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EXCAVATOR'S AND BULLDOZER'S DOWNTIME COMPARISON AND RISK MANAGEMENT: PRELIMINARY STUDY

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Abstract: Risk management of engineering systems is of vital importance, but very often there is no enough data to quantitatively evaluate risk and accordingly create risk management strategy. Proper maintenance of excavators and bulldozers maximizes fuel efficiency and reduces operating costs, as well as reduces equipment failure and enhances safety. Accordingly, previous research opens avenue to analyze these two machinery types when working in mining industry. This paper aims to create statistical comparisons on data collected about excavators' and bulldozers' as technological failure/stoppage, electrical failure/stoppage, mechanical failure/stoppage, misuse, organizational failure/stoppage and external cause of failure/stoppage. After performing descriptive statistics, hypothesis testing has not found significant differences between technological failures/stoppages of excavators vs. bulldozers, mechanical failures/stoppages between already mentioned machines or theirs hazard degrees or total downtimes. Further research focus should be directed to the sample enlargement and further analysis, which is expected to prove preliminary results.

Keywords: excavator, bulldozer, downtime, differences

1. INTRODUCTION

To fully profit from mechanization, mining machinery should be used continuously. One particular issue is the length of its downtime and their effect on mining process productivity, while another is its influence on safety (Edwards & Yisa, 2001; Seo & Kim, 2008). Mining sites managers should create appropriate contingency plans to lessen the effect of downtime if they could predict how long a site would be offline (Edwards & Yisa, 2001).

In order to properly plan the prevention of critical potentials of downtime and to prepare a response strategy in the case of failure with the goal of avoiding consequences, risk management is a requirement (Kumar & Kumar, 2016). As its prerequisite, the proper record keeping is a crucial component of all mining equipment maintenance, but it is rarely done in reality even though it is a requirement for effective risk management (Spasojević Brkić et al., 2022a).

Accordingly, further attention on those issues is nowadays requirement, as in previous research, which follows.

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2. PREVIOUS RESEARCH

The operation of any heavy machinery is associated with high risks, while the goal of risk management is to create a controlled work environment to ensure the safe operation of the high-risk systems (Bedi et al., 2021; Kirin et al., 2021). The risks associated with heavy machinery are influenced by the working environment, machine specification, mine design, and human factor, while most rarely focus is given to excavators and bulldozers (Duarte et al., 2021). It is also recommended to focus on active monitoring, in both equipment operations and maintenance (Berriault et al., 2017) and to pay more attention to ergonomic inconveniences in heavy mobile machinery cabs (Spasojević Brkić et al., 2023).

Although rarely, previous researchers have theorized and demonstrated that operation of excavators and bulldozers on mining sites has high risks (Zhang et al., 2006; Horberry et al., 2016; Rane et al., 2019; Brkić et al., 2022; Spasojević Brkić et al., 2022a).

Till now, there have been numerous attempts to understand underlying causes of injury incidents on mining equipment, but available studies very rarely analyse and usually do not systematically collect data on downtime types frequencies and its consequences, although those data are needed to calculate risk and later on create strategies to mitigate them. Most frequently authors base their research on qualitative data and use different types of FMEA - Failure Modes and Effects Analysis. Examples of such research are given in surveys such as Karasan et al. (2018), Kumar and Kumar, (2016), Misita et al. (2021) and Zeng et al. (2020). In contrast to FMEA analysis and the Fine Kinney approaches, a novel strategy proposed by Karasan et al. (2018), called analysis of safety and critical effects expanded by Pythagorean fuzzy sets, produced more accurate results. A new risk management strategy system for the program for optimal excavator maintenance has been proposed, which includes the functional analysis methods of FMEA and FMECA and aims to develop an effective methodology for excavator maintenance that reduces maintenance costs while effectively monitoring and maintaining technical constraints (Kumar & Kumar, 2016). The Fuzzy FMEA method was also used in a study that tracked hydraulic excavators' downtime over a year to determine the most important causes of downtime, i.e. risk selection (Misita et al., 2021). Using data from excavator failures, a reliability analysis and an FMEA analysis were carried out, which were then used to develop proper maintenance policies (Zeng et al., 2020). Evidently, more research is available about excavators, and very rarely data about downtime even there is collected, so risk calculation is mostly qualitative, although risk are expected to be high. One of rare research which is based on bulldozers' downtime is given in Spasojević-Brkić et al. (2022b), where authors have found that from the aspect of the risk of failure, the most frequent failures are heating repair, oil change, bulldozer cleaning, screw replacement, tonsil adjustment, filter replacement, part repairment, hose replacement, and bearing replacement.

3. METHODOLOGY

Previous research opens avenue to pay further attention to risk mitigation when managing operation of excavators and bulldozers.

This paper aims to create statistical comparisons on data collected about excavators' and bulldozers' downtime and based on these conclusions to arrive to conclusions about possible risk mitigation strategies.

Data collection is conducted on 6 mining sites in Serbia and Montenegro during a period of 18 months. Downtimes of both mining machinery types have been classified as technological failure/stoppage, electrical failure/stoppage, mechanical failure/stoppage, misuse, organizational failure/stoppage and external cause of failure/stoppage. Data were also collected on the type and number of failures of mining machinery as well as their duration, and based on that, the frequency of failure duration and the hazard degree were obtained. After descriptive statistics done, hypothesis testing done to elaborate of there are significant differences between downtimes recorded on those machinery types with aim check if similar strategies could be applied to both machinery types. If there differences would not be found the conclusion led would be that it is possible to use joint or available data and apply risk mitigation strategies on those basis.

3.1. Descriptive statistics

Table 2. shows data of descriptive statistics, according to the nomenclature in table 1.

Table 1. Nomenclature

Abbreviation	Meaning
EX-T	Excavator - technological failure/stoppage
EX-E	Excavator - electrical failure/stoppage
EX-Mc	Excavator - mechanical failure/stoppage
EX-Mu	Excavator – misuse
EX-O	Excavator - organizational failure/stoppage
EX-Ex	Excavator - external cause of failure/stoppage
EX-HD	Excavator - hazard degree
EX-TD	Excavator - total downtime
BU-T	Bulldozer - technological failure/stoppage
BU-E	Bulldozer - electrical failure/stoppage
BU-Mc	Bulldozer - mechanical failure/stoppage
BU-Mu	Bulldozer – misuse
BU-O	Bulldozer - organizational failure/stoppage
BU-Ex	Bulldozer - external cause of failure/stoppage
BU-HD	Bulldozer - hazard degree
BU-TD	Bulldozer - total downtime
N	enrollment number
n.e.	not examined (insuficient number of data 0-3)
Mp	mid point
Me	median
Min	minimum
Max	maximum
R	range
Sd	standard deviation
Cv(%)	coefficient of variation
U*	u* - Mann Withney
p - level	p sample level
VR	significance of comparison
i.d.	statistically insignificant difference
p<0.05	statistically significant difference
p<0.01	statistically highly significant difference
p<0.001	statistically absolutely significant difference

Table 2. Descriptive statistics

	N	Mp	Me	Min	Max	R	Sd	Cv(%)
EX-T	53	34.057	30.0	10	180	170	30.525	89.63
EX-E	3	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.
EX-Mc	112	84.866	30.0	5	1200	1195	149.443	176.09
EX-Mu	0	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.
EX-O	0	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.
EX-Ex	1	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.
EX-HD	169	1.716	1.0	1	5	4	1.221	71.14
EX-TD	169	75.917	30.0	5	1200	1195	136.232	179.45
BU-T	26	30.385	30.0	15	80	65	13.261	43.64
BU-E	0	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.
BU-Mc	74	76.622	60.0	5	350	345	77.265	100.84
BU-Mu	0	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.
BU-O	0	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.
BU-Ex	0	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.
BU-HD	102	1.980	2.0	1	5	4	1.169	59.02
BU-TD	102	64.216	30.0	5	350	345	69.120	107.64

Given that the coefficients of variation are far greater than 30%, the comparison was made using the Mann-Withney U* test and the results are shown in Table 3.

A scatterplot between the hazard degree and the failure/stoppage time of the excavators is shown in Figure 1, while the histograms for the hazard degree and the downtime/failure are shown in Figure 2 and 3 respectively.

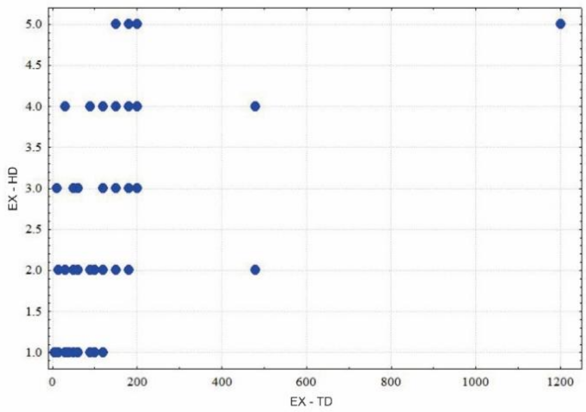

Figure 1. Scatterplot between hazard degree and the failure/stoppage time of the excavators

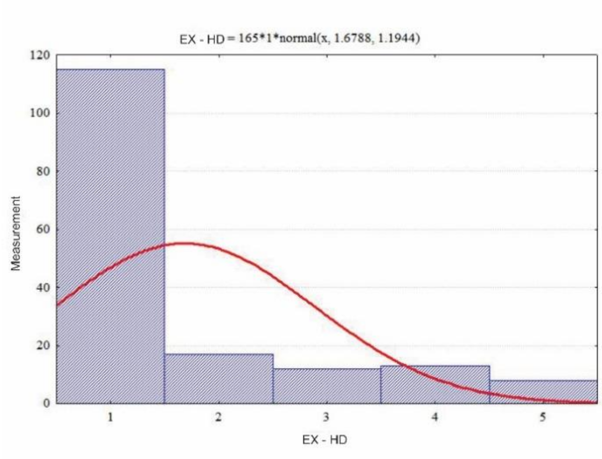

Figure 2. Histogram of hazard degrees for excavators

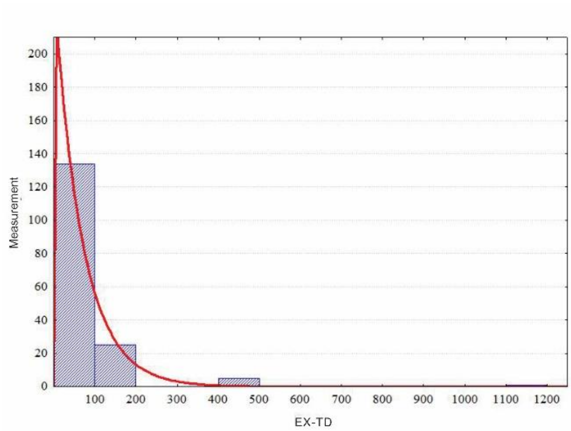

Figure 3. Histograms for failure/stoppage time of excavators

A scatterplot between the hazard degree and the failure/stoppage time of the bulldozers are shown in Figure 4, while the histogram for hazard degree is shown in Figure 5 and for downtime/failure times in Figure 6, according to Spasojević-Brkić et al. (2022b).

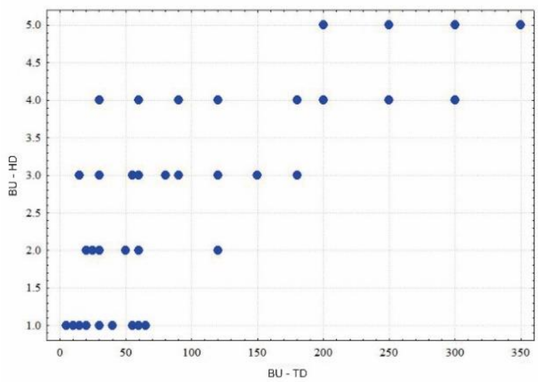

Figure 4. Scatterplot between hazard degree and the failure/stoppage time of the bulldozers

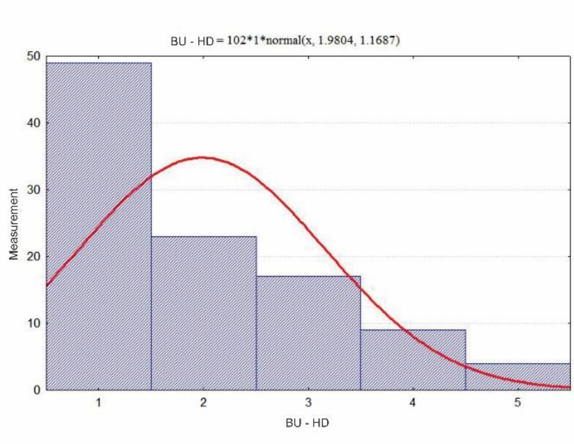

Figure 5. Histogram of hazard degrees for bulldozers

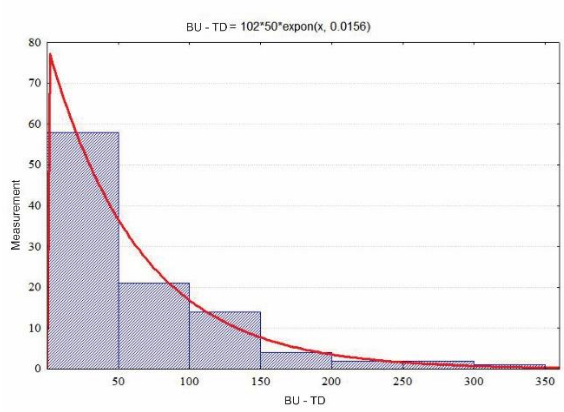

Figure 6. Histograms for failure/stoppage time of bulldozers

Table 3. Comparison of failure/stoppage parameters with U* by Mann-Whitney test

			U*	p - level	VR
EX-T	vs.	BU-T	0.000000	1.000000	i.d.
EX-Mc	vs.	BU-Mc	0.000000	1.000000	i.d.
EX-HD	vs.	BU-HD	0.540062	0.589155	i.d.
EX-TD	vs.	EX-TD	0.000000	1.000000	i.d.

The comparisons in Table 3 show that there are no statistically significant differences regarding the data we have in this preliminary research, and the differences are evidently the greatest in terms of the hazard degree between the compared machines.

4. CONCLUSIONS

Previous study suggests that more attention should be paid to risk mitigation when operating excavators and bulldozers. This paper aimed to make statistical comparisons based on data gathered about excavator and bulldozer downtime, and then drawn conclusions about possible risk mitigation strategies based on those findings. Following the completion of descriptive statistics, hypothesis testing was performed to determine whether there are significant differences in downtimes recorded on those machinery types, with the goal of determining whether comparable strategies could be applied to both machinery types.

The Mann-Whitney U* test results revealed that there was no statistically significant difference in the failure/stoppages between the machines ($p > 0.05$). This suggests that, with additional research, the same risk management strategy could be applied to both types of mining machinery.

The disadvantage of the work is the small sample, in which not all types are represented downtime (technological failure/stoppage, electrical failure/stoppage, mechanical failure/stoppage, misuse, organizational failure/stoppage and external cause of failure/stoppage) and therefore we consider it a preliminary analysis.

Further research focus should be directed to sample enlargement and further analysis, which is expected to prove preliminary results.

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