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Backhoe and Loader Excavator Operators' Workplace Health and Safety and Gaseous Pollutants

Vesna Spasojević Brkić[1], Ivan Mihajlović[1], Nemanja Janev[1], Martina Perišić[1], and Abdulghder Mohamed Alsharif[1,2]

[1]University of Belgrade – Faculty of Mechanical Engineering, Belgrade, Serbia
[2]General Electricity Company of Lybia, Tripoli, Lybia

ABSTRACT

Operating heavy machinery is both physically and mentally very demanding job, which still carries significant risks, especially at excavators, even with the current regulations in place. Given that working conditions have a substantial impact on the health and safety of both employees and local inhabitants of mining industry sites, it seems imperative to enhance them. The first part of this research surveys 45 backhoe and 22 loader excavator operators' attitudes regarding their satisfaction about health and safety at workplace and gaseous pollutants, while the second measures gaseous pollutants levels in machines operation and compares it to regulation documents. The findings of gaseous pollutants' measurements demonstrate that, even with new machines, there are occurrences where specific working condition parameters are exceeded. Mann-Whitney tests confirmed statistically significant differences between backhoe and loader excavator working conditions regarding measured average O_2, NO and CO_2, average overrun of NO_x and relation between maximum relative value measured of NO_x and allowed value in regulation documents, because the backhoe excavators have higher values of the examined parameters. The findings also show greater satisfaction of loader excavator operators, as Mann-Whitney tests confirmed statistically significant differences regarding importance of satisfaction with working environmental conditions, the air quality in the working environment and operators' knowledge to maintain or improve health and safety. It is evident that the workplace of loader excavator operator has lower human health and safety risk levels then backhoe excavator operator workplace. The proposal for future research is deeper analysis of causes of those differences.

Keywords: Backhoe excavator, Loader excavator, Operator, Mann-Whitney, Gaseous pollutants

INTRODUCTION

Due to its inherent features such as humidity, dust exposure, the risk of damage from falling rocks, falls from different levels, etc., the mining operation is both a significant economic sector in national economies and also one of the riskiest sectors (Sanmiquel et al., 2018; Čelebić et al., 2024). Open pit mines use a conventional cone-shaped excavation to extract minerals from near-surface, nonselective, low-grade zones, which frequently leads to great productivity, low operating costs, and significant capital investments

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(Altiti et al., 2021). Mining machinery used in open pit mining is designed for 40 to 50 years of operation (Czmochowski & Pietrusiak, 2012). Open-pit mines provide for the majority of Serbia's electrical power generation in terms of energy balance (Brkic et al., 2014).

Operating any heavy machinery still carries significant risks, even with the current regulations in place (Duarte et al., 2021; Spasojevic Brkic et al., 2023). Cash benefits payable under relevant legislation, medical benefits, disability benefits, etc. payable under the social security system, and other benefits payable under the business's own plan make up the direct cost of possible accidents (Arango-Retamozo et al., 2023). The time lost by injured workers, the time lost by other workers who stop work to help the injured worker, the time spent by first-aid attendants and hospital department staff, the cost of damage to machines, tools, or other property, the loss of profit due to the injured worker's decreased productivity and efficiency, etc. are all examples of the indirect costs associated with mine accidents (Nowrouzi-Kia et al., 2017). According to earlier research, human mistake accounts for more than 80% of all undesirable incidents involving mining equipment (Mirzaei Aliabadi et al., 2020). In EU15 Member States, workplace accidents in the mineral-extraction sector were projected to have cost 454,909,000 euros (Ural & Demirkol, 2008).

One of the most widely utilized heavy machinery is the excavator, while workplaces of backhoe and loader excavator operators are recognized as a physically and mentally very demanding jobs (McCann, 2006; Palega & Rydz, 2018). Given that working conditions have a substantial impact on the health and safety of both employees and local inhabitants of mining industry sites, it seems imperative to enhance them (Bettens et al., 2022; McCann, 2006). More research is needed in that field, so the structure of this paper starts with literature review, which indicates the actuality and insufficient research of the topic of the paper, continues with survey methodology section, and is followed by results and conclusions.

PREVIOUS RESEARCH

In the mining sector, excavators' operational efficiency is crucial since it directly affects project schedules and financial results (Kassem et al., 2021).

The operator of an excavator faces numerous risks associated with both the machine's operation and the workplace (Brkić et al., 2026; Kekeç et al., 2023; Palega & Rydz, 2018). An excavator operator must be perceptive, have constant focus, be precise, and have upper and lower limb dexterity in order to perform their hard and exhausting job. The excavator operator is subject to fluctuating weather conditions because they operate both inside and outside the cabin (Palega & Rydz, 2018). It should be underlined that the quality of the work completed and the working circumstances are significantly impacted by the ambient temperature, too (Palega & Rydz, 2018). One or three shifts are used for working at excavator. Noise, vibration, air dust, explosions, fire, and electric shock are just a few of the hazardous and damaging elements that an excavator operator may encounter (Palega & Rydz, 2018). Additionally, the excavator operator's work is linked to health

risks related to rheumatic and musculoskeletal disorders (Palega & Rydz, 2018; Perišić et al., 2024; Spasojević Brkić et al., 2024).

The studies by Edwards et al., (2002) and Spasojević Brkić et al., (2022a) concentrate on risk management and cost prediction while examining the effects of excavator downtime in the mining sector. Lee et al. (2019) demonstrate an autonomous excavator system that uses remote controls and 3D scanning to securely operate in hazardous regions, potentially minimizing downtime associated to health and safety.

One of the main causes of air pollution is non-road mobile machinery (NRMM) (Waluś et al., 2018). Excavators require particular attention because the emission characteristics of mobile air pollution sources from the non-road sector have not yet been fully studied (Jung et al., 2020; Khan et al., 2023). However, existing techniques for predicting multi-pollutant emissions factors are imperfect, and nothing is known about how NRMM emissions are affected by real-world testing settings. (Wang et al., 2024).

To fulfill the research gap, this research is composed of two parts, the first of which surveys backhoe and loader excavator operators' attitudes regarding their satisfaction about health and safety at workplace and gaseous pollutants, while the second measures gaseous pollutants levels in their operations at mining sites and compares it to available regulation documents, in aim to contribute to avoid potential occupational hazards there.

METHODOLOGY

The data used in this research is from two categories: the first one included values of operator workplace parameters measured outside of the cabin with specialized equipment on 10 open pit mine sites in Serbia and Montenegro on both types of mining machines, and the second category included operators answers to 6 survey questions regarding assessment of general importance of statements on health and safety and cleanliness of working environment. The list of questions is shown in the Table 1.

Table 1: List of survey questions.

Question	Label
General importance of statement "Working environment conditions (temperature, humidity, dust...) are satisfactory (I feel comfortable while working)"	Q1
General importance of statement "The air quality in the working environment is satisfactory"	Q2
General importance of statement "The cleanliness of the working environment is satisfactory"	Q3
General importance of statement "I know how to do my job in a safe manner"	Q4
General importance of statement "I know how to maintain or improve health and safety in my workplace"	Q5
General importance of statement "I know how to reduce the risk of accidents and incidents in my workplace"	Q6

During data collection on 10 backhoe excavators (Figure 1a) and 6 loader excavators (Figure 1b) the measuring device Testo 340 is mounted on outside of the cabin, in order to measure the percentage of oxygen (O_2) and carbon dioxide (CO_2) and concentrations of nitrogen oxides (NO_x), with individual measurement of nitrogen monoxide (NO). The results are later compared with regulatory documents and the relative exceedances were taken for the comparison.

Survey data was collected from the operators that actively worked on these types of machines in the same mining sites, and 45 operators of backhoe excavator and 22 operators of loader excavator willingly participated by giving answers on 6 questions using a Likert scale from 1 to 5 (with 1 meaning "not important", and 5 meaning "very important").

a) b)

Figure 1: Backhoe excavator (a) and loader excavator (b). (Tasevski et al., 2025).

Collected data, both from the measuring instrument and from survey firstly is checked for normality and descriptive statistics are done. As none of variables behaved according to normal distribution, according to the results of skewness and kurtosis, a comparison between two types of machines for all parameters was performed using nonparametric Mann – Whitney U test, and the results of it are shown in the next part.

RESULTS

Measurements were conducted on the 10 backhoe excavators and 6 loader excavators in real work conditions at open pit mines in Serbia and Montenegro. In total, eighteen different parameters were measured and in the scope of this paper the data about gaseous pollutants were selected for further comparison between two groups of machines. Descriptive statistics about parameters of interest are given in Table 2.

Table 2: Descriptive statistics of measured values.

Machine		Avg. overrun Value of NOx [%]	Maximum % of Allowed Value Measured of NOx
Backhoe	N	10	10
	Min.	12.5	147.5
	Max.	632.5	1765
	Mean	356.07	984.1
	Std. Dev.	205.36	576.21
	CV%	57.67	58.55
Loader	N	6	6
	Min.	6.74	67.5
	Max.	207.5	737.5
	Mean	76.85	296.29
	Std. Dev.	79.51	245.2
	CV%	103.46	82.76

Since the CV values are above 30%, dataset shows high variability and do not follow the normal distribution. Due to this reason, hypothesis testing was conducted using nonparametric Mann – Whitney test and results of which are shown in Table 3.

Table 3: Results of nonparametric tests on workplace measurement.

	Mann-Whitney
AVG % O2	0.002
AVG ppm NO	0.042
AVG % CO2	0.002
Avg. value of overrun of NOx [%]	0.040
Maximum % of allowed value measured of NOx	0.022

Along with the measurements, the machine operators were surveyed on questions from the field of safety and occupational health and safety. The structure of the respondents is shown in Tables 4, 5 and 6. In total, 45 backhoe excavator operators and 22 loader operators were surveyed.

Table 4: Age distribution of respondents.

Machine	Age	%
Backhoe	25 or less	4.40%
	26–35	20.00%
	36–45	44.40%
	46–55	22.20%
	56 or more	8.90%
Loader	25 or less	13.60%
	26–35	22.70%
	36–45	13.60%
	46–55	27.30%
	56 or more	22.70%

Table 5: Distribution of qualifications of respondents.

Machine	Worker Qualification	%
Backhoe	5 or less	13.30%
	10–15	37.80%
	16–20	11.10%
	21–25	13.30%
	26–30	13.30%
	31 or more	11.10%
Loader	5 or less	27.30%
	5–10	22.70%
	21–25	4.50%
	26–30	22.70%
	31 or more	22.70%

Table 6: Frequency of injured operators/ respondents.

Machine	Had Injury on Work	%
Backhoe	Yes	22.20%
	No	77.80%
Loader	Yes	9.10%
	No	90.90%

Survey answers were firstly checked for normality and descriptive statistics divided by groups are shown in Table 7.

Table 7: Descriptive statistics of survey questions.

Machine		N	Min	Max	Mean	Std. Dev.	Var	Cv (%)	Skewness	Kurtosis
Backhoe	Q1	45	1	5	4.13	0.92	0.84	22.2	–1.19	1.84
	Q2	44	1	5	4.11	1.15	1.31	27.9	–1.4	1.19
	Q3	44	1	5	4.34	0.94	0.88	21.6	–1.81	3.53
	Q4	44	2	5	4.73	0.62	0.39	13.2	–2.75	8.52
	Q5	44	3	5	4.61	0.58	0.34	12.6	–1.22	0.59
	Q6	44	3	5	4.75	0.49	0.24	10.3	–1.81	2.59
Loader	Q1	20	2	5	4.55	0.83	0.68	18.2	–2.05	4.08
	Q2	20	3	5	4.7	0.57	0.33	12.1	–1.84	2.86
	Q3	20	3	5	4.7	0.57	0.33	12.1	–1.84	2.86
	Q4	20	4	5	4.9	0.31	0.1	6.3	–2.89	7.04
	Q5	20	4	5	4.9	0.31	0.1	6.3	–2.89	7.04
	Q6	20	4	5	4.9	0.31	0.1	6.3	–2.89	7.04

Both, skewness and kurtosis values for all dataset shows that data do not follow normal distribution, so the nonparametric Mann-Whitney U test was chosen for testing the differences between the backhoes and loaders and results are shown in Table 8.

Table 8: Results of nonparametric Mann-Whitney U test.

Question	Mann-Whitney U
Q1	**0.039**
Q2	**0.033**
Q3	0.115
Q4	0.289
Q5	**0.042**
Q6	0.223

CONCLUSION

The first step in comparison of the examined mining machines was descriptive statistics on both data sets. Results show that both types of machines had serios exceedance of allowed values, with backhoe excavator maximum exceedances of more than 6.3 times over allowed, and loader maximum exceedances of 2 times over allowed. The difference can be seen also on the mean value of exceedance where backhoe averaged 3.5 times, and loader only 76%. From the view of data, one loader didn't even exceed permissible values during the period of measuring.

Nonparametric testing between machines for measured parameters of work environment, showed significant differences in several elements. Results show that average percent of oxygen and carbon dioxide concentrations have the most significant difference between machines, but concentrations of nitrate oxides together with nitrate monoxide also showed very significant differences.

Survey was conducted on the same mining sites as measurement, and it included 45 operators of backhoe excavator and 22 loader excavator operators. Majority of backhoe operators were between 36 and 45 years old with near equal distribution in groups of 26 to 35 years old and 46 to 55 years old, while operators of loaders were more uniform across all intervals with the most operators between 46 and 55 years old. The work experience of operators showed a bit different results with backhoe operators spanning uniformly across all groups with most operators with 10 to 15 years of experience, but loader operators are clearly divided in 2 separate groups with up to 10 years of experience (48%) and more than 26 years of experience (45.4%). Information about percentage of operators that had injury on work shows that more backhoe operators had injury at work, 22.2% of them, then the loader operators of which only 9.1% had it.

All six questions asked in the survey had the purpose of evaluating the general importance of a certain aspect of health and safety at work from the operator's perspective. Descriptive statistics showed a fairly good spread of operator's answers, but based on skewness and kurtosis of the individual questions, none of them have a normal distribution. Based on that conclusion, nonparametric Mann – Whitney test was conducted in order to compare two types of machines, and the results shown that significant difference exists in understanding of the importance of questions about work environment conditions (temperature, humidity, dust…), air quality in the working environment and maintaining and improving health and safety at work. Answers on the other three questions didn't show significant difference.

The result of testing could be correlated with higher average level of work experience, and higher percentage of operators that had work related injury during career.

For further research, apart from sample enlargement and inclement of operators from other types of mining machines, it could be very beneficial to include measurement of other parameters of working environment and conducting a correlation analysis between the responses of operators of a particular type of machine and the measured values on those same machines.

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