MINING MACHINES' DOWNTIME/FAILURE LEVEL OF DANGER OF CONSEQUENCES AND ESTIMATED RISK OF FAILURE – PRELIMINARY RESEARCH

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Abstract: Mining industry has a vital role in economy every country. That is the reason why is necessary to detect, remove or mitigate and prevent risk failures of mining machinery. In order to achieve that the first step is to identify and compare downtimes/failures and estimated risks. In this paper it was conducted the preliminary research that included 348 mining machines divided in 7 different types. The aim of the research was to determinate is there statistically significant difference between different types of mining machines in two criteria: level of danger of consequences of downtime/failure and estimated failure risk by using Kruskal - Wallis H Test. The results indicate that when it comes to level of danger of consequences there is no statistically proof that there is difference between different types of the machines. In case of estimated failure risk, there is statistically significance between some types of mining machines.

Keywords: mining machines, Kolmogorov – Smirnov test of normality, Kruskal - Wallis H Test

Introduction

Mining industry has significant role in economic growth and development (Mohsin et al., 2021) as well as huge impact on environmental e.g. air and water pollution (Down & Stocks, 1977). Productivity improvement, nowadays represents significant goal for mining industry (Balaraju et al., 2019).That mean that innovations are vital for improving efficiency in mining industry (Sánchez & Hartlieb, 2020). In order to determine which innovations are necessary for the development of the mining industry, it is first to determine the causes of downtime and failures of mining machines as well as to estimate potential risks of accidents, that are responsible for huge economic cost as well as additional environmental pollution.

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Taking that in consideration the research is conducted on preliminary samples in order to show whether there is difference between certain types of mining machines in terms of level of consequences of downtime/failure and estimated failure risk. The research itself consisted of several different stages. Firstly, data about level of danger of consequences of downtime/failure and data about estimated failure risk were collected from 7 different types of mining machines. Secondly, distribution of data was determined. Thirdly, hypothesis was set in order to determinate whether there is relationship between mining machinery failures and risks.

1. Literature review

Mining industry nowadays is facing with increased number of fatal accidents (Jansen, 2005; Ruff et al., 2011). Recently, security process control and security process risk assessment become really important topic (Golubović et al., 2022). (Blank et al., 1996) consider that technological development and occupational accidents can be regarded as conditional because the technological development is not enough to completely explain all variations in accident frequencies. Researchers suggest a lot of different solutions how to decrease number of accidents all over the world. Maintenance system management in the mining industry is recognized as a significant condition for their operation (Kumar & Kumar, 2016; Radosavljević et al., 2013). Nota et al. (2022) proposes predictive maintenance of machine tools that combines text mining algorithm and the cyber-physical system of a manufacturing industry. In order to decrease the downtimes and failures of mining machinery, Tubis et al. (2022) suggest new approach to the mining machinery maintenance management that considers safety issues and is based on the concept of risk-based maintenance (RBM). Brodny and Tutak (2022) developed the sensor-based methodology and IT system that records downtimes and failures and also identifies their causes. Pantelić et al. (2020) established a consistent risk quantification for bucket wheel excavators. Shahin et al. (2012) conducted a case study in order to find optimum maintenance strategy. They suggested a multi-criteria decision-making, the approach of analytic network process.

Also, downtimes and failures of mining machinery can result with serious economic consequences. Al-Chalabi (2022) developed a practical optimization model that can be used to estimate the economic replacement time of repairable equipment. Edwards et al. (2002) developed a model that is able to predict the hourly cost of downtime of machines that operating in the UK mining industry. The studies comes even further and some researcher developed a simulation algorithm to optimize inspection intervals for machinery maintenance in mining industry in order to decrease costs (Gölbaşı & Demirel, 2017).

2. Methodology

The aim of this research is to compare preliminary data on failures and risks obtained from 348 mining machines in 7 groups. In order to compare groups, it is necessary to determine the distribution that data are follow (Harwell, 1988). For sample more than 50, such as the case in this paper, the Kolmogorov – Smirnov test is used. (Mishra et al., 2019). If the level of significance is $p>0.05$ it can be said that the data follows a normal distribution,

otherwise, the data does not follow a Gaussian distribution (Mishra et al., 2019). After determining whether the data follows a normal distribution, it is necessary to choose between parametric and non-parametric tests. For data that follow Gaussian distribution parametric tests can be used, such as two-sample t test or J-sample Anova, etc, and in case that data does not follow Gaussian distribution it is necessary to choose a non-parametric test (Harwell, 1988) such as Mann Whitney U test or Kruskal-Wallis H Test (one-way ANOVA on ranks). In this paper, firstly the data distribution is tested and after that the Kruskal-Wallis H Test (one-way ANOVA on ranks) is performed to show whether there is difference between data or not.

3. Results

3.1. *Kolmogorov – Smirnov test of normality*

The conducted research included the collected data of 7 different types of mining machines, namely 50 excavators, 50 bulldozers, 48 drills, 50 dumpers, 50 backhoe loader, 50 bucket wheel excavators and 50 loaders. The aim of the research was to determine whether there is a relationship between the machines view from the aspect of level of danger of downtime/failure and the assessment of protentional risks. In order to be able to approach the comparison of machines, i.e., to choose an adequate test, descriptive statistics were first determined, in order to determine whether the data are subject to a Gaussian distribution or not. The normality test was performed using SPSS software. In Table 1 are given the results of the Kolmogorov – Smirnov test, and as it can be seen that the significance level is p=0.00 for the both criteria - level of danger of consequences of downtime/failure and estimated risk of failure.

Table 1. Data normality test results

	Kolmogorov-Smirnov[a]		
	Statistic	Degrees of Freedom	Significance (p)
Level of Danger of Consequences of Downtime/Failure	0,321	298	0,000
Estimated Risk	0,261	298	0,000

Given that the level of significance p in both criteria is less than 0.05 it can be concluded that the data do not follow a normal distribution and this can be shown graphically using histograms (Figure 1 and Figure 2).

Figure 1. Histogram of the level of danger of consequences of downtime/failure

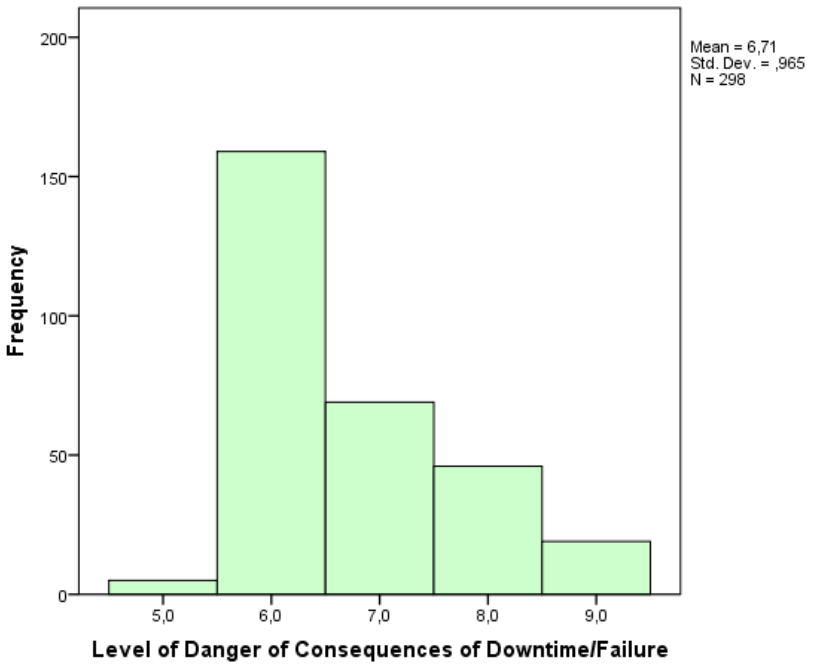
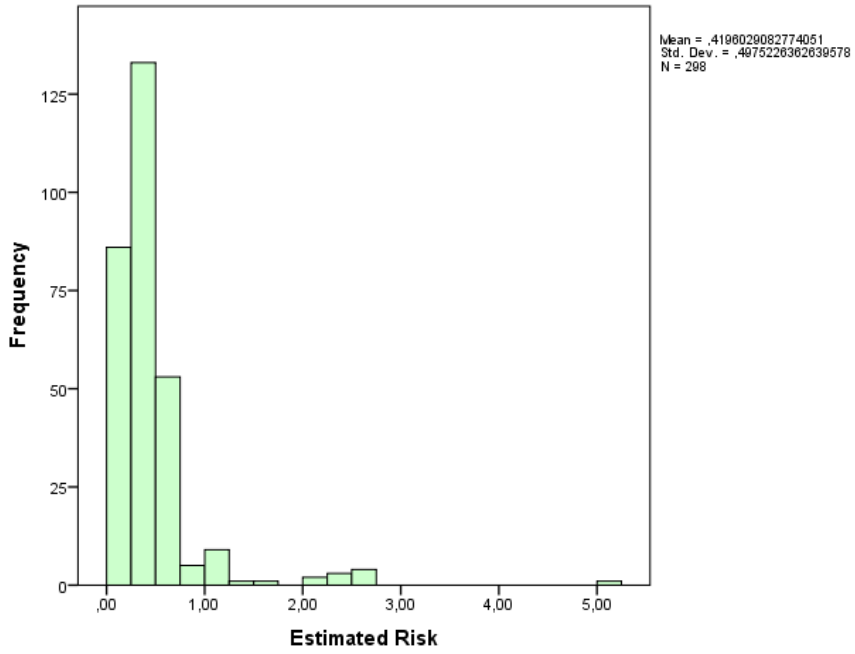


Figure 2. Histogram estimated risk



2.1 Kruskal - Wallis H Test (one-way ANOVA on ranks)

After the Kolmogorov – Smirnov test is done, the Kruskal - Wallis H Test was selected as adequate. Two hypotheses are set:

H0: There is no difference between data (level of danger and estimated risk are the same for all types of mining machines),

H1: There is difference between data (level of danger and estimated risk are not the same for all types of mining machines).

The results of the comparison of the level of danger due to downtime/failure are given in Table 2, and the results of the comparison of the estimated risk are given in Table 3, while their relationships are shown in Figure 3. In the SPSS software, the significance level is set to 5%, while the confidence interval is 95%. Note that the test statistic is adjusted for ties and multiple comparation was not performed in comparation of the level of danger caused by downtime/failure because the overall test dos not show significant differences across samples.

In Table 3. Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same. Asymptotic significances (2 side tests) are given.

Table 3. The results of the comparison of the level of danger caused by the downtime/failure of mining machines

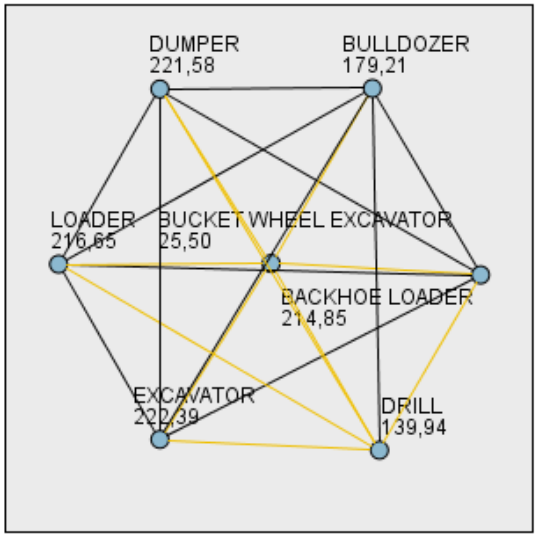
Total N	348
Test Statistic	8,205
Degrees of Freedom	6
Asymptotic Significance (2-sided test)	0,223

Table 4. Results of the comparison of the estimated risk of mining machines

Sample 1 – Sample 2	Test statistic	Std. Error	Std. Test Statistic	Significance	Adj. Significance
BUCKET WHEEL EXCAVATOR - DRILL	-114.438	20,249	-5.652	0.000	0.000
BUCKET WHEEL EXCAVATOR - BULDOZER	-153.710	20.041	-7.670	0.000	0.000
BUCKET WHEEL EXCAVATOR - BACKHOE LOADER	-189.350	20.041	-9.448	0.000	0.000
BUCKET WHEEL EXCAVATOR - LOADER	-191.150	20.041	-9.538	0.000	0.000
BUCKET WHEEL EXCAVATOR - DUMPER	-196.080	20.041	-9.784	0.000	0.000
BUCKET WHEEL EXCAVATOR - EXCAVATOR	-196.890	20.041	-9.824	0.000	0.000
DRILL – BULDOZER	39.272	20.249	1.939	0.052	1.000
DRILL – BACKHOE LOADER	74.912	20.249	3.700	0.000	0.005
DRILL – LOADER	-76.912	20.249	-3.788	0.000	0.003
DRILL – DUMPER	-81.642	20.249	-4.032	0.000	0.001
DRILL – EXCAVATOR	-82.452	20.249	-4.072	0.000	0.001
BULLDOZER – BACKHOE LOADER	-35.640	20.041	-1.778	0.075	1.000
BULLDOZER – LOADER	-37.440	20.041	-1.868	0.062	1.000
BULLDOZER – DUMPER	-42.370	20.041	-2.114	0.035	0.725

BULLDOZER – EXCAVATOR	-43.180	20.041	-2.155	0.031	0.655
BACKHOE LOADER – LOADER	-1.800	20.041	-0.090	0.928	1.000
BACKHOE LOADER – DUMPER	-6.730	20.041	-0.336	0.737	1.000
BACKHOE LOADER - EXCAVATOR	-7.540	20.041	-0.376	0.707	1.000
LOADER – DUMPER	4.930	20.041	0.246	0.806	1.000
LOADER – EXCAVATOR	5.740	20.041	0.286	0.775	1.000
DUMPER – EXCAVATOR	-0.810	20.041	-0.040	0.968	1.000

Figure 3. Relationships between the assessed risk of observed mining machines



Each node shows the sample average rank of TypeofMachine.

3. Conclusion

After preliminary research, and based on the conducted research, it can be concluded that there is no statistically significant difference in the data regarding the degree of danger from the consequences of downtime, because the lowest (asymptotic) value of the significance level is p=0.223>0.05 (Chan & Walmsley, 1997). The statistically significant difference exists from the perspective of the estimated risk of failure. That means that null hypothesis cannot be rejected. The data of bucket wheel excavator and drill, bucket wheel excavator and bulldozer, bucket wheel excavator and dumper, bucket wheel excavator and backhoe loader, bucket wheel excavator and loader, bucket wheel excavator and excavator, drill and backhoe loader, drill and loader, drill and dumper and drill and excavator are different. In these cases, the null hypothesis is rejected. The other comparation shows that null hypothesis cannot be rejected.

Given that this is preliminary research, its shortcoming is primary reflected in the amount of sample. More accurate result would be obtained if the sample size is bigger.

Proposition for the further research is to increase sample size and separate groups where exists difference between data samples and then according to obtained results by using methods techniques of industrial engineering, predict and reduce the risk of downtime/failure of mining machines in order to increase productivity, decrease number of accidents, downtimes and failures and reduce the repairment costs.

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СТЕПЕН ОПАСНОСТИ ПОСЛЕДИЦА ЗАСТОЈА/ОТКАЗА И ПРОЦЕЊЕНИ РИЗИК ОД ОТКАЗА РУДАРСКИХ МАШИНА – ПРЕЛИМИНАРНО ИСТРАЖИВАЊЕ

Резиме: *Рударска индустрија има виталну улогу у економији сваке земље. То је разлог зашто је потребно открити, отклонити или ублажити и спречити ризик од отказа рударских машина. Да би се то постигло, први корак је да се идентификују и упореде застоји/откази и процењени ризици. У овом раду спроведено је прелиминарно истраживање које је обухватило 348 рударских машина подељених у 7 различитих типова. Циљ истраживања је био да се утврди да ли постоји статистички значајна разлика између различитих типова рударских машина у два критеријума: степену опасности последица застоја/отказа и процењеном ризику отказа применом Kruskal – Wallis H Теста. Резултати показују да, када је у питању степен опасности,последица не постоји статистички доказ да постоји разлика између различитих типова машина. У случају процењеног ризика од отказа, постоји статистички значајна разлика између неких типова рударских машина.*

Кључне речи: *рударске машине, Kolmogorov – Smirnov test of normality, Kruskal - Wallis H Test*