

Aspects to improve cabin comfort of wheel loaders and excavators according to operators

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Abstract

Comfort plays an increasingly important role in interior design of earth moving equipment. Although research has been conducted on vehicle interiors of wheel loaders and excavators, hardly any information is known about the operator's opinion. In this study a questionnaire was completed by machine operators to get their opinion about aspects which need to be improved in order to design a more comfortable vehicle interior. The results show that almost half of the operators rate the comfort of their cabin "average" or "poor". According to the operators, cab comfort of wheel loaders can be increased by improving seat comfort. Besides improving seat comfort, cabin comfort of excavators can be improved by changing the cab design (including dimensions, ingress/egress), view, reliability, and climate control.

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1. Introduction

Comfort plays an increasingly important role in vehicle design. As machine operators of earth moving equipment often spend long hours in their vehicle—sometimes even more than 8 h a day—comfort is a major issue in interior design of these machines. Operating earth-moving machinery is not a physically heavy job and can be sustained for long periods. Nevertheless, operating such a machine appears to be a risk factor for musculoskeletal disorders, especially when the task is not interrupted by other working activities or breaks. Zimmerman et al. (1997) showed that the main problems of earth-moving machinery operators concern physical complaints in the neck/shoulder and low back region, general fatigue and feelings of discomfort. This might be attributed to a combination of static load during prolonged sitting—frequently in awkward postures—exposure to whole body vibrations, and handling and steering the machine

(Zimmerman et al., 1997; Tola et al., 1988; de Looze et al., 2000).

A comfortable well-designed vehicle interior may reduce awkward postures and provide an environment that stimulates optimal operator performance. Based on a literature review about musculoskeletal disorders and their risk factors, Zimmerman et al. (1997) made four recommendations for reducing work-related musculoskeletal disorders among operators: minimizing of magnitude and frequency of vibration reaching the operator; locating controls optimally to minimize reach distances, trunk flexion and trunk rotation; providing maximum operator visibility from an upright supported seated posture; and taking regular breaks to minimize the effects of sustained postures. Improvements of cab comfort are very often based on reducing the risk factors for work-related musculoskeletal disorders (Zimmerman et al., 1997; Attebrant et al., 1997). Only a few studies have mentioned aspects which operators wish to see improved. Nakada (1997) describes the desirability ranking for dump trucks and wheel loaders given by product creators, designers, design engineers, operators and young people. Nakada, (1997) shows that much design attention has been paid to instrument panel/monitors and meters and the operator seat.

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Unfortunately, the operators' opinions cannot be distinguished in Nakada's study (1997).

However, in order to design a comfortable vehicle interior, the opinion of the operators is important as they are the end-users of the machines. Their user experience may be of great help designing a more comfortable vehicle interior. The aim of the current study is to find aspects mentioned by wheel loader and excavator operators, which can be used to improve the comfort of vehicle interiors in the future. In this article we describe the results of a questionnaire given to 273 machine operators. They were asked their opinion about their current machine, their future demands and aspects they considered important to work well with the machine. This allowed us to identify aspects that need improvement in machine design.

2. Method

2.1. Subjects

A convenience sample was obtained through approaching operators visiting Bauma (the world's largest exhibition for construction equipment). Most of the participants were wheel loader operators ($n = 61$) and

excavator operators ($n = 212$). The others ($n = 65$) were operators of several construction machines (e.g., mobile cranes, dozers, tower cranes, off-road trucks). Only the results for wheel loader and excavator operators are presented in this article, as they account for 18% and 62.7% of the total number of respondents respectively. Figs. 1 and 2 show a typical wheel loader and excavator.

2.2. Questionnaire

Data were collected by means of a questionnaire which was completed during an interview. The questionnaire was divided into three parts: (1) characteristics of the population, (2) evaluation of the current machine being operated, and (3) future demands on earth moving machinery. In the first part we asked the operator's age, years of experience as operator, the kind of machinery being operated and its age. In the second part of the questionnaire, operators evaluated their machine by rating overall comfort and their opinion of specific parts of the machine on a four-point scale (very good, good, average, poor). Finally, two open questions asked about the operator's future demands: what improvements would make the machine more comfortable and what aspects are the most important to work well with the machine.



Fig. 1. Excavator.



Fig. 2. Wheel loader.

2.3. Data analysis

Data were sorted by machine type, after which the responses of wheel loader operators and excavator operators were separately analyzed. Within these groups, operators of older machinery (≥ 4 years old) were separated from operators of newer machinery (< 4 years old). In addition, the categories “very good” and “good” were combined (“very good/good”) and the categories “average” and “poor” were combined (“average/poor”).

Frequency tables were made of the operators’ opinions about overall machine comfort and about their opinions about specific parts of their machines. Chi-square was calculated between age of machine and overall comfort and between age of machine and the operators’ opinion of specific parts of the machine. We assumed that if fewer than 80% of the operators rated a part of the machine “good/very good”, improvement of this part could contribute to a more comfortable vehicle interior. In part three of the questionnaire, the operators indicated aspects to improve machine comfort and aspects they found necessary to work well with the machine. We classified these aspects into categories and calculated the percentage responses.

3. Results

3.1. Characteristics of the population

Both the wheel loader operators (mean age: 36.5 ± 9.4 years) and the excavator operators (mean age: 36.3 ± 9.3

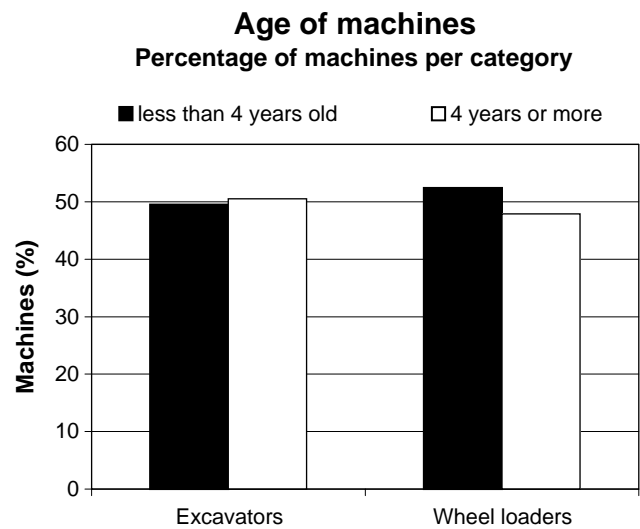


Fig. 3. The participant’s machines are divided into two categories: machines < 4 years old and machines ≥ 4 years old.

years) who participated in this study, were experienced with a mean of $12.3 (\pm 8.1)$ and $13.4 (\pm 9.2)$ years of service, respectively. Half of the operators operate machines less than 4 years old (53% of the wheel loader and 50% of the excavator operators; see Fig. 3).

3.2. Evaluation of current machine

57.4% of wheel loader operators and 55.9% of the excavator operators rated the overall cabin comfort “good/very good”. Fig. 4 shows that operators of newer machinery (< 4 years old) rated the overall cab comfort as “good/very good” more often than operators of older

General opinion about comfort of the cab
Percentage of operators rating "good/very good"

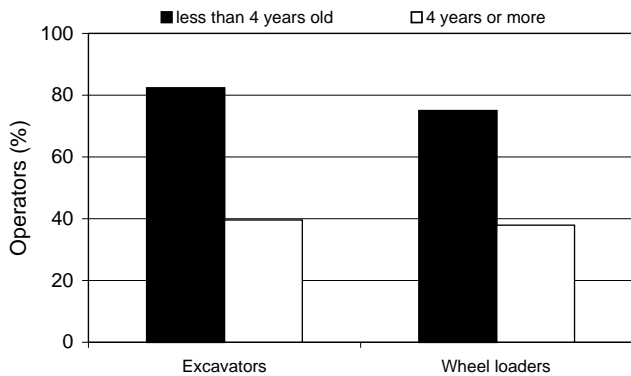
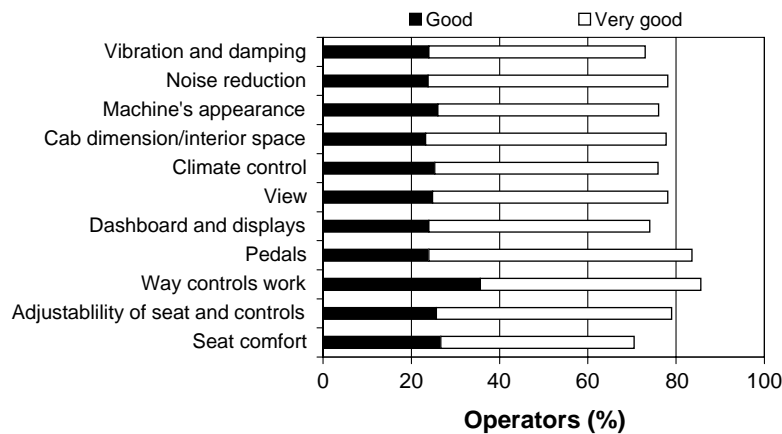


Fig. 4. Percentage of operators rating their machines "good" and "very good" on cab comfort.

machines (≥ 4 years old). This was found both among wheel loaders ($\chi^2(1) = 8.5, p < 0.04$) and among excavators ($\chi^2(1) = 23.0, p < 0.001$). Seventy-eight percent of the operators driving wheel loaders less than 4 years old, rated the comfort of their machine as "good/very good". With excavator operators this figure was 81%. These results show that during recent years the experienced cab comfort of excavators and wheel loaders has improved.

Fig. 5 illustrates the opinion of the operators about specific parts of the machines less than 4 years old. As seen in Table 1, fewer aspects of wheel loaders are rated "average/poor" by more than 20% of the operators, than excavators. Common aspects which can contribute to increase of cab comfort are dashboard and displays, adjustability of seats and controls, vibration and damping, noise reduction, and seat comfort. Excavator operators would also like to see improvement of climate

Excavators less than 4 years old
Percentage operators rating "good" and "very good"



Wheel loaders less than 4 years old
Percentage operators rating "good" and "very good"

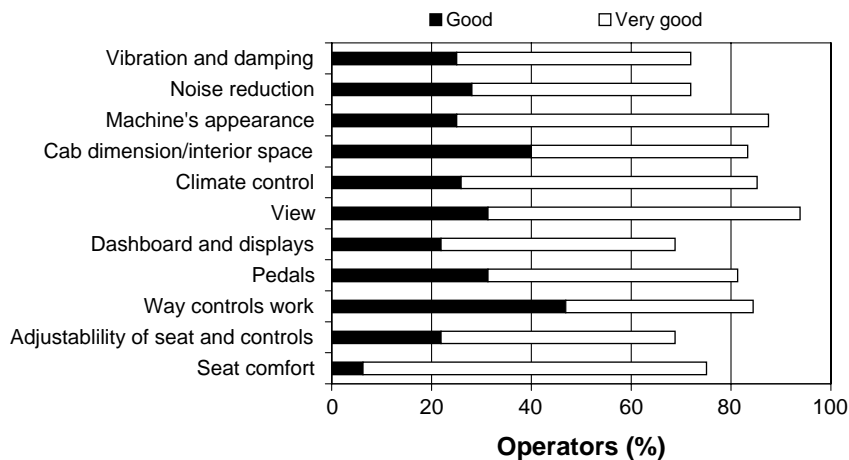


Fig. 5. Opinion of excavator and wheel loader operators about specific parts of the machines.

Table 1
Aspects rated “average” or “poor” by more than 20% of the operators for both wheel loaders and excavators less than 4 years old

Wheel loaders		Excavators	
Aspect	Operators (%)	Aspect	Operators (%)
Dashboard and displays	32.0	Seat comfort*	29.5
Adjustability of seat and controls	31.2	Vibration and damping*	27.0
Vibration and damping*	28.1	Dashboard and displays	26.0
Noise reduction	28.1	Climate control*	24.1
Seat comfort	24.9	Machine’s appearance	24.0
		Cab dimensions, interior space, ingress and egress*	22.3
		Noise reduction*	21.9
		View	21.9
		Adjustability of seat and controls*	21.0
		Reliability	20.9

Aspects marked by* are rated by significantly more operators of newer machinery (less than 4 years old) as “good” or “very good” compared to machines older machinery (4 years or more).

Table 2
Classification of aspects mentioned by operators

Categories	Examples
TCO (total cost of ownership)	Costs of machine (procurement, service costs, rest value)
Machine performance	Performance, hydraulics, gear
Serviceability	Cleaning of the machine, manufacturer service
Reliability	Reliability
Seat comfort	Seat pan, lumbar support, arm rests, curvature of back support
Adjustability of seat and controls	Adjustability of seat height, adjustability of controls
Operability	Joystick, steering wheel, interaction joystick and beam
View	View of work, dead angles, position of mirrors
Dashboard and displays	Usability of dashboard/controls, readability, absent information, position of displays
Climate control	Temperature, dust filters, ventilation, blower position
Design/dimensions/ingress and egress	Design and dimensions of cabin and machine, position of steps, grab rails
Noise and vibration	Noise, vibration, damping
Accessories	Radio, fridge, storage space, cup holder
Safety and stability	Feelings of safety, stability of machine
Environment	Noise outside the machine, exhaust fumes

control, improved machine appearance, and better cab dimensions (including interior space, ingress/egress), view, and reliability.

3.3. Future demands

The participants generated 467 items desired to improve the machine’s comfort. We classified these aspects into 15 categories (see Table 2). Fig. 6 shows

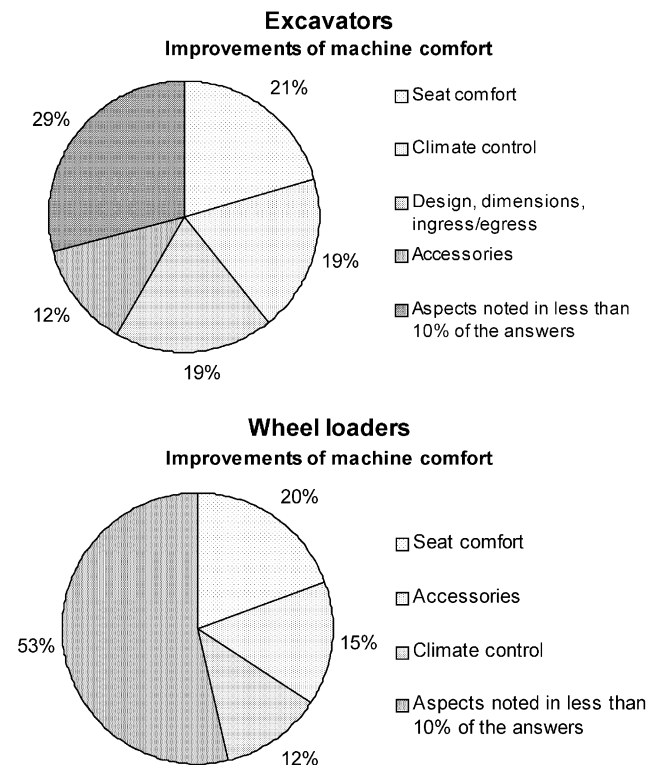


Fig. 6. Aspects which need improvement according to excavator and wheel loader operators.

which features should be improved according to the operators. Seat comfort, climate control and accessories are often mentioned for both wheel loaders (20%, 12%, 15%, resp.) and excavators (21%, 19%, 12%, resp.). Excavator operators also mention cab design (including dimensions, ingress/egress; 19%).

The aspects considered most important to work well with the machine are summarized in Table 3. Machine performance is by far the most important issue if we look at the averages. Other aspects like view and reliability play less important roles.

Table 3
Aspects considered most important to work well with the machine according to wheel loader and excavator operators

Wheel loaders		Excavators	
Aspect	Responses (%)	Aspect	Responses (%)
Machine's performance	40.3	Machine's performance	37.0
View	12.5	Reliability	14.6
Reliability	11.8	View	11.5
		Operability	11.1

The aspects noted in more than 10% of the answers are presented.

4. Discussion

The aim of the current study was to find aspects mentioned by wheel loader and excavator operators which can be used to improve the comfort of vehicle interiors in future. In order to find these aspects, we asked questions about three issues.

- about comfort of specific aspects of the cab (rating on a four-point scale);
- about aspects necessary to improve the cab comfort (open question);
- about aspects important to work well with the machine (open question).

Excavator and wheel loader operators mentioned improved seat comfort, climate control and accessories as ways to increase cab comfort. Excavator operators also mentioned cab design (including dimensions, ingress/egress). These aspects were also rated as “average/poor” by more than 20% of the operators (except accessories because this was not an item in the second part of the questionnaire). Other aspects which can be taken into account with cab design are those which operators mention as most important aspects to work well with the machine. Especially when these aspects are also rated as “average/poor” by more than 20% of the operators, they need special attention. Improving these aspects have priority in designing a more comfortable cab.

In our study, we collected our data among visitors to the Bauma exhibition in 2001. The advantage of this collection method is that it is possible to reach a large group of operators within a short period of time, at the same time getting a large response, which would normally be very difficult. A disadvantage might be that the vast majority of respondents were German which could mean that the results have a limited validity among operators in other countries. The German operators may have other ideas about cab comfort than operators, who work in other countries. The demands of the operators on their machine depend on the working environment (e.g., climate, landscape, dust) and their

tasks (e.g., driving off road, driving on the main road), which can be different between countries. Besides, the operators based their opinion on their current machine. It is possible that in Germany certain brands are overrepresented compared to other countries and that the operator's opinion might vary according to the brand. The most common brands would therefore influence the results of our study as many operators use one of these machines (Excavators: brand A 22.6%, brand B 22.2%; Wheel loaders: brand A 21.3%, brand B 18%, brand C 11.5%).

Since we used a short questionnaire to collect the data, no detailed information could be asked. The goal of our study was to get a global view on the operators' opinion. The open questions gave the operators the opportunity to think open-minded which may render valuable information. Open questions are less suitable for data analysis, because we needed to categorize answers. Inevitably information is lost in this process, but the goal of obtaining a global view was nevertheless achieved.

Our results show that seat comfort, climate control, accessories (for wheel loaders and excavators) and cab design (including dimensions, ingress/egress), view, and reliability (for excavators only) are the aspects which can improve cab comfort. All these aspects are rated “average/poor” by more than 20% of the operators and they are also mentioned as aspects which need improvement in order to increase cab comfort. In our opinion designers should give priority to these items when redesigning cabs. It is interesting that operators did not mention vibration as an aspect which can improve comfort, as it was ranked high on the list of machine parts rated “average/poor”. Besides, whole body vibration is a serious health hazard (Houtman et al., 2001). It is possible that the operators did not mention vibration because they may see vibration as an engine property or an inevitable consequence of working on earth moving equipment. Operators might have the idea that vibration cannot be reduced by redesigning only the cab. It is, however, unclear why operators did not mention vibration.

When comparing excavators and wheel loaders, improving seat comfort is an issue for both wheel loaders and excavators. Although seat comfort in excavators has been improved during recent years (see Table 1), improvements are still necessary. However, this is not easy as sitting comfort depends on many other factors more or less related to seat design: e.g., adjustability of seat and controls, vibration and damping, and view. For example, a bad view from the cabin can result in awkward body postures, which reduces comfort in spite of a comfortable seat.

Beyond the common aspect seat comfort, many differences exist between wheel loaders and excavators. One difference we found between the excavator and the

wheel loader was that excavator cab design (including dimensions and ingress/egress) needs improvement. This difference may be explained by access and space. First, there is a difference in machine access with grips generally quite wide apart and steps to the cabin far from optimal, being either too high or too narrow. Operators could experience this as a problem. Secondly, there is a fundamental difference between wheel loaders and excavators in the space available for the cab. With the present design, excavators have a limited width available for the cab as it must be positioned between the boom and the left machine side, leaving approximately 1 m for the cab.

Another difference is that improving view can increase the cab comfort of the excavator. View is a very important aspect to work well with the excavator. The boom of the excavator has a wide range of motion and the operator needs to see the bucket for the full range. A comfortable cab provides a clear view of the work place and the bucket, without necessitating awkward postures.

In the introduction, we stated that comfort plays an important role in cab design. It is therefore interesting to find that the operators did not mention comfort as one of the most important aspects to work well with the machine. They mentioned aspects such as the machine's performance, reliability, view and operability. It seems that operators think first about the basic requirements needed to perform their task and apparently do not see comfort as one of them.

If we compare our results with the results of Nakada, (1997), in both studies the operator seat is ranked as important. Instrument panel, monitors and meters are also ranked as important in Nakada's study. In our study vibration, dashboard and displays are high on the list of parts rated as "average/poor" by more than 20% of the operators, but they are not seen as aspects that can improve cab comfort. Nakada's study did not mention vibration at all. A reason for this may be that in our study, experienced operators played a larger role than in Nakada's and because that study was focused on interior design.

An increase in cab comfort has been achieved during recent years. From Table 1 it seems that wheel loaders have made progress on fewer aspects than excavators. But in fact, the improvements of specific aspects of wheel loaders (i.e., machine's appearance, climate control, and view) were of such a high level that these aspects were rated as "average/poor" by fewer than 20% of the operators and are therefore not mentioned in this table. However, 27.7% of the excavator operators

and 25.0% of the wheel loader operators of machinery less than 4 years old rate the cabin's comfort "average/poor". These results show that improvement of cab comfort is still needed. In our study, we found some important aspects which can contribute to improvement of cab comfort. Unfortunately, these aspects do not represent detailed information, and we can not say how they should be changed to get a more comfortable cab. Therefore, further research is necessary to indicate specific improvements for each machine individually.

5. Conclusion

Operators do not mention cabin comfort as one of the most important aspects to work well with the machine, yet when asked about it almost half of the wheel loader and excavator operators rate their cabin's comfort as "average/poor". Cab comfort of wheel loaders can be increased by improving seat comfort. Besides seat comfort, cab comfort of excavators can be improved by changing the cab design (including dimensions, ingress/egress), view, reliability, and climate control, according to the operators. Because we cannot say specifically how these aspects should be changed to get a more comfortable cab, further research is necessary to indicate specific improvements for excavators and wheel loaders individually.

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