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

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

Print:
PlantijnCasparie Heerhugowaard

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.

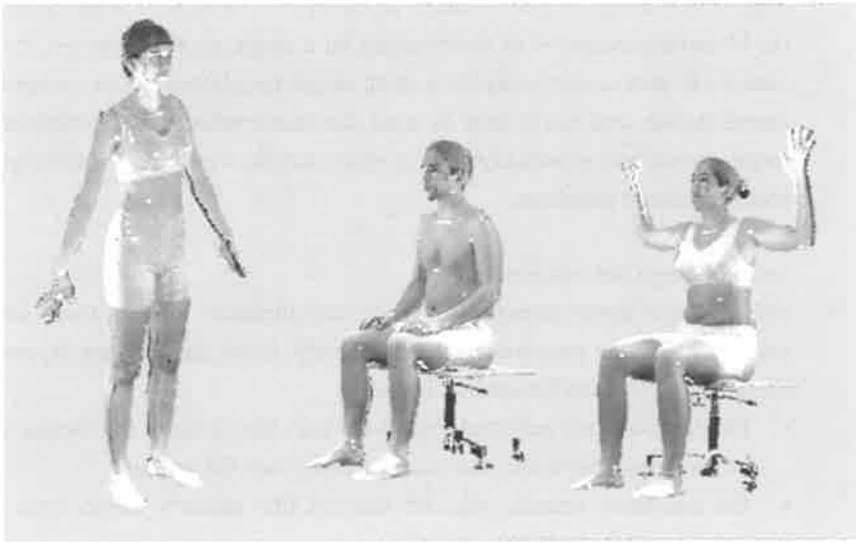

Figure 6.1 An example of 3-D surface scans of subjects

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 geometry. 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.