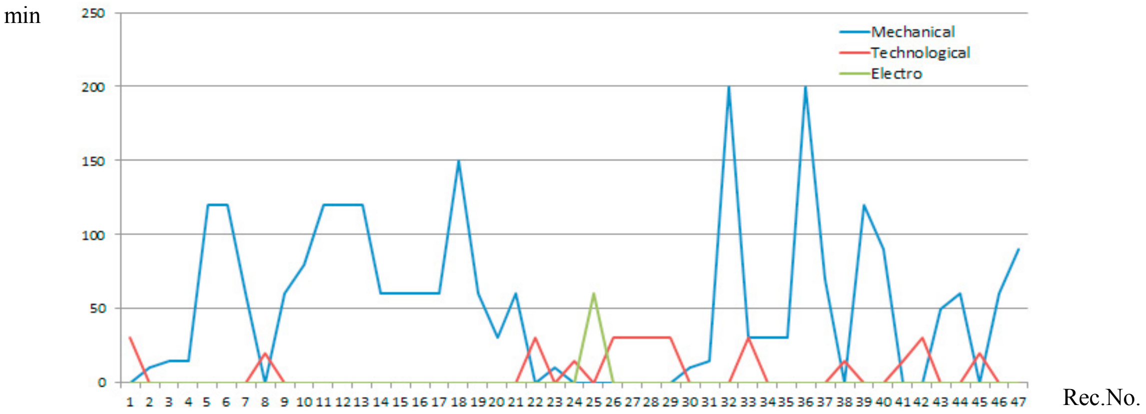

Fig. 2. Chronology of recorded stoppages by downtime and type of stoppage

The chronological presentation indicates the stochastic nature of the occurrence of stoppages, most often of a mechanical nature, which we classify as unplanned stoppages.

All the recorded stoppages were rated according to the level of danger on a scale from 1 to 10, with a score of 10 representing the most dangerous stoppage. In table 3, the percentage share of downtime of stoppages by types and level of danger is given. Based on the results, mechanical stoppages of danger level 6 have the largest percentage share of downtime (51.61%), and looking at the type of stoppage, mechanical stoppages have an estimated share of 84.15% in downtime of stoppage, table 1. The obtained results from table 1 are shown graphically in figures 3-6.

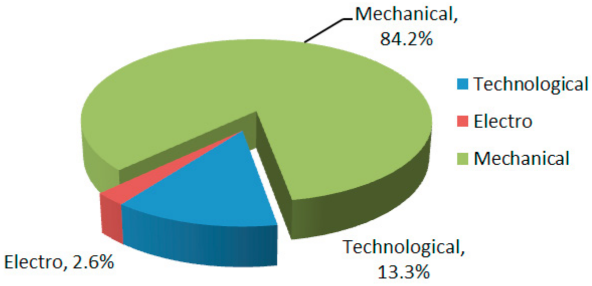

Fig. 3. Total percent by different stoppage types

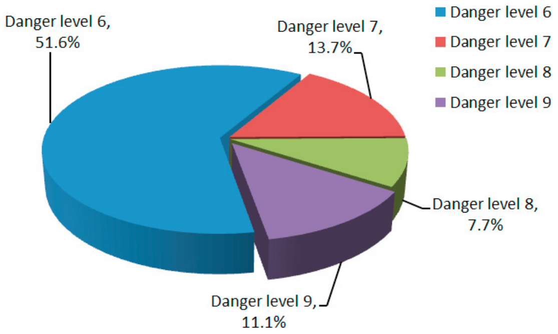

Fig. 4. Percent level of danger by different stoppage types

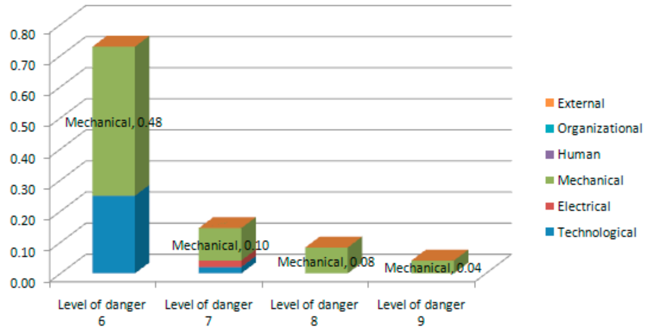

Fig. 5. The histogram according to the percentage share in the total stoppage frequencies, for each stoppage type by level of danger.

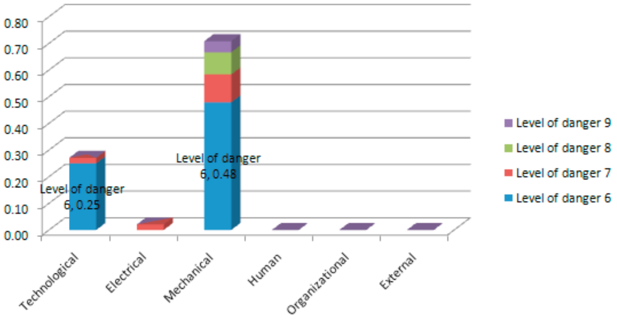

Fig. 6. The histogram according to the percentage share in the total risk calculation, for each stoppage type by level of danger.

According to the proposed methodology, it is necessary to conduct a risk analysis in the further research of the stoppages of the observed machine. As we calculate the risk as the probability of the occurrence of an unwanted event multiplied by the consequence score, it follows that for a certain type of stoppage, the product of the frequency of occurrence and the assigned level of danger would represent the magnitude of the risk for the observed type of stoppage, table 2.

Table 2 . Risk calculation according to frequency and danger level

Danger level/ Type	**Techno-logical**	**Mechanical**	**Electro**	**Grand Total**	**Technological**	**Mechanical**	**Electro**	**echnological**	**Mechanical**	**Electro**
Danger level 6	12	23		35	25.00%	47.92%	0.00%	1.50	2.88	0.00
Danger level 7	1	5	1	7	2.08%	10.42%	2.08%	0.15	0.73	0.15
Danger level 8		4		4	0.00%	8.33%	0.00%	0.00	0.67	0.00
Danger level 9		2		2	0.00%	4.17%	0.00%	0.00	0.38	0.00
TOTAL	**13**	**34**	**1**	**48**	27.08%	70.83%	2.08%	1.65	4.65	0.15

Table 3 shows the risk calculation for the estimated downtime by types of stoppages and different levels of danger. In this case, the percentage share in the downtime by type and the corresponding level of danger was taken as a parameter for risk assessment.

Table 3. Risk calculation according to percent of downtime and danger level

Danger level	**Technological**	**Electrical**	**Mechanical**	**Human**	**External**
Danger level 6	0.719		**3.096**	0	0
Danger level 7	0.090	0.180	0.959	0	0
Danger level 8			0.617	0	0
Danger level 9			**1.002**	0	0
TOTAL	0.809	0.180	**5.675**	0	0
% total	25.5%	2.2%	**71.2%**	0.0%	0.0%

The results obtained on the basis of Tables 2 and 3 indicate that from the aspect of frequency of occurrence, the greatest risk is with mechanical stoppages of danger level 6, followed by technical stoppages of danger level 6 (shaded fields in Table 3), while looking at downtime, the highest risk also have mechanical stoppages of danger level 6 but also of danger level 9 (shaded fields in table 5). Given results in Table 5, is shown on risk map, Figure 7. which clearly point mechanical stoppages danger level 6 in red zone.

Further, mechanical stoppages are investigated by type of causes. Brakedown causes of mechanical stoppages are given in table 4 and shown at Figure 8.

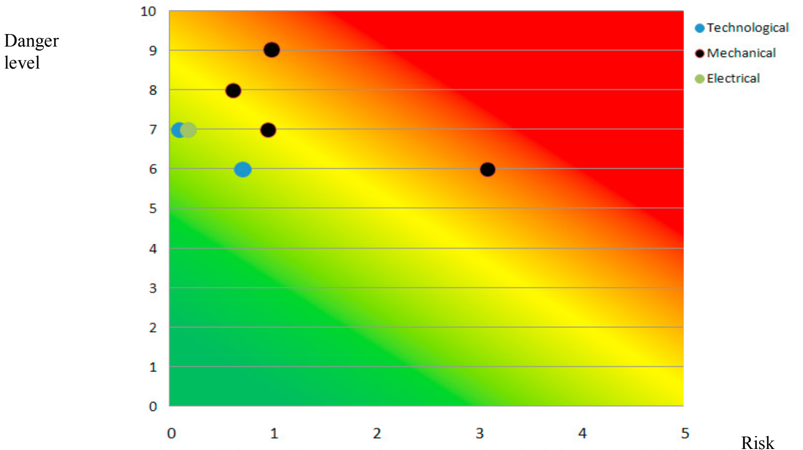

Fig. 7. Risk map by type of stoppage – level of danger and risk number

Table 4. Risk priorities by individual stoppage

Type	Causes of stoppage	Danger level	% of Downtime
Mechanical	Broke hose	6	25.17%
Mechanical	Rod clamp repaired	9	6.99%
Mechanical	Welding	8	6.99%
Mechanical	Bolt that keeps the rotation	8	5.24%
Mechanical	Hydraulic loading pump	9	4.20%
Mechanical	Mahindra assembly	8	4.20%
Mechanical	Oil	6	11.1%

The risk map facilitates the process of determining the risk zone, especially in cases where we have a lot of data. The ALARP zone in terms of the number of zones (most often 3, but very often 4), the width of the domain, but also the layout of the zones itself is a specific task that experts coordinate depending on the type of observed object and the effects of the unwanted event on people, the environment, property or business reputation. For the specific case of the surface top hammer drill rig, there were several stoppages that were assessed as more significant from the aspect of risk, primarily due to the high level of danger. In the specific case of the observed machine, urgent preventive maintenance measures were not implemented, given that the frequency of stoppages is not high.

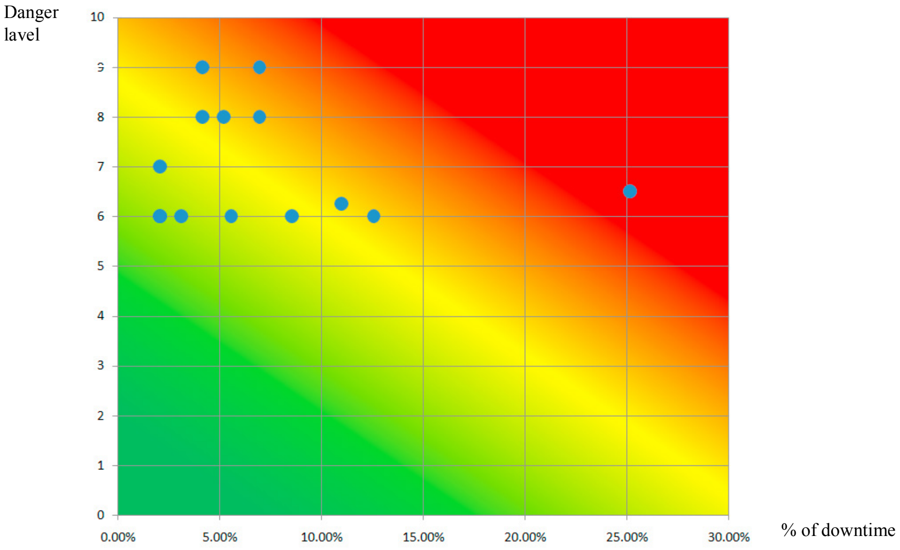

Fig. 8. Risk map by causes of stoppage – level of danger and % of downtime

4. Conclusion

The research shows an effective and innovative methodology of mapping and risk assessment of mining machinery on two levels, in relation to the criteria: level of danger, frequency of occurrence, percentage share in the total downtime, type of stoppage and cause of stoppage. With mining and construction machinery, we do not have standardized risk assessment procedures such as API 580, 581, etc. for process equipment, although the number of recorded accidents and injuries (on mining pits) is significant. The first level of analysis refers to the mapping and assessment of risk according to the type of stoppage in two dimensions: level of danger and risk number (calculated as danger level * frequency), while the second level of analysis is carried out for the first-ranked result of the first level of analysis and refers to the further analysis of stoppages according to causes and also in two dimensions: level of danger and frequency. In the presented paper, a defined methodology was implemented and results were obtained that indicate a significant share of mechanical stoppages in the structure of recorded stoppages. However, it must be emphasized that downtime (2860 minutes) amounted to 2.75% of the time spent in work (total time in work was 1728 hours). However, certain stoppages can lead to incidents and/or accidents. The greatest risk has been found with mechanical stoppages of danger level 6 and it followed by mechanical stoppages of danger level 9. The most frequent causes of stoppages come from the rupture of the hose (the frequency of occurrence of this unwanted event is 25.17% of all mechanical stoppages), although the danger level for this type of stoppage is 6, considering the frequency of occurrence of this event, it is considered that this cause of stoppages is primary, as it is clearly see on the risk map, picture 8. A burst hose can potentially cause numerous unwanted consequences for people and property, in addition to permanent work stoppages and production losses. Repairing the rod clamp is the second causal factor singled out as important from the risk aspect, considering the estimated risk level 9, although the frequency of occurrence of this unwanted event is low (participation in the total time stoppage is 6.99%, and the frequency of occurrence is 1). In the final considerations of the analysis of the specific machine, urgent prevention measures are not proposed, but the necessity of observing prevention measures and protection of employees, regular visual inspection of the condition of the equipment, regular technical maintenance and control of the condition of the machine is indicated. The promotion of preventive measures and the necessity of applying and following procedures for safety and health at work are the primary measures to prevent accidents and/or incidents when working with mining machinery, apart from regular planned and preventive measures of machine maintenance. Understanding the frequency structure and types of downtime when working with mining machinery is an aspect in order to manage the maintenance and organization of the safety function at work.

The proposal for further research refers to further performance prediction and the determination of optimum operating parameters for different working conditions. Methods of post-optimal analysis in risk management can enable the optimization of changeable factors of working conditions and their influence on the occurrence of risks. The possibility of implementing certain methods of post-optimal analysis in predicting the occurrence of risk events and their presentation on risk maps as scenario cases is a proposal for future research.

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