Advanced Cabin Design

How to Improve Comfort and Performance by Progressive Cabin Design

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Michiel P. de Looze

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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.

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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

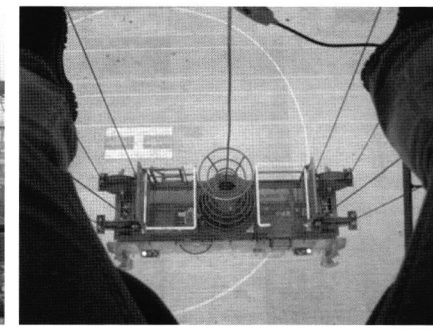

Figure 4.2 Crane driver's view on hoist and spreaders

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.

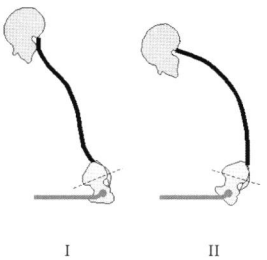

Figure 4.4 I Bending forward in the hip joint
II Bending forward by flexing the spine to a C-form

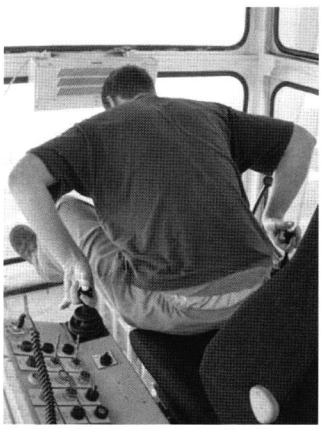

Figure 4.5 Crane driver operating the crane in extreme posture

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 an-

gled 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).

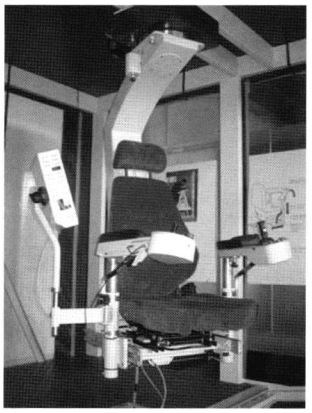

Figure 4.6a Ergoseat

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.)

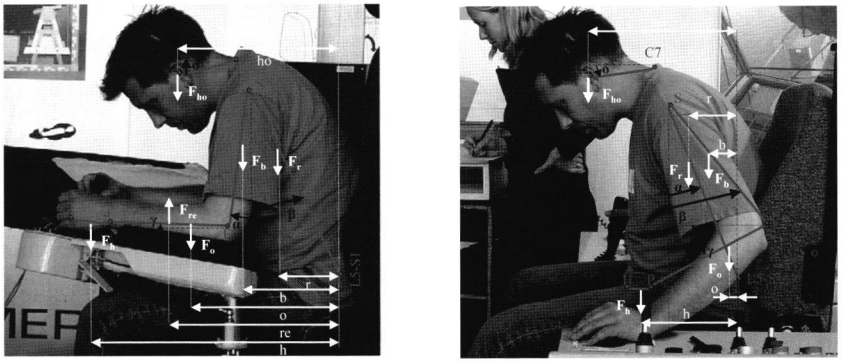

Figure 4.7 Ergoseat and traditional seat. Biomechanical context: forces and lever arms applied to operator in Ergoseat (left) and traditional seat (right)

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 op-

erators 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.

5 Cabin ergonomics and comfort of compact sweeping machines

Annemieke Leegwater

Current developments bring new challenges for the design of compact sweeping machines. In general, there is a growing attention for a healthy working environment. In addition, the operator has more demands with regard to his comfort and the ease of operation of the machine. These demands increasingly affect purchase decisions for new machines. To find opportunities for the future generation of sweeping machines TNO and a main producer of sweeping machines performed a project, addressing the issues of health, comfort and ease of operation. This chapter presents the outcome.

3.1 Present design

Compact sweeping machines are primarily made for the mechanical cleaning of alleys, paths, gutters, streets, market squares and road maintenance. A sweeping machine is in fact a large driving vacuum cleaner: two brushes spinning towards each other collect the muck off the street and move it towards the nozzle of a vacuum unit in the middle front of the machine, under the cabin floor. With great power the street dirt is vacuumed up into a build-in container. On board there is also a water tank from which nozzles spray a water film, to prevent dust getting blown up by the wind, and to bind the dirt in the container. The removed muck contains mainly plastic, paper garbage, leaves, grid, sand and water. An increasing amount of machines are equipped with a third brush, which is mounted in front of the machine. This third brush can be moved sideways and is exceedingly suitable to remove weeds between the pavement, to reach corners and to clean wide paths.

The main task of the machinist is to drive the machine safely, and simultaneously to operate the brushes and vacuum unit. The machinist has to concentrate on the traffic and public movements and on the work that has to be done properly. The tasks of the machinist are complex and demand substantial mental and physical effort. On top of that, the work includes environmental stresses on the machinist when dealing with aggravating circumstances as rain, coldness, (extreme) warmth and darkness.

The driver seat is at the right side in right-driving countries, so they have a good view on the right hand brush when cleaning the gutter at that side of the road and can easily move around the parking cars. For driving, this seat position is on the other side of the vehicle than usual.
Roughly, there are two types of sweeping machines, namely the big truck mounted machine and the compact machine (see Figure 5.1).

Figure 3.1 Truck mounted versus compact sweeping machines

The first is mainly used in the outskirts of cities who have a large scattered working area. The truck has more speed potential than most compact sweepers and is therefore appropriate for long distance driving. The cabin is spacious and is comfortable, dependent on the type of trucks. The container has, generally speaking, a larger capacity than the compact sweeping machine, which is mainly used in the urban areas.
The compact machine is designed mainly for the cleaning of small lanes, public footpaths, gutters, market squares and driving under porches and underpasses. In this machine the machinist has a better view on the working area, the brushes and the environment, and the machine is more manoeuvrable compared to the bigger truck mounted machine. Therefore, the work can be done more accurately, while the risk for any traffic accident is less. For a good view on the right brush, which is mounted just in front of the front wheels, a mirror is installed. By the windows in the front, the door and the cabin floor the operator can have a direct view on the right brush, on the third brush (in front of the machine), on the dirt on the street, and on the vacuum nozzle. Because of its compactness the cabin's inner space is restricted.
This project was aimed at the improvement of the design of the cabin of the compact machine.

5.2 Bottlenecks in present design

What can be improved in the design of the compact machine? How can we create more comfort ánd a good outside view on the tasks and the traffic within the restricted space within the cabin? To find answers we needed a basic investigation into the bottlenecks of the current design. This investigation comprised:

- a study of the documents about the layout of the present concept;
- a demonstration of the compact machine's functions by an instructor;
- interviews with staff members of the manufacturer about their ideas of improvement;
- observations of and interviews with five experienced operators during work (each for several hours) to analyse their working actions and to obtain their experiences and ideas about the functioning and ergonomics of the machine;
- interviews with supervisors of the machine operators and with ergonomic experts/advisors about their ideas of design improvement;
- a categorization of the results into ten main bottlenecks.

One of the main bottlenecks found concerns the static and awkward body postures that are adopted during the work. These postures comprise lateral and forward bending and rotation of the head and trunk. Hence, it is not surprising that the literature mentions neck and back pain as the predominant health problems for operators of sweeping machines (Massaccesi et al., 2003).
The observations showed us a remarkable variation in body posture across the five operators. The adoption of body posture seems to depend largely on individual strategy to perform the job and on individual preferences. For instance, some operators use the mirror to look at the right brush, while others prefer a direct view on the right brush through the window, which has a significant impact on the upper body posture. One of the operators had even an extra mirror fitted to see the right brush, to reduce bending of the neck. Another source of variation is the varying stature of the operators. Finally, the lack of support for the left arm, inviting some of the operators to lean on the steering wheel, leads to variation in posture.
During the interviews the drivers surprisingly did not mention their awkward body postures although clearly occurring frequently and for long periods of time.
From all observations and interviews we categorised the obtained bottlenecks, which resulted in a list of issues. Generally speaking, cabins in this kind of machines are too small in relation to the required tasks performed. There are definitely possibilities and requirements to improve the cabin but this will lead to

contradictions. To name one is more height required in the cabin but the total height of the machine is already at the maximum and lowering the cabin floor is impossible because of the structure and the vacuum equipment.

Examples of the issues leading to unwanted postures are shown in Figure 5.2 and 5.3.

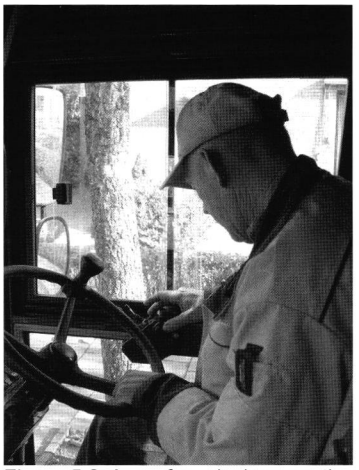

Figure 5.2 A preferred view on the right underbrush leads to an awkward body posture

Figure 5.3 The armrest with operating system dictates the operator in a fixed position

5.3 Future design

On the basis of the investigation results, TNO experts and manufacturers held a brainstorm session. The purpose was to address the main issues to be improved in a new to design compact sweeping machine.
It appeared that the ideas that were discussed could be clustered into two themes 'sight and view' and 'space, sitting position and layout operating system':

- to improve the view capabilities particular sensory aids are mentioned, for example lane keeping system, camera systems and pop-up displays, acoustic signal system, robotics and sonar aid;
- to improve sitting positions some options were mentioned and must be investigated to increase the space in the cabin and to modify the operating elements in relation to the seat.

5.4 Conclusions

The main challenges for cabin innovation in sweeping machines are to improve the basic body posture of operators (of varying stature) by changing the cabin size, optimising the body fixation points and using the aid of detection systems, to reduce the risk of injury by both robotizing regular sweeping functions and improving the positions of the controls and their way of handling, and finally, to improve the physical environment and to prevent fogging windows by optimising the climate control system.

By improving the ergonomic layout of the cabin we expect to promote comfort, to improve performance and to reduce the health problems as neck and back pain.
Based on expert view (and following the ergonomic standard for lorry cabins), the cabin of the compact sweeping machine can be considerably improved by applying modern technology such as sensory aids, lane keeping system, robotics, camera monitor systems and further automation of the manual task.
The left brush is sometimes used to clean the left gutter of the road. This task requires improvement in order to eliminate the unfavourable working posture (rotation of trunk and neck) as well as losing all view on the environment.

5.5 References

Massaccesi M, Pagnotta A, Soccetti A, Masali M, Masiero C, Greco F. Investigation of work-related disorders in truck drivers using RULA method. Applied Ergonomics 2003;34:303-307.