Advanced Cabin Design

How to Improve Comfort and Performance by Progressive Cabin Design

Robin E. Bronkhorst
Michiel P. de Looze

Advanced Cabin Design

How to Improve Comfort and Performance by Progressive Cabin Design

Editors

Robin E. Bronkhorst
Michiel P. de Looze

Cover photo:
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.

This publication can be ordered at:
TNO Work and Employment
P.O. Box 718
2130 AS HOOFDDORP
The Netherlands
Fax: +31 23 554 93 94
E-mail: receptie@arbeid.tno.nl
Price: 20 euro, excl. VAT

ISBN 90-5986-113-2

Editors:
Robin E. Bronkhorst, Michiel P. de Looze

Print:
PlantijnCasparie Amsterdam

3 Tram drivers' comfort optimised

Dirk Osinga, Peter Vink, Cor Becker[1]

The requirements put on trams regarding comfort, safety and capacity are high and numerous at the same time. Trams should be comfortable and safe for passengers and should allow fast getting in and out of the tram. Also, capacity should be enlarged due to the increasing number of passengers. Apart from passengers the driver's cab should meet the driver's needs. The cab should be comfortable for small, long, tender and corpulent drivers, and should stimulate safe driving as well as a good view and clearance. This chapter describes how a Dutch public transport organisation realised al those goals in a new tram design.

3.1 Driver's cab and passenger cabin requirements

The public transport enterprise of Rotterdam RET (Rotterdamse Elektrische Tram) is confronted with changing demands and therefore pays much attention to the process of designing their new trams. That's why requirements for a new tram were defined and after a European invitation for tenders, Alstom (France) was chosen to deliver the new trams, because their trams not only met most of the requirements, but also because adaptations were still possible.
An important advantage of the Alstom tram was the high passenger capacity, because the tram is relatively wide, which increases capacity. Furthermore, the tram has a low floor, which increases passenger comfort in getting in and out of the tram. Based on the existing Alstom concept the RET specified the outside look and many technical facilities. The requirements of the interior of the cabin were specified together with specialists from TNO regarding vehicle interior design. The process of the driver's cab specification is the focus of this chapter.

3.2 Reasons to optimise the driver's cab for a better performance

It is essential to adapt a driver's cab to human behaviour to enable optimal human performance. Nowadays, many software packages are available to support an ergonomic design, which is needed to check whether the various drivers fit in

1 RET, Rotterdam, The Netherlands.

the seat, if their view isn't obstructed and if the controls are within reach. These software packages are especially useful in an early stage of development. However, it is impossible to predict both human behaviour and the feeling of comfort. Therefore, in a later stage of design, participation of various drivers will always be needed to test the handling, view and comfort.

Participation of real drivers is essential, because:

- one of the requirements of the RET is that the driver should at least be able to see an object of one meter high located at one meter of the tram, in order for the driver to have a good sight on the traffic in front, left and right of the tram;
- real users should test controls and displays, because they know the driver's work best;
- only real drivers can judge the comfort of the cabin.

A healthy environment will prevent drivers from becoming ill or enable them to start working again after illness. Comfort will enable the driver to stay more alert during their shift without being diverted or becoming tired. Furthermore, nowadays drivers are used to the high comfort standards in their private cars or at home and therefore also expect high comfort at work.

3.3 The 5 steps design process

Ultimately, the driver's cab should be a workplace that enables an optimal driver's performance. Therefore, in the process of developing the new tram the driver played an important role. In this project a stepwise approach used in a train interior design process was used (Bronkhorst et al., 2002). Explicit attention was given to the communication in the process between designers of Alstom, drivers of the RET and researchers of TNO, among other things we tried to make the drivers and designers owners of the solutions (Wilson, 1995).

In each step of five successive steps the three groups met. A project group guided this process. The project group consisted of a 'manager tram' of the RET, a representative of the union of the RET, a number of drivers, an instructor of the drivers' training department and a specialist concerning work research. This project group guided the process of the optimal cab design through the five crucial steps.

At a few points in the process the project group had to report their progress to a steering group, that arranged the coordination with other project groups concerning technology, exploitation and passenger interior of the new tram. During the process Alstom delivered a number of mock-ups to evaluate the design and communicate about possible changes. TNO added an expert opinion and analysed the tests done by the drivers and converted these into redesign proposals.

Step 1: test first design

In the first step designers of Alstom made drawings of the cab interior based on the requirements. At the end of this step these designs were discussed, which resulted in some changes. Climate control was hardly possible in the proposed interior, because of the large dashboard. The dashboard was a large horizontal plane from close to the driver to the coach-work, which makes ventilation hardly possible, because the air flow is hindered. Also, and probably more important, by drawing sight lines in the design it was shown that the sight was reduced, because of the large dashboards. Smaller drivers were not able to have a good view of the traffic. The position of displays and controls could also be improved.

Step 2: test first mock-up

Based on the results of step 1 the project group decided to make a new design based on other for this tram available designs. This design consisted of adapted controls and displays and a more round surface of the dashboard enabling a better sight. Another adaptation was the addition of height adjustable pedals (see Figure 3.1) next to the height adjustable seats.

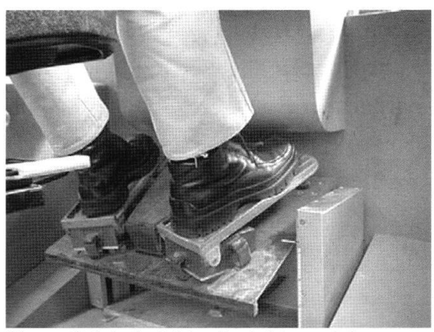

Figure 3.1 In height adjustable pedals

This is relatively new in trams. To enable good traffic sight for drivers of different lengths, height adjustable seats are often found and sometimes even height adjustable dashboards. Height adjustable pedals are not often found. The advantage of height adjustable pedals is that the sight lines of the persons relative to the dashboard and the coach-work can be fixed independent of the anthropometrics of the driver.

Figure 3.2 The mock-up used in the test

This design was shown in a mock-up (see Figure 3.2), which was evaluated by 8 drivers in 4 sessions using a protocol set-up by TNO. To test the adjustability drivers with extreme body characteristics were used. Tall and short drivers as well as tender and corpulent drivers participated in the test. Three seats that were chosen based on previous tests (two new seats and one used in the current tram) were tested in the mock-up. The height adjustability of seats and pedals were evaluated as positive. Traffic close to the tram could be observed during a simulation. All three seats were evaluated positively. Drivers mentioned during the test that in fact a dynamic test is needed to choose a seat, because the vertical vibration is not always damped effectively with a seat. It was decided to do a dynamic test in a comparable tram. New problems were also discovered during the test.

Figure 3.3 Armrests supporting precise handling

One new problem was the knee space. Knee space was theoretically (and in software) enough, but the real driver's behaviour showed that knee space was too small. Based on the discussion of the results of the test it was decided to make the dashboard more U-shaped to create space in front of the driver. Another problem discovered, was the fact that for precision handling and steering an armrest was preferable, which was now not sufficient. It was decided to add an adjustable arm support for the right arm and a fixed wrist support for the left hand (see Figure 3.3).

Step 3: test improved mock-up and emergency handle

In the third step six drivers evaluated the U-shaped mock-up and it was decided to choose this design. Now further refinements were made, like the positioning of the controls and displays, the instructor's seat for the instructor tram and a sunblind.

Figure 3.4 Emergency-stop, integrated in the drive-stop handle

In this step the emergency-break was also tested. Alstom could deliver a new emergency brake integrated in the drive-stop handle (see Figure 3.4). In existing RET trams drivers have to press a pedal continuously. Loosening this pedal creates an immediate stop. In the new tram the integrated handle could be used. Loosening the handle creates the emergency stop. In this way the hand cannot leave the handle. Drivers tested the new system in an existing tram. Based on the test the old system was preferred by drivers as well as by the experts, because of the armload. Therefore the old system will be built in the new tram.

Step 4: dynamic test of seats

The next step was the dynamic evaluation of three seats in an existing comparable tram. All three seats were tested by drivers according to a fixed protocol and objective tests were done regarding vibration and pressure distribution. Analysis of these tests showed that one seat was not appropriate for the tram in the Rotterdam area. The seat didn't provide enough support in lateral direction and didn't damp the vibration enough. One seat was best, but improvements were needed, like adjustment of the armrests to give more support, a more flat front of the seat and a better pressure distribution characteristic.

Other recommendations concerned technical aspects to improve stability and maintenance. The supplier was satisfied with the specific research based comments and was willing to adapt the seat.

Final evaluation

In the last step a complete mock-up was evaluated consisting of a part of the passenger cabin and the chosen colours, light, pictograms of displays and tested completely. Some details were adapted, but the total was evaluated positively.

Figure 3.5 The prototype to examine all parts of the interior and exterior design

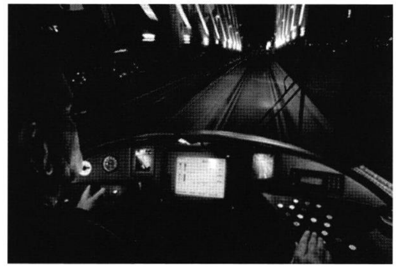

Figure 3.6 Reality has no surprises anymore

3.4 Conclusions

Because of the active involvement of several drivers and because of the research based redesign approach, all knowledge available in designers, drivers and experts is used.
Also, new knowledge came available in doing the tests. The final cabin interior of Alstom is optimally adapted to the needs of the drivers, because the designers of Alstom were made aware of the needs and were creative enough to adapt their design on the new demands.
The new tram is now a couple of months in service and the tram drivers experience the cab as comfortable. What is of more importance, because drivers have a good view on the traffic, the cab is more safe.
A couple of years ago RET designed their subway cab in a comparable way and this resulted also in a comfortable and safe workplace for the drivers and other participants in traffic. The 5 steps design process with a participatory approach is a successful formula.

3.5 References

Bronkhorst RE, Krause F. End-Users Help Design Mass Transport Seats. In: Human Factors in Seating and Automotive Telematics (SP-1670). SAE World Congress Detroit, Michigan, March 4-7. Warrendale (PA): SAE, 2002:1-6. SAE Technical Paper Series 2002-01-0780.

Wilson JR. Solution ownership in participative work design: the case of a crane control room. International Journal of Industrial Ergonomics 1995;15:329-344.

4 An Advanced Cab and Seat Design for a Quay Crane

Frank Krause, Michiel P. de Looze

In many types of cranes work requires the operators to look downwards almost continuously. Such a viewing angle forces the neck and back in an unfavourable, flexed posture. Consequently, many crane drivers suffer form neck and back complaints. Can this problem be solved by a progressive crane seat design? This chapter describes this problem and discusses the potential advantages of a new design of a quay crane cabin and seat.

4.1 The quay crane and its driver

With the expanding global market increasing amounts of containers and goods are shipped all over the world. For the handling of these materials cranes are crucial. There are many types of cranes. In ports we may see: quay cranes, ship cranes, rubber tired gantry cranes (RTGs), rail mounted gantry cranes (RMGs), and straddle carriers. These various cranes are used for different purposes. For instance, a quay crane is used to load container vessels from dry land to the ship or vice versa; a ship crane moves containers on the ship itself from one location to another; straddle carriers and mobile cranes, like RTGs or RMGs, are used to handle containers on dry land.

In this chapter our focus is on the quay crane, which is also called a ship-to-shore crane (see Figure 4.1). The driver's cabin is positioned at a height of 30 meter on a trolley that runs to and from the quayside along the boom. Also part of the trolley, right in front of the cab, is the hoisting mechanism to which the hoist is connected. The hoist is part of the equipment that together with the spreaders connects to the containers. Because of the cabs position relative to the hoist the viewing angle is almost vertical (see Figure 4.2).

Figure 4.1 Quay crane or ship-to-shore crane at Thamesport, UK

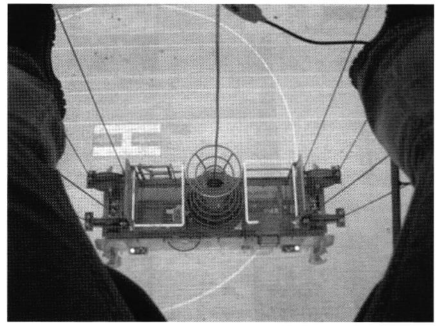

Figure 4.2 Crane driver's view on hoist and spreaders

The main job of the quay crane driver is to load and unload each container ship as fast as possible. The crane driver is located high in the crane to have a good view on his work. With joysticks he not only carefully controls the vertical and horizontal position of the container, he often also needs to control the swaying of the load. Because of the dangers and the required speed of work the job has a high mental load.

Usually, crane drivers also perform other tasks involved in container handling. If so, this may give some variation in the physical and mental loading for the crane driver, offering the opportunities to recover from the postural and mental stresses during crane driving.

4.2 Activities, postures and problems

The crane driver performs several activities. The viewing demands of some of these activities more or less dictate the crane driver's working posture. A lot of time is spent looking downwards while positioning the spreader on top of the container or positioning the container. Figure 4.3 shows typical examples of the working posture operators adopt. Typically the trunk does not remain straight and does not flex forward in the hip joint as sometimes depicted by simple manikins (see Figure 4.4-I). The hip angle remains around 90° and the trunk is flexed to a C-form (see Figure 4.4-II). The backrest can hardly be used. Because of this slumped posture the neck flexion is only moderate (20-30° from neutral). The legs are spread to be able to view downwards.

Figure 4.3 Typical crane driver's posture

For short periods of time extreme variants of this posture sometimes occur. This can be when the crane driver wants to look over a container, thus not having to use a stevedore helping him handle a container out of sight (see Figure 4.5) or when he wants to see what is below and behind him while moving from ship to shore. He then sometimes may even lean with a hand on the floor, depending on the maximum viewing angle the cab allows.

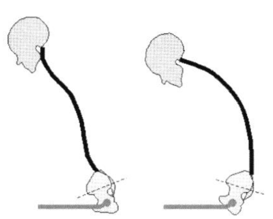

Figure 4.4 I Bending forward in the hip joint
II Bending forward by flexing the spine to a C-form

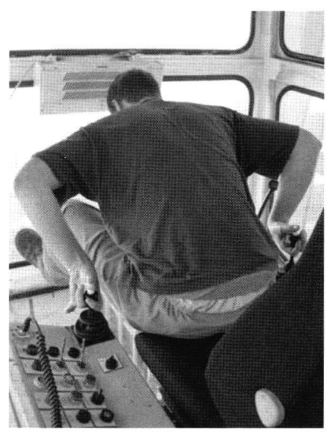

Figure 4.5 Crane driver operating the crane in extreme posture

During crane movements toward the ship the viewing direction can be less vertical. The crane driver may take this opportunity to sit up straight for a short moment or stretch his back over the back rest which is often kept in its most angled position. This is also the case when the crane driver needs to wait, for instance for a truck to unload the container on.

As illustrated above the crane driver's working posture involves slight to extreme back and neck flexion for prolonged periods of time. Prolonged bending of the neck and prolonged bending of the trunk are known as risk factors for the development of neck pain (Ariëns et al., 2000) and back pain (Hoogendoorn, 2001). In addition to the posture problems, the shocks of the cabin are an aggravating factor, therefore it is not surprising that many drivers have complaints. A study of Zondervan et al. (1989) mentioned that 64% of the crane drivers are suffering from back complaints and 42% of them from neck complaints, while Burdorf and Zondervan (1989) found a prevalence of back problems over the past year among crane drivers of 50% (see also Chapter 1).
Another point of concern is the mental load on the cabin driver, which may result from the pressure of responsibility, high demands on the pace of loading and unloading, and the severe safety instructions.
Other complaints that can be heard from crane drivers are bad climate conditions, noise and visibility.

4.3 A progressive new cab design

The question is whether a new design of the crane driver's seat and cab could solve the main problems. A promising attempt has been made by Merford, a Dutch manufacturer of quay crane cabs and other cabs.
Merford invented a new concept aiming at reducing the loads on the back and neck muscles and at the same time improving the outside view. The operator's bent forward posture is made easier by giving a new way of support. Within this concept, called Ergoseat (see Figure 4.6a), the support of the upper body is provided by the installation of two armrests with integrated controls, one on each side of the driver. These armrests are fully adjustable, which means that they can be adjusted in height, in a fore-aft direction and they can pivot towards each other. Thus, the driver is able to bend over with his body while leaning on his forearms. In addition, in the new concept the seat is no longer positioned on the cab's floor, but is suspended from the ceiling. This construction together with the armrest mounted controls allows for more glass in the cab's floor. The main viewing window can be extended underneath the operator and extra viewing

windows can be created to the left and right of the operator for viewing backwards. This idea was first elaborated in the Ergocab2000 (see Figure 4.6b).

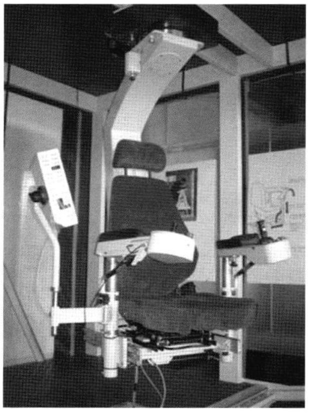

Figure 4.6a Ergoseat

Figure 4.6b Ergocab2000

To find out about the quantitative advantages of the Ergocab/Ergoseat compared to the more traditional cabins and seats for quay cranes, Merford asked TNO to make an objective comparison. Below are the results from a biomechanical analysis and a practical study performed at Thamesport in the UK.

4.4 Biomechanical evaluation

Figure 4.7 illustrates the biomechanical context of the traditional working posture of a crane driver and of the new posture that he can adopt on the Ergoseat. The figure shows that differences in neck and trunk posture between the Ergoseat and a conventional seat are only minor. In the traditional seat the low back is under significant stress since the back muscles need to generate muscle forces to counteract the forward torque of the upper body. However in the Ergoseat a significant part of the weight of the trunk, head, arms and hands is carried at the armrests. The mechanical loading on the low back is thereby reduced.

On the basis of the total body mass of the operators, the body segment lengths, the orientation of the body segments and the measured pressure at the armrests we quantified this reduction. It appeared that the Ergoseat is capable of reducing the loading on the low back by more than 50%, compared to the traditional situation. (The torque at low back level was 58 Nm and 27 Nm in the traditional seat and the Ergoseat, respectively.)

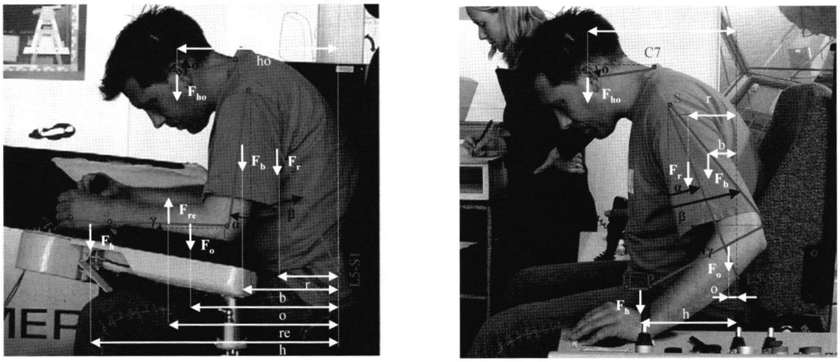

Figure 4.7 Ergoseat and traditional seat. Biomechanical context: forces and lever arms applied to operator in Ergoseat (left) and traditional seat (right)

With regard to the neck we did not find any significant difference between both types of sitting. Regarding the shoulder load the differences between seats are not clear. In the Ergoseat with arm support the stabilizing forces at shoulder level would be lower (e.g. Attebrant et al., 1997). However, this decrease in internal shoulder load might be counterbalanced by the muscle activity that is required at shoulder level when leaning on the armrests with 30-40 N per side as measured. Nevertheless, a clear advantage of the Ergoseat is the potential variation in shoulder load over the day: the crane operators may vary the load on their shoulders (and low back) by varying the extent to which they lean on the arm support (ranging from total support to none). In contrast, in the traditional situation the loading on shoulder and low back level while operating the crane is constant and continuous!

4.5 Practical evaluation

To find out about the experiences with the Ergocab in real life, TNO conducted a comparative study at Thamesport in the United Kingdom. Quite an ideal research situation was found, as the container terminal had six quay cranes in operation, two of which were equipped with an Ergocab. Operators were used to operating both type of cranes and regularly switched between cranes. Hence, we could make a clear comparison between the work in the Ergocab and the work in a traditional cab. For this comparison, we observed nine operators during a two hour shift in both the Ergocab and the traditional cab. During this shift the operators were observed, they were interviewed, they filled in a questionnaire and they were recorded by video. Table 4.1 shows the results of several questions in which the operators were asked about their cab preference with respect to several aspects.

Tabel 4.1 Number of operators preferring the traditional cab or the Ergocab (or no preference) with regard to general cabin aspects, the seat and the operation of joysticks

	traditional	Ergoseat	equal
Cabin in general			
Which cab offers the best view for your work?	1	8	0
Which cab offers the best climate conditions on hot and sunny days?	0	9	0
Which cab offers the best climate conditions in winter time?	0	7	1
Which cab do you prefer regarding noise and sound?	0	6	3
Which cab do you prefer regarding vibration and shock absorption?	0	9	0
Which cab do you prefer regarding sense of space?	7	1	1
All in all, which cab do you prefer?	3	5	1
Seat			
Which seat offers the best adjustment?	2	6	1
Which seat offers the most comfort?	3	5	1
Which seat has the best shock absorption?	0	9	0
Joystick operation			
Which joystick controls allow you to work most precisely?	4	4	1
Which joystick controls allow you to work the fastest?	5	4	0
Which operating station offers the most comfort?	4	5	0
Which operating station lets you control and position the spreader the best?	4	3	2
Which operating station is easiest to operate the flippers?	7	2	0
Which operating station lets you pick up a container faster?	3	4	2
Which operating station lets you pick up a container easier?	2	4	3
Which operating station lets you control a swinging container the best?	3	2	4
All in all, which operating station do you prefer?	4	4	1

Concerning the general cabin aspects, the Ergocab is preferred above the traditional cab. The outside view, the climate control (in heat and in cold), the noise insulation, and the suspension are all considered to be better in the Ergocab/Ergoseat. The only aspect they find not to be improved in the Ergocab compared to the traditional cabin is the 'sense of space'. This is quite clear since the

tested Ergocab was narrower than the traditional cab. The Ergoseat is also used in cabs with a more traditional appearance.
With regard to the seats one could say that the Ergoseat is preferred above the traditional seat, mainly because of its suspension characteristics and its larger adjustability. Those who prefer the traditional seat do this mainly because the back of the seat can be set back further. Operators left it in this position and stretched their back whenever they could. A feature of the Ergoseat that was widely appreciated was a wedge in the front part of the cushion. Not only does the seat no longer obstruct the view, leg support is also maintained while sitting with legs spread.
When asked about preference for joystick operation, the results are not clear. Some prefer the traditional, while others prefer the new situation. This result might be explained by the fact that the Ergoseats under investigation were equipped with joysticks that were somewhat too long. The larger for-aft travel of these joysticks and the use of armrests do not go well together. In fact, to some extent the armrests may even hamper the control of the joysticks. The latter would not have been the case, had smaller (mini) joysticks been used. Originally, the Ergoseat is specifically designed for application of finger operated mini-joysticks.

4.6 Conclusions

The Ergoseat is a good example of an attempt to improve posture, comfort and view by use of an advanced cab and seat design. The main conclusions from the evaluation are:

- the Ergoseat reduces the static loading on the low back by more than 50%;
- the Ergoseat provides the possibility for the crane operator to vary his body posture and, thereby, vary the load between the shoulders, upper back and lower back. Hence, internal structures in the back and shoulder can recover during work! Fatigue can be postponed;
- the armrests of the Ergoseat stabilize the trunk, which may further reduce the back load in case of shocks or vibrations. Though not tested it is quite likely that the armrests in combination with the seat's ceiling mounted suspension also reduce the influence of shocks and vibrations on stability of control because of the integral suspension of the seat and armrest mounted controls. This is different from most traditional seats in which only the seat is suspended and the controls are not;

- the outside view in the Ergocab is improved. Crucial in this respect are the seat's suspension from the cab ceiling and the armrest mounted controls. This eliminates any view obstructions by the seat and traditional control consoles. It also creates the possibility to improve outside view by extending the floor window pane underneath the seat and add windows to the seat's side. Also of importance are the reduced sill dimensions of the front and side windows and the introduction of a wedge in the seat pan;
- the Ergoseat is considered comfortable and is appreciated for its features;
- it is not unlikely that the Ergocab/Ergoseat will improve performance. A better view, less discomfort, less physical loading and less fatigue are all factors that may well increase task efficiency. Furthermore, it can be assumed that the armrests will provide more stability, which is specifically needed for high precision tasks. (In an additional comparative study on the performance at a computer-simulated crane task we found that the Ergoseat with small joystick grips scored slightly better compared to a traditional seat with no arm support and larger joystick grips);
- the Ergoseat may have a positive effect on health as two main risk factors are clearly reduced. First, the magnitude of the load on the low back is reduced by more than 50%. Secondly, the operators may vary between body positions, thereby breaking the monotony of the load and offering the chance on recovery to body structures.

The present study also provided some other issues that need to be stressed here.

- It has become clear that the armrests on the Ergoseat are less suitable for application of larger joystick handles. Therefore, the Ergoseat is recommended particularly in combination with mini-joysticks.
- Within the current design of the Ergoseat it is quite difficult to stretch the back during micro breaks in the cab. This aspect may be improved in the near future.
- A traditional seat requires a larger cabin compared to the Ergoseat. This might be advantageous in that a smaller cab can be applied. However, one should be aware of a potential drawback on the operator's 'sense of space'.
- The Ergoseat with its large variety of adjustment possibilities and its mini-joysticks requires a good introduction and some time to get used to as this differs from what most crane drivers are used to.

4.7 References

Ariëns GAM, Mechelen W van, Bongers PM, Bouter LM. Physical risk factors for neck pain. Scand J Work Env Health 2000;26:7-19.

Attebrant M, Winkel J, Mathiassen SE, Kjellberg A. Shoulder-arm muscle load and performance during control operation in forestry machines. Applied Ergonomics 1997;28:85-97.

Burdorf A, Zondervan H. An epidemiological study of low-back pain in crane operators. Ergonomics 1990;33(8):981-987.

Hoogendoorn WE. Work-related risk factors for low back pain. Wageningen: Ponsen & Looijen bv, 2001. PhD Thesis Vrije University of Amsterdam.

Zondervan H, Burdorf A, Wingerden S van, Duuren L van. Aandoeningen van het bewegingsapparaat bij kraanmachinisten. Tijdschrift voor toegepaste Arbowetenschap 1989;2(2)17-22.