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COMPARISON OF FAILURE DURATION AND FAILURE FREQUENCY OF MINING MACHINES USING THE KRUSKAL-WALLIS H TEST (ONE-WAY ANOVA ON RANKS) - PRELIMINARY RESEARCH

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Abstract: Mining is considered one of the most risky industrial operations. Development and application of risk assessment methods has the greatest impact on improvements in terms of safety in mining equipment. Risk is analyzed in many aspects i.e. human factor, environmental impact and operational aspects. Analyzing the mining machinery is a way to determine which ones have the greatest tendency to fail. The aim of this research is to compare data on failures obtained from 348 mining machines. All machines are arranged in 7 groups, namely 50 excavators, 50 bulldozers, 48 drills, 50 dumpers, 50 backhoe loaders, 50 bucket wheel excavators and 50 loaders. In order to compare the data, it is necessary to first determine the distribution under which the data belong. That is achieved by using Kolmogorov-Smirnov test. After that the Kruskal-Wallis test was used to determine whether there is a relationship between the machines, viewed from the aspects of failure duration and failure frequency.
Key words: risk assessment, mining machinery, Kolmogorov – Smirnov normality test, Kruskal - Wallis H Test (one-way ANOVA on ranks)

INTRODUCTION

Mining is considered one of the most risky industrial operations, and the accidents that occur leave great consequences, namely economic, operational, as well as environmental and health and safety consequences. Development and application of risk assessment methods has the greatest impact on improvements in terms of safety in mining equipment. Recognizing the need for risk analysis leads to the realization of the necessary efficiency and effectiveness of the system [1]. Recently, interest in risk assessment and management in the mining industry has a growing path, and this is confirmed by the increasing number of reports dealing with this topic. Risk is analyzed in many aspects i.e. human factor, environmental impact and operational aspects. Systematic maintenance is one of the basic factors for the normal functioning of the system, and this can be achieved by analyzing the mining machinery to determine which ones have the greatest tendency to fail [2].

LITERATURE REVIEW

Tubis et al. [3] proposed a systematic review of risk assessment methods in mining industry. They selected 94 papers in that area. Based on the results obtained from different databases, they identified the biggest gaps in research in this area. Groves et al. [4] used Mine Safety and Health Administration (MSHA) and Current Population Survey (CPS) to examine injuries which are equipment-related in mining industry and came to conclusion that off-road ore haulage was the most common source of injuries and fatalities. Petrovic et al. [2] used fuzzy sets theory, fuzzy logic and min–max composition to show risk assessment of coal mine technical system. They compared these methods to FMEA method with standard RPN calculating, showing that fuzzy methodology has more advantages. Joy [5] in addition to risk assessment methodology, also considered incident and accident aspects of risk in mining industry. Badri et al. [6] presented new practical approach to risk management using Analytic Hierarchy Process (AHP) and discussed importance of taking occupational health and safety (OHS) into account when talking about all mining activities. Md-Nor et al. [7] presented the results of research which characterized risks of fatal incidents in US mining. Mikhailov et al. [8] considered the environmental aspect of risk management and came up with a package of ecological risk reduction measures. Nawrocki et al. [9] used fuzzy logic to compare operational risk in mining enterprises in Central and Eastern Europe from two perspectives: internal and industrial.

METHODOLOGY

The aim of this research is to compare data on failures obtained from 348 mining machines. All machines are arranged in 7 groups, namely 50 excavators, 50 bulldozers, 48 drills, 50 dumpers, 50 backhoe loaders, 50 bucket wheel excavators and 50 loaders. In order to compare the data, it is necessary to first determine the distribution under which the data belong. For determining the distribution, when processing more than 50 data, the Kolmogorov - Smirnov test is used. With this test, if the level of significance is $p>0.05$, we can say that the data belong to the Gaussian distribution, while in the case of $p<0.05$, the data do not behave according to it [10]. When it is determined which distribution the data belong to, it is necessary to use parametric or non-parametric tests. When the data behave according to the normal distribution, parametric tests can be used, while in the case when the data do not behave according to the same, non-parametric tests must be used. Some of them are Mann-Whitney U test or Kruskal-Wallis test. Given that more than 2 samples are taken into account in this paper, the Kruskal-Wallis test was used.

RESULTS

Kolmogorov – Smirnov normality test

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 loaders, 50 bucket wheel excavators and 50 loaders. The aim of the research was to determine whether there is a relationship between the machines, viewed from the aspects of failure duration and failure frequency. In order to be able to approach the comparison of machines, that is, to choose an adequate test, descriptive statistics were first determined, in order to determine whether the data are subject to a Gaussian distribution. For samples greater than 50, the Komologorov-Smirnov test is used [10]. If the level of significance is $p>0.05$, it can be said that the data follows a normal distribution [10]. The normality test was performed using SPSS software. The results of the Komologorov-Smirnov test are given in table 1 for the criteria of duration of failure and frequency of failure.

Table 1. Normality test results

	Kolmogorov-Smirnov[a]		
	Statistic	df	Sig.
Failure Duration	0.278	298	0.000
Failure Frequency	0.278	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 is also shown on the histograms (figures 1 and 2).

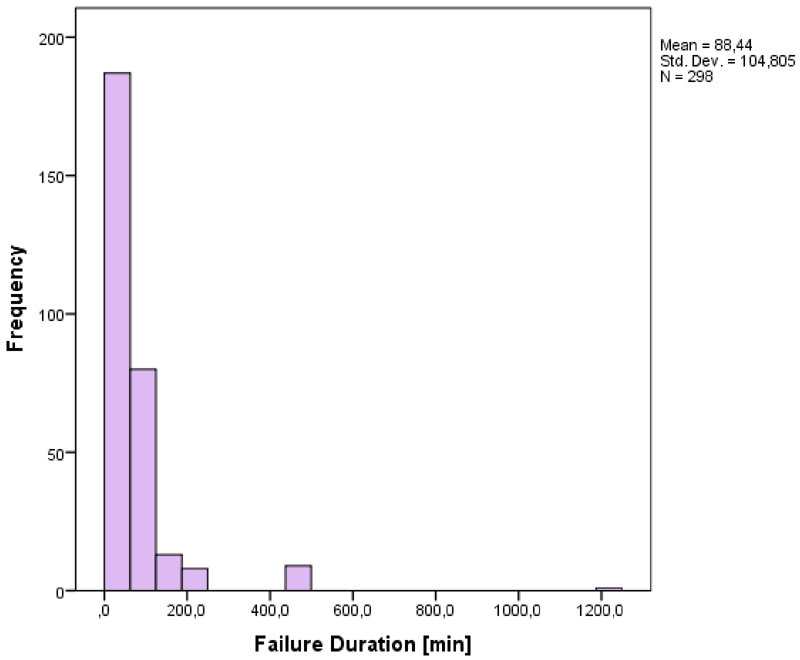


Fig. 1. Histogram of machine failure duration

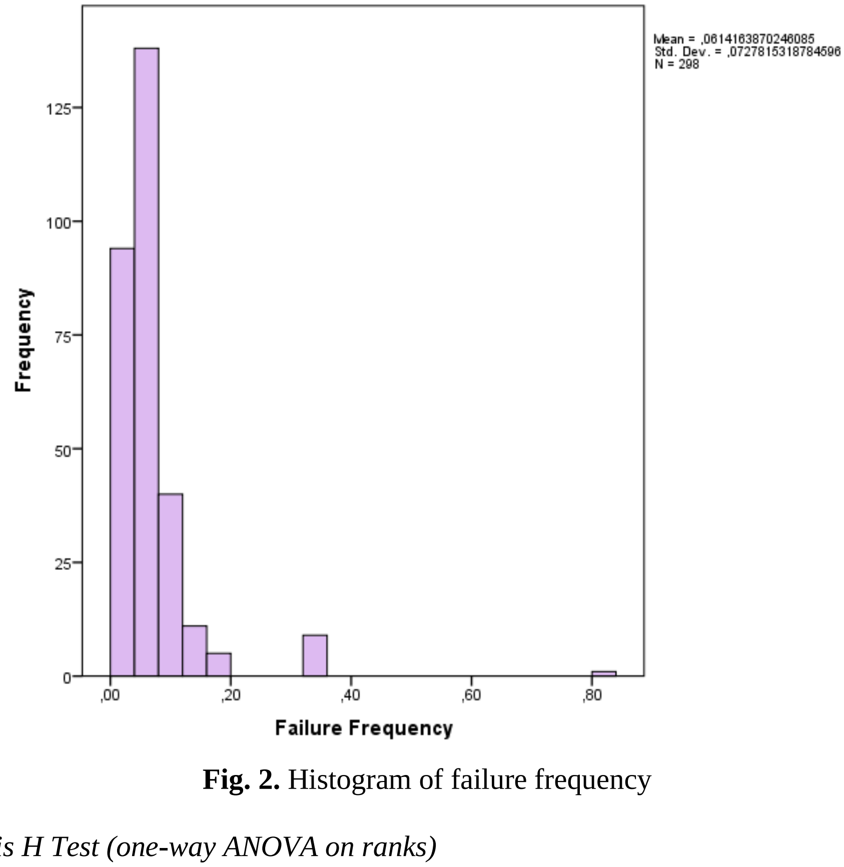
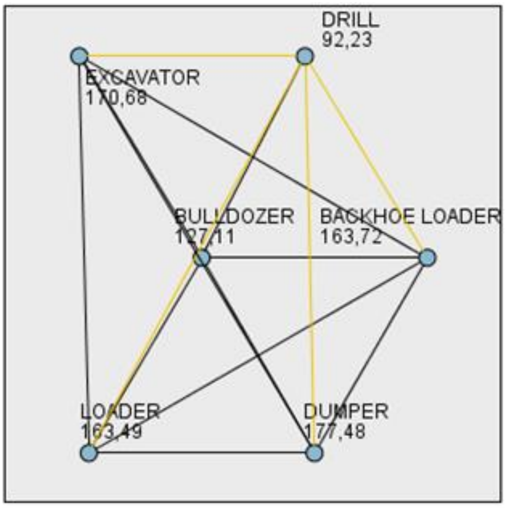


Fig. 2. Histogram of failure frequency

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

After the Komologorov-Smirnov test, the Kruskal-Wallis H test was selected as adequate. The results of the comparison of failure duration are given in Table 2, while the relationships between them are given in Figure 3, and the results of the comparison of failure frequency are given in Table 3, and their relationships are in Figure 4. In the software, the significance level is set to 5%, while the confidence interval is 95%.



Each node shows the sample average rank of TypeofMachine.

Fig. 3. Relationships between the failure duration of the observed machines

Table 2. Results of the comparison of the duration of failure of mining machines

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
DRILL - BULLDOZER	34.881	17.079	2.042	0.041	0.864
DRILL - LOADER	-71.261	17.079	-4.172	0.000	0.001
DRILL - BACKHOE LOADER	71.491	17.079	4.186	0.000	0.001
DRILL - EXCAVATOR	-78.451	17.079	-4.593	0.000	0.000
DRILL - DUMPER	-85.251	17.079	-4.992	0.000	0.000
BULLDOZER - LOADER	-36.380	16.904	-2.152	0.031	0.659
BULLDOZER - BACKHOE LOADER	-36.610	16.904	-2.166	0.030	0.637
BULLDOZER - EXCAVATOR	-43.570	16.904	-2.578	0.010	0.209
BULLDOZER - DUMPER	-50.370	16.904	-2.980	0.003	0.061
LOADER - BACKHOE LOADER	0.230	16.904	0.014	0.989	1.000
LOADER - EXCAVATOR	7.190	16.904	0.425	0.671	1.000
LOADER - DUMPER	13.990	16.904	0.828	0.408	1.000
BACKHOE LOADER - EXCAVATOR	-6.960	16.904	-0.412	0.681	1.000
BACKHOE LOADER - DUMPER	-13.760	16.904	-0.814	0.416	1.000
EXCAVATOR - DUMPER	6.800	16.904	0.402	0.687	1.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same. Asymptotic significances (2-side tests) are displayed. The significance level is 0.05.

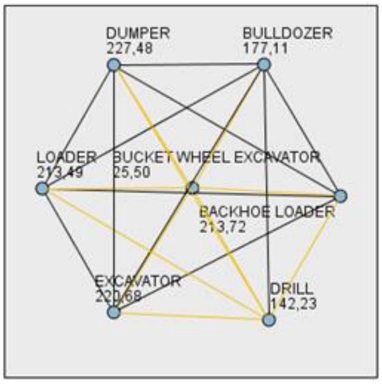


Fig. 4. Relationships between failure frequency of observed machines

Table 3. Results of the comparison of the frequency of failure of mining machines

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
BUCKET WHEEL EXCAVATOR - DRILL	116,729	20.055	5.820	0.000	0.000
BUCKET WHEEL EXCAVATOR - BULLDOZER	151.610	19.849	7.638	0.000	0.000
BUCKET WHEEL EXCAVATOR - LOADER	187.990	19.849	9.471	0.000	0.000
BUCKET WHEEL EXCAVATOR - BACKHOE LOADER	188.220	19.849	9.482	0.000	0.000
BUCKET WHEEL EXCAVATOR - EXCAVATOR	195.180	19.849	9.833	0.000	0.000
BUCKET WHEEL EXCAVATOR - DUMPER	201.980	19.849	10.176	0.000	0.000
DRILL - BULLDOZER	34.881	20.055	1.739	0.082	1.000
DRILL - LOADER	-71.261	20.055	-3.553	0.000	0.008
DRILL - BACKHOE LOADER	71.491	20.055	3.565	0.000	0.008
DRILL - EXCAVATOR	-78.451	20.055	-3.912	0.000	0.002
DRILL - DUMPER	-85.251	20.055	-4.251	0.000	0.000
BULLDOZER - LOADER	-36.380	19.849	-1.833	0.067	1.000
BULLDOZER - BACKHOE LOADER	-36.610	19.849	-1.844	0.065	1.000
BULLDOZER - EXCAVATOR	-43.570	19.849	-2.195	0.028	0.591
BULLDOZER - DUMPER	-50.370	19.849	-2.538	0.011	0.234
LOADER - BACKHOE LOADER	0.230	19.849	0.012	0.991	1.000
LOADER - EXCAVATOR	7.190	19.849	0.362	0.717	1.000
LOADER - DUMPER	13.990	19.849	0.705	0.481	1.000
BACKHOE LOADER - EXCAVATOR	-6.960	19.849	-0.351	0.726	1.000
BACKHOE LOADER - DUMPER	-13.760	19.849	-0.693	0.488	1.000
EXCAVATOR - DUMPER	6.800	19.849	0.343	0.732	1.000

CONCLUSION

After preliminary research, and based on the research conducted, it can be concluded that there is a significant difference in the data regarding the duration of failure between the drill and the loader, then between the drill and the backhoe loader, the drill and the excavator and the drill and the dumper. There is no statistically significant difference in the data between the other machines. From the point of view of the frequency of failures, there are differences between bucket wheel excavator and backhoe loader, bucket wheel excavator and bulldozer, bucket wheel excavator and drill, bucket wheel excavator and loader, bucket wheel excavator and dumper, bucket wheel excavator and excavator, drill and dumper, drill and excavator, drill and combine and drill and loader. In other cases, there is no significant difference between the data on the frequency of dismissal.

Research and analysis like this could be further developed in a way that is much more detailed, and for that a larger sample of data would be needed, so that the results would be more accurate.

By increasing the sample size with more precise results, we could achieve concrete guidelines for the further management of such a system, as well as the introduction of new measures to reduce risk, and therefore better results of the mining system such as this one.

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