Comfortable earth moving machinery

Knowledge and experiences from the Eurocabin project

Editors
F. Krause
R.E. Bronkhorst
M.P. de Looze

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: EUR 20 excl. VAT

ISBN 90-6743-977-0
© 2003 TNO Work and Employment
© Figures 16.2 and 16.3 Hans Rakhorst and Figures 16.4 and 16.5 Lodewijk Vormer

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

Print:
PlantijnCasparie Heerhugowaard

No parts of this manuscript may be reproduced in any form, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, or otherwise, without prior written permission from the publisher.

Editorial

'I will work for you but if you want me to have a high output, I will need to work with the ONT 3000^{cmfrt} excavator'

'Deal!'

The operator's comfort is increasingly recognized as a factor of importance in the design of cabins of all kinds of vehicles. This book addresses the comfort of cabins of earth moving machinery. It is the result of a two and a half year European project (1999-2002), known as 'Eurocabin'. In this project three manufacturers of earth moving machines joined their strengths to improve the comfort of their machines: Paus GmbH from Germany, Etec BV from the Netherlands and Kaiser AG from Liechtenstein. They were assisted by TNO, the Dutch Organisation for Applied Scientific Research. The Eurocabin project was performed within the European Union's Fifth RTD Framework Programme, called 'Competitive and Sustainable Growth'.
In the Eurocabin project, scientific knowledge as well as practical experiences were added to 'the state of the art' with respect to the comfort of earth moving machinery. This book shares the most recent knowledge and experience with the reader. By doing so, information is provided with regard to the direction that other manufacturers may follow in the design of their future machines.

The book is divided into three parts.
In part 1 the most recent state of knowledge behind comfortable cabin design is described. Experts from various research institutes contributed to part 1. In subsequent chapters they addressed various comfort-related aspects like vision, seat comfort, vibration reduction, human dimensions, and joystick controls. For each aspect, the current knowledge, the current practice and the future challenges are described.
Part 2 is focussed on the user. It describes why it is important to have a user-centred approach to cab design and how and when the user can become involved in the process. Much attention is paid to the experiences, expectations and wishes of the operators. This information was collected through interviews with 273 operators of excavators and wheel loaders at Bauma 2001. For the project a team of ergonomics experts thoroughly reviewed three types of earth moving machinery. How this information was collected is also described in this part.

The future in cab design is what part 3 is about. First it describes future demands on comfort in construction vehicles' interiors according to manufacturers. This information was obtained through interviews at Bauma 2001 with 80 professionals in marketing and design and through the subsequent workshops where the results of the interviews were discussed. Whether operators agree to these demands is answered next, when other results from the Bauma 2001 survey are presented concerning the question: what would operators like to see in their future cab? The automotive industry can be regarded as trend setting regarding design. What this means for cab design is described after. The last chapter shows some interesting ideas from two design studies performed for Eurocabin.
Part 1, 2 and 3 as well as the individual book chapters are written in such a way that they can be read independently from each other.

This book might be of great value for all people who are, in one way or the other, involved in the design of cabins of earth moving machines. We hope it will contribute to the further improvement of cab comfort in earth moving equipment.

Enjoy the reading.

F. Krause, MSc
R.E. Bronkhorst, MSc
M.P. de Looze, PhD

Contents

Part 1

The knowledge behind cab design: information from research institutes

1 Introduction

The levels of comfort and ergonomics in earth moving machinery have increased over the recent years. By and large, it has been common sense that has brought manufacturers to where they are now. Actually we are now at a point, that it becomes hard to find ways to further improve the product. Common sense will probably not be enough to achieve just that extra innovation that might keep a manufacturer ahead of competition. Instead, further cabin improvement requires more research-based fundamental knowledge as well as in-depth investigation into the user-requirements.
In this part we focus on the research-based knowledge. Various specialists from three renowned research institutes shed their light upon the most important aspects influencing the comfort and ergonomics of a cab.

Michiel de Looze (TNO, The Netherlands) provides the latest insights about comfort and presents a new model of comfort, in which the underlying factors of comfort and discomfort on a human, product and context level are described. In the next chapters, various comfort-related aspects are highlighted.
Denis Coelho (Beira University, Portugal) addresses the operator's seat being one of the major interfaces between the human operator and his machine. The importance of seat comfort in the wheel loader, the current state in seat design and the future challenges are described.
Vision is of the utmost importance in many of the tasks of the operator's of earth moving equipment. Matthias Roetting (Aachen University of Technology, Germany) provides the background information and gives some direction for future improvements related to this issue.
In the next chapter, Roeland Hogt covers the issues of interior noise and vibration reduction as related to the operator's comfort and future cabin design.
Aernout Oudenhuijzen (TNO) describes the fit of the cabin to the anthropometric dimensions, and specifically, the changes in human dimensions and its consequences for cab design.
Finally, Frank Krause (TNO) shares some thoughts on joystick controls and the adjustability of the consoles they are fit into.

2 A new model of comfort

Michiel de Looze
TNO Work and Employment, Hoofddorp, The Netherlands

2.1 Introduction

In Western societies the comfort of products has developed into an important issue. This holds not only for the end users of products. Producers recognize comfort as a major selling point, as it is thought to play an increasingly important role in product-buying decisions. Also, employers are getting interested in comfortable equipment for their employees in order to create a healthy and stimulating working environment. For the design of comfortable equipment (e.g. the cabins of vehicles) it is important to have a good notion of the concept of comfort. What is comfort?

Comfort as well as discomfort are very common terms in common parlance. Everyone seems to have some kind of idea about their meanings. While comfort is generally associated with some pleasant state, discomfort is associated with an unpleasant state.

The concepts get more complicated if we think about 'when experiencing (dis)comfort' (Vink, 2002). You may experience discomfort, when it is too hot in a room or cabin. A similar experience may occur when feeling pressure points in your bottom when sitting in a driver's seat. You may also feel discomfort when working in bad body postures like neck flexion of trunk torsion. You may experience comfort when you feel 'at home' in your company or your cabin. You may feel comfortable because of the unexpected good looks of a new cabin's interiors or a surprisingly pleasant feeling when operating a new vehicle.

Hence, comfort and discomfort are influenced by many factors. For designing purposes it would be helpful to have a model in which (dis)comfort is defined and the factors that may contribute to the comfort and discomfort of an operator are incorporated. This model will be presented and illustrated in this chapter.

2.2 What is comfort?

The frequent use of the term comfort in common parlance and in the literature suggests that it represents a consensually held construct. Yet, there is no widely accepted definition of comfort. Webster's dictionary defines comfort as a state or feeling of having relief, encouragement and enjoyment. Slater (1985) defines comfort as a pleasant state of physiological, psychological and physical harmony between a human being and its environment. Richards (1980) stresses that comfort is a state of a person involving a sense of subjective well-being, in reaction to an environment or situation. In conclusion: comfort is not yet clearly defined, yielding an on-going debate in the literature, but there are some issues that are not under debate, namely

- comfort is a construct of a subjectively-defined personal nature;
- comfort is a reaction to an external factor, a product or environment;
- comfort is affected by factors of a various nature (physical, physiological, psychological).

In other words: though comfort is an individual subjective matter, we need an environment or product to experience comfort, while this experience is physically, physiologically and psychologically mediated.

Discomfort versus comfort

How is discomfort related to comfort? Roughly, there are three views on this matter.

First, some have conceptualised comfort as two discrete states: comfort presence and comfort absence, where comfort has been simply defined as the absence of discomfort and vice versa (Hertzberg, 1958; Floyd & Roberts, 1958). This has two meaningful implications. Comfort does not necessarily entail a positive affect (Branton, 1969), and the ultimate goal of product designers is reaching the state of absence of discomfort, where the working individual is oblivious of the fact that he or she is seated (Bishu et al., 1991).

Secondly, many believe that comfort and discomfort are two opposites on a continuous scale, ranging from extreme discomfort through a neutral state to extreme comfort. One can distinguish ordered levels of subjective responses across the entire continuum from strongly positive (extreme comfort) to strongly negative (extreme discomfort).

Third, some argue that comfort and discomfort are not strictly the opposites to each other. Instead, they state that comfort and discomfort are different constructs which are affected by distinctly different variables (Kleeman, 1981; Kamijo et al., 1982). Feelings of discomfort are mainly associated with pain, tiredness, soreness and numbness which are assumed to be imposed by physical factors like joint angles, tissue pressure and circulation blockage. Comfort, on the other hand, is associated with feelings of relaxation and well-being, which do not only result from physical factors but also from psychosocial and emotional factors. This view is supported by experiments showing that aesthetic design matters with respect to comfort, but not to discomfort (Helander & Zhang, 1997). It was also found that at low discomfort rates, comfort rating may range form very low to very high. At high discomfort rates however, comfort ratings are also low. Thus, discomfort has a dominant effect.

For the designer, this third view is interesting, as within this view he is confronted by two challenges (Paul et al., 1997). First, he should reduce discomfort by creating physically well designed products. Secondly, and even more challenging, he should increase comfort, which goes further than the physical optimization. Creating feelings of safety, exceeding expectations, or even provoking 'Wow-sensations' are important in relation to the end-user's comfort.

A model for comfort and discomfort

The view of comfort and discomfort as different entities is modelled in figure 2.1, where underlying factors are presented on a human, product and context level.

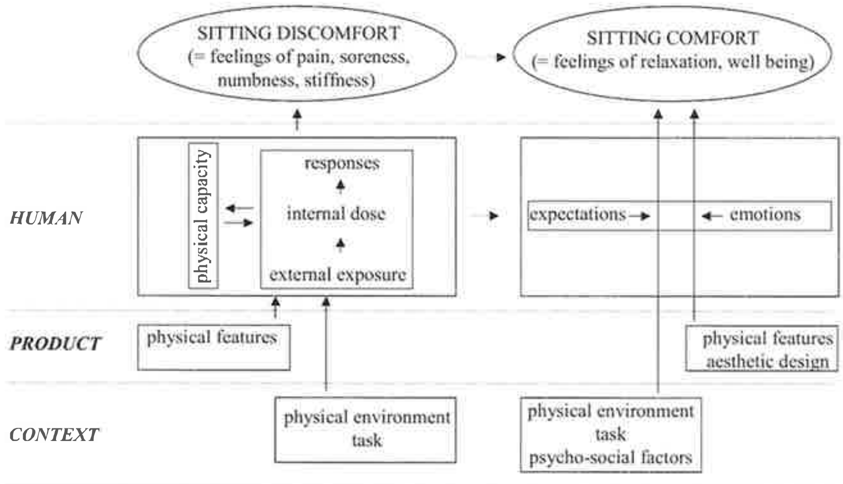


Figure 2.1 Theoretical model of comfort and discomfort and its underlying factors at a man, product and context level

The left part of this model concerns discomfort. Physical processes underlie discomfort. For an operator of an earth moving machine the physical characteristics of the cabin (e.g. location of seat and handles, climatic conditions), the environment (the riding surface, window reflections) and his task (the operation of the handles or steering wheel) expose the operator to physical loading factors (pres-

sure, force, joint angles, micro-climatic loading), which may lead internally to a loading dose in terms of muscle activation, internal force, intra-discal pressure, nerve and circulation inclusion, and skin and body temperature rise. These invoke chemical, physiological and biomechanical responses. The perception of these responses underlies the feelings of discomfort.
The right part of the model concerns comfort, i.e. feelings of relaxation and well-being. Again, the influential factors are presented on a human, product and context level. At a context level not only the physical features are assumed to play a role, but also psychosocial factors like job satisfaction and social support. At the product level the aesthetic design of the cabin may affect the feelings of comfort. At human level the influential factors are assumed to be individual expectation and other individual feelings or emotions.

2.3 From model to design

The model in figure 2.1 shows us the aspects that are important for comfort and discomfort. From the model we can deduce several issues that should be recognized by the designer who aims to design a cabin with minimal discomfort and maximal comfort for the operator:

- comfort and discomfort are affected at a human, product and context level. Therefore, it is important in product design to involve the end-user in the design process and to take the relevant features of the task and the environment into account;
- for reducing feelings of discomfort it is important to pay attention to all possible loading factors. These include awkward body postures (back angle, neck angle, upper arm and wrist angles, knee and ankle angles), pressure distribution and shear forces at the contact level of human body and seat and back rest, back compression, whole body vibrations, as well as micro-climatic loading factors. The challenge is to design such that all possible loading factors we can think off are minimized;
- for creating comfort it is important to pay attention to the aesthetic design of the cabin. It is important to get the right picture of the end-user, his emotions and expectations about a new cabin. Factors affecting these emotions (smell, noise, former experiences, and others) should be known. Exceeding the expectations of the future end-user is difficult, but of major importance.

2.4 References

Bishu RR, Hallbeck MS, Riley MW. Seating comfort and its relationship to spinal profile: a pilot study. International Journal of Industrial Ergonomics 1991;8:89-101.

Branton P. Behavior, body mechanics and discomfort. Ergonomics 1969;12:316-327.

Floyd WF, Roberts DF. Anatomical and physiological principles in chair and able design. Ergonomics 1958;2:1-16.

Helander MG, Zhang L. Field studies of comfort and discomfort in sitting. Ergonomics 1997;40:895-915.

Hertzberg HTE. Seat comfort. In: WADC Technical report 56-30. Dayton (OH): Wright-Patterson Airforce Base, 1958:297-300.

Kamijo K, Tsujimara H, Obara H, Katsumatu M. Evaluation of seating comfort. In: SAE Technical Paper Series 820761, 1982:1-6.

Kleeman W. The challenge of interior design. Boston)Massachussettes): CBI, 1981.

Paul RD, Helander MG, Morrow J. Comfort and discomfort at work: the nurturing and pampering paradigm. In: Seppälä P, et al., eds. From experience to innovation - IEA '97. Proceedings of the 13th Triennial congress of the International Ergonomics Association, Vol. 5. Helsinki: FIOH, 1997:504-506.

Richards LG. On the psychology of passenger comfort. In: Oborne DJ, Levis JA, eds. Human factors in Transport Research, volume 2. London: Academic Press, 1980:pp 15-23.

Slater K. Human comfort. Springfield, IL: CG Thomas, 1985.

Thakurta K, Koester D, Bush N, Bachle S. Evaluating short and long term seating comfort. In: SAE Technical Paper Series 950144, 1995:33-37.

Vink P. Comfort. Delft (The Netherlands): Technical University, 2002. Inaugural address.

3 Seat comfort

Denis A. Coelho
Human Technology Group, Dept. of Electromechanical Engineering, University of Beira Interior, 6201-001 Covilhã, Portugal

3.1 Introduction

In the context of the design of a wheel loader cabin, comfort can be viewed from several important perspectives - thermal, auditory, sitting, or cognitive (usability). The focus of this contribution is on seat design and comfort. The aim is to describe the current state of knowledge in this field, to review current designs of wheel loader cabin seats and to outline design challenges for the near future.
The cabin seat is one of the interfaces between the human operator and the wheel loader. In terms of vehicle design, four design criteria for the automobile driver/operator seat were listed by Reynolds (1993): the seat must position the operator with unobstructed vision and within reach of all vehicle controls; it must accommodate the operator's size and shape; it should be comfortable for extended periods; it should provide a safe zone for the operator in an accident. In addition, the seat should support him, or her, in achieving a way of sitting that helps to prevent health problems in the back, shoulders and neck. As a work tool the wheel loader seat has to be comfortable for long uninterrupted periods of time that can reach several hours. Travel to and from work sites adds to the time the operator sits in the cabin. Accidents may occur in both the work periods when the wheel loader is used as a tool and in the periods when the wheel loader's function is then primarily of a transport vehicle to the operator. The operator is subjected to vibration from the wheel loader operation (engine, terrain irregularities and bucket load cycles).

3.2 State of knowledge

Seat design needs to consider accommodation, support, comfort and health requirements. Accommodation and adjustments refer to seat dimensions and reach to controls. Fitting the seat configuration to the occupant's size and shape refers to support, comfort and health requirements. Comfort also refers to stiffness, contour, climate, memory and vehicle features that promote occupant comfort.

Reynolds (1993) gives a review of automobile seat design guidelines for accommodation and comfort requirements.

Accommodation and support

Seat cushion size is dimensioned for accommodation of the seated occupant's buttock and thigh dimensions. The cushion must be contoured and soft at the 'waterfall' under the knee to avoid occlusion of fluids in the leg (Åkerblom, 1954). Lateral space in the seat backrest must accommodate the physical dimensions of the torso. Horizontal adjustments accommodate differences in leg length that are associated with seat cushion height and preferred knee angle. Seat back angle adjustments accommodate differences in arm length and occupant preferred hip angle, and affect intervertebral disc pressure. According to Pheasant (1996), in designing a seat the lumbar spine should be supported in its neutral position (i.e. with a modest degree of lordosis) without the need for muscular effort. This can be achieved by a semi-reclined sitting position with a backrest contoured to the form of the user's lumbar spine. Seat back inclination has less effect on lumbar lordosis than the supporting surface (Porter & Norris, 1987).

Comfort and health

Seat comfort has been the object of research concerning the factors that influence subjective comfort. Factors considered include muscular activity, posture, interface pressure, elasticity and dampening of the seat. Time sitting and frequency of posture changes are also considered.

The seat should reduce postural stress and optimize muscular effort. An electromyography study of the torso muscles activity of a sample of 8 people of the male sex was carried out by Reed et al. (1991). The study reveals that the frequency of muscular activity was higher in the seats with firmer padding and smaller width, increasing postural stress and muscular effort. The study by Reed et al. (1991) also identified a threshold sitting time of about one and a half hour separating short term from long term subjective comfort impressions. Surface electromyography was used by Lamotte et al. (1996) to investigate the headrest comfort in car seats, with the participation of 8 volunteers. The study assumed that the automobile seat used was more comfortable when fitted with a headrest, than without one. However, differences found between experiments with and without headrests were weak. Only half of the subjects exhibited lower surface electromyography with a headrest.

The amount of posture change that occurs during sitting has been sought for use as an aspect of behaviour and indicator of seat comfort. Difficulties have been found with using this concept - it is generally agreed that some changes in posture are desirable, and of course some are necessary due to task demands (Corlett, 1990). Orthopaedics, as well as ergonomics, recommends frequent or at least occasional changes of position. This calls for a 'dynamic' seat that allows easy changes of sitting posture (Grandjean, 1993). Seat dimensions, contour, stiffness and cover materials should enhance the occupant's ability to change positions, since comfortable support for many postures is essential. In an experiment, using a static adjustable platform simulating the automobile driving workstation, Porter and Gyi (1998) aimed at finding the optimum posture that would promote comfort in automobile driving. These authors present ranges of joint angles adopted by the subjects when requested to find a comfortable posture in long term sitting evaluations (two and a half hours). This data cannot be applied to wheel loader cabin seats, given the visual demands of work, which are connected with the operative range of the lift arm and bucket. The preferred postures of wheel loader operators, which ought to be investigated, are likely to consist in more upright sitting. Orthopaedics has developed an extensive understanding of low back pain, its symptoms and treatment. The connection between seat design properties and low back pain is not, however, thoroughly understood. A general recommendation of orthopaedists is that a good seat should support the natural curves of the back.

The body is composed of soft and hard tissues that have different load-deflection characteristics. The seat is composed of different materials; seat contour, upholstery seams, foams and suspension affect pressure distribution in the seat/occupant interface. Pressure distribution represents a complex interaction between occupant and seat. A flatter seat cushion surface will raise pressure under the ischial tuberosities and a contoured surface will distribute pressure under the soft tissues (Pheasant, 1996). Gyi and Porter (1999) demonstrated that the simple quantification of interface pressure as an indicator of discomfort is not satisfactory, making it impossible to find a simple relationship between pressure and discomfort in seats. Furthermore, Goonetilleke (1998) presents evidence for a complex relationship between these two variables and introduces the concept of a threshold value of pressure to delineate between the experience of a positive sensation and discomfort. This author suggests that if pressures are below the threshold value it would be best to distribute the forces, while higher pressures, closer to the 'mean tolerance value', should be localized to relieve discomfort caused by simultaneous neuron firings over large areas.

Exposure to vibration has been linked to low back pain (Troup, 1978). Thus, seat design must also consider the vehicle, cabin and seat suspension system and the vibration transmitted to the seat occupant. Significant correlation between subjective comfort of the seated person and some technical properties of seats was found by Park et al. (1998). The main variables significantly associated with comfort were the level of deformation of the seat and its backrest and also the dynamic constant of elasticity and the hardness of the foam padding in the seat and backrest. Ebe and Griffin (2000a) have shown that judgements of overall seat discomfort (in flat seat cushions made of foam or wood and without any contour or backrest) are influenced by both static seat characteristics (e.g. seat stiffness) and dynamic seat characteristics (e.g. vibration magnitude). In a subsequent report (Ebe & Griffin, 2000b) a predictive equation of overall subjective seat discomfort was presented, based solely on seat stiffness and vibration magnitude variables, and assuming the form of Steven's psychophysical law. These results indicate a certain tolerance to vibration caused by discomfort, which however decreases with the further increase of vibration dose and the increase of seat stiffness.

Discussion

The complexity of seat comfort has not yet been understood. There is a considerable amount of research that identifies relevant factors for the evaluation of overall seat comfort. This research is centred in physiological and biomechanical aspects. However, the correlation between the multitude of identified factors and subjective comfort is not yet established. For this reason, the pragmatic and industrial evaluation of seat comfort will continue to rely on the subjective judgements of humans performing sitting trials. Radically new seat designs are, therefore, not encouraged and instead the development should progress towards the gradual evolution of existing ones (assuming their design has been evolving based on people's experiences with the seats). Subjective evaluation of the seats in real task settings (in a moving vehicle and in work conditions) should always be part of the development process. Occupant's behaviour and personal preference need to be accounted for in seat design using questionnaires and interviews (for a feasibility review of some methods on subjective evaluation of seats see: Coelho & Dahlman, 2000). A good balance between the design for task, occupant comfort and safety is needed; this requires a scientific approach and collaboration between medicine and engineering. In addition, informed and collaborative seat occupants are in a better position to optimize their sitting comfort.

3.3 Current wheel loader seat design

This section is based on a survey of some of the cabin and seat designs of wheel loaders in the European market and unstructured observations of wheel loaders in operation.

Accommodation, seat adjustments and headrest

Accommodating the operator's size and shape requires the seat to be designed with the anthropometric dimensions of the target population of users in mind. For most wheel loader makes surveyed, a standard seat is offered for the world market. Limiting user restrictions such as thigh length (small user) or hip breadth (big user) may lead to dissatisfaction of users in the opposite extreme of the anthropometric range, unless compensating seat adjustments are included. Currently available adjustments of the seat include fore-aft position, seatback angle, lumbar support, bottom cushion height, armrest angle and seat suspension stiffness.

A headrest is fitted in some of the models surveyed. However, experience from field studies in automobile seat comfort shows that many times the headrest is not used as a rest for the head but either as a rest for the neck or not used at all. Power adjustments are not commonly fitted into the seat, nor are seat settings memories (both may increase comfort and efficiency in changing posture during work periods or changing settings for different operators). The human spine differs in size and shape among people; providing support and comfort to the seated person requires a seat backrest, that is adjustable towards people's individual characteristics. Providing adjustable lumbar support (in height and depth) an articulation at roughly shoulder level and an adjustable headrest (in height and tilt angle) would be advantageous improvements from the current designs towards supporting the spine and its normal curvatures (Coelho & Dahlman, 1999a).

Lateral support and seat belt

An inclined ground where the wheel loader is working may force the operator to slide laterally in the seat. Such effect can affect efficiency of the task, comfort and posture of the operator. Seat side supports would be beneficial to counteract these effects on the operator. To avoid conditioning the accommodation range and losing functionality the side supports should be adjustable in width (Coelho & Dahlman, 1999b). In the same way, the headrest can act as a side restrainer, if it is fitted with side supports. The absence of side supports may condition the operators to prefer level rather than inclined terrain. Providing side supports in the backrest should then be accompanied by the provision of a terrain gradient information display, warning the operator if inclination level of the terrain is too big for safe operation of the lift arm and bucket. A retractable seat belt 76mm (3inch) wide is currently fitted in compliance with SAE J386 ("operator restraint system"). Three or four point seat belts could contribute to assuring body stability in the seat in case of inclination, besides adding to the restraining of the operator in the event of a crash or rollover.

Armrests and wrist support

Armrests are provided in most cabin seats of the surveyed wheel loader models, some also provide an adjustable padded wrist support associated with the right armrest for a more comfortable operation of hydraulic control levers. Armrests contribute to support the weight of the torso. The armrests should contact the fleshy part of the forearm, but unless very well padded they should not engage the bony parts of the elbow where the highly sensitive ulnar nerve is near the surface (Pheasant, 1996). Facilitating ingress/egress to and from the seat may require the armrests to be articulated.

Position in the cabin and visibility

Current wheel loader designs position the seat in the middle of the cabin (usually the cabin is designed for one person only; however, some models can be fitted with an optional instructor seat). This placement of the seat is probably the most adequate providing a centred view to the lift arm and bucket and the front wheels. Most models have a big window area all around the cabin and a curved hood to improve rear outside visibility.

Thermal and friction aspects

Heated seats and air conditioning are proposed as optional equipment by some of the manufacturers, contributing to the operators' control over thermal discomfort. Vinyl seat covers are not recommended due to low friction (giving lower postural support) and low vapour permeability.

Dampening of vibrations

Mechanical vibrations transmitted to the operator are, in current designs, absorbed by the seat suspension (mechanical and adjustable for the operator's weight or an air suspension). The operator contacts other interfaces (floor, pedals, steering wheel, lever controls), which are presently not dampened. This causes different modes of vibration in the operator's contact with the cabin, which is bound to be uncomfortable and affects the precision of movements. Other vibration dampening solutions, such as providing a block suspension for the cabin as a whole instead of for the seat, may improve operator comfort.

Other requirements common to the professional drivers seat
A wheel loader seat should also fulfil the requirements of the professional driver seat including being extensively adjustable (including seat cushion length adjustment), providing increased support (side supports, headrest, armrests), having user-friendly controls, and being fitted with a high friction, durable and high vapour permeability cover.

3.4 Future design challenges

In summary (concerning the directions for improvement pointed out in the previous section), what should be thoroughly evaluated and subjectively assessed in the near future towards extending the seated occupant's comfort and postural support, is: adjustable lumbar support (in height and depth), providing an articulation (with adjustable angle) at roughly shoulder level in the seat backrest, fitting adjustable headrests (in height and tilt angle), fitting lower torso side supports (adjustable in width), providing key power adjustments and a seat settings memory function, fitting the seat with three or four point seat belts, and providing a block suspension for the whole cabin instead of the current seat air suspension. An empirical investigation into operators preferred working postures should be part of the development process.

3.5 References

Åkerblom B. Chairs and sitting. In: Floyd WF, Welford AT, eds. Human Factors in Equipment Design. London: H. K. Lewis & Co. Ltd., 1954:29-35.

Coelho DA, Dahlman S. Articulation at Shoulder Level - A way to improve car seat comfort? Covilhã/Göteborg: Univ. of Beira Interior/Chalmers Univ. of Technology, 1999a. Technical report.

Coelho DA, Dahlman S. A pilot evaluation of car seat side support: Leading to a redefinition of the problem. International Journal of Industrial Ergonomics 1999b;24:201-210.

Coelho DA, Dahlman S. Evaluation of methods, approaches and simulation quality in the experimental evaluation of car seat comfort and functionality. Proceedings of the 14th triennial congress of the International Ergonomics Association, HFES, Santa Monica, California, 3, 2000:353-356.

Corlett EN. The evaluation of industrial sitting. In: Wilson JR, Corlett EN, eds. Evaluation of human work, 2nd ed. London: Taylor & Francis, 1990:621-636.

Ebe K, Griffin MJ. Qualitative models of seat discomfort including static and dynamic factors. Ergonomics 2000a;43(6):771-790.

Ebe K, Griffin MJ. Qualitative prediction of overall seat discomfort. Ergonomics 2000b;43(6):791-806.

Grandjean E. Fitting the task to the man, 4th ed. London: Taylor & Francis, 1993.

Gyi DE, Porter JM. Interface pressure and the prediction of car seat comfort. Applied Ergonomics 1999;30:99-107.

Lamotte T, Priez A, Lepoivre E, Duchêne J, Tarrière C. Surface electromyography as a tool to study the head rest comfort in cars. Ergonomics 1996;39(5):781-796.

Park S, Lee Y, Nahm Y, Lee J, Kim J. Seating Physical Characteristics and Subjective comfort: Design Considerations. SAE Technical Paper No. 980653, 1998.

Pheasant S. Bodyspace, 2nd ed. London: Taylor & Francis, 1996:244 pp.

Porter JM, Gyi DE. Exploring the optimum posture for driver comfort. International Journal of Industrial Ergonomics 1998;19(3):255-266.

Porter JM, Norris BJ. The effects of posture and seat design on lumbar lordosis. In: Megaw ED, ed. Contemporary Ergonomics 1987. London: Taylor & Francis, 1987:191-196.

Reed MP, Saito M, Kakishima Y, Lee NS, Shneider LW. An investigation of driver discomfort and related seat design factors in extended duration driving. SAE Technical Paper No. 910117, 1991.

Reynolds HM. Automotive Seat Design for Seating Comfort. In: Peacock B, Karkowski W, ed. Automotive Ergonomics. London: Taylor & Francis, 1993:99-116.

Troup JDG. Driver's back pain and its prevention. A review of the postural, vibratory and muscular factors, together with the problem of transmitted road shock. Applied Ergonomics 1978;9:207-214.

4 Vision

Matthias Roetting
Institute of Industrial Engineering and Ergonomics, Aachen University of Technology, Bergdriesch 27, 52062 Aachen, Germany

4.1 Introduction

Vision is of paramount importance in many of the tasks carried out by a wheel loader operator.

The whole area of vision encompasses three aspects:

1. the visual capabilities of the operator,
2. the characteristics of the environment the wheel loader is operated in, and
3. the design of the wheel loader itself.

This chapter will focus on the design of the cabin and other parts of the wheel loader. The influence of certain environmental conditions, e.g. weather, will be taken into account. It will be assumed that the operator has normal visual capacities.

Wheel loaders come in many different sizes and typically consist of two units with one axis each. The two units articulate around a central pivot arrangement which enables the vehicle to be steered. The driver cabin can be on either of the two main units. If the operators workplace is positioned on the front unit, the relation between cabin and bucket is constant.

Wheel loaders are typically used for loading and unloading goods, mainly bulk material, and in transporting goods over short distances. In addition, longer distances have to be covered to bring the vehicle to different sites. Sometimes wheel loaders will be equipped with other machinery instead of the bucket, e.g. for milling the surface of snowy roads or with a log grapple for loading logs. But the demands on vision during such tasks are very similar to the operation with the standard bucket.

Driving a vehicle and positioning goods can both be described in a control model of nested loops of navigation, guidance and control (cf. Sheridan, 1992; see figure 4.1). Visual perception is needed for all levels. Vision is needed in navigation, the planning of a driving task or the planning of a goods loading and unloading task, e.g. for the selection of a travel route. In vehicle and goods guidance as well as during the stabilization of the vehicle or the goods (control), optical features of the environment need to be analyzed.

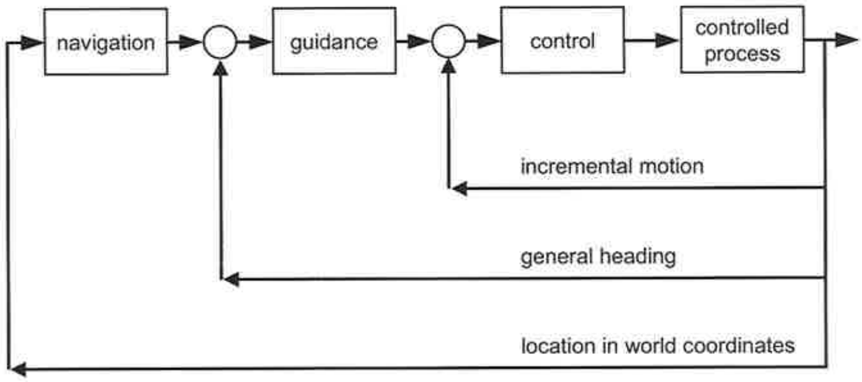


Figure 4.1 Navigation, guidance and control model (Sheridan, 1992). Applied to the operation of a wheel loader, the controlled process is the position in space and time of the wheel loader itself and of the goods handled

Four steps are proposed by NIOSH Mining Safety & Health Research (2001), citing Sanders and Kelley (1981), to assess the visibility line of sight:

1. specify the information requirements (conducting a task analysis);
2. identify, rate and locate visual features (determine which visual features provide the information the operator needs for a certain task);
3. specify the visibility requirements (either by (1) specifying "visual windows" of given size or location or by (2) specifying specific points in space that must be visible);
4. assess the fields of visibility (rate the visibility from operators station).

The information required is either located in the environment the wheel loader is operating in, can be perceived from the wheel loader itself, e.g. the position of the bucket or can be displayed within the drivers cabin.

Outside views are required for the driving and loading tasks in a changing environment. Other vehicles and people have to be observed, shifting of material has to be anticipated and taken into account. Inside views are required to check the state of the wheel loader, to read the displays, to locate controls or to locate other items within the cabin.

The viewing of the outside can be either direct through the windows and other openings of the drivers cabin or indirect with the help of mirrors or cameras.

Special consideration is required for work under adverse environmental conditions, e.g. during night, looking directly into the sun, or during rain, fog or snow.

Figure 4.2 shows the percentage of time an operator views certain areas of interest for a coach and a combine harvester. Despite the difference in the tasks involved, the time spend viewing the inside of the cabin is of the same order with 5% for the coach and almost 7% for the combine harvester. Similar results were reported by Göbel et al. (1998) and Göbel (1999) for short haul bus and tram drivers with values of about 5% to 8% for inside views including communication with customers. Greater influence of the task is seen when comparing the time spend looking into the mirrors: the values are 12.3% for the tram (Göbel, 1999), 10.2% for the short haul bus (Göbel et al., 1998), 2% for the coach and less than 1% for the combine harvester (Rötting et al., 2000). Depending on the task, values in the range reported are to be expected for the wheel loader for views directed to the inside of the cabin and the mirrors.

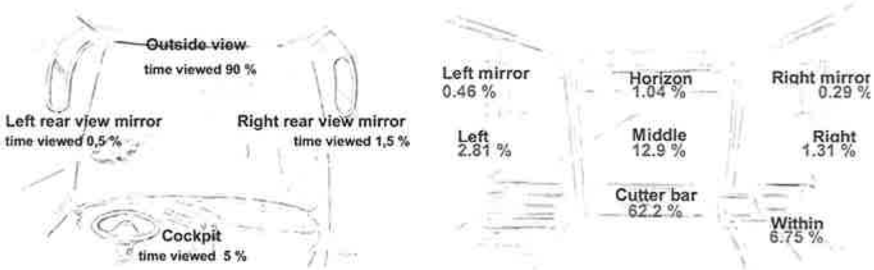


Figure 4.2 Percentage of time an operator views certain areas of interest for a coach (left) and a combine harvester (right) (Rötting et al., 2000)

4.2 Inside vision

Inside views are required to read displays, might be needed to locate and operate the controls or to locate other items within the cabin.

Displays should be positioned within areas A or B depicted in figure 4.3. The more important the information displayed, the more central to the normal viewing axis the display should be positioned. But it must be kept in mind that information from the environment might be more important and therefore it should be checked which part of the outside view is obscured by the display. Differences in the eye point of drivers of different size and due to variable seat positions have to be taken into account (Vedder, 1997).

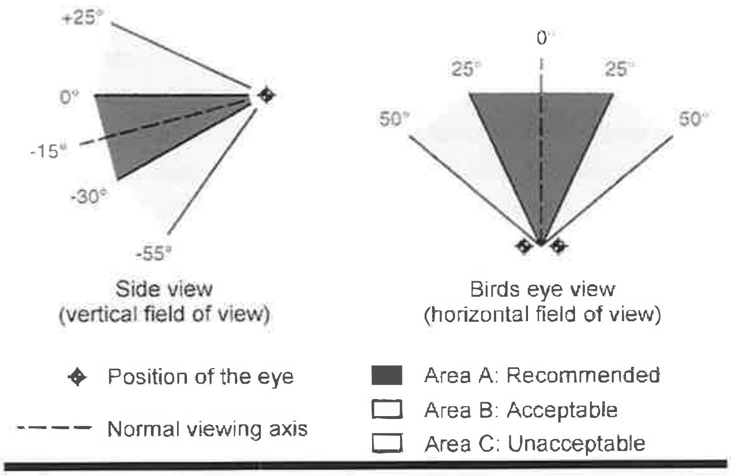


Figure 4.3 Position of displays in the vertical and horizontal field of view (Vedder, 1997, cf. DIN EN 894, part 2, 1992)

Information from the displays within the cabin should be comprehendible within short amounts of time to minimize the 'eyes off the road time' (e.g. Rötting, 2001). Zwahlen et al. (1988) proposed the graph reprinted in figure 4.4 to determine the acceptable number of looks and average duration per look inside a car to safely operate a car. The data in figure 4.4 are based partially on the results of an experiment driving a car with 40 mph on a straight lane road while operating a simulated CRT touch panel control. The speed of a wheel loader will be considerable slower, but the driving environment is very often narrower and more demanding. In addition, the operator has to control not only the vehicle, but the load as well.
Vibration in the cabin should be on a low level, not only to minimize adverse affects on the operators health, but not to interfere with the legibility of the displays (e.g. Boff & Lincoln, 1988).

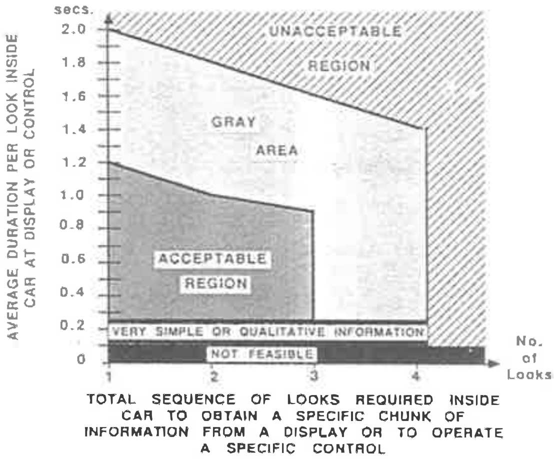


Figure 4.4 Acceptable number of looks and average duration per look inside a car to safely operate a car (Zwahlen et al., 1988)

4.3 Outside view

Three areas can be distinguished in the outside view: the area in front of the vehicle, the area behind the vehicle and the working area. In manoeuvring the sides the vehicle must be in good view as well, since accidents have been reported involving others working close to the moving vehicle (e.g. GROLABG, 2000).

Vedder (1997) developed a guideline for the ergonomic design of commercial vehicles and proposes to weight the importance of these three areas depending on the task (see table 4.1). The typical tasks of a wheel loader can be characterized as loading/unloading with transport, moving forward and backward, yielding an almost equal importance of the three areas.

Table 4.1 Weight factors for the different areas of the outside view (Vedder, 1997, abbreviated)

Task	front view	work area view	rear view
Transport	0.8	–	0.2
Transport with loading/unloading	0.6	0.2	0.2
Loading/unloading with transport	0.4	0.4	0.2
Loading/unloading with transport, moving forward and backward	**0.3**	**0.4**	**0.3**
Loading/unloading or handling/processing without transport	0.2	0.7	0.1

The evaluation of the visibility can not be done for wheel loaders in general, but only for specific makes. A recent study by Vedder (1997; 1999) evaluated the ergonomic design of two wheel loaders (Zettelmeyer ZL 4002, 1990 model; Volvo BM L 180 C, 1996 model). Vedder asserts a satisfactory visibility of the area in front of the vehicle and the working area, but, due to the design of the wheel loaders, a considerably worse visibility of the rear area.

Vedder (1997) further states that since the bucket of the wheel loader is positioned at the front, it will hinder the view of the front area. This hindrance is dependant on the position of the bucket. The restrictions are less if the bucket is in the lowest or highest position. In addition, the A-columns of the cabin occlude the front view. The view of the work area is not occluded except of the area directly in front of the bucket. The rear view is obstructed by the long engine compartment. Especially the view close to the vehicle, important in manoeuvring, is restricted. The view is further occluded by the exhaust and the air filters. Both wheel loaders are equipped with windshield washer and wiper for the front and windshield wiper for the rear window. The wipers cover a sufficient area. Fogging can be prevented by the ventilating system. Only one of the wheel loaders is equipped with a sun shade of sufficient size (Vedder, 1997).

The forward visibility of different construction vehicles was compared by Hella and Schouller (1999). Figure 4.5 shows the different elements that make up the occlusion for these different machines. For the loader, the main element is the engine cover, followed by other elements and the uprights of the cab.

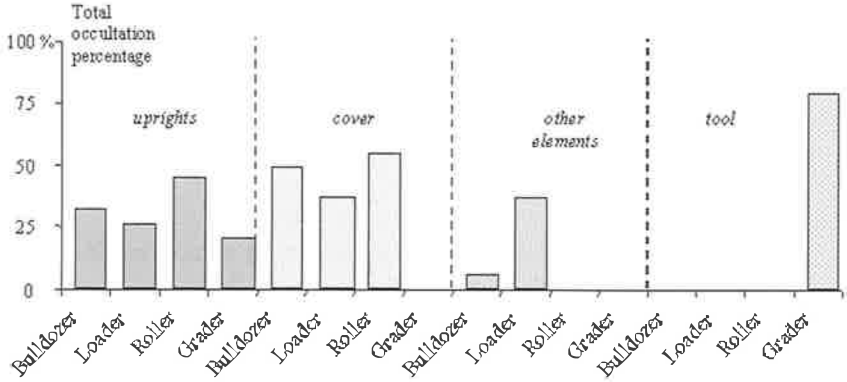


Figure 4.5 Contribution of elements making up the machine to the masking of forward field horizontal band, expressed as total occultation percentage (Hella & Schouller, 1999)

Direct view

Different methods are in use and/or proposed to identify blind spots in the field of view of an operator (e.g. Giguère & Larue, 1996). Most of them calculate the visibility for an average person (e.g. 50th percentile male) and only assume a static posture of the operator. Whereas this makes it easier to compare different vehicles or to quantify changes made to a vehicle, it is a gross simplification. Operators with different statures will operate a wheel loader and they can and will change their head and body position dynamically (cf. Land & Horwood, 1996, for a study of the relation of head and eye movements in driving).

The demands for the direct view of a wheel loader cabin can be summarized as follows:

- the windows should allow the view of as much of the surrounding environment as possible. Table 4.1 gives an indication of the relative importance of the different areas for different tasks. The windows should be as low as possible to allow the viewing of the immediate surrounding;
- the number of occlusions (e.g. parts of the cabin frame, the bucket, the bucket arm, mirrors, displays and other elements within the cabin) should be minimized. If occlusions can not be prevented, their size should be minimized;
- all windows that are essential for the outside view should be equipped with windshield wipers and washers. The field of coverage of the windshield wiper should be maximized;
- reflections from the inside of the cabin should be minimized;

- blinding by the sun should be prevented by a blind and/or coating of the window;
- fogging of the windows should be prevented by heated windows and/or adequate ventilation;
- distortions due to curvatures of the windows should be minimized.

Indirect view

Indirect vision systems serve two purposes. They reduce the time necessary to view e.g. areas behind the vehicle by moving parts of the rear view into the front view field (Flannagan & Sivak, 1993) and they give access to information necessary for a safe task execution in areas not directly viewable, so called "blind spots". Indirect "view" can be achieved by means of mirrors or cameras or by other (technical) means (e.g. collision avoidance systems). There is always a trade off between the area made visible by the indirect view system and the occlusion of information in the forward visual field.

The demands for the indirect view for a wheel loader operator can be summarized as follows:

- provide indirect view systems to minimize the number of blind spots;
- do not occlude important areas of information with indirect view systems;
- all indirect view systems should be easily adjustable to different operators and different operating conditions (e.g. servo adjustable mirrors);
- all indirect view systems should be provided with means to ensure their function even during adverse environmental conditions (e.g. heated mirrors to prevent fogging);
- indirect view systems should be evaluated under working conditions (e.g. vibrations can reduce the usefulness of indirect view systems).

4.4 Future challenges

Future challenges in the development of wheel loaders under the aspect of vision are the following:

- development of "dynamic" ways of analyzing vision in wheel loaders (and other commercial vehicles). This dynamic analysis should account for operators of different stature and size, should consider body, head and eye movements and should differentiate different demands of the task (e.g. demanding foveal versus peripheral vision);

- further reduction of occlusions by the vehicle itself. E.g. by minimizing uprights of the cabin, minimizing covers, rounding of covers, positioning of exhausts etc. outside of the visual field. This can be achieved by an early simulation of the viewing conditions with the help of computer models of the wheel loader and a representative operator population. Ergonomists should be involved in the development of a new wheel loader as early as possible;
- technical systems can provide information for the different operating tasks. Here lies the challenge in presenting the information to the operator without making up new burdens. Possible ways of achieving this are seen in head-up displays, augmented reality systems, displays utilizing peripheral vision, and changing the modality e.g. vision to sound.

4.5 References

Boff KR, Lincoln JE. Engineering Data Compendium: Human Perception and Performance. Wright-Patterson AFB, OH.: AAMRL, 1988.

Flannagan M, Sivak M. Indirect vision systems. In: Peacock B, Karwowski W, eds. Automotive Ergonomics. London: Taylor & Francis, 1993:205-217.

Giguère D, Larue C. The Visibility Audit: A Conceptual Framework for the Assessment of Visibility Around Trucks and Industrial Vehicles. In: Gale AG, et al., eds. Vision in Vehicles V. Amsterdam: Elsevier, 1996:371-378.

Göbel M. Blickbewegungsregistrierung bei der Gestaltung von Fahrerarbeitsplätzen des ÖPNV. In: Rötting M, Sefert K, eds. Blickbewegungen in der Mensch-Maschine-Systemtechnik. Sinzheim: Pro Universitate, 1999:118-132.

Göbel M, Springer J, Scherff J. Stress and strain of short haul bus drivers: psychophysiology as a design oriented method for analysis. Ergonomics 1998;41(5):563-580.

GROLABG. Vom Radlader überfahren. Unfall-stop, 3/Mai 2000, p. 5. (available online: http://www.grolabg.de/d/download/ustop300/seite5u6.pdf).

Hella F, Schouller J-F. Development of a computer-based method of assessing the visibility from construction site machinery. Proceedings of the International Conference on

Computer-Aided Ergonomics and Safety - CAES '99, May 19th-21st, 1999, Barcelona Spain, 1999. CD-Rom.

Land M, Horwood J. The Relations Between Head and Eye Movements During Driving. In: Gale AG, et al., eds. Vision in Vehicles V. Amsterdam: Elsevier, 1996:153-160.

NIOSH Mining Safety & Health Research. Human Factors Design Recommendations for Underground Mobile Mining Equipment, 2001. (available online: http://www.cdc.gov/niosh/mining/hfg/).

Rötting M. Parametersystematik der Augen- und Blickbewegungen für arbeitswissenschaftliche Untersuchungen. Aachen: Shaker, 2001.

Rötting M, Rösler D, Lohse K, Göbel M. Activity and eye movement analysis as basis of vehicle cabin design. Proceedings of the IEA 2000/HFES 2000 Congress. July 29 - August 4, 2000, San Diego, California USA. Santa Monica (CA): Human Factors and Ergonomic Society, 2000:3-341 - 3-344.

Sanders MS, Kelley GR. Visual Attention Locations for Operating continuous Miners, Shuttle Cars, and Scoops - Volume 1 (contract J0387213, Canyon Research Group, Inc.). USBM OFR 29(1)-82; NTIS PB 82-187964, 1981. Cited by NIOSH Mining Safety & Health Research, 2001.

Sheridan T. Telerobotics, automation and human supervisory control. Cambridge (MA): MIT-Press, 1992.

Vedder J. Systematische Bewertung der ergonomischen Gestaltung ausgewählter Nutzfahrzeuge. Düsseldorf (Germany): VDI-Verlag, 1997.

Vedder J. Ergonomics in commercial vehicles – problem, challenge, or resolved issue? Proceedings of CybErg 1999. http://cyberg.curtin.edu.au/members/papers/68.shtml.

Zwahlen HT, Adams CC, DeBald DP. Safety Aspects of CRT Touch Panel Controls in Automobiles. In: Gale AG, et al., eds. Vision in Vehicles II. Amsterdam: Elsevier, 1988:335-344.

5 Interior noise and vibration reduction

Roeland M.M. Hogt
TNO Automotive, Delft, The Netherlands

5.1 Introduction

Interior noise and vibration is one of the design aspects of machines. This becomes of major importance when the machine and man operate together for a long period (i.e. working day). The EuroCabins project investigates the ergonomics of cabins of earth moving machines. Interviews with a representative selection of operators have shown that noise and poor seat comfort are important aspects where improvements are needed.
This chapter briefly introduces the state of art around this topic, divided in:

1. interior noise;
2. hand-arm and whole-body vibration.

The chapter, based on a literature search and TNO projects, will give the designer some directions to go in optimizing these comfort aspects of the earth moving machines. First the state of knowledge for both areas is described. Next to pragmatic solutions new advanced developments will set new targets for noise and vibration reduction, i.e. active control systems. These will be presented in the paragraph after. Concluding remarks, a list of (internet) links and standards and the references will complete the paper.

5.2 State of knowledge

Reduction of the workload by increasing the comfort level has been subject of many studies. It is therefore impossible to give a complete overview of the developments in the past and present. Literature has been studied and from this study some developments have been selected for this chapter. More detailed information can be found through the references, the internet links and the standards.
The next paragraphs describe the state of knowledge for the area of interior noise and body vibration.

5.2.1 *Interior noise*

Requirements and standards

By legal requirements the maximum noise level for a workplace is set to 80 dB(A). Additional to this requirement comfort, market or company targets may set the admissible maximum value of interior noise to a lower level. To interpret the value of interior noise correctly it is important that this value is determined according approved measurement standards and that the operating conditions are well defined.

The noise level measured at the driver's ear is defined by the

- the noise level of the sources (like engine, fan, hydraulic pump and motors, hydraulic valves);
- the transmission of the noise;
- the design of the cabin.

Optimal reduction can however only be achieved if noise reduction is integrated in the whole design process. In the next paragraph a method for low noise design will be presented. This type of noise can be classified as structural and has a repetitive character. Following to this, so called *squeak and rattle*, which can also cause inadmissible increase of the workload, will be discussed too.

The design process

The design process consists of the following stages:

- package of demands;
- conceptual design;
- detailed design;
- prototyping.

- Package of demands

  In contrast to the standards for the noise level on the place of work, no specific demands are available for the noise level exposed to the operator of earth moving machines. The investment in noise reduction is therefore a deliberation between costs and the added value to the product form marketing's point of view.
- Conceptual design

  The design systematic has been developed in the European Brite-Euram project Equip (Dittrich, 1999). This development includes a software package (briefly introduced later in this paragraph). This systematic tool is supplementary to ISO Technical report 11688-1/2 for design of low noise machinery and equipment ISO (1998;2000). The choices made in the conceptual design are essential for the obtainable comfort level with respect to noise and should be applied for:

- engine (type of engine, position, mounting in the chassis),
- hydraulics (pump + valves, cylinders, tubes),
- pneumatics (pump + valves, cylinders, tubes) and
- electrical components.

Basic rules to minimise the noise level are:

- apply low noise active sources: engine (by using a gas engine or an electrical motor instead of a diesel engine), fan (optimized blade geometry, efficiency, minimum tip speed, smooth flow, no close obstacles in flow), transmission (use a belt instead of gear wheel transmission), pumps/motors/valves (use gear pumps if possible) and in general minimise rpm, loading and flow velocities, tip speed and turbulence;
- balance noise emission of various sources to avoid excessive noise control (and cost). This can only be done by first assessing by measurement the ranking of sound radiators for a particular machine;
- minimise noise transmissions through:
  1. air-borne (AB) paths like leaks, panel and window insulation engine enclosure.
     Use absorption in engine housing and in cabin; sealing of leaks; optimized window and panel insulation for cabin (materials + design); selection and positioning of best intake + exhaust muffler with cap;
  2. structure-borne (SB) paths like engine mounts, cabin mounts pump/motor and valve mounting. Use effective elastic mounts for engine, cabin and hydraulics; avoidance of resonance;
  3. liquid-borne (LB) paths like hydraulic hosing and piping hydraulic damper/resonator by optimized dimensioning and positioning of piping and hoses;
- minimise sound radiation from radiators to cabin surface like the engine exhaust and intake (keep distant and direct away from cabin), fan and cooling intake turbulence engine radiation and hydraulics radiation;
- apply or optimize elastic isolation, engine enclosure and absorption and damping materials where effective. Integrate noise damping in conceptual design;
- detect and avoid obvious noise control errors such as leaks (cabin), unnecessary transmission through the structure, resonance, rattle, squeak,

high turbulence, and direct excitation of the cabin (air-borne or structure-borne).

- Detail design
  In the detailed design stage further reduction can be obtained by checking the design on unnecessary clearance, noise leaks and reasoning panels.

  Example
  For reducing the noise by the engine an "Engine near-field shield" (Wolf & Portal 2001) can be applied. The shields consist of a basic load bearing body (generally made of a polyamide compound) in conjunction with an absorption element made of acoustically effective polyurethane foam. The fastening of the neutralising components consists of an elastomeric mixture corresponding to the vibration technological requirements. For the functionality a distinction has been made between frequency in the range of the engine levels and higher frequency engine noise (i.e. combustion noise). In order to minimise the excessive and unavoidable noise resulting from the design of components in the area of the lower engine levels, it is necessary to employ a sufficiently rigid structure for the cover as well as suitable insulation of structure-borne noise by means of tuneable decoupling elements. Depending on the on the frequency a reduction can be obtained up to 8 dB (Yamaki et al., 1999).

- Prototyping
  However the possibilities are limited in this stage of the design, measurements of the noise level may lead to a further optimization. Possible solutions can be found in relocating components and the use of damping and absorbing materials.

Diagnostic measurement techniques for source identification and ranking are for example:

- sound intensity measurement,
- order analysis and
- vibration measurements.

Applicable calculation techniques are dynamic and acoustic finite element calculation and Statistical Energy analysis. It is however most important to create a visual noise path model of the machine, indicating the relevant components generating the noise, AB/SB/LB transmission paths and radiators, and the receiver (operator ear position). Once this is clear, even without detailed measurements or calculations, a first proposal for noise control measures can be made. TNO's EQUIP+ software for noise path modelling provides a tool to perform this task (see figure 5.1).

This development partly took place within the Brite-Euram project 'EQUIP' (Dittrich, 1997). The resulting software is now in part available for industrial application. The Noise Path Modelling System is based on a library of:

- noise generation mechanisms;
- generic machine and structural components;
- acoustic devices (enclosures, isolators, etc.);
- receivers.

Focussed on the cabin only vibro-acoustic optimization can be done using Multi-Disciplinary Optimization (MDO) techniques (Miccoli, 1999). This technique, integrated in Computer Aided Engineering (CAE) tools, creates Response Surface model (RSM) of each design output as function of the design input. With a minimal of simulation runs it turns out possible to identify the most critical design inputs, quantify how the design inputs influence the design outputs, detect correlated design outputs, predict design output values for untried design input values and estimate the manufacturability of the product with regard to the design outputs. Figure 5.2 shows the earth moving machine cab 3D structural model.

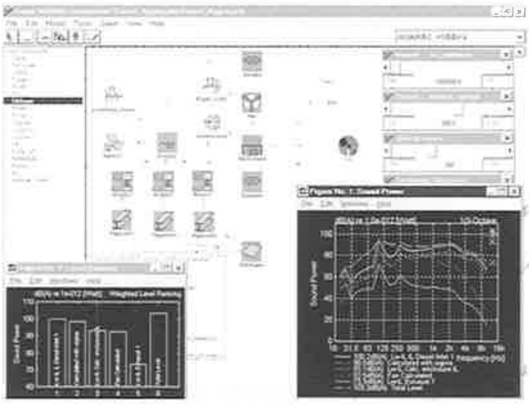


Figure 5.1 Noise path model of a diesel engine aggregate

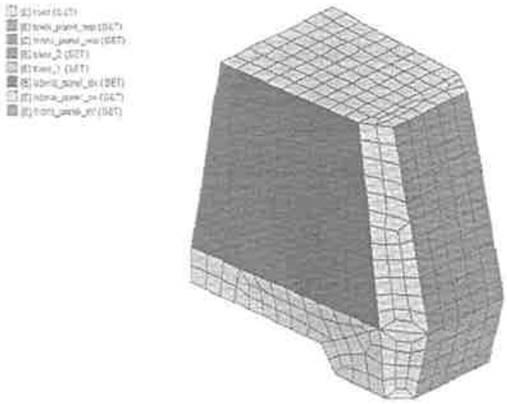


Figure 5.2 The earth moving machine cab 3D structural model

Squeak and rattle noise

Not mentioned in the previous part is the non-repetitive noise of Squeak and Rattle (S&R) (Automotive Engineering, 2001). S&R noise is highly dynamic, presenting difficulties for some types of analysis. Furthermore, S&R events measured in real driving environments often have other, higher-level acoustic events. For example, when a vehicle crosses a large, abrupt road irregularity, a non-S&R acoustic event usually will be generated by the impact. There also can be a corresponding S&R event, but at a very low level compared to the acoustic impact. This low relative level merely adds to the analysis difficulty. Many squeaks and rattles occur from sliding contact between interior plastic parts. A tensile tester was used to measure the friction force of a plastic sliding on itself. When stick slip occurred during sliding, amplitude of the stick slip was used to describe the tendency for the sliding pairs to make noise. The plastics examined are polypropylene (PP), polycarbonate (PC), acrylonitrilebutadienestyrene (ABS), polyamide 6 (PA6), polyoxymethylene (POM), PC/ABS blend and ABS/PA blend. PP had the lowest stick slip amplitude. The ranking of the test materials, according to increasing stick slip amplitude, are PP, ABS, PC/ABS, PC, ABS/PA, POM, and PA6.

5.2.2 *Vibration (body)*

Vibration control in drivers' seat is a permanent research topic. Not only the importance of prolonged exposure to excessive vibration influence us stressed but also the importance of exposure to occasional large bumps is inevitable in reality.

Requirements and standards

A guide for the evaluation of human exposure to whole-body vibration in the range 0-80 Hz is described in the ISO standard 2631. In this range the standard distinguishes two ranges:

- 0.5 Hz to 80 Hz for health comfort and perception and
- 0.1Hz to 0.5 Hz for motion sickness.

Limits are given for use according to the three general recognisable criteria of preserving comfort. These limits are influences by the measuring position and also scaled by frequency weighting curves. The frequency weighting curve is defined per direction (x , y and z) and for respectively the exposure to health, comfort, perception and motion sickness.

The design process

General rules like those that have been discussed for the interior noise are also applicable for the whole body vibration. Further to this a special area is the driver seat comfort. Here a compromise should be found between comfort and control. A stiff seat spring reduces the comfort but increases the controllability and prevents for the motion sickness.

Research (Hogget et al., 1995) has shown that for standard driver seats with air spring a strong coherence between the input and output signal is found for frequency up to 2 Hz. With increasing frequency up to about 10 Hz this coherence drops down to zero. The transfer function is very much depending on the configuration of the driver chair. One of the problems comes from the height control of the chair. A combination of reducing height with an upward vertical acceleration may result in high acceleration shocks. These can be prevented by a case sensitive height control or by adding additional damping at the end of the stroke.

A compromise between comfort and controllability has been found in for example electro pneumatic active seat suspension systems (Stein, 2000). The vibration control is facilitated by a combination of a 'sky hook' feed back loop and a feed forward loop working in the so-called 'sky cloud' principle, compensating for base vertical vibration. The system is especially of interest for vehicles with an unsprung chassis like earth moving machines.

In order to optimize the seat comfort, computer aided techniques like vehicle dynamics simulations can be of great help. Here the following stages should be distinguished:

- modelling the vehicle as a whole;
- definition of the movements of the vehicle (for example by logging them on a existing vehicle at work) and the seat relative to the vehicle;
- analysis of the effects of the present configuration on comfort, etc. and motion sickness;
- validation of the model;
- optimization the seat suspension (or maybe also the cabin mounting to the chassis) with respect to comfort, etc. and motion sickness.
  Human sensing models as presented in paragraph 5.3 can be of great help to an objective rating of the present and future configuration.

Thus an solution could be found in replacing some components or if necessary revising the complete design of the seat suspension by for example replacing it by an active suspension. In this way, the use of computer simulation can give the necessary data to decide for the optimum between costs and performance.

5.3 Future design challenges

Future design of cabins may be improved by use of following developments:

1. development op active systems;
2. application of sensing human model in simulations.

Not worked out here but a general future design challenge is the reduction of the noise by optimizing conventional solutions (§ 5.2.1) and the deliberation between costs and added value to the product from marketing's point of view.

Development of active systems

Active control is sound field modification, particularly sound field cancellation, by electro acoustical means. In its simplest form, a control system drives a speaker to produce a sound field that is an exact mirror image of the offending sound (the "disturbance"). The speaker thus "cancels" the disturbance, and the result is no sound at all. In practice, of course, active control is somewhat more complicated (Ruckmann, 2001).

The name differentiates "active control" from traditional "passive" methods for controlling unwanted sound and vibration. Passive noise control treatments include "insulation", silencers, vibration mounts, damping treatments, absorptive treatments such as ceiling tiles, and conventional mufflers like the ones used on today's automotive application. Passive techniques work best at middle and high frequencies, and are important to nearly all products in today's increasingly

noise-sensitive world. But passive treatments can be bulky and heavy when used for low frequencies. The size and mass of passive treatments usually depend on the acoustic wavelength, making them thicker and more massive for lower frequencies. The light weight and small size of active systems can be a critically important benefit; see later sections for other benefits (Ruckmann, 2001).
The most successful demonstrations of active control have been for controlling noise in enclosed spaces such as ducts, vehicle cabins, exhaust pipes, and headphones. Note, however, that most demonstrations have not yet made the transition into successful commercial products.

Application of sensing human model in simulations

Research of the rating of the comfort level earth moving construction equipment (Kumar et al., 1999) has compared the subjective and objective rating of comfort. In this research three pieces of earth moving construction equipment have been used by each operator. The equipment was grouped into three size categories (small, medium and large). Both static and dynamic activities were evaluated. The psychophysical ratings of the vibration level have been compared with the objective measures. The study demonstrated that the size of the equipment and activity were significant determinants of the psychophysical ratings. Also the psychophysical ratings of vibration levels and discomfort correlated well. But weaker correlation was evident between subjective ratings and quantitative vibration levels.
A better understanding of the subjective ratings can be achieved by application of human models in simulations. These kind of models have been developed for the MADYMO multi body simulation package (Oudenhuizen et al., 2000). A range of MADYMO human models has been developed and validated for impact simulation. These include multibody full body models, multibody detailed segment models, FE segment models and a full FE human model. The human models are multi-directional and are therefore applicable for frontal, lateral and rearward impact.
The multibody mid-size male model is currently being validated with the aim to develop a virtual-testing-tool which can predict comfort in automotive driving conditions. Using the human model in a virtual test environment instead of tests with dummies has the following advantages:

- the human model accurately represents the geometry of the human body, which is important in the analysis of pressure distributions;
- the effects of muscle activity can be incorporated in human models;
- virtual testing is a relative cheap and efficient tool in the design process.

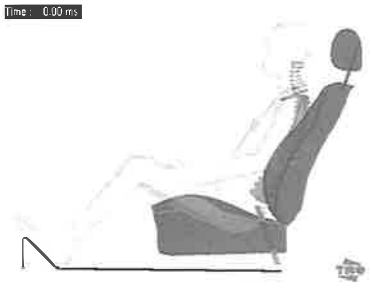


Figure 5.3 The MADYMO multibody model

The MADYMO human model will be used to model the interaction between the human and the vehicle, with the objective to predict mechanical parameters that are related to the subjective feeling of comfort. Both static and dynamic comfort are considered. The static comfort analysis focuses on the prediction of posture, joint angles, joint forces and torque, and seat pressure. The dynamic comfort analysis includes predictions of the dynamic body motion due to vibrations, joint forces and torque, seat pressure, and accelerations. A number of vibration tests with volunteers has been performed to validate the human model for dynamic comfort. Next to the multibody human model, detailed FE sub models will be used for the pressure analysis. The multibody human model is presented in figure 5.3.

5.4 Concluding remarks

This chapter has presented all kinds of measures which can be taken to reduce the noise and vibration focussed on earth moving vehicles. It has shown that targets only can be reached if noise and vibration reduction is incorporated in all development stages of the vehicle.

For the reduction of noise and high frequency vibration a pragmatic solution like the use of a noise path model can already lead to good results. Computer aided techniques are relevant too. In the low frequency vibration with respect to seat comfort aided techniques are a necessity to reach the optimum between comfort and controllability of the earth moving machines.

Concluding this chapter it is clear that both noise technology and vibration technology give enough chances to come to a significant improvement. If a manufacturer wants to apply these, is however a deliberation between costs and the added value to the product form marketing's point of view.

5.5 Internet links and international standards

Internet links

- www.sae.org
- www.NVHmaterials.com

International Standards

- Interior noise:
  - ISO/DIS 6394: 1995
    Acoustics. Measurement of airborne noise emitted by earth moving machinery. Operator's position. Stationary test condition
  - ISO 6396:1993
    Acoustics. Measurement at the operator's position of noise emitted by earth-moving machinery. Dynamic test conditions
- Exterior noise (not discussed in this paper):
  - ISO 6395/DAM 1: 1996
    Acoustics. Measurement of exterior noise emitted by earth-moving machinery. Dynamic test conditions
  - ISO/DIS 6393: 1995
    Acoustics. Measurement of exterior noise emitted by earth-moving machinery. Stationary test conditions
- Body vibration:
  - ISO 2631-1: 1997
    Mechanical vibration and shock – Evaluation of human exposure to while body vibration- Part 1 general requirements

5.6 References

Automotive Engineering Online. Detecting Squeaks and Rattles. NVH reduction trends, 2001.

Dittrich MG. The EQUIP project: Methodology and a Computer Tool for Low Noise Design. Delft (The Netherlands): TNO-TPD, 1997. Presented at Internoise 1997.

Dittrich MG. Een kennissysteem voor geluidsarm ontwerpen. Delft (The Netherlands): TNO-TPD, 1999.

Hogget RBJ, et al. Analysis of the vertical movement a an air spring driver seat. Delft: TNO-WT, 1005. TNO-report 95.OR.VD.021.1/RH. In Dutch.

ISO Technical report 11688-1. Acoustics-Recommended Practice for the design of low-noise machinery and equipment, Part 1: planning. ISO, 1998.

ISO Technical report 11688-2. Acoustics-Recommended Practice for the design of low-noise machinery and equipment. Part 2: introduction into physics of low noise design. ISO, 2000.

Kumar Kittusamy, et al. Subjective response to whole-body vibration among operators of construction equipment. Huntington (USA): Marshall University, 1999. Presented at Internoise 1999.

Miccoli G. Vibro-Acoustic optimization of earth-moving machine cab structural components. Italy: Earth moving Machinery and Off-Road Vehicle Institute, 1999. Presented at Internoise 1999.

Oudenhuizen AJK, Verver MM, Happee R, Delleman N. ACHIEVE: An overview of Driver Comfort. Soesterberg: TNO-TM, 2000. TNO-Report 'Company confidential': TM-00-D011.

Ruckmann CE. Active noise control Frequently asked Questions; www.NVHMaterials.com; 2001.

Stein GJ. New results on an electropneumatic active seat suspension system. Journal of Automobile Engineering 2000;214:533-544.

Wolf A, Portal W. Requirements to noise reduction concepts and parts in future engine compartments. Woco Group; SAE paper 2001-01-0027.

Yamaki T, et al. Engine noise reduction using close fitting acoustical enclosure based upon new concept. Yokohama (Japan): Dept. of Mech.Eng., Kanagawa University, 1999. Presented at Internoise 1999.

6 (Changes in) human dimensions

Aernout J.K. Oudenhuijzen
TNO Human Factors, Soesterberg, The Netherlands

6.1 Introduction

TNO is involved in various automotive R&D projects. Next to these projects we are involved in procurement programs involving vehicles for land, sea and air. Often we are confronted with anthropometric accommodation problems concerning vehicles. These problems involve tall people not fitting in the vehicle, small people not able to reach to essential/task critical controls and displays/controls positioned so that they are obscured and therefore not quite or poorly visible. For instance 38% of cars submitted were rejected resulting from 'ergonomic problems' in a procurement project involving service-cars for the Royal Netherlands Army. Most of them did not provide the seated operator with enough space to be seated properly. In other words, these cars were too small for the tall Dutch males. It is evident that these tall Dutch males were overlooked during the design process of these vehicles. A step-by-step process, involving simple anthropometric rules, is described to overcome these kinds of problems during the design of cabin's of wheel-loaders.
This chapter is written to provide a guideline for the anthropometric design process for cabin's of wheel loaders. Special attention is given towards the determination of the target population for the cabin being designed. Several anthropometric data-sources are introduced as well as how to use these data in order to determine the design limits for the cabin.
Various geometric representations are described: 2-D, 3-D, hardware and computer supported digital human modelling systems. The next issue is to determine the occupants' seated posture in the cabin as well as the needed free space between the occupant and the cabin. After this several guidelines and recommended practices about positioning of controls and displays are discussed.
Finally the use of prototyping techniques (digital and hardware mock-up testing) will be discussed.

6.2 Anthropometry during the concept phase

'One of the first steps in designing a new motor vehicle is to create the "occupant envelope". This procedure involves establishing the required interior space, and arranging interior and structural components in a manner that is consistent with the driver and passenger safety, comfort, convenience and accommodation' (Roe, 1993). This 'occupant envelope' is a crucial element in the conceptual stages of the design of a cabin. An improper envelope will directly result in ergonomic problems for a lot of people. This envelope is to be created as follows:

a. determine the target user population for the cabin. This is being determined based on market expectation (EU, World-wide sales, specific country's), life of type (how many years will the vehicle be in use);
b. gather the anthropometric data for the target user population (a wide range of databases is available);
c. select the design limits for the cabin;
d. create geometric manikins of the target user population;
e. determine the seated posture in the cabin (high, middle or low initial seat placement);
f. position the manikins in the determined seated posture;
g. determine the amount of needed free space between occupants and the cabin;
h. determine the occupant envelope around the seated manikins and position the workplace elements (steering wheel, side stick controllers, pedals controls and displays) as well as other structural elements (windows, doors, ceiling, etc.) around the manikin.

The steps a-h will be discussed in detail in the sections below.

The target user population

One of the first and very essential steps is to determine the user population for the cabin being designed. This is a difficult task since one has to make a prognosis of the future users. Marketing specialists need to have a solid opinion of the market and therefore the future users. This step is very essential because it determines the anthropometric boundaries for the design. It will determine who will fit, and who will not fit in the vehicle. This decision lays constraints on the vehicles market opportunities. A vehicle accommodating a relative small population may not fit the rather tall Dutch population; the marketing opportunities for this vehicle are then restricted to "smaller" countries. This is caused by an anthropometric variability amongst different nations, even in the EU itself. It is evident that it will be more difficult to construct a cabin for a wide variability array of nations compared to constructing for a single nation. However, it must be mentioned that constructing for a small target population can be pennywise but pound-foolish. One has to bear in mind that many vehicles were originated for a single nation and eventually sold in other nations resulting in anthropometric accommodation problems.

Anthropometric data sources

Today several anthropometric databases are available. Most of these databases represent military populations. Unfortunately, these data do not represent the consumer population for several reasons:

- the databases are outdated and do not take into account the secular trend of acceleration (this is the increase in stature over the years);
- the databases contain selected samples (the military select their recruits based on anthropometric criteria);
- the age-range of subjects measured (the military usually measure young recruits for selection purposes);
- insufficient national coverage (e.g. no available data on a specific needed nation);
- the physical condition (training).

There are several databases available for international anthropometry. One of them is a study from Jurgens (1992). Jurgens gave an overview on the variability in anthropometric measurements and body proportions of the world population. In this study Jurgens classified the world population in 20 groups according to anthropometric similarity. Data on several percentiles are provided on 19 anthropometric values.

Another study is in progress: the CAESAR program (see www.nedscan.nl, www.sae.org (use the SAE (Society of Automotive Engineers) search-engine for CAESAR, http://hec.afrl.af.mil/cardlab/caesar). 2-D and 3-D anthropometric data are gathered in this co-operative project, sponsored by the SAE, between the US Air Force and TNO Human Factors. The results of this program incorporate conventional anthropometric data as well as 3-D surface scans of subjects (see figure 6.1). These surface scans are a copy of the subjects skin. This database will consist of 3,000 American, 1,255 Dutch and about 1,250 Italian civilian subjects.

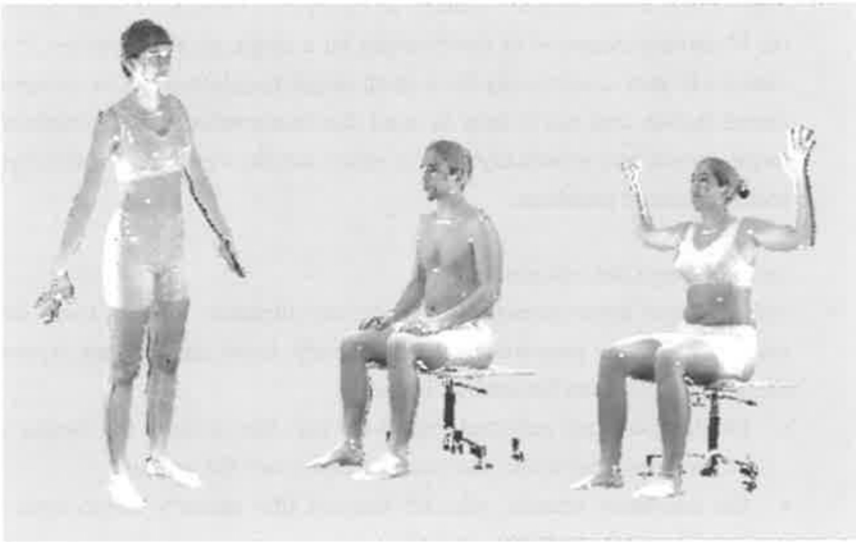


Figure 6.1 An example of 3-D surface scans of subjects

Other databases are more nation specific. Stoudt et al. (1965) reported the results of a representative study, concerning the American adult population, consisting of 6,672 subjects. Abraham et al. (1974) reported a similar study based on US men and women aging 18 to 79 years of age. Both studies are based on measurements on civilians. However, these data are somewhat outdated and do not take into account the secular trend of acceleration.

Select the design limits for the cabin

In many vehicles compromises must be made. For example: the depth of the cabin of a wheel loader could be restricted for a higher capacity of the vehicle. This limited depth could result in a poor accommodation of some people in the intended target population.

Ideally, the cabin would fit all targeted people. However, this is not always possible or feasible. For instance: the target user population could involve both the Chinese and the complete Northern European market. This would mean that all adult Chinese and Northern Europeans have to be accommodated. The smallest Chinese women should fit as well as the tallest Dutchmen. This would result in the necessity to accommodate a person with a stature of about 1.32m (the P0 Chinese female) and a person with a stature of about 2.65m (P100 Dutch male). This could only be made possible by constructing two or more vehicles, a vehicle for the 'smaller' and for the 'taller' subset of the target user population. The de-

velopment costs for these two vehicles would probable be doubled. This would result in a very expensive product line that is not affordable any more.
Usually compromises are made by means of defining 'design limits'. A design limit expresses the accommodated percentage of a target user population. Design limits often use an accommodation target of 90%, 95% or even 97.5% of the target user population. The variability that should be taken into account increases with a higher accommodation target. It is advised to consider a number of issues in the determination of the design limits. These issues are safety, comfort and costs.

It is advised to follow the recommendation below when selecting the design limits for the cabin:

- determine the design limits, based on percentiles, step by step: in the very first conceptual stages of the cabin design process one is not quite interested in the detailed anthropometry of the occupants hands. Other dimensions may be more critical: one has to determine the main dimensions of the cabin first: needed design limits are for instance:
  a. sitting height, the vertical distance between the seat pan and the top of the head;
  b. knee height (sitting), the vertical distance from the floor to the top of the kneecap with the lower leg at an angle of 90° with the upper leg;
  c. buttock knee length (sitting), the horizontal distance from the buttocks to the knee with the upper leg placed horizontal (and the lower leg vertical).

  Later in the design process other dimensions will be needed, for instance one needs the detailed dimensions of the hands to position controls within reach of the target population. **In short: use design critical parameters for design limits!**
- **do not combine percentiles!** It is virtually impossible to define one P5 female. Some body measurements correlate. However, there is no assurance that a manikin defined on the basis of stature would have fifth percentile arms and legs (Robinette & McConville, 1981);
- the anthropometric databases provide data on non-clothed people. However, additions for personal equipment such as boots, clothing, helmets, etc. may not be forgotten. These items can reduce free space between the occupant and the cabin significantly. For instance the free space of 40mm between the 'naked' head and the ceiling may prove insufficient for somebody wearing a helmet.

Create geometric manikins of the target user population

The next step is to create geometric representations of the target user population based on the design limits determined above. There are several options to create these manikins. Each of these options is described below as well as the inherent advantages and disadvantages.

- Accommodation practices

  Today several accommodation practices are available for purposes of cabin design. Philippart (1985) described the truck driver workspace in general. Aspects covered in this paper are anthropometry, modelling, location of drivers in truck cabins, the driver eye ellipse, head contour, shin contour, knee location, etc. The SAE J1521 gives recommendation for the position of the truck driver shin-knee position. A wide range of SAE practices determine the occupants eye range (SAE J941), the selected seat position (J1517), the driver hand control reach (J827), etc. These kinds of practices are available for cars, trucks, busses and off road equipment. There is even a special standard for the design of cabins of busses, trucks and utility vehicles for the Dutch market (NEN 5526 and 5518).

  Manufacturers developing cabins to accommodate a specific target population use these tools or can use these standards and recommended practices as a guideline. These practices are very easy to follow and give direct feedback with regard to the dimension of the cabin and the position of various workspace elements.

  The disadvantage is that these standards are based on a specific target population. They are not target population independent. For instance, the standard NEN 5518 focuses on the Dutch population, it specifies requirements based on a population ranging in stature from 1.55m to 2.00m. The standards and practices can be used very well as long as the target population for the cabin is covered by the accommodation practices and standards. These practices are not very well usable to design cabins for a population not covered in the practice. Another shortfall of these practices is that they do not integrate very well with design tools, such as 3-D CAD (Computer Aided Design) and manufacturing systems. These practices were more oriented towards the use of drawing tables.

- Human Modelling System's (HMS)

  HMS's are a very cost-effective means to assess anthropometric issues of cabins during the design process (Chaffin, 2001). They interface or even reside in CAD systems. These HMS combine the CAD- with the human geome-

try. With HMS one can study a target users populations fit, reach to controls and view inside and outside the cabin.
Advantages of HMS are that design problems become visible early in the design process, studies are flexible and not time consuming (compared to hardware mock-up tests with subjects). They can also foresee future accommodation problems in considering fit of the future (and thus taller) population. Bowman (2001) described a study where HMS were used in the development of a heavy vehicle. The HMS were used to prove compliance with the Federal Motor Vehicle Safety Standard, the reachability and visibility to/of the vehicles instrument panel and a study about the vehicles ingress and egress. Most of these HMS are based on anthropometry. It must be mentioned that accommodating occupants is more than only anthropometry; biomechanics and biodynamics come also into play. Biomechanics are important to predict the deformation of a seat and the buttocks once an occupant is seated. Biomechanics are also important to have adequate reach and posturing algorithms in the HMS.
The disadvantages of some HMS are that they do not take the biomechanics into account. This may cause improper results for reachability and accommodation studies (Oudenhuijzen, 2001).

Both accommodation practices and Human Modelling Systems support the cabin design process effectively. Especially because these systems are integrated into CAD. However, it may be advisable not to fully rely completely on these practices and systems. These systems can be used to reduce, but do not eliminate, design risks. It is therefore recommended to perform mock-up and field tests for critical design issues.

Determine the seated posture in the cabin (high, middle or low initial seat placement'
There are several approaches to accommodate seated occupants in cabins. The seated posture can be very upright, reclined or in between these two extremes. Each of these postures have their specific occupant envelope. The reclined-seated posture requires more cabin depth and less cabin height. The upright-seated posture requires more height and less cabin depth. The reclined seated posture is used in cars; upright postures are often used in cabins for trucks, vans or wheel loaders. The seated postures differ in the placement of the seat. The seats are positioned higher, in comparison to other seated postures, for the upright posture. Three seated postures, to be used for the design and evaluation of cabins, are defined in NEN 5518 (2000). NEN 5518 (2000) also specifies the corresponding

occupant envelopes as well as the positions and needed adjustment ranges for several workplace elements (steering wheel, seat, controls, displays, etc.).
The next step is to position the geometric representations of the target user population in the determined seated posture and to determine the amount of needed free space between the seated occupants and the cabin. Free space is needed all around the occupant's body:

- above his head to avoid collision with the ceiling (wheel loaders may operate in open terrain, vertical acceleration due to this type of operation should be taken into account);
- free space between controls and the occupant's hand and feet (special attention must be given to additions due to personal equipment).

There are no standards available on free space for vehicle design. A reference that may be of use is the MIL-STD-1333b (1976). This reference specifies the free space as follows: 'a minimum clearance of 1.5 inches (= ca. 38 mm) between the wheel and the structure shall be maintained in addition to a minimum clearance of 0.5 inch (= ca. 13 mm) between the crewmembers hand and body (...) when operated throughout the critical anthropometric range as specified by the acquiring activity'.

Determine the occupant envelope around the seated manikins and position the workplace elements

One can determine the occupant envelope once the previous steps are fulfilled. This occupant envelope will be used for the determination of the position of the floor, ceiling, knee guards, kick plates and the back wall of the vehicles cabin in relation to the seated occupant. The NEN 5518 (2000) specifies the occupant envelope for the Dutch population (stature ranging from 1.55m to 2.00m).
When the occupant envelope has been determined, one can start to position the workplace elements on the cabin. It is impossible to provide a detailed guideline for this process, especially because compromises will be made during the cabins design process. Some guidelines (NEN 5518 (2000), MIL-STD-1333B (1976)) give detailed information regarding the position and adjustment ranges of the pedals and the steering wheel in relation to the seated driver.
The placement of controls and displays is a difficult task. There are many controls and displays (components) to be positioned in a limited amount of available space. Many of these components have an optimum place in relation to the seated driver/occupant. However, the space available in this optimal area is insufficient to arrange all components combined. Sanders and McCormick (1983)

gave guiding principles of component arrangement. They defined the following principles:

1. *the importance principle*: this principle deals with operational importance: 'the degree to which the performance of the activity with the component is vital to the achievement of the objectives of the system';
2. *the Frequency-of-Use principle*: this principle applies to the frequency with which a component is used;
3. *the functional principle*: this principle refers to arrangement of groups of components according to their function;
4. *the Sequence-of-Use principle*: 'in the use of certain items, there are sequences of patterns of relationship that frequently occur in the operation of equipment'.

In a discussion Sander and McCormick (1983) state: 'in putting together the various components of a systems, it is manifest that no single guideline can, or should, be applied consistently, across all situations. But in a very general way, and in addition to the optimum premise, the notions of *importance* and *frequency* probably are particularly applicable to the more basic phase of locating components on a general area in the workspace; in turn, the sequence-of-use and functional principles tend to apply more to the arrangement of components within a general area'.

6.3 Expert opinion on anthropometry in the current designs of wheel loader cabins

This chapter gave an overview on current anthropometric practices in cabin design. Special attention was given towards the determination of the target population for the cabin being designed. This aspect should not be overlooked when developing a new vehicle. Several anthropometric data-sources were introduced as well as how to use these data in order to determine the design limits for the cabin. The application today of all these tools is somewhat overlooked. Too often we are confronted with fitting problems, people that are too small or too tall for the cabin. Too often elements that should be easily reached are not reachable for the seated operator. It must be said that anthropometry should be considered early in the design process. The step-by-step process can be used as a guideline in order to ensure a better-fitted and more comfortable cabin of wheel loaders.

6.4 Future design challenges

It must be clear that there is room for improvement in the area of anthropometry. This should be one of the near future challenges for the design of wheel loader cabins. Another issue is a change in hardware: the cabins will be fitted with more and more IT-elements. This introduction has a three-way influence on the design of wheel loader cabins:

- conventional displays and controls will be replaced with flat panel displays and keyboard;
- the controls and displays will be more integrated: several information sources will be displayed on a multifunctional display, the information will be inputted using a keyboard instead of a wide array of buttons. This will result in a reduced number of controls and displays;
- more information sources will be available for the wheel loader operator.

6.5 References

Abraham S, Johnson CL Najjar MF. Weight and Height of Adults 18-74 Years of Age, United States 1971-1974. Washington DC: Division of Health Examination Statistics, US Department of Health, Education and Welfare, 1979.

Bowman D. Using Digital Human Modeling in a Virtual Heavy Vehicle Development Environment. In: Chaffin DB, Nelson C, eds. Digital Human Modeling for Vehicle and Workplace Design. Warrendale, PA: Society of Automotive Engineers, 2001.

Chaffin DB, Nelson C, eds. Digital Human Modeling for Vehicle and Workplace Design. Warrendale, PA: Society of Automotive Engineers, 2001.

Jurgens HW, Aune IA, Pieper U. International data on anthropometry. Geneva: International Labour Office, 1992. Occupational safety and health series #65.

MIL-STD-1333B. Aircrew Geometry for Military Aircraft. Lakehurst, New Jersey: Systems Engineering and Standardization Department, 1976.

NEN 5518. Ergonomic Requirements for the design and evaluation of cabins of trucks and vans. Delft: Nederlands Normalisatie Instituut, 2000. In Dutch.

NEN 5526. Ergonomic Requirements for the design and evaluation of cabins of busses. Delft: Nederlands Normalisatie Instituut, 2000. In Dutch.

Oudenhuijzen AJK, Hudson JA, Zehner G. Verification and Validation of Human Modeling Systems, 2001. In preparation.

Philippart NL, Kuechenmeister TJ. Describing the Truck Driver Workspace. SAE paper 852317, December. Warrendale, PA: Society of Automotive Engineers, 1985.

Robinette K, McConville J. An alternative to percentile models. SAE paper 810217, February. Warrendale, PA: Society of Automotive Engineers, 1981.

Roe RW. Occupant packaging from "Automotive Ergonomics". London/Washington, DC: Taylor & Francis, 1993.

SAE recommended practice J833. Human physical dimensions. Warrendale, PA: Society of Automotive Engineers, 1989.

SAE recommended practice J941. Motor vehicle driver's eye locations. Warrendale, PA: Society of Automotive Engineers, 1997.

SAE recommended practice J1052. Motor vehicle driver and passenger head position. Warrendale, PA: Society of Automotive Engineers, 1997.

SAE standard J826. Devices for use in defining and measuring vehicle seating accommodation. Warrendale, PA: Society of Automotive Engineers, 1995.

SAE standard 1517. Driver selected seat position. Warrendale, PA: Society of Automotive Engineers, 1985.

SAE standard 1521. Truck Driver Shin-Knee Position for Clutch and Accelerator. Warrendale, PA: Society of Automotive Engineers, 1985.

SAE standard 1522. Truck Driver Stomach Position. Warrendale, PA: Society of Automotive Engineers, 1985.

Sanders MS, McCormick EJ. Human Factors in Engineering and Design. New York: McGraw-Hill, 1983.

Stoudt HW, Damon A, McFarland R. Weight, Height and Selected Body Dimensions, United States 1961-62. Rockville, Ma: U.S. Department of Health, Education and Welfare: 1965. Public Health Service Publication Series II, No. 8.

7 Joystick controls and consoles: the implications of joystick use for the design of the joystick console (or control console)

Frank Krause
TNO Work and Employment, Hoofddorp, The Netherlands

7.1 Joystick controls

Joysticks are widely used as controls in heavy equipment. They have often replaced larger and more forceful movements necessary for lever control and have the advantage that one can control two machine tool movements in one handle. Through electronic switches even more movements or functions can be operated. Joysticks are appreciated by the operators. Therefore it is safe to conclude that joysticks have improved both operator comfort and productivity[1].

The older large lever controls had risks for work related musculoskeletal disorders (WRMD's). The use of joysticks has reduced these risks. The joystick has however replaced the larger forceful movement by a more static posture with more localized small movements. This may have possible adverse effects for localized fatigue build up and on the longer term WRMD's. Also more functions are added to the joystick through extra buttons and switches. They too may influence the onset of WRMD's as the positioning and amount of extra functions are not necessarily based on knowledge about human factors.

There is still quite a lot unknown about joysticks and their use in heavy equipment. Long term health effects are not well known. Not a lot is known about the optimal size and shape of the joystick relative to the user and the tasks or about the number of extra functions and their positioning. This requires research.

The new challenge of creating optimal joystick controls cannot be isolated from the joystick configuration in the workplace-operator interaction.

'New' controls change workplace requirements. The operator-seat-control interaction is different for a short, finger operated joystick than for the joysticks that are used in most earth moving machinery. Therefore depending on the type of joystick the requirements may differ. In this chapter we will focus on the larger joysticks because generally bucket and boom controlling joysticks are designed with the intention to be manipulated using a closed grip. That operators use different ways of controlling the joysticks is discussed shortly further on.

---

[1] From research among over 300 operators at BAUMA 2001 we know that the ability to be productive with a machine plays a large role in machine appreciation.

Before making some comments about the design of your console we would like to mention some basic requirement regarding the operator-seat-control interaction. They are based on:

- the static posture that is maintained during work;
- the precision handling;
- the intended grip;
- the intensity with which a machine is used[2].

Also changes in working population and the levels of ergonomic standards add to the requirements the workplace should meet. All of this of course has consequences for console design.

7.2 General workplace requirements

From a human factors point of view the following criteria are considered to be important:

• (regular) arm support near the elbow is necessary	when trunk and upper arm are in a relative static position during work, as is the case in joystick controlled earth moving machinery, proper arm support should be provided to unload shoulder muscles. Good arm support can also provide extra stability to the trunk and reduce the load to the lower back by carrying some of the weight of the upper body. This could reduce the risks of back problems
• angle between upper arm and trunk should be minimal	the angle between upper arm and trunk should not be more than 20 degrees, as this can cause shoulder problems, especially with the unsupported arm
• extreme angles of the wrist should be avoided	the design should not force the user into extreme joint angles. It may, however, be difficult to prevent operators from operating the joystick in a more risk full posture (see further)
• upper legs supported, horizontal or slightly tilted from the knee downwards • knee angle 90°-110° • hip angle 95°-110°	these criteria basically apply to all upright seated workplaces hip and knee angle should more or less correspond. If the knee angle is a lot larger than the hip angle it will influence the pelvic tilt

2 2,000 operating hours/year in the Netherlands is no exeption.

For the workplace this would mean that it should meet the following requirements:

- the seat should be adjustable in fore-aft direction, to allow differences in buttock-knee length, and preferred knee angle;
- the seat should be height adjustable because of differences in lower leg length;
- the seat pan and backrest should be tiltable;
- hand controls should be adjustable preferably fore-aft as well as in height; this is necessary to position the controls depending on one's trunk and upper arm posture and the length of the lower arm;
- arm support should be height adjustable and preferably in width.

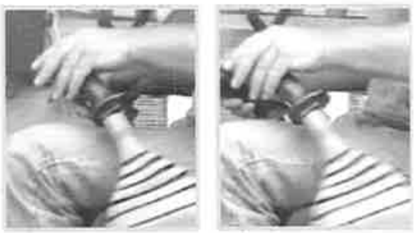
Anthropometry
The adjustability ranges, one chooses to build into a product, should be considered carefully. In the Netherlands it can be seen that on one side of the range Dutch men are becoming taller, on the other side however, due to a multicultural environment, also shorter people will become part of the operator population. Therefore it is increasingly important to offer very wide adjustment ranges to make a machine comfortable for all intended users.

7.3 Joystick gripping

As stated before, in most earth moving machinery the joystick is designed in a way that it intends the user to grip the joystick with the closed hand while operating it. In practice however, various ways of gripping and moving the joystick can be seen. They are likely to be connected to factors such as joystick size, angular range, optional buttons, operator preference, operator motor skills, hand size and other anthropometric variables as well as disturbing machine movements.
Roughly the gripping techniques can be divided into the following:

hand grip
closed fist

hand grip
open hand



finger grip
side handling

finger grip
top handling

The photos are from hydraulic excavator operators. Except for the 'finger grip top handling' the shown techniques were also observed in wheel loader operation.

Apart from the above mentioned factors, the technique may also result from the alignment of joystick and operator, e.g. the finger grip top handling may result from a seated position that is too high compared to the joystick. This of course should be avoided.

Finger gripping may also be chosen for other reasons. With this grip the elbow remains rested on the armrest and does not have to slide. The fixating of the elbow may render more control over de precise moving of the joystick.

7.4 Review of consoles generally found in earth moving equipment

Against the above mentioned criteria and requirements, TNO reviewed the consoles that are used in the machines of the Eurocabin participants. From this we learnt that recent consoles can be improved.

Fore-aft adjustability

In general the controls can be adjusted in fore-aft direction relative to the seat by sliding the seat relative to the consoles. This fore-aft adjustment mechanism is not optimal as it forces an adjustment sequence that is also considered not optimal (see further). Because the seat slides relative to the joystick, first the joystick position must be changed. After that an operator can change the fore-aft position of the seat relative to the pedals and viewing requirements. This may introduce a sub optimal positioning of the joystick relative to the operator.
From other research we know that seat height and fore-aft position are considered being very important by operators. Operators might only use the joystick adjustability to adjust their fore-aft position in the cab, therefore leaving the position of the joystick relative to themselves sub optimal.

Height adjustability

With most consoles, if the operator adjusts his seat to get a proper seat height, the joystick does not follow. As a consequence, operators with short or very long lower legs may find the controls too high or too low respectively. The seat position will therefore be a compromise between an optimal position relative to the floor/pedals or relative to the joystick. If the seated position is too low relative to the joystick, it may lead to elevated shoulders which can cause muscle problems in this region. If it is too high, it may result in the above described top handling technique.
In some machinery the control consoles are attached to the seat construction. These consoles move up and down together with the seat height adjustment. This is considered to be good. Still, the console cannot be adjusted to the differ-

ences in elbow height that exist between people[3]. Although this lack of adjustment should not be considered as a large problem, it does not mean that one should not strive to improve the adjustability.

Arm support

Mostly if arm support is available, it is provided by armrests connected to the seat. Height adjustment is generally brought about by changing the angle of the armrest. If the angle is changed, the amount of arm support is reduced: point pressure and shear forces are introduced leading to more discomfort (see figure 7.1). Additionally in some seats the armrests can slide in their mountings for approximately 2 cms. This mechanism is not suitable in situations where different operators utilize the vehicle and may want easy quick adjusting.

In our opinion such a mechanism is no longer adequate. Proper arm support should be provided.

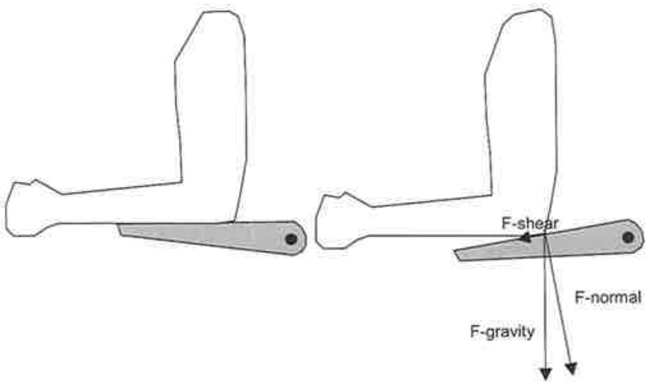


Figure 7.1 Armrests

Arm support is sometimes provided by an armrest connected to the console (see figure 7.2). This armrest can be adjusted relative to the joystick. This adjustability range is less functional as the vertical position of the fore arm of short and tall users will differ only slightly relative to the joystick.

We believe it to be more important to be able to adjust the armrest height (and joystick height) relative to the seat surface as this distance can differ strongly between users.

---

[3] For the Dutch population the difference in elbow height between a short person (p5) and a tall person (p95) is almost 10 cm.

Modern interiors: progress or not?
Further on in this book we will mention that the automotive industry has a strong influence on the interior design of industrial vehicles. This could also be observed at the Bauma 2001, where several wheel loader manufacturers showed driver cabs with car-like dashboards. The 'wrap-around' trend is followed by some as they extend the dashboard to the right side (see figure 7.3). The right hand controls are fitted into the console and have little or no adjustability, whereas in other designs the joystick can at least be adjusted in fore-aft direction. The progress in the field of styling the cab compartment is therefore counteracted by the lack of adjustability. From a human factors point of view this is not advisable.

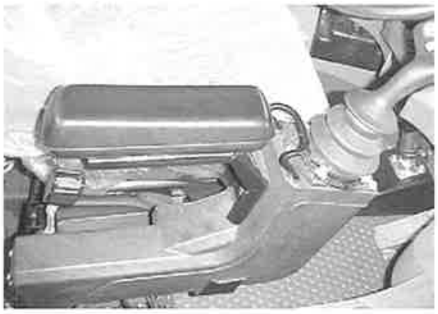


Figure 7.2 Armrest connected to console

Figure 7.3 Joystick in wrap around console

7.5 Future design challenges: towards new consoles

The requirements seat-armrest-console combinations should meet are made clear through an ideal sequence of adjusting the workstation to the operator, based on a cab in which pedals form a fixed point. This ideal sequence would be:

1. seat height and seat pan angle;
2. backrest;
3. seat-pedal distance;
4. steering wheel (where applicable);
5. armrest and joystick height, simultaneously;
6. joystick distance;
7. fine tuning of joystick height and position.

In this adjustment sequence the operator can choose his optimal seating position relative to the pedals and visual tasks he has to perform. As armrests and joysticks are adjusted relative to the shoulder, they should come later in the process[4].

A consequence of the simultaneous adjustment of the arm rest and joystick height is, that armrests and control consoles need to be linked and fitted above the height adjustment mechanism. By doing so they will also be fitted above the spring assembly, which is good.
To be able to fit 90% of the operator population the combination should be able to move up and down 10 cm, from approximately 19 cm above compressed seat surface to 29 cm. In Dutch office seats the standard for armrests is 20 to 27 cm (NEN 1812).

In the middle position armrest and console should be aligned in such a way that the joystick endplate is equal to or slightly under armrest level. (see figure 7.4). The armrests should not be wider apart than 50 cm. Ideally they can also be adjusted slightly in- or outwards.
Because of the large angular range the operation of the joystick requires a translation of the fore-arm when gripping the joystick with the hand. To avoid uncomfortable friction between the armrest and the fore-arm it should be considered to allow the armrest surface to slide 7-8 centimetres.
Regarding armrests it pays to take a look at the office seat market as they offer the widest range of features.

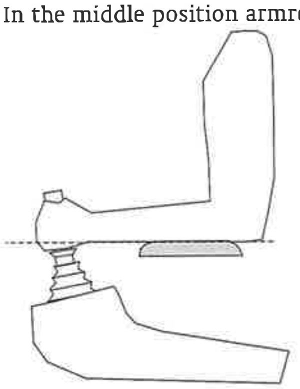


Figure 7.4 Armrest-joystick alignment

4 An addition should be made. Depending on the construction of the seat and controls there can be some freedom in the sequence of adjustment. If the joystick console does not move together with the seat, joystick adjustment comes end in line. If seat, arm support and joysticks move together up-down and fore-aft, the joystick adjustment relative to the operator can be done separate from other adjusting of controls (steering wheel) and adjusting to controls and fixed points (pedals, view).

A fore-aft adjustment is necessary. The mechanism should be such that the console moves relative to the seat instead of the other way around as is the case in present consoles. The drawbacks of this system were described above. When defining the range of adjustment, not only differences in fore-arm length are to be considered, also some flexion of the upper arm should be allowed.
Then, to fine tune the grip position of the hand relative to the joystick, either the joystick should be able to move easily up and down in the console, or the console should be able to move relative to the armrest.
To achieve a large freedom for the operator to choose his own preferred technique is far more difficult. Without changing the position of the joystick axis it would involve a larger range of up-down adjustability. However, when changing to a finger grip top handling, the position of the joystick axis should be changed to avoid extreme wrist angles and create a movement pattern inside the range of motion of the wrist. Creating such an adjustment feature is far more difficult (see figure 7.5).
In cranes it can often be seen that operators work with the trunk slightly bent forward. This changes the arm position as well. The fore-arm is not horizontal but pointed downwards. To be able to accommodate the console to such behaviour, it should be able to pivot around an axis near the elbow (see figure 7.5). This adjustability feature however can be debated for earth moving machinery.

Figure 7.5 Armrest - joystick configuration

7.6 Concluding remarks

- A large adjustability also has its drawbacks. As often can be seen in the office seat market users, that know how to optimally adjust their seat and also do this, are a minority. As in the office seat business it should be seen as a challenge to design a seat-control configuration that is easily and intuitively adjustable.

- From above we can learn that it are actually not only the seat, armrest and control console that cannot be seen separately. Also the form, size, extra switches, movement range and pivot point of joysticks should be considered, to gain an optimal balance between productivity on one side and health on the other. In this respect there is still work to be done.

Part 2

A user-oriented approach to cab design

8 Introduction

In the previous part of this book experts from several research institutes have given the most recent information regarding some very important aspects of the cab. This knowledge is valuable when designing new equipment. Part 1 has also shed some light on the future challenges that - according to these experts - design departments will face in their thrive to create better machines.
However, when designing better and more comfortable machines, the success of such work does not only depend on the level of technological knowledge that is used. The type of approach to design is another factor of importance. Design history shows many examples of products that may be technologically well-thought but fail to appeal to the user it is designed for, or even worse, fail to connect to the way a user uses the product. These products are not satisfactory to the end-user and may even be dangerous. In our opinion designing good machinery that helps the operator to achieve a high performance with the machine without jeopardizing health and safety, can only be established by involving the end-user in design. The next chapters are about such a user-oriented approach to cab design.
Chapter 9 is about the methodological aspect of a user-oriented approach. What can be expected from it and in what stages should the user be involved? Chapter 10 is an example of what users may learn us. At the 2001 Bauma Construction Fair 273 operators of earth moving machinery were interviewed and asked about their opinion of the current machine they were operating. The results are presented in this chapter. Furthermore, a team of ergonomics experts with the help of many users thoroughly reviewed three types of earth moving equipment that are sold by the Eurocabin participants. This served as a basis for the question of how and what to redesign. Chapter 11 describes the process and some of the outcomes of this information gathering.

9 On user involvement

Frank Krause, Robin E. Bronkhorst
TNO Work and Employment, Hoofddorp, The Netherlands

9.1 The importance of user involvement

Years of designing machinery for people to work with have shown, that it is important to consider human factors in the design. There are many of these factors to take into account.
Human dimensions and especially the differences humans show in their dimensions, are an important issue in the design of a machine. Designers should carefully consider for which population they are designing and then select the proper data on dimensions. Data on human force exertion are important in the design of levers and controls.
The role of the operator is changing. From hard work moving the levers, his job is changing into one in which the machine is operated by multi-functional joysticks that require co-ordinated actions from the arm, hand and fingers. (Semi)-automatic systems further shift his task towards a complex controlling task. These new dimensions to machine operation require knowledge on other areas than before mentioned.
Scientific knowledge about comfort can be used in the design process to try to design a product that is comfortable to the largest group of users.
These are just a few human factors issues, other issues such as knowledge on whole-body vibrations, noise and all aspects connected to vision are also of great importance in the design of machinery.
However, does using this information in the design process of the vehicle then automatically lead to the perfect product? Not necessarily. Creating a functional and comfortable working environment is far from easy. There are many factors influencing the comfort aspect, some of which may conflict. They may also conflict with machine functionality. Also, knowing what people need is one thing, being able to predict what they like is something very different.
Therefore, input from the user should be added to this information. This means the user should be involved in the design process.
There are several stages in the process in which the user can be involved, each with its own advantages. They are mentioned below.

9.2 Stages of user involvement

Reviewing existing machines

As a starting point for (re)design it is important to have information on existing machines. When designing a new machine the manufacturer wants it to be better than its predecessor. The existing machine serves as a benchmark for the new machine. Therefore it serves to have exact information on strong and weak points of all machines serving as a benchmark. The best way to gain this information is through a thorough review of these machines. Manufacturers not often have an independent party perform a detailed, more or less scientific, review of a certain machine among its operators. Generally they rely on the information they will receive during the lifetime of a machine from users through contact with sales and/or service people. This information, mostly concerning weak points, is forwarded to the design department. Often designers also speak to machine operators. It is our experience that this method of information gathering will generate 80% of all weak points of a machine. The question is whether this is enough for the decision making in a (re)design process.

A detailed review will pinpoint all weak points as no subject is overlooked. It will produce data showing frequencies that certain answers have been given. By having data on how often a weak point is mentioned, and by having detailed opinions on weak points, it is possible to prioritize points of improvement.

Further advantages of a detailed review by an independent partner are that the machine is looked at with 'new eyes' and by someone who is not directly involved with the manufacturer. In the Eurocabin project a thorough review by independent experts was performed. How this was done, is explained partly below and in chapter 11.

There are several ways to gather information from the user. The expert may use a structured or non structured interview. Obviously the chance of overlooking a subject is present if the interview is not structured. Then it is also possible to use questionnaires. The questionnaire may be read to the operator or he may fill it in at a suitable time. In the latter case there is always the risk of not returning the questionnaire. However, reading out the questionnaire relies heavily on the time the operator is available for questioning, which is generally not a lot.

In Eurocabin a combination method was used. Operators had little time to stop and extensively speak to interviewers. Therefore we chose to use a short questionnaire that was used both as checklist for a structured interview both as questionnaire. After the interview we handed the operator an extensive questionnaire and asked him to fill this in at home. The non-response was significantly reduced by having first met the operator and by calling the operator as a reminder (see figure 9.1).

Of course this method is less suitable when wanting to collect the opinion of large numbers of operators, unless large numbers of the specific machine can be found within small, easy to reach distances of each other, which in Eurocabin was seldom the case.

Figure 9.1 Interviewing an operator at work in the mountains

Redesign/finding solutions

In the redesign phase the input from the user is restricted. To find solutions to the weak points identified in the review users may take part in brainstorm sessions. They can come up with great and simple ideas. Their involvement also has the advantage that user satisfaction is higher, if the user recognizes typical solutions only users could come up with. However, mostly the redesign phase requires technological input for the detailing of the new machine and therefore there is less room for user input. Though not directly involved it is of course still very important to remain focussed on human factors. In all design changes concerning the operator-machine interface human factors knowledge should be used.

Prototype testing

In some stage of the redesign process prototypes are built of complete machines or part of the machine. When testing these prototypes the user's input should again be valued as it will increase the chances of designing a product well accepted by all users.

Prototypes should be tested under conditions that compare to daily use. The evaluation of a prototype should ideally take place by experts as well as users. It is not enough to have test drivers evaluate new solutions. Although very experienced with the machine they do not have the experience of using a machine many hours a day.

Knowing that discomfort mostly takes time to build up, especially in machines that are already quite comfortable, it is important to test prototypes over a longer period of time. Only then the manufacturer can be sure that the solution designed to solve a weak spot in the machine, is really a solution. If a choice has to be made between two or more solutions an experimental test set-up may be

required. In such a test the conditions are controlled as much as possible so that results from the test can be compared.
The testing of the prototypes will generate input for further decision making.

9.3 The expert versus the user

In a good design process both the human factors expert and the user are involved. Why the user is needed, we explained above. In this part we would like to explain the role of the expert with respect to the user. User centred design does not mean that all user wishes are incorporated in the new design. Apart from financial consequences this is probably impossible, as wishes will differ. So many users, so many wishes. The expert can help in this process as he can interpret the outcome of data from users.

Second it is arguable whether the user is capable enough of making the right choices in his desire to not only have a comfortable workplace but also one in which high productivity can be achieved. Third it may be very difficult for the operator to imagine what consequences certain desired changes might have. This appears to be especially true regarding health. Workers often adapt postures that require minimal energy expenditure. However these postures may put extra stress on the musculoskeletal system and thus pose a health risk for the long term. The expert is necessary to judge the situations that do not seem hazardous, however may be so in the future.

In general it can be said that while user participation in the design process is of utmost importance, the expert is needed to guide this process. Table 9.1 contains an overview of the user's and human factors expert's strengths and weaknesses regarding design input.

Table 9.1 Strengths and weaknesses of users and experts in the design process

	user	expert
strength	• target group of design • only person capable of testing real usability and comfort • not employed by manufacturer, independent	• asks the right questions in a user test to get the right useful answers • weighs answers and translates this in design requirements • has knowledge on what's comfortable, healthy and functional • independent, if not employed by manufacturer
weakness	• ignores financial consequences of own wishes • less capable of identifying long term musculoskeletal risk factors	• little or no experience in machine operation

9.4 Conclusions

To be able to design the best machine possible requires the involvement of experts and users, who are in fact of course also experts, only in their own field. Designing without user-input will lead to sub optimal solutions, because they are less functional or fail to address the demands an operator places on his machine. Not using expert knowledge on human factors will also lead to sub optimal solutions. They will be less ergonomic and thus directly influence the operator's opinion about the machine's comfort. In the long run they may cause health problems. The fact that operators are increasingly becoming the ones who decide what machine is to be bought, in our opinion increases the need for both user and human factors expert involvement.

10 Bauma 2001: information from 273 users

Lottie Kuijt-Evers, Peter Vink
TNO Work and Employment, Hoofddorp, The Netherlands

10.1 Introduction

In the previous chapter we described the collection of information from users of a specific machine with the purpose to redesign this machine. It is also valuable to have information from operators in general regarding their opinion about nowadays machines. The Bauma 2001 was the right place to collect these data. During a short interview, 273 operators filled in a questionnaire (212 excavator operators and 61 wheel loader operators). The operators answered questions about overall cab comfort and specific parts of the machine related to comfort. We also asked the operators what they found to be the most important aspects to work well with the machine.
The wheel loader operators and the excavator operators who participated in this study, were experienced with a mean of 12.3 and 13.4 years of service respectively. The mean age was 36.5 (± 9.4 years) for wheel loader operators and 36.3 (± 9.3 years) for excavator operators. The machinery they used differed in age. In the data analysis we split up the machinery in older machines (4 years or more) and newer machines (less than 4 years old). Approximately 50% of the operators used a machine of less than 4 years old.

10.2 Operators' opinion about cabin comfort

The operators rated their opinion about overall cab comfort and comfort of specific parts of the machine on a four-point scale (poor, average, good, very good). In the data analysis these categories were merged into two categories ('poor/average' and 'good/very good'). When less than 80% of the operators rated a part of the machine as 'good/very good', we concluded that comfort could be increased by taking into account this part when redesigning the machine. In the next two sections the operator's opinion is shown separately for wheel loader and excavator operators.

Wheel loaders

Regarding the overall cabin comfort 57.4% of all wheel loader operators rated this 'good/very good'. Figure 10.1 shows that operators of newer machines (<4 years old) rated the overall cab comfort more often as 'good/very good' than operators driving older machines (≥4 years old): the figures are 38% en 75% respectively. These results show that during recent years wheel loader manufacturers have succeeded in improving cab comfort. To find which parts of the machine can increase cab comfort in the future we analyzed the data of newer machinery regarding the operator's opinion about specific parts of his machine.

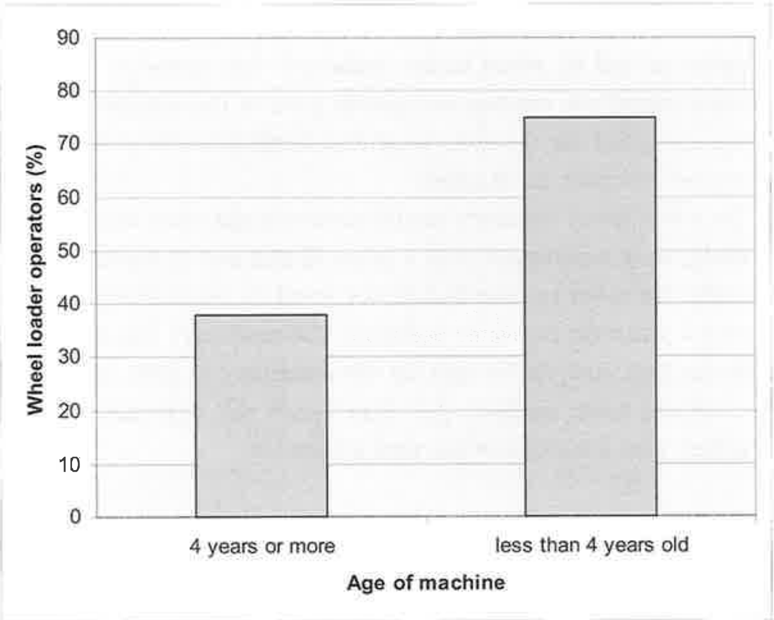


Figure 10.1 General opinion about comfort of the cab of wheel loader operators. More operators of the newer machinery (<4 years old) rate the comfort of their cab as 'good/very good' compared to operators of older machines (≥4 years old)

These specific aspects the operators were asked to rate were: vibration and damping, noise reduction, what the machine looks like, cab dimensions/interior space/in and egress, climate control, view, dashboard and displays, pedals, way controls work, adjustability of seat and controls, and seat comfort. Figure 10.2 shows the percentage of operators who rate these aspects as 'good/very good'. Five aspects are rated as 'good/very good' by less than 80% of the operators: vibration and damping, noise reduction, dashboard and displays, adjustability of seat and controls, and seat comfort. This score might be explained by the following. Whole body vibration in earth moving machinery remains a health risk and is surely detrimental to comfort, although improvements have been made by using dampened seats and load stabilizers limiting the pitching of the machine. This may also account for the seat's score as it is linked to the aspect of vibration. Noise levels are seldom damaging to the ear. However, on a comfort scale they are often still quite high, especially when compared to automobiles. The adjustability of seats and controls has two aspects: the amount of items that can be adjusted and its user friendliness. In our opinion both aspects can still be improved as was also described in chapter 7. They should be addressed together as user friendliness is very important when the adjustability is increased. Last, an explanation for the score on dashboard and displays is difficult to give. It is imaginable that operators compare the dashboard with their luxury car and thus find it less appealing. These data show on what aspects manufacturers should focus their attention when working on new machines.

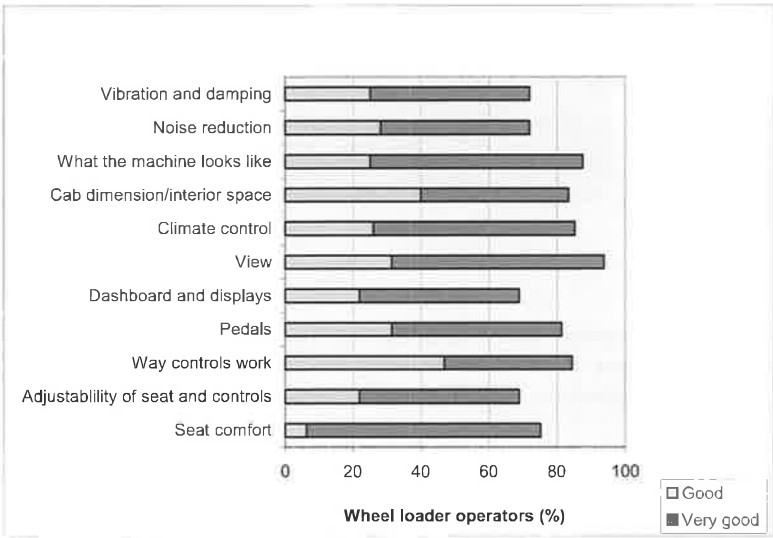


Figure 10.2 Percentage of wheel loader operators of new machines (<4 years old) who rate the comfort of specific parts of the machine as 'good/ very good'

Excavators

The excavator operators also rated the overall cab comfort on a four point scale. Of all excavator operators little more than half of them (55.9%) rated the cab comfort as 'good/very good'. Almost the same was seen among wheel loader operators. However, when looking separately at the older and newer machines, we see a large difference. Figure 10.3 shows that operators of newer machinery (less than 4 years old) are far more satisfied with the overall cab comfort than those driving older machinery (73.3% versus 39.6%). Obviously manufacturers have improved their machines in recent years. To find what aspects are left to be improved in the future we analyzed the data of newer machinery as we did for wheel loaders.

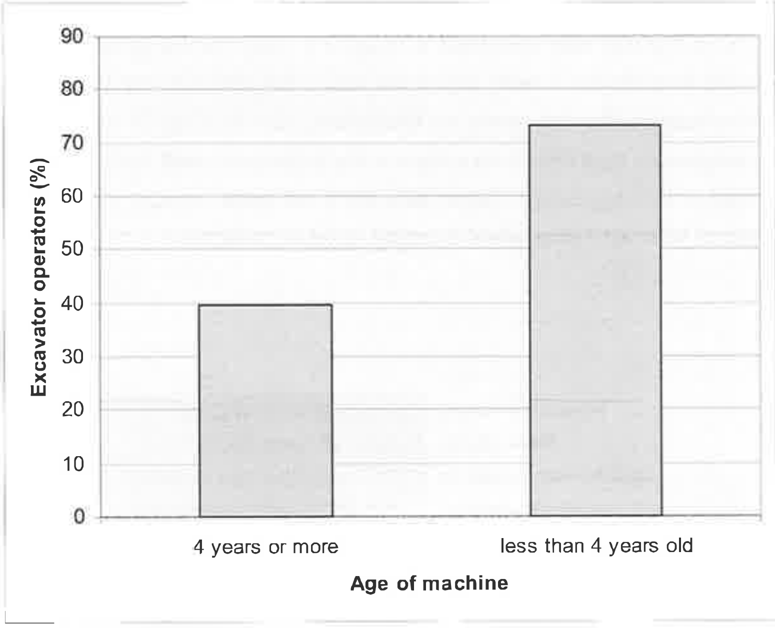


Figure 10.3 General opinion about comfort of the cab of excavator operators. More operators of the newer machinery (<4 years old) rate the comfort of their cab as 'good/very good' compared to operators of older machinery (≥4 years old)

Figure 10.4 shows the ratings of the operators of newer machinery only. Machine parts which are rated as 'good/very good' by less than 80% of the operators are: seat comfort, vibration and damping, dashboard and displays, climate control, what the machine looks like, cab dimensions/interior space/in and egress, noise reduction, view, adjustability of seat and controls, and reliability.

Compared to the wheel loaders a few aspects are added. Climate control is possibly under appreciated, because less excavator cabs have air conditioning built in than wheel loader cabs. Manufacturers are reluctant to install air co as operators tend to work with either the door or the front window opened, thus making air conditioners useless. It is no surprise that cab dimensions/interior space falls below the 80% mark. Regardless of manufacturer the available space for the cabin is limited for all dimensions. The same counts for view as the current machine layout inevitably leads to dead angles for the operator. Mirrors reduce the problem; however, it is likely that only cameras are able to substantially increase the operator's field of view.

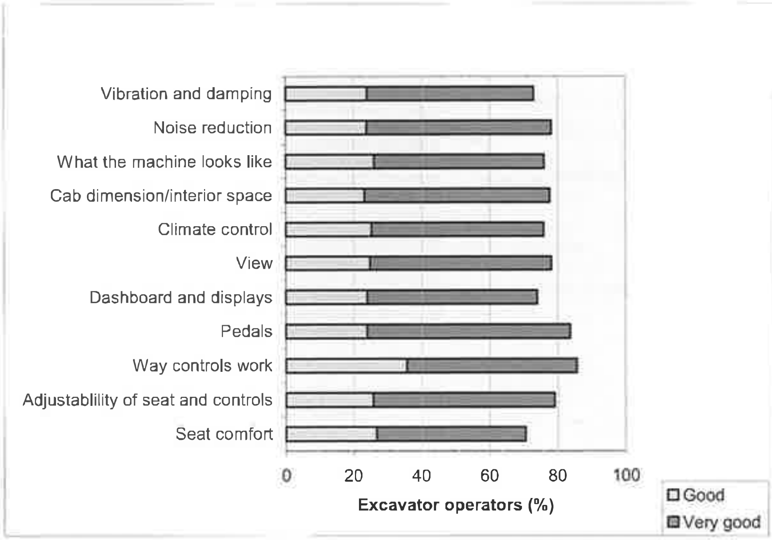


Figure 10.4 Percentage of excavator operators of new machines (<4 years old) who rate the comfort of specific parts of the machine as 'good/very good'

10.3 What has been improved in recent years?

In the previous section we saw that operators of wheel loaders and excavators of less than 4 years old are more satisfied with the overall cab comfort than operators of older machines. But which aspects of the machines have been improved? In this section we compare the ratings on specific aspects of newer machines with older machines.

Wheel loaders

Most parts of the machine are rated better by operators of newer wheel loaders compared to operators of older wheel loaders. After statistical analysis only four aspects of the machine are rated by significantly more operators of newer machinery as 'good/very good' than the same aspects of older machinery. These aspects are: view, climate control, what the machine looks like, and vibration and damping (figure 10.5).

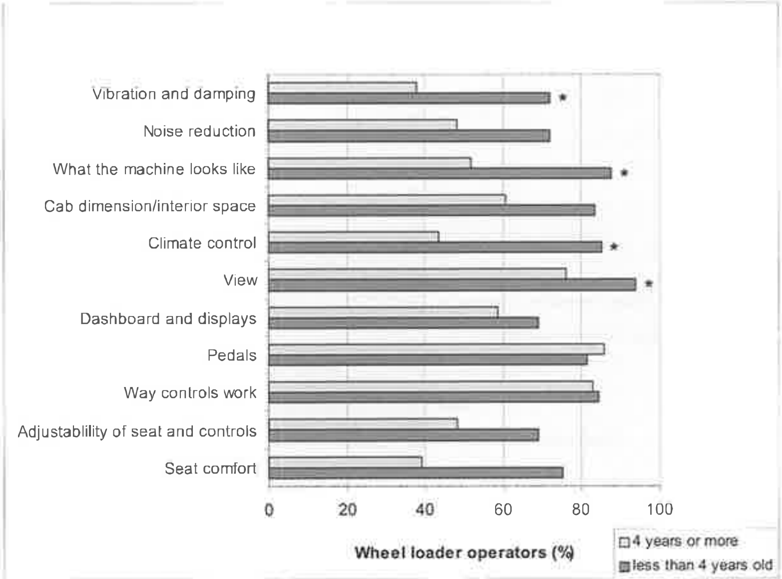


Figure 10.5 Rating of machine parts by operators of newer machines compared to operators of older machines. Machine parts marked with an * are rated by significantly more operators of newer machines as 'good/ very good' than by operators of older machines

Vibration and damping have been reduced by introduction of the load stabilizer, which results in more comfort due to less pitching of the machine. The looks of the machine have been improved because of the use of new materials like synthetics for the cabin. These materials have given many machines a more modern rounded look. Rounded forms are also found in the design of the front windows. They too are curved. By narrowing or reducing the number of window posts a better view from the cabin is accomplished. Additionally the view has been improved by the design of a slanted hood. The increase in standard fitting of air-conditioning in wheel loaders accounts for better scores in climate control. From figure 10.5 one might conclude that seat comfort has also been improved. However, though mean scores have increased, the difference is not statistically significant due to the fact that operators show strongly divided opinions on this subject. This is not shown in the figure.

Excavators

The machine parts of excavators, which have been improved over the last years, are shown in figure 10.6. Statistical analysis shows that the comfort of seven aspects has been increased significantly: seat comfort, adjustability of seat and controls, climate control, cab dimensions/interior space/in and egress, what the machine looks like, noise reduction, and vibration and damping.

Manufacturers have reduced exterior noise. Environmental rules are likely to have played a large role on this matter. The operators appreciate the noise reduction. Cab dimensions and interior space cannot be very different compared to older machines, because they are restricted by the position of the boom and the maximum excavator width and height for transport. However, the sense of space might be changed by a different design and usage of new synthetic materials. A better climate control (by use of air co) can also positively contribute to a sense of space. Interestingly there is a significant increase in seat comfort score, though mean scores do not show the increase wheel loaders show. The increase is probably connected to a increased upgrading of standard machines as we can see in the automotive industry.

In contrast with the results of the wheel loader, the view from the excavator cabin has not been improved. As mentioned before, the excavator's design is constrained by the machine lay-out and by several transportational rules.

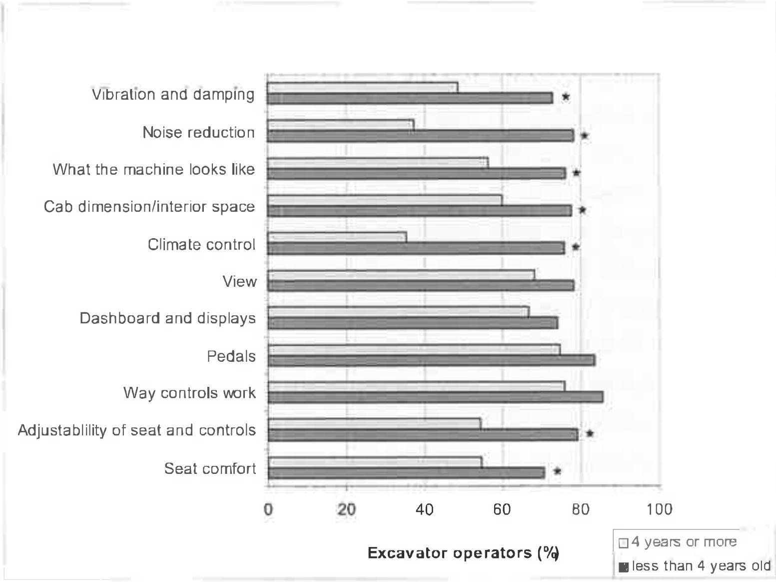


Figure 10.6 Rating of machine parts by operators of newer machines compared to operators of older machines. Machine parts marked with an * are rated by significantly more operators of newer machines as 'good/ very good' than by operators of older machines

The statistical analysis demonstrated that more aspects of the excavator have been improved than aspects of the wheel loader. This does not mean that the development of the wheel loader is backward. The number of subjects (61 wheel loader operators versus 212 excavator operators) influences the statistic results.

10.4 Most important aspects to work well with the machine

The previous sections focussed on cab comfort, because a comfortable cab contributes to more job satisfaction. However, job satisfaction relies on more aspects. Therefore we were also interested in the operators' opinion about the most important machine characteristics. To get this information we asked them to list the three most important aspects to work well with the machine.
Operators mentioned many different aspects. We classified the answers into 15 categories. Table 10.1 shows the 15 categories followed by an explanation of the kind of answers which suits the category.

Table 10.1 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, service of manufacturer
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 distance between seat and controls, adjustability of controls
operas ability	joystick, steering wheel, interaction joystick and beam
view	view on 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, position blowers
design/dimensions/ingress-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

After having categorized the operator's answers we calculated the frequencies of answers for each category. Based on these frequencies a top 3 of most important aspects was composed for wheel loaders as well as excavators.

Wheel loaders

Wheel loader operators find that the most important aspects to work well with the machine are

1. machine's performance;
2. view;
3. reliability (figure 10.7).

40.3% of the answers were classified into the category 'machine's performance' (containing descriptors such as gear, performance, and hydraulics). The categories 'view' (e.g. view on work, dead angle, mirrors) and 'reliability' both count for 12.5% and 11.8% respectively.

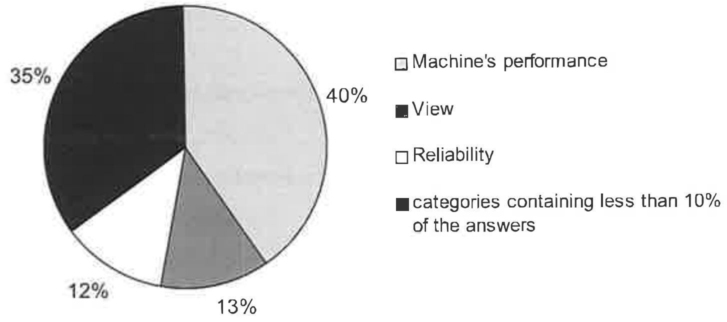


Figure 10.7 Most important aspects to work well with the machine according to wheel loader operators. Percentage answers is given for each category

Excavators

The top 4 of most important aspects to work well with the excavator contains:

1. machine's performance;
2. reliability;
3. view;
4. operas ability.

The same figure is seen for excavators as well as wheel loaders. The category machine's performance contains most of the answers (37%). This category is followed by reliability (14.6%), view (11.5%), and operas ability (11.1%) (figure 10.8).

It is not surprising to find (for wheel loaders as well as excavators) that performance is mentioned as most important, because this factor is indeed of great importance to work at a high pace. Apparently 'working well' with a machine is interpreted by operators as doing a lot of work more than working under pleasant conditions. Although not a subject of this study it would be interesting to find out more about what exactly operators mean with machine performance. Are plain figures on e.g. horse-power satisfying facts or is it the felt ease of digging? This remains to be investigated.

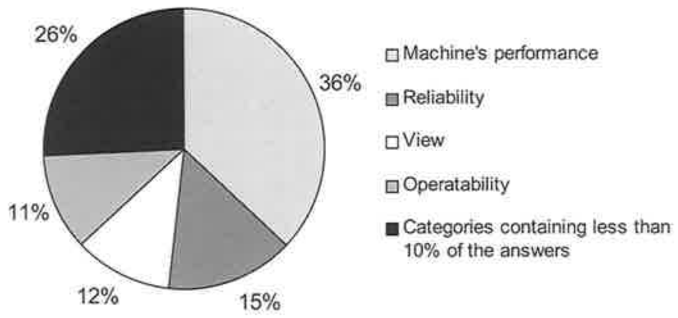


Figure 10.8 Most important aspects to work well with the machine according to excavator operators. Percentage answers is given for each category

11 The Eurocabin project

Frank Krause, Robin E. Bronkhorst
TNO Work and Employment, Hoofddorp, The Netherlands

11.1 Introduction

The participants in the Eurocabin project were three SME manufacturers of earth moving machinery: the German Hermann Paus Maschinenfabrik GmbH (Paus), the Dutch ETEC Van Vliet bv (ETEC) and the Liechtensteiner KAISER AG Fahrzeugwerk (Kaiser). They manufacture small sized wheel loaders, medium sized excavators and special purpose excavators.


Paus


Kaiser


ETEC

The company's size limits the investments the company can make in the field of research and development. The European Union provides such SME's the opportunity to obtain funded research. This is created by one of the four thematic programmes of the Fifth RTD Framework Programme, called 'Competitive and Sustainable Growth'. For this purpose the Eurocabin project was started with the goal to collect information on how to create the best possible comfortable cabin and using this information to improve their own cabins.
This section describes how we collected information from the users of these machines as a starting point for further improvements.

11.2 Collecting information

In an ideal situation we would have liked to collect standardized information using different methods, from a great number of users. This means using detailed questionnaires and, while the operator is at work, observing and inter-

viewing him and monitoring parameters such as movement frequencies and joint angles.
However, it was not possible to sit in the cabin while the operator was at work. Observations therefore had to take place outside the cabin or sometimes standing in the door opening. Interviewing the operator in the hours of work also was not easy. Earth moving machinery in The Netherlands, especially excavators, are used very intensively. Operators easily make more than 2,000 machine hours a year. Labour is quite cheap and so companies were initially not very anxious to have us interview the operators for more than 30 minutes.
Because of this we chose to use detailed questionnaires and to visit some of the respondents for a short interview and observations. The manufacturers supplied the companies which we called to ask if they would participate and how many operators would fill in the questionnaire. Whenever possible we also spoke to the operators before sending the forms. This was done to get as much operators as possible to fill in the questionnaires and return them. All together 46 operators received a questionnaire. They worked for two of the three participating manufacturers. Although we also made reminder calls 19 questionnaires were returned by the operators. After this we visited 10 operators at the site they were working. Because we already knew a lot about their opinion, we could go into detail about certain subjects and nonetheless keep the time the operator was not working within acceptable limits. The number of operators that was visited, was mainly based on the operator's availability and his employer's willingness to co-operate.
The third manufacturer in the project preferred to use a different approach. For this client observations and interviews were combined. We shortened the original questionnaire in such a way that it could be used as a basis for a structured interview. Using this we interviewed and observed 12 operators on location. The sales department had prepared our visits. Each interview took between 30 and 45 minutes time. After each interview we asked the operator whether he was inclined to fill in the long questionnaire. If so it was handed to him together with an answering envelope. Half of the operators filled in the questionnaire and by doing so supplied us with extra information. All operators received a small gift as a token of gratitude.

Measurements

In addition to the information collected from interviews, observations and questionnaires, experts performed measurements regarding cab dimensions and control positions, forces necessary to operate the machine and noise levels (see figure 11.1).

Figure 11.1 Measuring the cab

11.3 Information processing

Statistics were used to evaluate the results from the 19 long questionnaires. All other results were brought together and categorized by subject (view, seat, controls, etc.) in which we kept the different sources of information separately. We had specific information on the machines from the manufacturers, the experts and the operators and we had ideas about the trends for the future from sales people, designers and from what operators wanted to have improved and how they wanted it.

We presented the results to the manufacturers. Much of the information was either known to the manufacturer or sounded very familiar, yet was found to be very valuable as their ideas for the future had largely been supported by researchers.

After having presented these results it was then up to the manufacturers to decide which issues would be tackled in the new design. In the decision making process money obviously plays a large role. This is even more the case in the earth moving machines industry as there are so many competitors offering very similar machines at the lowest prizes. As a consequence not all important issues were on the list of adaptations the companies chose to address in the redesign.

11.4 Comparison of the two evaluation methods

The extensive questionnaires and the following statistical analysis did not render more information with respect to the operators' opinion about their machines and what they would like to have changed, compared to the structured interviews and observations used with the third manufacturer. In some ways the second method was advantageous as all interviewed operators were also observed.

This led the expert to form a better opinion of the machines which again is necessary to be able to value the operators' opinions.
The large questionnaires were not necessarily filled in inside the vehicle. Although the operators are very familiar with their machines, filling in a questionnaire e.g. at home may influence the answers given.
However, a distinct advantage of using a questionnaire over interviews is that it will give an objective analysis of the machine, provided enough questionnaires are available. Through statistical analysis scientific information is obtained on how the machine is evaluated by its end-users. This information is obviously very suitable as a basis for redesign. Interviews, even structured, leave more room for influencing operators in the answers they give.

11.5 Redesigning

After having chosen the items the manufacturers would redesign to optimize the cab comfort, they started redesigning these items. TNO supported the manufacturers in the process with technological input. We supplied them with redesign suggestions regarding several points e.g. general design, noise reduction, ingress-egress and the configuration of seat and controls with respect to each other. To investigate what the proper position would be of the seat relative to controls and view, we used an instrument called Ergomix, in which it is possible to mix real persons with drawings of the workplace, in this case an operator's cab (see figure 11.2). In the next section we will describe a few of the improvements that were made to the machines.

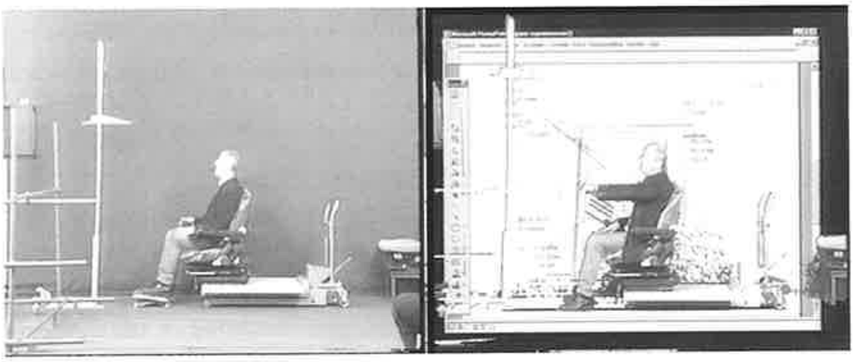


Figure 11.2 Ergomix session: left the filmed operator, right the mix with the cab drawing

11.6 Examples of improvements

Seat positioning relative to view and controls

In two cabins the seat position was changed slightly to increase the cab's suitability for a wide range of operators. We gave measures to the exact positioning of a new steering column (see figure 11.3).

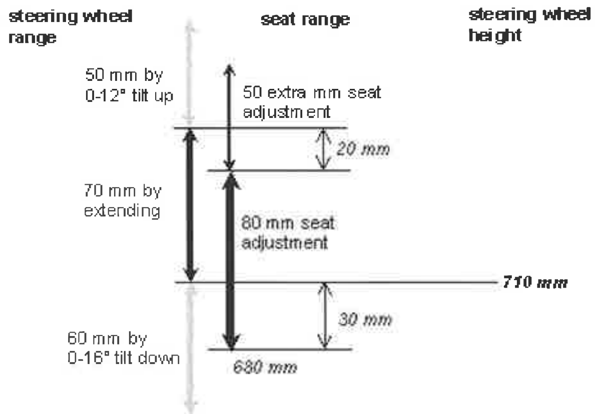


Figure 11.3 Defining the position of the steering column

The seat manufacturer Grammer AG was found willing to co-operate in the project and presented a prototype to one manufacturer. In this prototype the ideas mentioned in chapter 7 were applied. The armrest, that can also serve as a mounting pod for a joystick, is fully adjustable relative to the seat and therefore enables operators to find a perfect position relative to the controls. Because the seat stays in place while armrest and joystick move, it is also easier for the operator to find a proper working position. Unfortunately at the writing of this book the seat was still in a prototype stage, therefore it was agreed to not yet show pictures of this seat.

Noise

General measurements showed for earth moving machinery relative low noise levels. This was somewhat surprising as the technical measures the manufacturers had taken to reduce exterior sound pressure and interior noise level were sub optimal. In some positions where insulation should have been present there was no insulation applied. In two cases the engine mounting was not adequate resulting in materials vibrating and thus producing noise. This noise was not necessarily audible yet caused an unpleasant sensation to the operator in the cab. Measurements revealed the source of this noise. By stiffening the engine and the window suspension the noise was reduced significantly and, equally important, the irritating sensation was taken away. In all machines the sound insulation of the engine compartment and the cab have been improved.

Outside view

Outside view stands on top of the list of important items in the cabin. It was therefore also chosen to perform a specific design study into this subject, the results of which can be found in chapter 16. Outside view is directly connected to comfort because, when view is obstructed, operators need to sit in awkward postures. Through the remarks made by operators improvements were made to the position and shape of certain window sills (see figure 11.4) and to the positioning of mirrors and (extra) lights. On the excavator a camera solves the problem of the boom obstructing the view sideways.

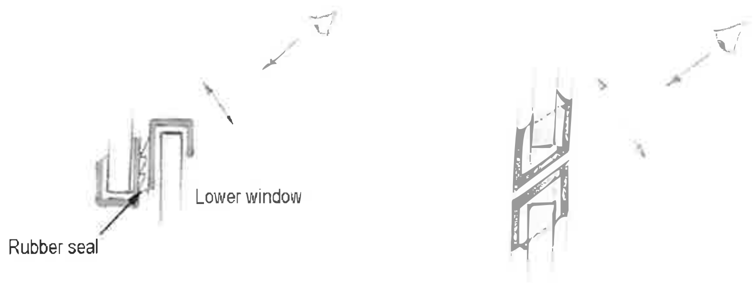


Figure 11.4 Two possible solutions to create a narrower window will between upper and lower excavator front window

Ingress/egress

Ingress/egress may be of less importance when the operator seldom leaves the cabin. In all investigated machines, however, operators estimated the amount of times they went in and out of the cabin up to 50 times a day. This fact makes an easy and safe ingress-egress very important. Therefore in improving the machine comfort much attention was paid to this aspect. Some grips were extended to widen the range at which the operator could reach for a grip. Grip diameter was set at 25 mm for a comfortable grip. On one cab the grips were positioned closer to the cabin, thus reducing the vulnerability of the grips. The distance between the cab and the grips was set at 65 mm to allow an easy grip with gloves.

Next to these changes there were several small items which all together add to a satisfying feeling about the machine:

- repositioning air filters to make servicing easier and by doing so, to reduce fuel consumption;
- being able to fill the windscreen wiper fluid from the outside;
- creating extra storage space; operators gave us several ideas to do so;
- operators on the wheel loader required a gauge giving information on the shovel position. Because operators do not continuously drive the vehicle, they do not have the feel of the machine as e.g. an excavator operator does;
- in one type machine operators mentioned that both feet were not equally heated. This was improved.

Although vibration is known to be a large health problem in earth moving machinery, it was not mentioned by all operators. Nevertheless all manufacturers wished to address this problem, as European guidelines on wholebody vibration are prepared. However, in this project the manufacturers chose not to. Reducing machine vibration would imply doing elaborate research and possibly making large changes to the machines. The required investments would be too great for the manufacturers involved.

Part 3

Developments, trends and future challenges

12 Introduction

What will it take to remain competitive in the market for earth moving machinery? This last part of the book is about the future. In chapter 13 the results are presented of interviews held with 80 professionals in marketing and design. The interviews were held at the 2001 Bauma fair for construction machinery. The following day the results of these interviews were discussed in workshops with the interviewed professionals. This chapter tells us about the direction manufacturers believe should be followed to increase comfort in machinery.

Chapter 14 is again dedicated to the operator's opinion. These are other results from the interviews with operators at the Bauma. This time the answers come from the question what operators would like to see in future machines. It is interesting to see if manufacturers are set to develop machines according to what operators would like to see.

Chapter 15, in part has little to do with earth moving machinery. It is directed at the automotive industry. This industry is generally regarded as trend setting regarding design. As there are enough examples of innovations in construction machinery, that were originally sighted in automobile industry, it is interesting to take a look at where this industry is heading.

After this we are already at the last chapter of this book. For Eurocabin two design studies were performed, one about joysticks and the other about improving the view in excavators. Chapter 16 shows some interesting ideas from these design studies.

13 Future demands on comfort in construction vehicles' interiors according to manufacturers

Peter Vink, Tammo A. ter Hark
TNO Work and Employment, Hoofddorp, The Netherlands

13.1 Comfort, a key issue

To be competitive in the market of construction vehicles attention should be paid to the interior comfort. Operators of wheel loaders, cranes and other construction equipment demand this comfort, not in the least because at home and in automobile cars they are used to high comfort levels. On the other hand construction companies need their operator to feel comfortable to increase health and productivity. To understand more on the future demands on vehicle interiors the vision of different manufacturers on comfort is asked in this study.

13.2 Question of this study

What are important comfort aspects in vehicle interiors of construction equipment according to manufacturers?

13.3 Approach

To get an answer on above mentioned question 84 persons from manufacturing companies were interviewed. The interviews took place at the 2001 edition of Bauma, the world's most important trade fair for construction machinery, building material machines, construction vehicles and construction equipment (see figure 13.1). The most important question in the interview is shown in table 13.1. In averaging the data a value of 10 was given to the most important issue and a value of 7 to the second important issue. In case more issues were mentioned the points were equally divided over the issues. The results of the interviews were discussed with some manufacturers in two workshops during the Bauma.

Figure 13.1 The 'Bauma' is the largest trade fair for construction equipment in the world

Table 13.1 Example of one of the questions asked at the Bauma

Which comfort aspects will be the most important in the coming years?		
	1st most important	2nd most important
seat	O	O
steering wheel	O	O
controls/pedals	O	O
cab dimensions	O	O
climate	O	O
noise	O	O
vibration	O	O
vision	O	O
other	O	O

13.4 Results of the interviews

Four persons (5%) of four different manufacturers reported that comfort was not a key issue and were not able or willing to answer the question. Of the other 80 persons 22 were active in design and engineering and the other 58 subjects were active in sales and marketing.

In figure 13.2 the results are summarized. The most important aspect in the future will be the seat according to the manufacturers. The second most important aspect will be noise and the third vision. The steering wheel is an aspect which will not get much attention the coming years.

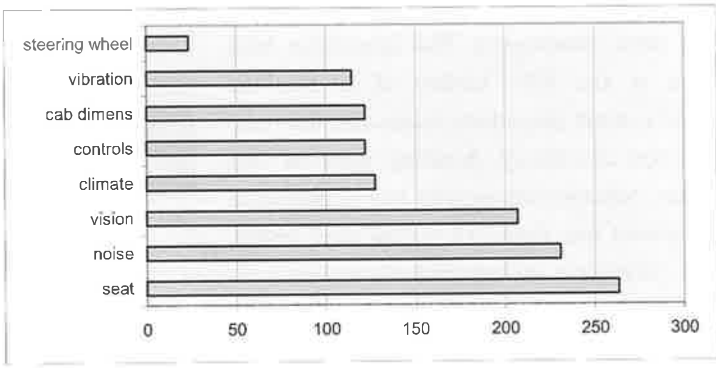


Figure 13.2 Total score of 80 subjects regarding the most important aspect the coming years. A high score is more important

The group sales/marketing and the group design/engineering had a different opinion (see figure 13.3). More then 30% of the scores of design/engineering representatives indicate that the seat is the most important comfort aspect the coming years, while this percentage is 18% for the sales/marketing group. Another difference can be found with respect to controls/pedals. According to design/engineering controls/pedals are the second most important aspect while for sales/marketing vision, noise, climate, vibration and cab dimensions are more important.

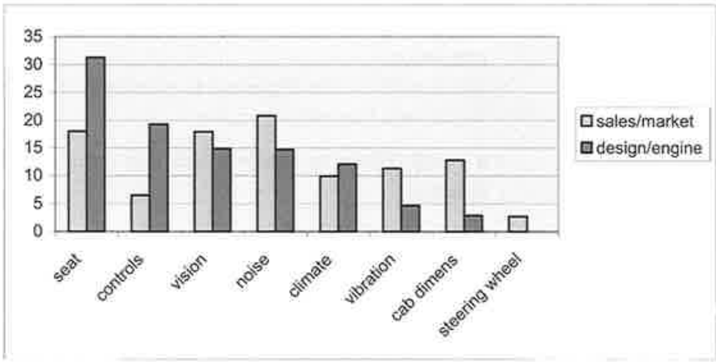


Figure 13.3 Percentage of the total score of 58 sales/marketing representatives and 22 design/engineering representatives. A high score means more important

13.5 Results of the workshop

The first workshop was attended by representatives from Ljungby Maskin, Man Wolfkran, O&K and Liebherr. Some comments on the results of the interviews were:

aspect	comment
seat	• of course the seat will still be important because long periods of sitting will still occur in the future • improvement is still possible - just have a look at the office seat market - and manufacturers will have to stay close to these developments leading to new standards, so they can maintain a competitive position in the market • mobility in the seat, passive as well as active, could be a future issue • adjustability is important to anticipate on growing length of the population • adjustability is important to anticipate on growing length of the population • adjustability is also important to anticipate on more female drivers and drivers from other cultures
vision	• it is still difficult to design a cab with a good view in all needed directions
controls/pedals	• some companies have their own joysticks, this makes integration in the whole cab and combination with the functions easier • natural feel is important, the joystick should feel like an extension of the human body
vibration/noise	• the coming regulations oblige manufacturers to take these items into account
vision/climate	• a better vision is closely linked to climate as more glass automatically means higher temperature
general	• an integral approach is essential as the cab dimensions, vision, seat, pedals and controls together influence the posture and thus the comfort and vision are again connected to climate (see previous point). It is difficult to find the optimum. The Ergomix (see figure 13.4) could be a helpful instrument

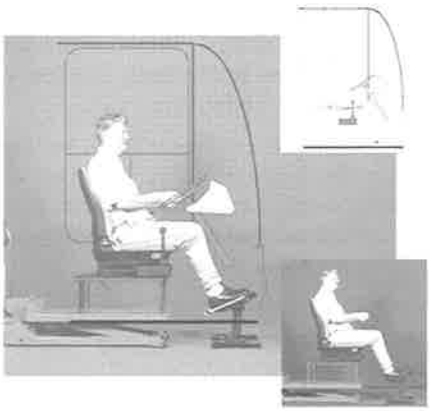


Figure 13.4 The Ergomix of TNO: a system in which real drivers and (computer) drawings are mixed. Designers, users and ergonomists can see immediately the consequences of redesign proposals and discuss them

Table 13.2 New comfort aspects found in the automotive industry

Air-conditioning almost standard
Lumbar support
More adjustability
Seat heating and humidity systems
More roominess in less space
Same seat for different cars
Seat stimulates drivers mobility
Joystick controls/computer screens
Every car is made custom specific

The second workshop was attended by representatives from Kobelco, Daewoo, Komatsu, STA and Bosal. Some comments on the results of the interviews were:

aspect	comment
seat	• in some countries drivers spend more than 12 hours in the seat • the seat is the connection between vision, controls and pedals and therefore also the most important element in the future • it is important to take over ideas from the automotive industry, like heat and humidity control in drivers' seat (see table 13.2) • in fact, in the future seats should be smaller with increased comfort experience to give more room in the cab for other elements or to reduce the cab
controls/pedals	• it is important to have feeling for joystick or other control use; some people seem to lack this feeling • the above could also be seen as a challenge to design controls that enable operators with less 'feeling' to be able to work well with a machine. In times when it is hard to find operators this may prove valuable • one company agreed that the joystick is indeed a future issue, while another company mentioned that there is not so much to be done by them anymore

aspect	comment
noise	• a difference should be made between sound and noise. Drivers should like the sound of the machine whereas at the same time noise should be reduced. Noisy environments may cause fatigue and also lead to stress reactions in the body
vision/dimensions	• on company improved comfort and interior space by making the console (with instruments) height adjustable. This is related to cab dimensions and vision, because the driver can decide on the optimal vision/space combination. The steering wheel adjustability is already found in many machines
general	• every machine should be customized to a specific driver. However, this is not possible because different drivers use the machines, but also because it is very expensive to manufacture. Perhaps ideas from automotive industry can be borrowed • all aspects are important. Common sense is no longer enough to improve the cabin comfort. Therefore several companies use questionnaires among drivers. They are useful in getting ideas for improvement. However, users should also be involved in the next steps of the design process. In that case special research techniques are needed to get the right information from the users/drivers • the styling is an important issue to the manufacturer, as was shown by O&K at the Bauma (see figure 13.5)

Figure 13.5 Styling is an important aspect. O&K showed its latest model at the Bauma

13.6 Conclusion

In a study in 1997 (see table 13.3) the seat was one of the most important comfort aspect in the cabin.

The present study shows that 4 years later the seat is still the most important comfort aspect in construction vehicle interiors. In both workshops the integral design was stressed. The seat should therefore be seen in relationship with other aspects. In fact the seat is the link between vision, controls, pedals and cab dimensions.

Table 13.3 The priority given by users to the different parts of a cabin with respect to comfort (1 = high priority, 7 = low) (Nakada, 1997)

	Kansei desirability ranking: Kansei ranking importance			
	types of construction machinery			
cab interior	bulldozers	dump trucks	wheel loader	passenger vehicles
operator seat	1	2	2	1
instrument panel, monitors, meters	3	1	1	2
levers, switches, pedals	2	5	3	7
temperature control, audio equipment	4	7	6	4
interior finish, trimming (ceiling, sides and pillars)	5	4	5	3
steering wheel	–	3	4	6
windows (shape, glass, colour)	6	6	7	9
console box and glove compartment	7	9	9	8
floor mat	8	8	8	5

In the future operators will remain working inside the vehicle over prolonged periods of time, which supports the need for a comfortable seat.

Noise and vibration are regarded second most important, because of guidelines that are now developed and because it is essential to reduce fatigue (long periods result in more fatigue).

The third most important aspect is vision. Good view on the work will remain very important for quality and it is not always easy to make that possible.

Engineers and designers also see the controls as important, because operating should be simple, easy, precise and comfortable. The controls should be a logical extension of your body.

14 What would operators like to see

Lottie Kuijt-Evers, Frank Krause
TNO Work and Employment, Hoofddorp, The Netherlands

14.1 Introduction

What would operators like to see in their future cabins? What are their wishes and their needs? To get answers to these questions we questioned 273 wheel loader and excavator operators during the Bauma 2001.
In this chapter we describe the operator's demands and wishes for future wheel loaders and excavators. We also pay attention to the feasibility of these wishes and needs.

14.2 Future demands according to operators

The operators were asked to answer two questions about their future machine. The first question was about the changes needed to improve comfort. The second question was about other aspects, not necessarily connected to comfort, that should be improved in the future. Both questions were open-ended and the operators gave a lot of different answers.
As was done before we classified the answers into 15 categories (see table 10.1). We then calculated the percentage answers for each category. Based on these percentages the future demands are listed. We only mention the categories which contain more than 10% of the given answers.

Wheel loaders
Wheel loader operators find, that their overall comfort during working in the machine can be increased by improving seat comfort (e.g., seat pan, lumbar support, arm rests, curvature of back support), climate control (e.g. temperature, dust filters, ventilation, position blowers), design/dimensions/in- and egress (design and dimensions of cabin and machine, position of steps, grab rails), and accessories (e.g. fridge, cup holder, storage space, and radio).
The largest category is 'seat comfort', as 17.3% of the answers are classified into this category (figure 14.1). Climate control is second largest with 16% of the answers, followed by design/dimensions/in- and egress (13.6%), and accessories (12.3%).

When asked what other aspects should be improved, the operators are quite unanimous: 64.1% of all answers fell inside the category 'Machine performance'.

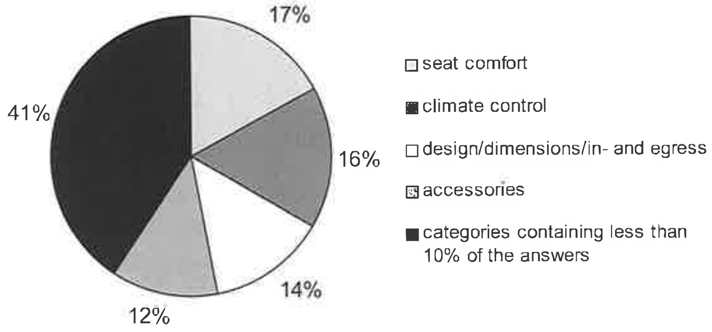


Figure 14.1 Future demands of wheel loader operators: changes that are needed to improve the comfort

Excavators

In the excavator group the top 4 of desired changes to improve comfort consists of climate control (18.9%), seat comfort (17.9%), design/dimensions/in- and egress (16.3%), and accessories (13.6%) (figure 14.2). These are the same categories as the wheel loader operators mentioned, though in a slightly different order.

Regarding other aspects to be improved it was the category 'machine performance', that was again the largest category with 56.7% of the answers. View was also mentioned in more than 10% of the answers (10.2%).

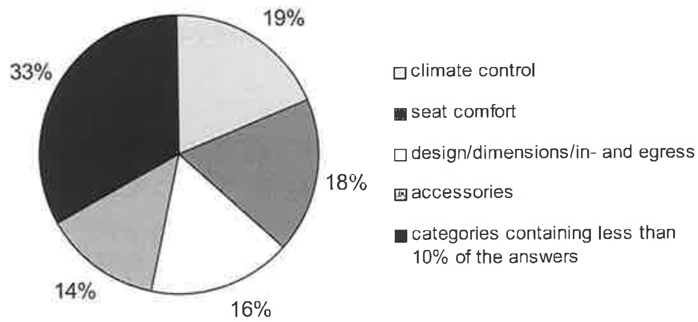


Figure 14.2 Future demands of excavator operators: changes that are needed to improve the comfort

14.3 Feasibility of future demands

Climate control

Continuous attention is paid to improving the operator's viewing area when designing new machines. The O&K study that was shown at the Bauma is an example (see chapter 13) There is a general tendency towards an increased glass area, not only in earth moving equipment but also in the automobile industry (see chapter 15) and even in architecture. Obviously the increased glass surface places higher demands on the climate control inside the cab. To keep temperature within comfort ranges air-conditioning would be necessary.

Preventing heat build-up from radiation requires different techniques such as coloured glass, specific coatings or electro-chromatic glass that can be obscured electrically. Some of these techniques are already in use. Air-conditioning, if not already standard, is mostly optional in a cab. Electro-chromatic glass is applied in automobile prototypes and may therefore not yet be ready for use in heavy industry. The fact that these features will probably increase the price of a cab, will not add to a speedy introduction.

Seat comfort

Improving seat comfort should be seen as wide as possible. Beside the comfort of the seat itself and the damping of vibrations, it includes making sure that the operator is correctly positioned with respect to hand and foot controls and viewing area, while maintaining a healthy posture. Improving seat comfort therefore requires more than improving the seat and its suspension. Improving the comfort of seat and backrest may even prove to be useless if other factors are not optimized.

Nevertheless, should one wish to further improve the seat's comfort, scientific knowledge on comfort is required as described in chapter 2. The comfort experience is highly individual and varies accordingly. The challenge lies in satisfying as many operators as possible, without creating widespread opinions about the seat.

With respect to vibration damping, there is still work to do done. In present seats damping characteristics change with the chosen seat height. This should not be the case. Also, the pitching of the cabin has not been taken into account. Operators often complain of getting 'hit' by the back rest when the machine moves violently.

In addition solutions should be sought in all other interfaces between the earth and the cab or the carried load and the cab, such as boom hinges and cylinders and cab suspension. Because of the possibility of resonance, solutions should be phased. This might be the largest challenge because seats are ready-to-buy products and are therefore generally not adapted to a certain specific machine.

Cab design/dimensions

Operators would like to have a larger cab. Especially in excavators this is quite logical considering the limited available space for the cab. Apparently space or the (sense of) roominess of a cab is closely connected to the comfort feeling. Also it is often the storage space that is being missed. Adding storage space in the back of the excavator cab should be possible by extending the cabin's footprint to the back. This, however, will generate a conflict with the general desire to reduce machine size while maintaining or increasing machine power.

In wheel loaders there is also a conflict with the direct viewing area. Increasing the size of the cab to the back and sides will impair the operator's downward view. As view is scored second (after machine performance) on aspects needed to work well with the machine, creating more space or the sense of space is a challenge to the designers.

Machine performance

Machine performance is high on the operator's list of wishes. We mentioned above that it is not yet clear what aspects of machine performance are most important to the operator. This should first be investigated. With the outcome designers will have better information on how to make sure the machine lives up to the expectations of the operator, which is very important considering the influence operators have on the buying of equipment.

The trend towards more power in the same machine is already present. Here also the trend comes into conflict with other machine demands such as compacting the machine and reduction of exterior noise production. Making the machine compact to increase viewing area and application areas mostly requires a minimization of the engine compartment. On the other hand noise reduction requires space for insulation materials. In addition an increase in power requires more cooling, which not only needs space but can also be noisier. With increasing environmental regulations with respect to exterior noise it will not be easy for manufacturers to keep increasing machine performance without a deterioration of other important factors.

14.4 Conclusion

It is clear that with so many operator demands covering aspects that are in the same time strongly interrelated, machine design should be taken as a whole. There should be a close co-operation between all involved disciplines, not only technical but also with respect to human factors. A complicating factor is the fact that manufacturers are increasingly becoming system integrators as is the case in automobile industry. Many components that form the interface between the operator and the machine are purchased, making it more difficult to create a cab including all controls and functions that is built around the operator. A large manufacturer may be able to influence his supplier, for a small company this is near to impossible.

15 Following the automotive industry

Karin N. Reijneveld
TNO Work and Employment, Hoofddorp, The Netherlands

15.1 Introduction

Designers of wheel loader and excavator cabins generally take a sharp notice of design trends in the automotive industry. Though strongly functionality based, the interiors of construction vehicles also follow design trends that can be seen in the automotive industry. Heavy equipment should also have a comfortable car-like cab. Because the automotive industry is most advanced in investigating future design and in setting design trends, it pays to take a look at trends in the automotive industry and what can be expected in future vehicle interiors.
Some general design trends and trends in automobile design, including examples of several concept cars, are explained below.

15.2 General trends in design

At the beginning of the 21st century design magazines, like the Japanese Axis, considered the current trends in design as well as the possibilities for the future. First of all, technological advances in the 21st century will realise things we cannot now imagine. Many products that are developed today, could not have been made until just several years ago.
Secondly, people from outside the designing industry will be designing things and the consumer's status will not be as purchaser, but as trend-setter for design. You could even say each consumer will become a designer. An example are the guest rooms in a London hotel, which are done in white without intense colouring for the most part. Guests can design their room by selecting the colour of the room's lighting. As all the guests choose their own lighting, which can also change very easily, they together are the 'designer' of part of the hotel's presentation to the outside world. Further, art and product design are moving closer together and design itself will blend more completely into daily living.
Thirdly, as thought and sensibility become more important to design, we will require the act of designing to give more consideration to all five senses. Even the feeling of how food goes down your mouth is likely to become a subject of design. The object of design will shift from objects to more conceptual, philoso-

phical aspects. As the virtual world progresses, people's desire for the physical will increase.

Finally, one of the current trends is that working space, which became separated from living space during the industrial revolution, is returning to the home thanks to the IT revolution.

15.3 The general trends in automobile design

In automobile design the advances in technology will become evident in the ways of control, the 'intelligence' of the car and the use of cameras and monitors. Technology also creates possibilities for the consumer to become a designer of the car interior. The trend of the disappearing separation between working space and the home results in the creation of cars as a 'home-away-from-home'. This trend is also connected to the worker's desire, when spending long hours in a confined space be it an office room or a cabin, to create a pleasant environment, a home-away-from-home as the truck cab in figure 15.1 shows.

Figure 15.1 On the road in a 'home-away-from-home'

The ways to control an automobile are expanded by driving by wire, joystick steering and force feedback. The way to control the information presented to the driver has endless possibilities. The Seat Salsa Emoción, for example, has a big Plexiglas bubble that covers the entire dashboard, including its information area. A trackball on the steering wheel regulates all the data projected on to the surface of the bubble from the inside.

The cars of the new millennium are increasingly attractive and ever more intelligent, with the aid of cutting edge technology. Accident prevention systems might eliminate the need for cumbersome protective structures (thereby leaving more room for the car's occupants). A Johnson Control concept cabin is fitted with electric seats which adapt 'bio mechanically' to

Figure 15.2 The Volvo Safety Concept Car makes adjustments to the interior based on the eye position of the driver

their occupants body. The Volvo Safety Concept Car recognises the driver's eye-position and adjusts the steering wheel, the floor, pedals and console automatically to create a safe sitting position. The driver can fine-tune the adjustments afterwards. Figure 15.2 shows the Volvo SCC.
The use of cameras and monitors will replace mirrors and elements such as dashboard lights.
The transparent dashboard of the Lancia Nea concept car houses five monitors (see figure 15.3): the one behind the steering wheel displays information such as driving speed, others the view form the rear relayed by the cameras. The one on the central unit is a services monitor. The safety concept car by Volvo has hood and trunk cameras and the Nissan Fusion has a main VDU which sits on the dashboard between two tiny screens that are connected to cameras that replace door mirrors. The driver's position in the Citroen Osée in which he sits between the two passenger seats, is possible because of the built-in cameras.

Figure 15.3 The dashboard of the Lancia Nea contains 5 monitors

In the future, our cars will become a sort of blank sheet on which we shall be able to use the car's computer system to 'design' our own dashboard, our own cabin, our own colour scheme much as we do now on our computer screens. The roof of the Nissan Fusion, for example, seen from above or from inside the cabin, looks like a glass dome (see figure 15.4), at the centre of which 'floats' a sheet of Plexiglas incorporating optic fibres which allow the driver or his passengers to change the colour of the interior lighting at will. It allows them to choose a lighting scheme to suit the mood of the moment, so that they become their own interior decorators and can create the interior décor that suits their mood at the time, similar to the guests in the London hotel. On the other hand, the desire for flexible production offers possibilities for design by the consumer as well. The entire body work of the Ligier Be Up (the wearable car) has been designed with a 'wardrobe' of elements that can be combined in various ways (see figure 15.5). Another invention designed for maximum flexibility is the 'super integrated cockpit': an integrated modular cabin that includes the dashboard, storage unit and the seats. This structure is mounted on a central magnesium crossbeam equipped with a system of flat cables and a plug and play assembly style that allows for the rapid updating of electronic systems.

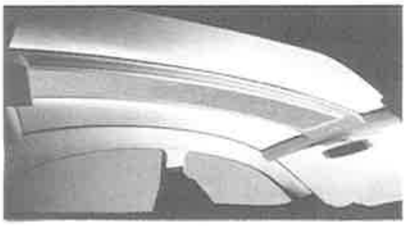


Figure 15.4 The roof of the Nissan Fusion incorporates optic fibres that change the colour of the interior at the passenger's will

Figure 15.5The entire body work of the Liger Be Up has been designed with a 'wardrobe' of elements that can be combined in various ways

The difference between working space and the home will disappear. The Johnson Control cabin is a sort of multimedia living room where people can work or play games (figure 15.6). It is an extension of the home and the office. The core concept of the Lancia Nea is the creation of a 'home-away-from-home' in the cabin around which the rest of the car is developed and Ford's vision is that of a practical, driving communication centre.

Figure 15.6 Johnson Control developed a sort of multimedia living room where people can work or play games

15.4 Other trends in automobile design

Other trends in automobile design are the attempts to add more space to the interior or at least to the feeling of more space. Barriers between the interior and the outside world are eliminated. On the other hand, there are designers that aim for a wraparound interior.

Designers are trying to add more space to the interior. The Johnson Control cabin trim was designed to take up the least possible space (see figure 15.7). The Nissan Fusion was designed to offer a particularly spacious interior. In the process the designers came up with a way of expanding the cabin while reducing the front and the rear overhangs. In the Citroën C5 every effort has been made to make the car look larger than it really is and the whole interior is exceptionally spacious. In the new Ford Mondeo 50 mm was added to the wheelbase, to allow the designers to optimize the interior package and create an even roomier interior.

New concept cars look as if the barriers between the interior and the outside world have been eliminated. The Lancia Nea bodywork looks generously proportioned but almost see-through, thanks to the big glazed cabin roof. The Volvo SCC has a different starting point - safety - but the effect of the reinforced Plexiglas A-pillar has a similar effect, as does the extension of the windscreen to the roof in the Nissan Fusion.

Between all these roomy aspects, designers want to create a wraparound feeling as well. When the door of the Nissan Fusion is closed, the panel and the dashboard elements come together to create a wraparound shape (see figure 15.8).

Figure 15.7 The sophisticated yet linear and minimalist cabin trim was designed by Johnson Control to take up the least possible space

Figure 15.8 The wraparound interior of the Nissan Fusion

15.5 Conclusion: usability for heavy equipment

General design trends have already found their way to the concept cars of the automobile industry. The glass roof can already be found in production cars from Mercedes and Peugeot. Obviously wheel loader and excavator cabins differ from automobile cabins in a number of ways. For one thing the functional requirements differ widely. Also controls differ from the automotive industry. Nevertheless there are several examples of innovations in earth moving machinery that were first seen in automotive industry such as plastics for dashboards, airconditioning, low sound levels and curved windows.

Further it is to be expected that seat and control adjustment will become electronic, cameras will replace mirrors and multifunctional screens will become standard in the operator's cabin.
In general it is safe to conclude that with the increasing comfort level of cars and their number of accessories, so will the operator's wishes increase to minimize the difference in comfort level between cars and machine.
Equipment manufactures will therefore need to closely watch developments in automotive industry.

15.6 References and sources

Axis, vol. 89, jan/feb 2001.

Auto & Design, 125, dec 2000, jan 2001, nr 6 (bimonthly).

FORM, The European Design Magazine form197, may-June 3/2001.

Design Report 5-01.

16 Future cabins

Hans Rakhorst, Lodewijk Vormer
TNO Work and Employment, Hoofddorp, The Netherlands

16.1 Intuitive control

Hans Rakhorst

All modern hydraulic excavators are nowadays joystick operated. This has reduced the physical exertion necessary to operate machines of the former generation. Though this may easily be regarded as an improvement - as do all operators - it does not necessarily mean that it is without health risks. As in other professions repetitive strain injuries (RSI) are also present among operators. The transition to joystick operation has led to a working posture, in which only small movements of the arms are required. Furthermore as movement ranges have become smaller, the need for precise muscle activity has become larger. This requires adequate armrests not only to support the arms and alleviate shoulder muscles, but also to stabilize the arm when precision is required.

Excavator seats do not yet meet the requirements to provide this arm support to a large population of users. The seats often lack arm support. This is then supplied by an armrest connected to the console, in which the joystick is mounted. Their adjustment ranges are mostly limited. This was described in chapter 7.

Present joystick design may not necessarily be the most suitable to the various tasks an excavator operator performs. The precision requirements lead several operators to move the joystick by fingers as they are not able to reach the necessary level of precision while gripping the joystick with the full hand. This finger operating technique leads to joint positions, that are far from optimal (see figure 16.1).

Figure 16.1 Extreme joint angle in joystick operation

The above mentioned conditions are known to be a risk for RSI. This study aimed at improving the adjustability of the operator's control position and at improving the joystick's position relative to the operator to reduce the risk of musculoskeletal disorders. This has lead to an idea for a very adjustable workstation, in which also the joystick's form can also be adjusted to suit the operator's preferred working technique (see figure 16.2).

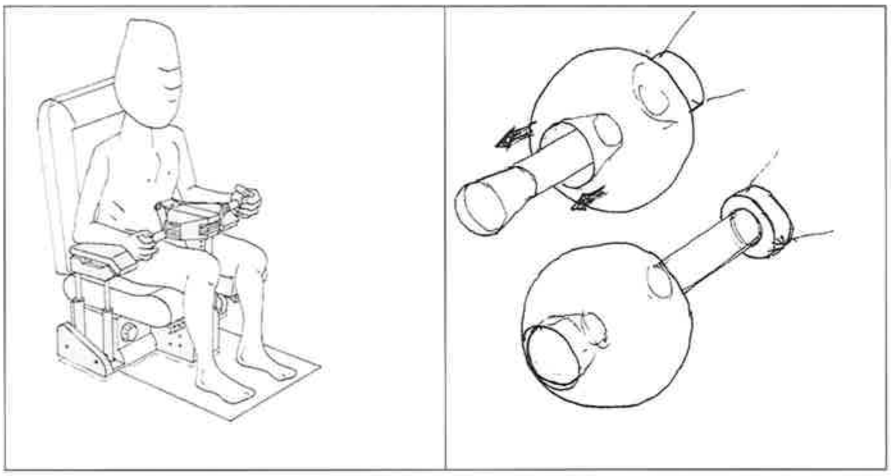


Figure 16.2 New ways of joystick controlling

We have also looked at new ways of operating the excavator without using a joystick. The result is an idea for an alternative control. The new control requires larger movements of the hands and arms. The machine can be controlled bimanually and with one hand. By doing so the load on hands and arms is varied. This reduces the risk for overuse injuries. Besides wanting to reduce the risk factors we have looked for a very intuitive way of controlling the machine. This may reduce the time necessary for an operator to learn the trade, which in some countries is important because of the difficulties companies may have in finding suitable personnel.

The result is the shown in figure 16.3. At the time of writing this book the presented control still only exists as a three dimensional rendering. It would be interesting to build such a control and to have operators test it under realistic conditions to see, whether this innovative control can live up to its expectations and be of value to future operators.

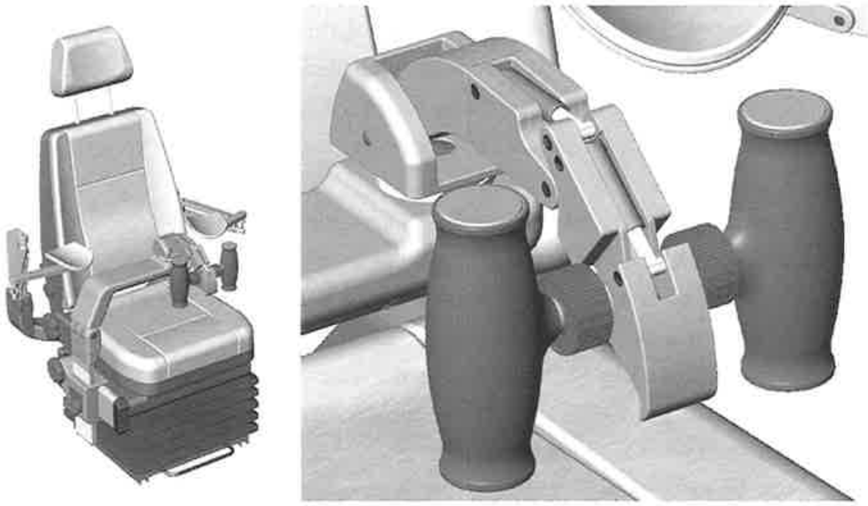


Figure 16.3 An intuitive control system

16.2 I see, I see what you cannot see

Lodewijk Vormer

The purpose of the project was the development of a conceptual cabin design for future excavators. The project's main goal was the improvement of the outside view from within the operator's cab. The project focused on excavator models ranging from 10 to 50 tons and concerned both crawlers and wheeled excavator models.

Based on an extensive analysis of existing excavators, excavator cabins and its users, potential problems concerning the visibility have been charted. These problems have been sub-divided into three areas. First and most important there are restrictions in the operator's view of the direct working area. The downward view is limited and the view on the reaching area of the hydraulic arm is interrupted by the cabin frame. Second the view of the area surrounding the working area is restricted. To the right the view is obstructed by the boom and the downward rear view is limited. Lastly the view of the vehicle's sides should be mentioned. There is little or no view of the vehicle's right side, the right rear corner and the back of the vehicle.

Additionally, problems directly concerning the windows also play an important role in aggravating the restricted visibility of the outside. Curved windows can

lead to reflections and distortion of the view. Glazed windows provide very little protection against glare and the heat of the sun. Windows become soiled, yet not every window is equipped with windshield wipers and washers.
Quite different from these problems nevertheless, something that may also reduce productivity is the fact that windows are also prone to vandalism.

Trends and developments in the field of operator view
When trying to find solutions to these problems, it is important to take a close look at trends and developments regarding this matter. With respect to glazing there is still an increase in glass surface of the cab. For solutions to the problems connected to large glass surfaces the glazing industry can provide solutions. Laminated glass with coatings or incorporated films can make operator life behind the window a lot more comfortable. E.g. with electro-chromatic glass the transmission of light and heat can be adjusted, thus reducing glare or heat build-up. By using self cleaning coatings containing titanium dioxide combined with a hydrophobic surface, soil and rain will have less influence on the outside view.
Legislation requires cars to have glass front and side windows. However, synthetic materials are rapidly evolving into good and in some ways even better alternatives to glass, including their scratchproofness. In cars there are already synthetic back and roof windows. It is a matter of time and these materials will have found their way to all kinds of cabins with their advantages of being light, relatively cheap and easy to mould.
Rather different are the developments towards a moveable cab. A few excavator manufacturers offer the opportunity of mounting a cab of which the vertical position can be adjusted. Several manufacturers of mobile cranes have a tiltable cab installed to improve upward visibility.
With respect to indirect viewing and alternative means of viewing there are also many developments. Already mirrors are being replaced by cameras offering large flexibility regarding camera positions, display positions and the operator's choice of what is to be displayed. By using GPS[5] in combination with several sensors (radar, sonar, heat, etc.) it will be possible to create a computerized image of reality giving the operator a see-through view of the earth he is excavating. The images might either be projected on the front window or even on a screen in a separate working place from where the operator controls his machine.

5 Global Positioning by Satellite.

The 'Turtleneck' concept

Based on the existing trends and developments, in an attempt to further enhance the operator's direct view of his work, solutions have been sought on four different levels:

- the location/position of the cabin;
- the location/position of the driver;
- the cabin exterior;
- the cabin interior.

A multitude of ideas generated in the course of this project have led to several concepts. These concepts were in turn used to compose a single final concept: the 'Turtleneck' concept of which a three-dimensional computer model was built. The 'Turtleneck' concept boasts the following qualities:

- the moving cabin allows repositioning in order to achieve the best possible view. This cabin can be elevated to look over obstacles. It can be moved forward to look down over the undercarriage. The cabin can also be tilted forwards and backwards to optimize view through the front windscreen of the working range of the hydraulic arm (see figure 16.4)

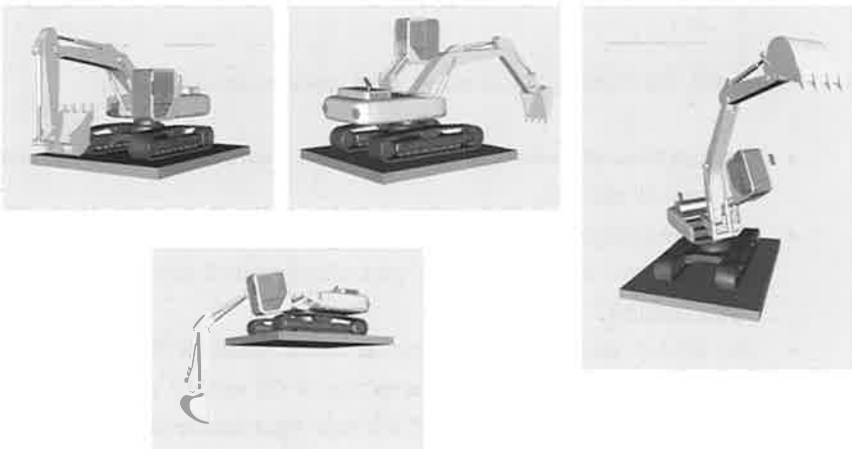


Figure 16.4 Renderings of the 'Turtleneck' concept showing the movements of the cab

- the front windscreen of the cabin is enlarged by integrating front, top and a bottom window affording more view on the working range of the hydraulic arm;
- a sliding floor panel can be uncovered to reveal a window underneath, thus enabling a direct downwards view;

- the cabin's main door is a sliding door and can thus be easily be opened and shut by the driver in a seated position. Because the door can be set in different positions of closure, adjustable ventilation is also achieved;
- the driver's seat can be adjusted to support the driver's body in multiple positions (see figure 16.5);

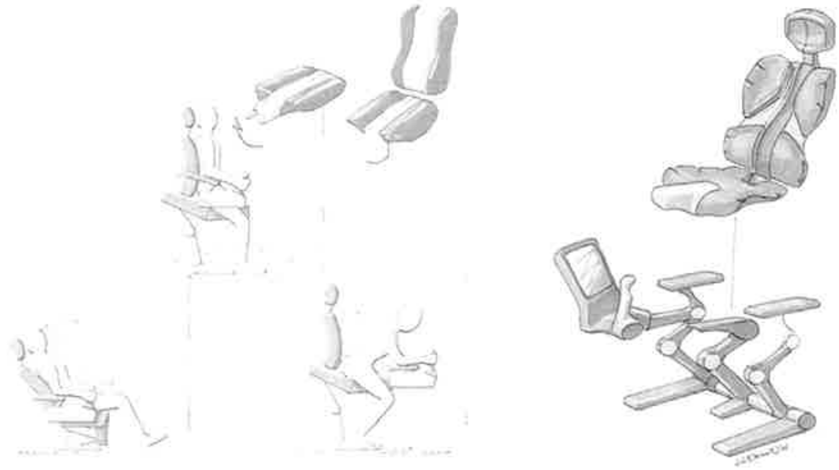


Figure 16.5 The 'Turtleneck' seat adapts to the operator's chosen posture

- the functions of steering wheel and travel levers have been incorporated in the joystick controls;
- all the control panels have been substituted by a single touch-screen display, providing the driver with easy centralised control and overview of all the cabin features;
- the display also provides additional views obtained through cameras and sensors mounted on the upper structure of the vehicle. In this manner views to the right, the right flank, and the back right corner of the vehicle are provided.

Compared with contemporary cabin design, the view of the outside provided by this new cabin design has been improved significantly.

17 Acknowledgements

The Eurocabin participants wish to thank the European Union for granting the opportunity to perform this project. Special thanks goes to our EU-officer Georgios Katalagarianakis for his support during the project. Through Eurocabin we have been able to learn many things, including learning to pronounce his name.

Of course, we would also like to thank all the operators who talked freely about their machine and thus helped us form an opinion about the machines. Without them this project would not have succeeded.