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Advanced Cabin Design

How to Improve Comfort and Performance
by Progressive Cabin Design

TNO Arbeid, Hoofddorp



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In co-operation with the public transport enterprise RET in Rotterdam and the manufacturer of the tram, TNO developed a cabin that provides all drivers with a safe and comfortable working environment. This could only be achieved by designing the tram from scratch. The adjustments involve more than just the adjustment of the chair and the range of the controls.

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6 Improving Earth Moving Machines: Mind the Details!

Frank Krause, Maarten P. van der Grinten

This chapter addresses the final results of the Eurocabin project in which three medium sized companies together with TNO explored how their machinery could be improved. The focus was on how to further innovate and optimise the cabins of the machines.

The improvements were based on the problems spotted by experts and mentioned by end-users. Those improvements are in fact details. However, the details solve problems and in the re-test the end-users mention that most details have a positive effect on comfort and even on work output. They did create a changed cab.

6.1 Keeping up with large competitors

When we interviewed over 300 operators of construction machinery (Kuijt-Evers et al., 2003), one thing became clear: they wanted power! This is actually quite logical because the operator wants to perform the job and cannot do this if insufficient power is available. Of course if the operator has a boss, he too will be satisfied mostly by the operator's output.

However, this doesn't mean that no attention needs to be paid to the operator's comfort. On the contrary. If you want to get the most out of the machine's power over a long period of time, the operator must be able to perform in an optimal manner. Therefore the machine must be optimally attuned to the operator. Especially in those cabs where operators spend eight hours or more in the cab, you would want the cab to be comfortable.

Large OEMs² are expected to have large resources available for research and development in this field. Also the large production numbers make it more profitable to apply materials in rounded forms, thus giving machinery a modern car-like interior and exterior. Small and medium sized enterprises (SMEs) could be at risk to fall behind and lose competitiveness. To further innovate their machinery and thus try to secure a competitive position, three medium sized manufacturers formed a consortium and founded the Eurocabin project together with TNO as R&D partner. The project was partly funded by the European Union. The companies concerned were Maschinenfabrik Paus GmbH from Germany, Van Vliet b.v.

² OEM - original equipment manufacturer.

(manufacturing ETEC machines) from the Netherlands and Kaiser AG from Liechtenstein (see Figure 6.1).

The goal of this project was to further innovate and optimise the cabins of the machines.



Figure 6.1 The companies concerned and their machines

For one thing it became clear that with these SMEs their size was also their strength. Because of their size all involved departments of the company (service, design, sales) stand close to their customer. Furthermore they are able to adapt faster to their customers' needs, even if individual. Nevertheless expert support was valued to progress in the field of comfort and ergonomics.

This chapter describes the changes that were made to two of the three machines to improve comfort. Characteristically, no very expensive and impressive changes were needed to improve the operator's comfort, most improvements lie in the detail.

6.2 How to give the operator what he wants

It is our strong opinion that designing the best machine possible requires the involvement of experts and end-users as will become clear when reading this chapter.

For this project we took the following steps to secure that the end-product would appeal to all users (Vink and Kompier, 1997; Noro and Imada, 1991).

Step 1: getting to know what the machine does and what is done with the machine

This served as a first orientation on the type of work and machinery and was very important in order to be able to ask the right questions to the operators.

Step 2: end-user's opinion

Gaining access to the opinion of large numbers of operators is difficult in this type of machinery, due to the fact that you will seldom find large numbers of the same machine within a close range. Notwithstanding its time consumption we tried to visit as many operators as



Figure 6.2 Discussions with end-users

possible to observe their work and interview them (see Figure 6.2). Extra information was gathered from questionnaires sent by the manufacturer to specific operators. Sometime phone calls were made to clarify answers. The information we got from interviewing more than 300 operators at the Bauma regarding comfort aspects (Kuijt-Evers et al., 2003) was used as background information.

Step 3: expert opinion

A group of experts studied the machines, sometimes with specific evaluation methods to study the fit (with ergomix) or to study vibration or noise.

Step 4: adaptation proposals

Based on the end-user opinion and expert evaluations the main problems on the specific machines were described and improvement proposals were defined.

Step 5: first redesigned machines

Based on the advice some machines were redesigned and were tested by end-users again.

Step 6: implementation in the new production process

In this step the companies decided which changes would be standard in the new machines, which ones could be bought as an additional feature and which would not be implemented.

6.3 The changes that improved comfort of the Paus machine

Ingress-egress

From the previous steps it was known that ingress-egress often takes place between 20 and 50 times a day. Each time the height difference between the ground and the cabin (approximately 1.2 m) needs to be mastered. Therefore improving ingress-egress was considered to be important, with respect to both ease and safety.

To do so the climbing aid's grip diameter was increased to 25 mm and the hand clearance between climbing aid and cabin was increased to 65 mm, thus improving the feel of the grip and the ease with which the grip can be grabbed, even with gloves. The steps were also modified: all step heights are now more or less equal and a third strip was added to each step. This increases step depth to improve the stability for the foot (see Figure 6.3).



Figure 6.3 The step modification: left the old situation, right the new situation

Operators were mostly satisfied with the offered ingress-egress helps (steps and grips). All operators find the new grips more comfortable, yet all state that they still require the same amount of strength for ingress-egress. This can be explained by the fact that the height difference between ground and cabin is still the same. They find the new steps more comfortable and safer though it requires getting used to because of the changed step height.

Seat

The seat height adjustment range was lowered 30 mm to improve seating, especially for smaller persons. This was achieved by modifying the seat pedestal. A necessary elevation of the seat can be effected by means of spacer blocks.

The lowered seat height was mostly appreciated. Surprisingly one small operator was not pleased with the new height. He liked to use the seat in the highest position to be able to have a good view on the ground and the shovel, because he had less 'feel' of the machine. This can be explained by the fact that more than one driver often uses this type of machine for generally short periods of time. For drivers it is harder to acquire the same feel of the machine as an experienced driver.

Steering column

A steering column being adjustable in height and inclination was installed (see Figure 6.4). At the same time changes were made to the dashboard support, the support structure in the cabin floor and the cabin matting. This was done to reduce rattle, an annoying feature of the older cabin.

The new adjustable steering column is very much appreciated. All operators found that they could now find a better seating position in the cab. Additionally, operators all agreed that ease of ingress-egress had improved because the steering wheel folds away with one easy lever movement increasing the space for the body movements.



Figure 6.4 The new adjustable steering column

Dashboard

The instrument board was changed completely according to TNO's design suggestions (Figure 6.5). This implied constructing a new casing, re-grouping gauges, control lamps and switches, changing electric wiring and building a new steel support for the casing. In the redesign process and in the manufacturing careful attention was paid to avoid rattle and squeak of the new dashboard.

Other aspects that were considered in the design were avoiding reflections and making the machine easy to maintain. The latter was done because Eastern Europe is a target market and the owner mostly does servicing is mostly done by the owner.



Figure 6.5 Dashboard improvements

The operators evaluate the new dashboard as equal to the former model. They do not notice the improved layout of gauges and switches, most likely because the amount of time spent looking at the dashboard is very small. Also, the quality and speed of work are not affected by the way the dashboard is laid out. They do find the new dashboard more appealing to the eye than the previous model.

Controls

The possibilities to adjust the joystick relative to the driver are now limited, due to the design of the control console. Adjusting the seat for optimal viewing and operation of pedals could result in a sub-optimal joystick position. Therefore an increase in adjustment of the joystick or control console was proposed. Grammer, a large manufacturer of operator seats, cooperated in the project and came up with a new and important prototype seat with a multi-adjustable armrest to which the joysticks can be attached. Such a system is preferred because a seat adjustment does not lead to a changed position relative to the joystick. Further, the adjustability of the joystick relative to the driver is increased and the seat offers good arm support. Unfortunately it could not yet be built in the test machine and therefore was not tested.

Climate

In the Paus machine as in the other tested machines climate was a point often mentioned by operators. Due to large glass surfaces, heat build up can easily take place on sunny days. Therefore many would appreciate having air-conditioning in their cab. However, installing air-conditioning is not necessarily a solution to the problem as operators prefer to work with the door or window open, for reasons of outside view, communications and sense of space. The desire for air-conditioning is also likely to be connected to the fact that their luxury cars often have air-conditioning as a standard feature. In most machines air-conditioning is already optional.

Installing air-conditioning as a standard feature was economically not feasible. A simple and feasible measure to at least reduce blinding by the sun was attaching a sun protection foil (green) to the upper part of the windows.

Besides this basic problem, another problem was the insufficient defrosting of the windows. For defrosting and defogging new air routing systems were built in the machine. Together with the new instrument the defrosting unit was changed. The purpose was to create more vents. Two additional vents aimed at the side panels of the front window were especially needed to defrost this window (see circled part in Figure 6.6).



Figure 6.6 Improvements in the defrosting and defogging vents

Mirrors

The mirror suspension was a problem in the old machine. The inflexible part of the suspension protruded too far from the cab and the flexible part was too small (see Figure 6.7 left). Often mirrors and mirror suspension got damaged. The improvement is shown in Figure 6.7 to the right. Operators all find the new mirror suspension an improvement compared to the older machine. The risk of damaging cab structures when the mirrors collide with a tree or similar protruding object, has become a lot smaller. The view through the mirrors remained equal.

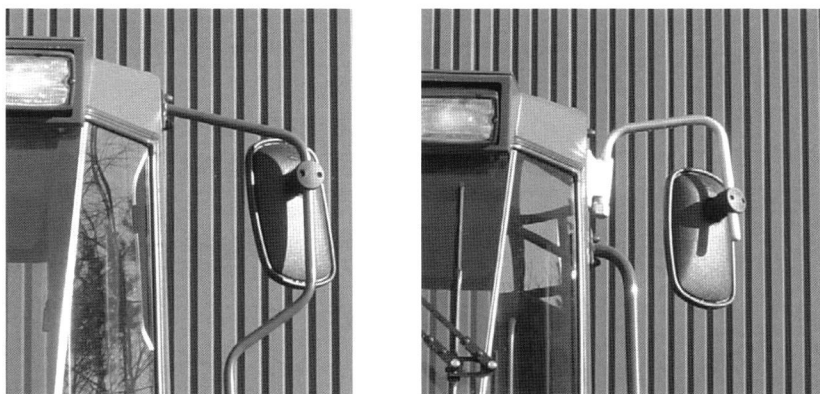


Figure 6.7 Mirror suspension: left the old inflexible situation, right the new flexible situation

Noise

To reduce interior noise the following measures have been taken:

- the flexible sealing which was used to connect the three windows that form the front and rear window, was replaced by a stiffer glue to reduce resonance at idle engine revs;
- steering column and instrument casing were designed and mounted paying careful attention to the avoidance of rattle and squeak;
- insulating material under the cabin bottom plate was thickened (from 15 to 30 mm);
- openings around the engine were closed and damping measures were taken for the engine air intake and engine cooling. Careful attention was paid not to disturb the engine's heat balance.

The measures that were taken to reduce interior noise in the cabin, have had effect according to the operators. They all find that the sound level is lower and more pleasant in the new machines.

6.4 The changes that improved comfort of the Kaiser machine

Seat

The choice of seat suppliers is limited. There are only a few major players in the market. From questioning the operators it became clear that operators in general rated the seat itself as fairly comfortable. Improvements were desired with respect to the following aspects:

- armrests: they were considered to be very important. The seat offered sub-standard armrest adjustability and comfort. Some seats come without armrests in which cases armrests are often fitted onto the joystick console (see Figure 6.8). Operators often complain about the width, hardness and improper height of armrests;
- adjustability: adjustment levers are often not easy to reach and require too much pressure to be operated. Also, it is often unclear what the lever's function is. Weight adjustment of seats with mechanical springs is difficult. As a result, the adjustment is often not done;
- suspension: seat suspension can still be improved. Several operators complain about the seat bottoming out, which leads to peak forces on the lower back. Also the damping characteristics of the air suspended seats change with the chosen seat height.



Figure 6.8 A console mounted armrest has poor adjustment qualities (here mounted in a wheelloader)

Obtaining these improvements was not possible inside the project. Buying a more expensive seat from the seat supplier would not necessarily solve the problems and in the market, being as competitive as it is, construction companies are not willing to pay for many extras.

However, one improvement could be made. The seat's adjustment range was larger than needed. By restricting the range extra storage space was created in the very confined space of an excavator cab.

Ingress-egress

Also, with the Kaiser machine the grips were improved. This was expected to be an improvement as operators step in and out of the machine 20-50 times a day. The grips were extended downwards to be able to catch them standing on the ground or climbing up one of the legs in steep terrain. In general the extended grip is appreciated by all but one test operators. This operator finds the grip equal to the older type. Surprisingly the questionnaires show no increase in safety experienced by the operators due to the new grip. This may be caused by the fact that the prototype was hardly tested in very steep terrain, in which the new grip would show its qualities best. The retest further revealed a new operator wish that was not recognized in the first testing. The test operators also

wanted to have a grip on the left inside of the door opening. This is further investigated.

Pedals

This type of excavator is designed to work in very difficult terrain (see Figure 6.9). Foot rests were added to improve operator support possibilities while working with the machine in a tilted position. Also, the outer pedals were turned 10 degrees to enable a more neutral position of the leg and foot (see Figure 6.10). A foot switch requiring frequent pushing and 90 degree turning, was removed and its function allocated in a joystick switch.



Figure 6.9 The Kaiser machine of this study

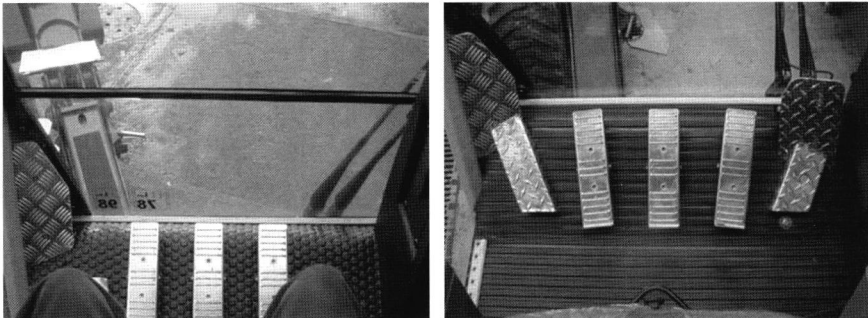


Figure 6.10 The position of the pedals: left the old configuration, right the new one

Though corresponding with a more natural foot position operators did not find the changed position of the pedals better than the parallel position. Neither did they find them worse.

Operators appreciate the fact that they no longer have to operate the switch with the foot. The operators had different opinions about the new footrest to the right. Some said it was not needed. However, as it hardly obstructs the operator's view, they agree that it should be left in place. The new footrests in front of the tilted foot rests are appreciated by the shorter operators, though they should be extended a bit toward the operator. As one operators stated: he likes the seat

up high so the air suspension in the seat works properly. With the new footrests it is easier to reach the floor.

Joysticks

A thumb-operated switch on the joystick that, when used, needed frequent depressing during longer periods of time, was replaced by a switch operated by the index finger (see Figure 6.11 left and middle) thus improving its position. By doing so the above mentioned foot switch could be replaced by a joystick switch to improve handling and reduce leg load. This switch had approximately the same position as the first mentioned thumb-operated switch, only higher up on the joystick to improve thumb position (see Figure 6.11 right).



Figure 6.11 The frequently used thumb-operated switch on the joystick (left) was replaced by an index finger operated switch (middle). The foot switch was replaced by a joystick switch (right: lower middle switch)

In a meeting with six experienced operators their opinion was asked and an expert checked whether different hand sizes could operate the switches safely. With respect to joysticks operator preferences vary greatly. A consensus was reached that the joystick would definitely need getting used to. However, it was better than the existing one. The switches have a better position, the joystick is lighter, therefore the operating force can be reduced and it fits to more hands than the older type.

Front window

The opening mechanism was improved, thus significantly reducing the load on the operator's shoulders and back. The standard pane was replaced by special heat reflecting glass reducing heat build-up from radiation in the cabin. Half of

the test operators finds the changed window sliding system easier to operate, the other half finds it equal to the older type. One operator finds it easier, but he also believes that one has less control over the closing of the window when the cab is tilted forward. The effect of the heat reflecting glass could not yet be evaluated.

Heat regulation

The position and design of the air vent near the feet was changed in order to prevent inadvertently closing the vent with the foot. Also, heat regulation in the cab was difficult because of a hard to control regulation switch. The regulation switch was replaced by a better one. All operators find the new position of the air vent better. They also found that the new switch enabled them to adjust the temperature better than before.

Noise

Several measures were taken to reduce the noise among which the padding of the cab's outside floor and side panels (see Figure 6.12). Though measurements reveal a decreased interior sound level of 5 dB inside the cab, most operators had not noticed this due to the fact that they mostly work with either the front window or the door open. Measurements had been made with both door and window closed. Surprisingly the retest brought another fact to the light that had not been noticed previously. One operator experienced an increase in cab noise while working with an opened front window compared to a closed window. This may well be caused by the reflecting of noise against the window. In open condition the window covers the padded cab ceiling. This certainly deserves attention in the future.

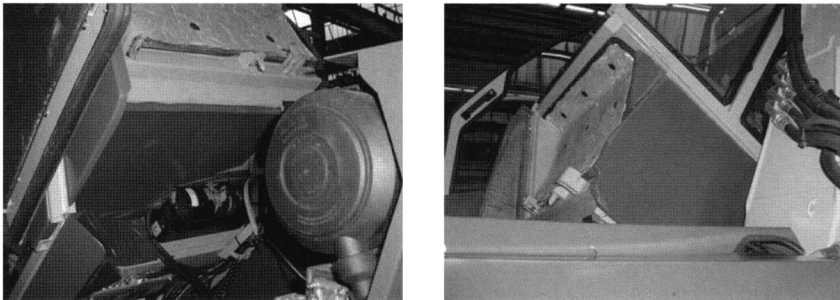


Figure 6.12 The padding of the cab's outside floor (left) and side (right) panels with sound insulating material

6.5 Conclusion: it pays to mind the details

The above mentioned improvements are in fact details. However, the details solve problems mentioned by end-users and in the retest end-users mention that most details have a positive effect on comfort and even on work output.

The retests showed that as a whole the prototypes have better cab comfort than their predecessors, due to the various small improvements in the seat, controls, climate, view and noise. An important step in work related musculoskeletal risk reduction in the arm was taken together with seat manufacturer Grammer who designed a multi adjustable armrest on their seat to which a joystick can be mounted. This was the first seat-control system for earth moving machinery where armrests and joysticks are adjusted together and therefore are easier to adjust by the operator and offer a better positioning of the controls relative to the operator.

In the final meeting of this project the companies mentioned that they considered the retest to be a very important part of the project. Through this the effects of improvements were explicitly known by the manufacturers. Although the improvements were based on the problems mentioned by end-users, they did create a changed cab. Only retesting by end-users could reveal whether the right adjustments to the cab were made. With this information manufacturers are better capable of making plans for their future products. This is very important considering the competition in this market sector.

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