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Excavators' Cabins Ergonomic Design Influential Factors Modelling: Preliminary Study

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ABSTRACT

Excavator operators encounter demanding work environments with very high risks for discomfort, musculoskeletal disorders, and workplace accidents. In line with that, this study examines the relationship between ergonomic design influential factors using the structural model of excavator cabins design factors, using a sample of 32 excavator operators. Descriptive statistics were performed to describe the operator's age, height, weight, working experience, and excavator's lifespan. After that, the structural equations model was developed to describe the impact of latent variables related to ergonomic design of the cabin. This model was constructed by using 17 questions, which were categorized into 5 groups based on ergonomic design characteristics such as seat, armrests, commands, cabin, and working conditions. The findings indicate that the model exhibits favourable reliability and validity coefficients, a substantial effect size, and a satisfactory model fit. Further research is needed to increase the sample size, despite the preliminary nature of the current research and its satisfactory results.

Keywords: Excavator, Operators, Factor, Construct, Ergonomic design

INTRODUCTION

Any heavy machinery operation has serious risks (Bedi et al., 2021; Kirin et al., 2021). Also, it is well known that human error accounts for almost 85% of all mining accidents (Patterson and Shappell, 2010). But, according to Akyeampong et al. (2014) and Reiman et al. (2016), researchers in the field of heavy machinery frequently concentrate on the technical components of the system while ignoring the human operator as a crucial component of the whole system. Understanding the complexity, effectiveness, and failures of heavy machinery can assist to improve production outcomes, enhance safety on mining sites and lower unforeseen and unnecessary expenses (Odeyar et al., 2022).

It is well known that operators of heavy mining vehicles are at a considerable risk for discomfort, musculoskeletal disorders, and workplace accidents (Reiman et al., 2016). Numerous accidents are not unexpected given that it appears heavy equipment is still not ergonomically suited to its users while operating in challenging conditions (Apud, 2012; Spasojević Brkić et al., 2015; Zunjic et al., 2015; Dempsey et al., 2018). When it comes to excavators, accidents occur even more frequently than in the other heavy machinery types (Jeon et al., 2013).

Due those facts the aim of this paper is to analyse and model exavators' cabins ergonomic design influential factors. The first part of this paper describes previous research, and after that methodology based on structural equations modelling and its results are given. Finally, conclusions are drawn, the shortcomings of this research are described and further directions for future research are given.

PREVIOUS RESEARCH

Work as an excavator's operator is strenuous and physically challenging. The functioning of the equipment and the working environment subject the excavator operator to a variety of risks. In addition to significantly improving the operator's working conditions, a well-designed cabin has an impact on site safety when heavy machinery is used (Spasojević Brkić et al., 2015). Only 6.4% of the mining sector and 15.8% of the construction industry, according to Eger et al. (2011), have self-reported ergonomics practice adoption. Boudreau-Trudel et al. (2014) underline how difficult it is to enhance safety and ergonomics in the field of heavy machinery.

A poor design of the cabin or poor working procedures could result in operators' awkward postural requirements, such as static sitting, while the operator is performing their duties in the cabins (Schneider et al., 2001; Kittusamy and Buchholz, 2004; Waters et al., 2008; Zunjic et al., 2015; Jeripotula et al., 2020; Sadeghi et al., 2021). In addition to these risks, operators' working conditions may also involve shift and prolonged work, whole-body vibration, psychosocial factors, dust, exhaust gases, noise, extreme temperatures, and time constraints (Kittusamy and Buchholz, 2000, 2004; Viswanathan et al., 2006; Jorgensen et al., 2007; Joy and Middendorf, 2007; Kurtz et al., 2012; Lutz et al., 2015; Sun and Azman, 2018). Additionally, the operator's annoyance is connected to the body's sitting position and the repetitive nature of the tasks done, which put an undue strain on the muscular and skeletal systems (Kittusamy, 2003; Darabad et al., 2017; Afshari et al., 2018; Pałega and Rydz, 2018). Furthermore, several studies have demonstrated that operators experience whole-body vibration, which when coupled with hunched over posture, increases lower back pain, resonance excitation of the individual, and communication problems (Hoogendoorn et al., 2000; Kittusamy and Buchholz, 2004; Kurtz et al., 2012; Caffaro et al., 2016; Chi et al., 2017). It is clear that cabin design, work requirements, and operators' anthropometric measurements influence operator posture (Spasojević Brkić et al., 2015). When in an uncomfortable position, backrests and armrests are unlikely to be utilized on purpose even when they are there (Munro et al., 2021). However, checklists for the evaluation of the cabin design are not frequently found in the literature. A relatively small number of tools for assessing the design of construction or mining equipment cabins exist, and one of them for construction machines was created by Kittusamy (2003). Recently, Spasojević Brkić et al. (2023) considerably updated that list in a way that made it useful for mining equipment.

METHODOLOGY AND RESULTS

The research was conducted on the sample of 34 excavator operators (N). Data regarding their age, height, weight, working experience, and the excavator's lifespan was collected. The mean value (mean), median (Med), minimum (Min), maximum (Max), standard deviation (SD), coefficient of variation (CV), and standard error (SE) were calculated as an initial step. The outcomes are presented in Table 1.

Table 1. Descriptive statistics of the excavator operators.

Variable	N	Mean	Med	Min	Max	Variance	SD	CV	SE
Operator's age	34	34.2647	34.00	19	53	84.3824	9.1860	26.80889	1.5754
Operators' height	34	179.1471	180.00	166	187	31.0383	5.5712	3.10985	0.9554
Operators' weight	34	89.2941	90.00	60	135	261.4866	16.1706	18.1093	2.7732
Working experience	34	10.6765	9.50	1	33	101.0134	10.0505	94.1373	1.7236
Excavator's lifespan	34	6.0294	7.50	1	13	4.13767	4.1377	68.6248	0.7096

To gain a more comprehensive understanding of the data distribution, histograms were generated. The provided visual representation, depicted in Figure 1, illustrates the excavator's operator height and weight. It is evident that the weight distribution spans from 60 to 135 kg which indicates a significant diversity in the weight of operators, while the height measurements range between 166 and 187 cm revealing the average height. Figure 2 pertains operator's age and work experience. It can be observed that a significant proportion of operators have a mixed-age demographic profile, and most of them possess brief professional experience. Figure 3 illustrates the lifespan of the excavator, where different lifespan can be seen, with a span from 1 to 13 years of usage.

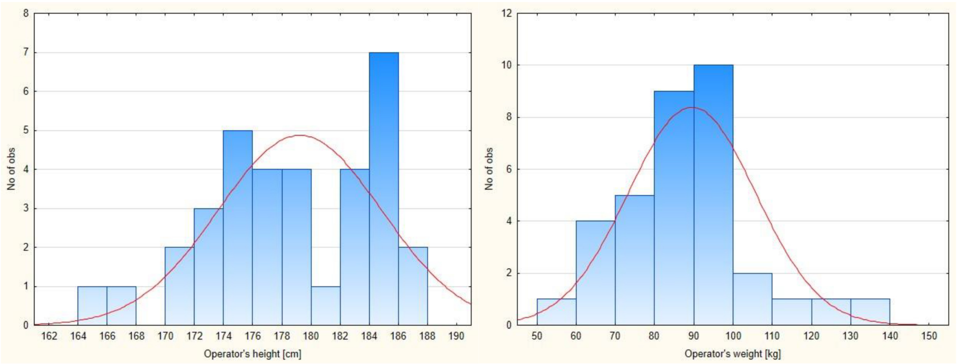

Figure 1: Excavator operator's height and weight.

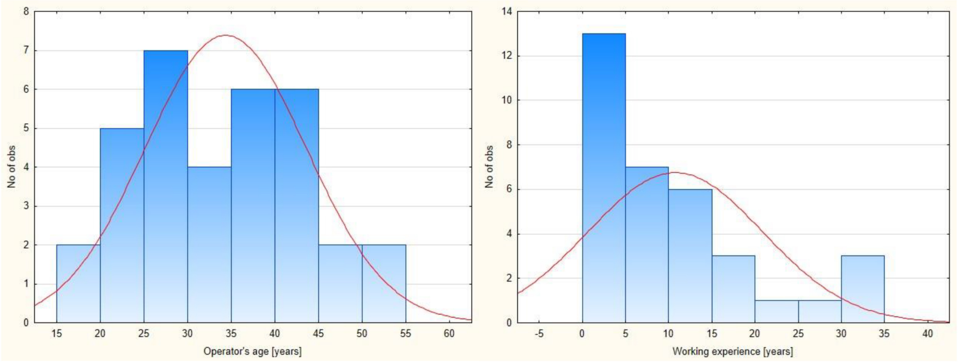

Figure 2: Excavator operator's age and working experience

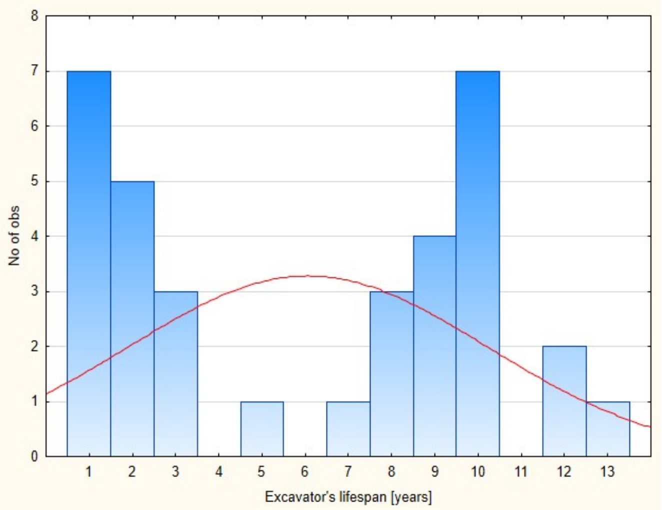

Figure 3: Excavator's lifespan

In addition, excavator operators have been asked to fill the questionnaire proposed in Spasojević Brkić et al. (2023) which contained 17 questions regarding seat, armrests, commands and cabin ergonomic design characteristics, and working environment conditions, as presented in Table 2. Using the SMARTPLS 4 software, a structural model depicting the dependence and relationships between the 17 questions divided into 5 above mentioned categories (constructs). In the applied social and behavioural sciences, the use of SMART PLS is appropriate when dealing with data that do not follow a typical multivariate distribution, require more complex models (many constructs and many variables observed), are formative models, have "little" data, and/or are models with less established theoretical support. In these circumstances, variance-based structural equation modelling (VB-SEM) or partial least square models (PLS-SEM) are advised rather than covariance-based structural equation modelling (CB-SEM) or models based on maximum likelihood estimation (MLE) (Hair et al., 2014).

Table 2. Questions used for data collection.

No.	Question	Category/Construct
Q1	Is the seat height adjustable?	Seat Characteristics
Q2	Can the seat be adjusted horizontally?	
Q3	Is the seat set at the correct height?	
Q4	Can the seat be reclined?	
Q5	Does the seat have lumbar support?	
Q6	Are there armrests?	Armrests Characteristics
Q7	Are the armrests adjustable?	
Q8	Are the armrests placed at the appropriate height?	
Q9	Can the location of the controls or handles be adjusted?	Commands Characteristics
Q10	Can you easily reach controls or handles?	
Q11	Can you easily operate controls or handles?	
Q12	Is the cabin big enough for you (space that does not constrain you)?	Cabin Characteristics
Q13	Do you have sufficient visibility in all directions?	
Q14	Can you open/close the cabin door easily?	
Q15	Can you get in/out of the cabin easily?	
Q16	Due to poor working conditions, I often miss work (sick leave)	Working conditions Characteristics
Q17	You don't mind the exhaust gases of the machine you operate	

To check if construct consists of proposed factors, reliability and validity analysis is done. Table 3 provides a summary of constructs reliability and validity. Cronbach's alpha values are greater than 0.7, indicating a high degree of reliability (Wong, 2013). In addition, the composite reliability (rho_a and rho_c) is very good, with a value between 0.717 and 0.99.

According to the Fornell and Larcker criteria (Henseler et al., 2009), it is recommended that the Average Variance Extracted (AVE) should exceed 0.5. As shown in Table 3, all AVE values in the proposed model are greater than 0.5. Additionally, the lowest AVE value observed in the proposed model is 0.531, while the highest is 0.952.

Table 3. Constructs' reliability and validity - overview.

	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
Armrests Characteristics	0.975	0.975	0.984	0.952
Cabin Characteristics	0.699	0.717	0.817	0.531
Commands Characteristics	0.789	0.723	0.785	0.573
Working Conditions Characteristics	0.797	0.797	0.799	0.665
Seat Characteristics	0.835	0.861	0.732	0.605

The coefficient of determination R-square values obtained in this study are highly favourable, ranging from 0.565 to 0.882. This finding suggests that all categories exhibit a moderate to strong effect size, as stated by Moore et al. (2011). Table 4 presents the R-square values for all latent variables.

Table 4. Quality criteria – R-square.

	R-square	R-square adjusted
Armrests Characteristics	0.590	0.565
Cabin Characteristics	0.882	0.831
Commands Characteristics	0.699	0.648
Seat Characteristics	0.756	0.721
Working Conditions Characteristics	0.773	0.713

Standardized Root Mean Square Residual (SRMR) values of 0.073 for the saturated model and 0.076 for the estimated model indicate a satisfactory model fit (Hu and Bentler, 1998). The Normed Fit Index (NFI) for the saturated model is 0.981 and for the estimated model it is 0.901, both of which are above 0.9, indicating a satisfactory fit (Lohmöller, 2013). Model fit parameters are presented at Table 5.

Table 5. Model fit.

	Saturated model	Estimated model
SRMR	0.073	0.076
Chi-square	242.597	243.097
NFI	0.981	0.901

Lastly, Figure 4 displays the structural model with all factors' loadings.

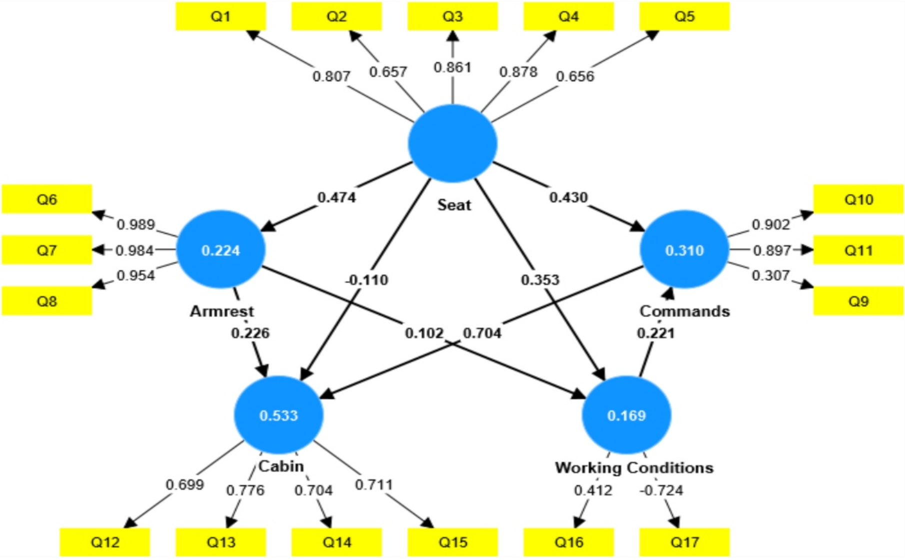

Figure 4: Exavators' cabins ergonomic design influential factors structural model.

CONCLUSION

Previous research show that excavator operators encounter demanding work environments with very high risks for discomfort, musculoskeletal disorders, and workplace accidents, whereas heavy equipment, and especially excavator, is still not ergonomically adjusted to its users while operating in challenging conditions. Anyhow, till now previous research concentrate on the technical components of the system while ignoring the human operator as a crucial component of the whole system. In that aim this research focuses to human factors issues in excavator operation.

This preliminary study involved the examination of 32 excavator operators. The operators' ages, heights, weights, working experience and the excavators's lifespan varied significantly, as indicated by descriptive statistics. Additionally, it can be concluded that the majority of operators have limited experience in this field.

In addition, a structural model was developed and tested with a set of 17 questions using the software SMARTPLS and they were categorized into five distinct constructs. Reliability and validation analysis showed that all constructs have a high level of reliability based on the values of Cronbach's alpha, composite reliability (rho_a), composite reliability (rho_c), and AVE. The R-square values show a moderate to strong effect size, which implies that the created model is satisfactory. Both saturated and estimated models show a good fit, with values for SRMR of 0,073 and 0,076 respectively and values for NFI of 0,981 and 0,901, respectively. The structural equations model obtained in this research proves that the cabin interior design is influenced mostly by commands characteristics, but also by seat and armrests characteristics. Working conditions quality is influenced mostly by seat design characteristics, but also by armrests design. There are also significant relationships between armrests, seat and commands characteristics. It is also evident that seat characteristics are connected to all other factors and that working conditions influence commands usage.

In conclusion, considering the preliminary stage of the study and the excellent outcomes seen, it is essential to augment the sample size substantially in future researches.

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