Ergonomics Integration and User Diversity in Product Design

by

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Abstract

Consideration of products' ergonomic qualities is one important component for successful product development. Product designers engaged in the core activity of product development need methods that support the consideration of ergonomics along with other product requirements. This thesis aims to address these needs.

The first part of the thesis investigates how people working within product development organisations communicate with and about users of their products. The general need for methods to support communication of user aspects in product development is identified through formal interviews with product developers and a review of the management, ergonomics and design literature.

The second part of the thesis studies the factors which affect the integration of ergonomics in product design. Supportive methods, including User Characters, for evoking user consideration among designers together with Overlapping methods for scheduling ergonomics evaluation in product design processes are introduced and argued.

The third part of the thesis reviews and discusses computer aided ergonomics as a means for integration of ergonomics in product design. A web-based support system for effective employment of human simulation tools is developed using a participative approach and evaluated based on the system's usability.

The objective of the fourth part of the thesis is to study how human simulation tools can aid designers' consideration of human diversity to accommodate users of diverse anthropometric characteristics in multivariate design problems such as automobile cockpits. The work involves the evaluation of different approaches for the generation of specific manikin families which can be used as test groups for fitting trials in the virtual design process.

The research demonstrates enhancements in design methodology knowledge to support integration of ergonomics in product design processes with a focus on anthropometric diversity in vehicle design.

Keywords: product design, design ergonomics, design methods, human simulation, human diversity.

To

Thim & Nea

Human accommodation in vehicles, according to my son Thim (driver is stretching out his tongue, if anyone wonders).

Acknowledgements

I guess doing a PhD on an overseas part-time basis is never straightforward (perhaps no PhD is). Completing the PhD, being engaged in teaching and other responsibilities at University of Skövde as well as being the father of two lovely kids meant that I sometimes felt insufficient of living up to all expectations. I want to thank everyone that supported me to make all ends meet.

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Note. Images on each chapter's first page from Starobinski, J. (1965) *Medicin*. Wahlström & Widstrand.

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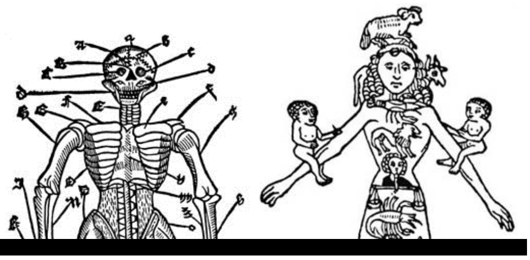
Chapter 1
Introduction



This chapter defines the problem area, general aims and objectives. Two central hypotheses are presented. The chapter also describes the conditions (industry contact/collaboration) for the research conducted, gives definitions of related terms as well as presenting an outline of the thesis.

1.1. Context

Companies put considerable effort into marketing, developing and producing products. In order to stay competitive there is a need to do this as well, or better, than other present or coming players in the same field. One important task for companies is to successfully identify what creates value for their present and prospective customers, and to translate this information into attractive differentiated products.

Value can be seen as arising from practical benefits (functionality, usability) as well as from emotional benefits, and a customer is likely to perceive a product as a whole; a package of benefits. Product development that focuses only, or mainly, on a few distinct value-generating issues, e.g. technical functionality, cost, manufacturability or aesthetics, leads to a risk of sub-optimising the product. This calls for a holistic approach, where utilitarian and emotional benefits are merged in the design process.

Nearly all products interact with humans in some way. In many cases the main interaction happens during the product's user phase, but if not, most products still interact with humans during production or service. The human might interact as a power source, as a sensor or as a decider. It might also be as representing a volume with certain properties, e.g. when sitting in a car or entering a door. All these kinds of human-product interactions (or man-machine interactions) are treated in the area of ergonomics (or human factors, see definitions later in the thesis). It is important to include ergonomics considerations throughout the design process, and ideally from the very start. The area of ergonomics positively influences the value of the product by improving human-product interaction. Since good ergonomics practice takes human diversity into account when contributing to product development, enhanced ergonomics consideration in product design can also lead to increased human-product interaction quality for more people.

1.2. Problem Statement

Several sources report on deficiencies in considering ergonomics when designing products and workstations. Haslegrave and Holmes (1994) believe that views of the relationship between ergonomics and design range from the opinion that ergonomics constrains design and inhibits innovation, to the opinion that they are closely related and are but two sides of the same coin. Porter (2000) considers that there are broad differences between ergonomists and designers as professionals. For example, ergonomists may be described as problem-focussed while designers, by contrast, are solution orientated. Cross (2000) expresses this as designers solve problems by synthesis, whereas scientists solve problems by analysis, an approach generally also adopted by ergonomists. Porter (2000) highlights that ergonomists and designers have significant differences in their abilities, education, professional experience and working languages and, consequently, effective communication between the two professions is non-trivial. MacDonald and Jordan (1998) comment that product designers tend to be generalists, combining aesthetic, ergonomic and technological elements to produce an improved or innovative product, and that the designer may utilise many forms of specialist knowledge during the design process to help bring a product 'into being'. By comparison, many ergonomists see their own discipline as a science. The ergonomist tends to be more of a specialist in one area of his or her field, assisting the designer with particular expertise or data during the design process, e.g. at the outset with standards and anthropometric data, and later with user trials (MacDonald and Jordan, 1998).

1.2.1. Ergonomics in the constrained design reality

Common arguments for why the integration of ergonomics in design is a problematic issue relate to the identified call for ergonomics and ergonomists involved in product development to adapt to the nature of designing products. Product design is typically carried out as project work where demanding constraints on product performance, time and costs are prevalent. During development, the design team has to consider a full spectrum of requirements, e.g. technical performance, market constraints, competition, manufacturing, materials, costs, weight, aesthetics, quality and reliability, safety, packaging, installation, environmental issues and...ergonomics. All these considerations are to be balanced appropriately and eventually synthesised into an innovative, competitive product, available on the market on time and at the right cost. In this context it would come as no surprise if ergonomics (and indeed other matters), intentionally or unintentionally, sometimes might be given low priority by designers or project managers.

1.2.2. Designers as users of ergonomics information

Fulton Suri (2000a) believes that, in order to make effective contributions to design, ergonomics practitioners need ways of influencing the thinking and behaviour of people with very different priorities from their own. The challenge to ergonomics practitioners is to find ways of inspiring, informing and influencing a design team to address important ergonomics issues effectively throughout the product design process. It must be the ergonomics professional's responsibility to interpret research findings and begin to bridge the research gap by learning to talk the language of design (Fulton Suri, 2000a). Fulton Suri and Marsh (2000) comment that ergonomics practitioners need to form a link between analysis and synthesis; they need to help translate ergonomics information into a form which stimulates well-conceived, user-centred design ideas. For product design, designers regularly prefer to acquire precise data instead of general guidelines. However, many ergonomists seem to think that their task is complete when they have provided general guidelines and turned them over to engineers and designers to interpret and implement (Chapanis, 1995). Burns and Vicente (2000) consider that, to leverage ergonomics into design, ergonomics guidance needs to be richer than laboratory results or guidelines. Fulton Suri (2000b) believes that it is a rare designer or design team that is inspired by anonymous descriptions of capacities, limitations or statistical data of 'users'.

Although end users are beneficiaries of ergonomics, they are not usually the users of ergonomics results. The real users are designers; the people who create products and systems and whose decision-making should be influenced by ergonomics considerations (Meister, 1987a). Porter (2000) comments that, whilst ergonomists promote user-centred design, they do not always remember that the main users of their recommendations, data or methods will be designers.

1.2.3. Difficulties of contribution from an ergonomics perspective

Commonly ergonomists working in product development report that one of the major sources of dissatisfaction is the possibility of 'making a difference', i.e. making relevant and usable design contributions. Often the ergonomist is not a full member of the product development team, and is not involved in planning the design program and the schedule of activities (Fulton Suri, 1998). Ergonomists complain that ergonomic factors frequently get left out of the design process, and that ergonomics is relegated to being a 'post-design' evaluation, leaving ergonomists little opportunity to make significant and important design changes (Burns and Vicente, 2000). The authors argue that this leads to products being designed that are not nearly as usable as they might otherwise have been.

Most ergonomics professionals have developed within a strong tradition of written and verbal presentation of material, but many designers are impatient of long, written arguments; many have a strong predisposition for visual material and want to grasp the main point and move on (Fulton Suri, 2000a). MacDonald and Jordan (1998) remark that designers typically are visually literate (visualate), and that they respond well to visually-oriented learning and reference material. This may cause difficulty when ergonomists favour communicating via technical reports, which often are seen by designers as dull, produced in a difficult-to-use format, and more suited to laboratory use rather than employment in a design context (MacDonald and Jordan, 1998).

MacDonald and Jordan (1998) argue that design seldom is a precise science; design processes often contain so-called 'fuzzy' problems with no readily identifiable correct solution. Ullman (2003) states that design problems are characterised by being ill-defined, having many potential solutions and no clearly best solution. As a result, designers tend to be speculative; to have the ability to progress an idea without knowing all the facts, and doing this within a given time scale and budget (MacDonald and Jordan, 1998). Fulton Suri (1998) believes that it is uncomfortable for many ergonomists, who may have built up their reputation upon well-designed studies in support of design recommendations, to have to adjust to the commonly more or less chaotic activity of design, which sometimes, unfortunately, involves late and last minute changes, beyond the control of the designer.

1.2.4. Significance of integration of ergonomics in design

Fulton Suri and Marsh (2000) report that product designers are demanding earlier involvement from their ergonomics colleagues; that they want to have as much ergonomics inspiration as possible in the conceptual design phases of a project, to ensure that their efforts are directed appropriately.

Today's designers work at a distance from their widely diverse communities of users. In many cases, they are expected to rely upon other specialist functions, such as market research and ergonomics, to act as interpreters of peoples' needs and desires (Fulton Suri, 2000b). The author adds that, in addition to support from specialists, designers would be given a great service if they were offered ways to take them beyond their own experience and culture to explore what it is like to be someone else.

Evidently, mutual understanding, interest and respect among designers and ergonomists for each other's competences are central aspects to facilitate efficient integration of ergonomics in design. Haslegrave and Holmes (1994) argue that it is important for ergonomists to understand the main aspects of engineering design, both related to process, product and business constraints, as well as it is important for design engineers to get some formal education in ergonomics, so that both professions understand each others' approach to design problems.

1.3. Aims and Objectives

As discussed, consideration of products' ergonomic qualities is important for successful product development where ergonomics is one of many components that product designers need to consider. As detailed in Section 1.2 *Problem Statement*, there are communication difficulties between designers and ergonomists, difficulties for designers in utilising ergonomics information as well as problems for ergonomists in contributing to the design process. Still there is a shared request for enhanced ergonomics input.

The aim of this research is to assist in making ergonomics information relevant and easily available to designers and to improve communication patterns between ergonomists and designers.

Product designers would benefit from a design methodology that facilitates the consideration of ergonomics along with other product requirements in the complex time and budget constrained design reality. This call may indeed be remedied in a variety of ways and it is unlikely that there is one cure-all method that would suit all types of product development. Central in this thesis is the argument of human simulation tools' contribution in supporting designers to consider ergonomics in the design process.

1.3.1. Hypotheses

Two hypotheses were established to specify the position maintained (i.e. the *thesis*) in this research. These two hypotheses build the foundation for the research activities and discussions in this thesis. Figure 1.1 aims to illustrate the hypotheses.

Hypothesis 1 - '*means for ergonomics communication*'

Human simulation tools act as a means to support communication of ergonomics with other members of a product development team, particularly between designers and ergonomists.

This hypothesis is based on the assumption that the tool will support communication of ergonomics to and among members of the product development team. In particular, it helps in packaging ergonomics information in a way that is compatible with designers' working methods and conditions. The information may be obtained directly from an ergonomist, or indirectly through ergonomics information, where both approaches involve a human simulation tool.

Hypothesis 2 - '*designers tool*'

Human simulation tools assist designers in considering ergonomics issues in product design concurrently with other design requirements.

This hypothesis is based on the assumption that the designer himself or herself uses the human simulation tool, in a similar way as he or she uses other tools, e.g. CAD (Computer Aided Design) and CAE (Computer Aided Engineering) tools. The human simulation tools' capacity to offer the designer quick feedback of the product's ergonomic qualities supports generation and evaluation of design alternatives, where ergonomics is reconciled with other product qualities.

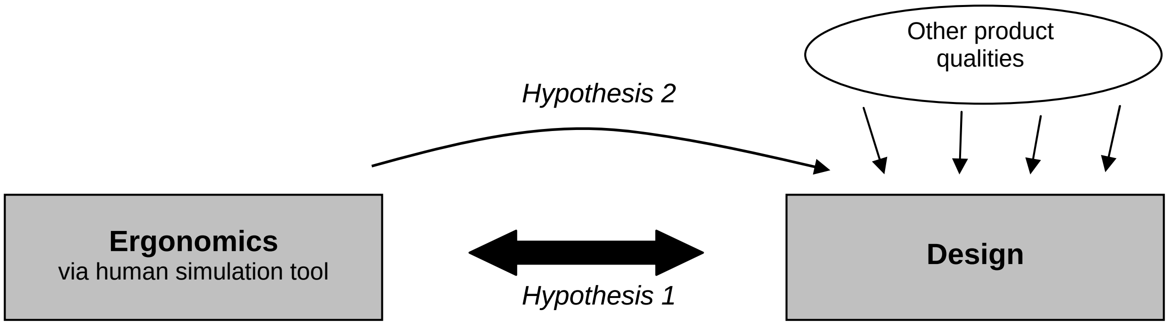


Figure 1.1. Illustration of hypotheses.

Both hypotheses are argued throughout the thesis where Hypothesis 1 relates most closely to Chapter 3 and 4 and Hypothesis 2 relates most closely to Chapter 4 and 5. Chapter 6 discusses the findings in relation to the hypotheses and Section 7.1.7 includes a reflection of the hypotheses' function in the thesis.

1.3.2. Research objectives and chosen approach

The overall research objective is to study, discuss and to argue the validity of the two hypotheses in respect to:

- The basis of the field of difficulties when considering ergonomics in product design.
- The way in which computer support in the shape of human simulation tools can aid designers to consider ergonomics issues in product design.

In general the thesis covers the interrelated areas of *Ergonomics*, *Design methods* and *CAD* (white area in Figure 1.2).

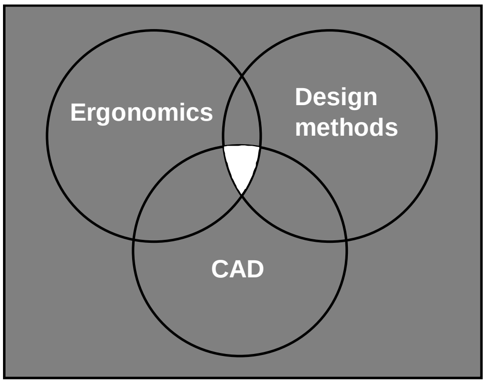


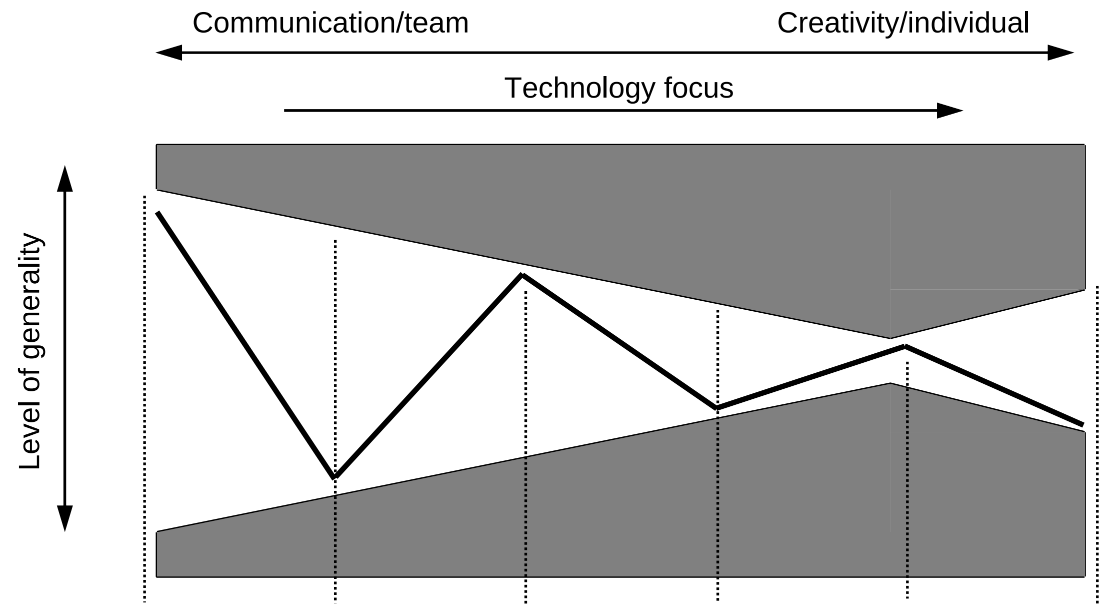
Figure 1.2. General research area.

The research is directed to result in enhanced design methodology knowledge to support integration of ergonomics in product design processes. The employment of computer-based tools by designers is an important means associated with this objective. The field of physical ergonomics, and more specific, anthropometric diversity, will be given special attention. The overall research objective is broken down into the following six sub-objectives:

1. *To better understand how product developers interact with users*.
2. *To investigate the User Characters method as a way of considering users in product design*.
3. *To investigate overlapping ergonomics evaluation in the design process and to determine the conditions under which ergonomics evaluation may be conducted concurrently with other design aspects*.
4. *To investigate the current methods for human simulation and the extent of their use within the automobile industry*.

5. *To propose and evaluate working methods by which human simulation might be integrated into an established design process.*
6. *To investigate and propose a pragmatic approach by which computer manikin families might be defined for human accommodation in the automobile industry.*

The research is divided into five phases (A to E in Figure 1.3). The objective of each phase is elaborated in the following pages.



Phase	A	B	C	D	E
	Study user aspects consideration in general in product development.	Study ergonomics and design integration. Advise on supportive methods.	Study computer aided ergonomics. Advise on methods for integration in design.	Study anthro-pometric diversity. Test and advise methods to accommodate diverse users in multivariate design problems.	Briefly discuss concepts for expanded assessment.
Investigation methods	Interviews Review	Case study Review	Case study Review	Simulations Case study Review	Discussion Review
Key nature	Descriptive	Descriptive/ Prescriptive	Descriptive/ Prescriptive	Descriptive/ Prescriptive	Descriptive
Thesis chapter	2	3	4	5	

Figure 1.3. Research action plan.

Phase A (Thesis Chapter 2, Study 1)

Phase A (Figure 1.3) investigates how people working within product development organisations communicate with and about the users of their products (Study 1, Section 2.5). The chosen investigation method is formal semi-structured interviews with product developers performed at four different companies in Sweden that develop products that have some sort of human-product interaction interface. The purpose is to assess the need for methods to support communication of user aspects in product development.

Phase B (Thesis Chapter 3, Studies 2 and 3)

Phase B (Figure 1.3) studies and discusses the issues of integration of ergonomics in design. User Characters as a supportive method for consideration of user aspects is investigated (Study 2, Section 3.2). The discussion is supported by a case study. The development of a framework for the identification of appropriate timing for evaluating ergonomics in product development processes is presented and the outcome is assessed in a case study (Study 3, Section 3.3). The purpose is to review the range of issues that affect the integration of ergonomics in design and to advise on methods to support integration.

Phase C (Thesis Chapter 4, Studies 4 and 5)

Phase C (Figure 1.3) narrows down the review and discussion to computer aided ergonomics as a means for integration of ergonomics in product design, and proposes ways for effective employment of the tools. An interview study is carried out to develop an understanding of current use procedures and problems of using human simulation tools (Study 4, Section 4.2). A web-based support system for effective employment of human simulation tools is developed using a participative approach and then evaluated based on the system's usability (Study 5, Section 4.3).

Phase D (Thesis Chapter 5, Study 6)

Phase D (Figure 1.3) reviews issues related to anthropometric diversity and assesses methods that support designers in their work when aiming to accommodate users of diverse anthropometric characteristics in multivariate design problems, such as automobile cockpits. A generic design methodology is proposed that incorporates a manikin family whose members are to be used as a standardised test group for fitting trials in the virtual stages of the design process (Study 6, Section 5.2).

Phase E (Chapter 5)

Phase E (Figure 1.3) briefly reviews and discusses aspects of human simulation tools as a means of expanding the assessment of user aspects in order to aid designers to more fully consider user aspects in product design.

1.3.3. Scope of the thesis

The concentration of the research is directed towards designers' consideration of physical ergonomics, and anthropometry in particular, in product design. Other areas of ergonomics will be treated briefly in discussions. The thesis considers the design of products that have a high degree of physical interaction with humans. Automobiles are of particular attention (Figure 1.4). However, much of the discussion and results will be valid for other types of products as well, or in a context of human work and design of workstations.

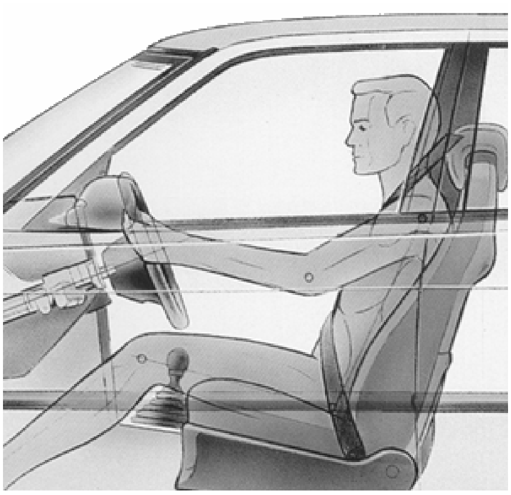


Figure 1.4. Example of product design context (image from Saab Automobile).

Most of the discussions will arise from the designer's perspective basically due to the author's background and interest area. The results of the research are aimed at being valuable contributions to design science as well as being relevant in an industrial product development setting.

The focus of the thesis lies in the development of *processes* and *methods* as well as consideration of *environments*, but not on the actual development of *tools*. The definitions of process, methods, tools and environment are according to the PMTE Paradigm as described below, illustrated in Figure 1.5 and further described in (Martin, 1997).

Process: a logical sequence of tasks performed to achieve a particular objective. Defines 'WHAT' is to be done, without specifying 'HOW' each task is to be performed.
Methods: consists of techniques for performing a task, the 'HOW' of each task. Each method is usually considered as a process itself. Methods usually imply a degree of discipline and orderliness.
Tools: instruments that, when applied to a particular method, can enhance the efficiency of the task.
Environment: surroundings, external objects, conditions or factors that influence the actions of an object, individual person or group. These conditions can be social, cultural, personal, physical, organisation or functional.

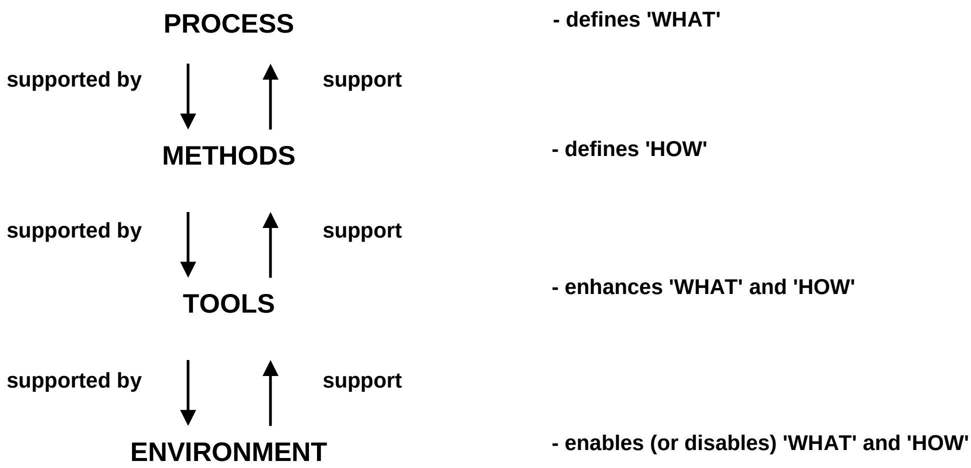


Figure 1.5. The PMTE Paradigm (Martin, 1997).

1.4. Industrial Links and Collaboration

For this kind of research, industry contact is considered as being important. Since the research subject centres on the use of human simulation tools in product development it was valuable to get in contact with companies who currently are using such tools. As a result, from January 2002 to June 2004 the author was a member of a Swedish research project called VERDI (Virtual Ergonomics Design Integration). The industrial partner was Saab Automobile in Trollhättan, Sweden. The company develop, produce and market cars (about 130 000 vehicles annually), such as the Saab 9-3 SportCombi (Figure 1.6). Saab Automobile is part of the General Motors Corporation and has about 8500 employees. Of these, 1500 work at the Saab Technical Development Centre.

Figure 1.6. Saab 9-3 SportCombi (image from Saab Automobile).

Other partners in the VERDI project were: the University of Lund, Chalmers University of Technology, the National Institute of Working Life (NIWL) and the University of Skövde (all located in Sweden), as well as Loughborough University in the UK through the author's affiliation and supervision. Two PhD students came from Lund, one PhD student from Chalmers/NIWL and the author from University of Skövde/Loughborough University. From each academic institution there were supervisors who were senior lecturers or Professors. Each PhD student had his/her own research subject that in some way related to computer support for designers to consider ergonomics. In addition, all four PhD students worked jointly on a common research topic that aimed to unify the separate research subject areas. The project had quarterly two-day gatherings, and in between these meetings the PhD students worked separate and jointly within the research projects.

In addition to the involvement in the VERDI project, it was considered relevant to do general surveys at companies that do not currently use human simulation tools, but where there might be a potential gain from using such tools. Therefore, as well as to gain more understanding of product developers' relation to their product users, an interview study was conducted at four Swedish companies. This study was performed together with Jenny Janhager, PhD student from the Royal Institute of Technology in Stockholm in Sweden, who had a related research interest area.

The major part of this thesis is based on the author's own work, and it will be clarified when results come from joint contributions.

1.5. Definitions of Related Terms

Long lasting and wide spread acknowledged definitions are hard to find, probably as a result of differences in peoples' opinions, consequences of semantic changes due to knowledge development or as a result of the general dynamics of the world around us. However, this section attempts to express some relevant definitions in order to exemplify and clarify definitions adopted in this thesis.

1.5.1. Engineering and design

The American Heritage Dictionary of the English Language (Pickett, 2000) gives the definition of *engineering* as: *the application of scientific and mathematical principles to practical ends such as the design, manufacture, and operation of efficient and economical structures, machines, processes, and systems*. As a verb *engineer* can mean: *to plan, manage, and put through by skilful acts or contrivance*, and the word *engineer* comes from the Latin *ingenium*, ability. Pahl and Beitz (1988) state that the engineer's main task is to apply his or her scientific knowledge to the solution of technical problems and then to optimise that solution within given material, technological and economic constraints.

The word *design* can mean a lot of things, both as a verb and noun, e.g. *to conceive or fashion in the mind* [verb], *to formulate a plan for* [verb], *a drawing or sketch* [noun], *the purposeful or inventive arrangement of parts or details* [noun] or *something designed* [noun] (Pickett, 2000). *Design* comes from the Latin *designare* and means to designate, to mark. von Stamm (2003) defines design as the conscious decision-making process by which information (an idea) is transformed into an outcome, be it tangible or intangible. Hubka and Eder (1996) define the task of designing as consisting of thinking ahead and describing a structure, which appears to be a (potential) carrier of the desired characteristics. Bruce and Bessant (2002) propose that design is the conception and planning of manmade objects and that design encompasses three-dimensional objects, graphic communications and integrated systems from information technology to urban environments, furniture, textiles, cars and computers. Ulrich and Eppinger (2003) acknowledge the definition of industrial design by IDSA (The Industrial Designers Society of America) as broad enough to include the activities in the entire product development team. The definition of design goes: "*...creating and developing concepts and specifications that optimise the function, value and appearance of products and systems for the mutual benefit of both user and manufacturer*."

When design is performed in the context of products it may be entitled *product design*. However, if the definition of *product* by Kotler et al. (1996) is followed, which states that a product is anything that can be offered to a market to satisfy a need or want (e.g. goods, services, persons, places, organisations, activities and ideas), design and product design become very similar. However, a public transportation system would rarely be identified as a product, and the design of such a system would rather be described as *system design* or *systems engineering*. The term *system* is very general, and products can in many cases be represented as functional systems (e.g. as described in (Cross, 2000)). Pahl and Beitz (1988) state that a system is characterised by the fact that it has a boundary which cuts across its link with the environment, and that these links determine the external behaviour of the system so that it is possible to define a function expressing the relationship between the inputs and outputs (typically expressed as flows of energy, material and information/signals).

Dym and Little (2004) describe design as an open-ended and ill-structured process, from which there is no unique solution, and that the candidate solutions cannot be generated with an algorithm. Meister (1987b) expresses the necessity to distinguish between design viewed as an abstract phenomenon (the 'ideal'; the way in which design *should* proceed) and design as actually practised in an engineering facility (reality). Meister means that reality deviates from the ideal in many ways, e.g. that in the real world the designer is biased due to experiences, which may make him or her focus on particular design alternatives. Other examples given by Meister are that some of the analyses the designer performs are somewhat unconscious, and that engineers often are intuitive in their thinking and fail to fully think through the design problem. They often have an urge to come grips with the hardware-/software-specific aspect as quickly as possible, which may cause the preceding analytical activities to be rushed. Pahl and Beitz (1988) consider that design is the intellectual attempt to meet certain demands in the best possible way, and describe design as an important ingredient in most engineering activities, regarded as *engineering design*. Cross (2000) goes into the differences between *engineering* and *engineering design* and comments that a lot of engineering design is intuitive, based on subjective thinking, but that an engineer might be unhappy doing this, since he or she wants to be able to prove things. Dym and Little (2004) define engineering design as the systematic, intelligent generation and evaluation of specifications for artefacts whose form and function achieve stated objectives and satisfy specified constraints.

1.5.2. Ergonomics

The International Ergonomics Association (IEA, 2004) defines the discipline of ergonomics as: "*Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimise human well-being and overall system performance. Ergonomists contribute to the design and evaluation of tasks, jobs, products, environments and systems in order to make them compatible with the needs, abilities and limitations of people*." Shackel and Richardson (1991) state that the prime purpose of ergonomics is to study the situation of people at work and play, and thus be able to improve the whole situation for the people, and that ergonomics always remains user-centred and focused on user's well being rather than on productivity, even though managers and designers sometimes need the argument of improved productivity or economy to employ ergonomics knowledge. In short the aim of ergonomics can be described as "fitting the system (or the product) to the user".

Among the basic disciplines contributing to ergonomics are *psychology*, *cognitive science*, *physiology*, *biomechanics*, *applied physical anthropometry* and *industrial systems engineering* (Kroemer et al., 2001). The field of ergonomics is commonly divided into the areas of *physical ergonomics*, *cognitive ergonomics* and *organisational ergonomics* (IEA, 2004).

The term ergonomics was formally accepted in 1950 by a newly developed society consisting of researchers active in the field that was to become ergonomics. The first international conference of the International Ergonomics Association (IEA) was held in 1961 (Eason and Harker, 1991). The word is derived from the Greek terms *ergon* indicating work and effort, and *nomos,* meaning law or usage (Kroemer et al., 2001). Pheasant (1986) adds that the term 'work' may be applied to almost any planned or purposeful human activity, particularly if it involves a degree of skill or effort of some sort. The terms *ergonomics*, *human factors*, *human factors engineering* and *human engineering* are usually considered synonymous (Pickett, 2000; Kroemer et al., 2001), and that opinion is adopted in this thesis, where ergonomics is the term used. The term *ergonomist* represents persons working in the area of ergonomics.

Usability is a term related to ergonomics. The International Standards Organization (ISO, 1998) defines usability as: "*the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use*." Krug (2000) offers a more straight forward description:

"*usability really just means making sure that something works well: that a person of average (or even below average) ability and experience can use the thing, whether it is a website, a fighter jet, or a revolving door, for its intended purpose, without getting hopelessly frustrated*."

Wilson (2000) sees ergonomics as being comprised of elements of craft, science and engineering; it has aims to implement and evaluate (craft), to explain and predict (science), and to design for improved performance (engineering).

'Classic' research in the area of ergonomics typically deals with characteristics of the human body and mind, e.g. related to dimensions, limitations, capabilities or expectations. Compilations of detailed ergonomics information can be found in sources such as (Sanders and McCormick, 1993) and (Kroemer et al., 2001).

Sagot et al. (2003) make a distinction between *design ergonomics* and *corrective ergonomics*. They define design ergonomics as an approach where ergonomics starts in the initial design phases with a needs analysis and then is applied throughout the design process. This is in contrast with corrective ergonomics, which involves modifications to existing products or systems, often within very restricted limits, to overcome problems relating to safety, health, comfort and the efficiency of the human-product system. In this thesis, when the term ergonomics is used it relates to the definition of design ergonomics.

An important area within ergonomics is *Anthropometry* which is the science of measurement and the art of application that establishes the physical geometry, mass properties and strength capabilities of the human body (Roebuck, 1995). The name derives from *anthropos*, meaning human, and *metrikos*, meaning measuring. Anthropometry belongs to the branch of physical ergonomics. Issues in the consideration of anthropometric diversity in product design and how human simulation tools may support appraisal of accommodation are of major concern in this thesis and are discussed in Chapter 5.

1.6. Outline of Thesis

The thesis is fundamentally structured as follows:

Chapter 1 defines the problem area, general aims and objectives. Two central hypotheses are presented. The chapter also describes conditions (industry contact/collaboration) for the research conducted, gives definitions of related terms as well as presenting an outline of the thesis.

Chapter 2 is of a broad and discussive nature and covers reflections on product development in general and issues such as differences in view and objectives amongst roles involved in product development. The aim is to highlight some possible underlying problems regarding user requirements important in product development. An interview study was carried out to build on the topic.

Chapter 3 goes closer into the area of ergonomics integration in product design. The literature review was directed towards problems and suggestions for improvements, as identified mainly by the design and ergonomics research community. The chapter includes presentation and discussion of User Characters as a method to support user consideration, as well as the development of a framework for defining appropriate timing of ergonomics evaluation in the product design process. The outcome was assessed in a case study.

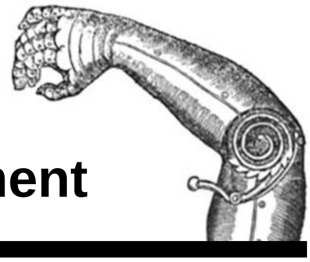
Chapters 4 and 5 are more specifically aimed towards computer aided ergonomics and the consideration of user diversity in product design. Chapter 4 describes and discusses computer aided ergonomics in general and proposes methods to aid integration of human simulation tools in product development. Chapter 5 introduces the complexity of considering human anthropometric diversity in multivariate design problems. The chapter builds on Chapter 4 and suggests a pragmatic approach as to how human simulation tools can be used to consider ergonomics, and anthropometric diversity in particular, in design. The context in focus is the design of automobiles. The work involves proposing a generic design methodology, incorporating a manikin family, the members of which are to be used as a standardised test group for fitting trials in the virtual stages of the design process. The end of Chapter 5 reviews and discusses aspects of human simulation tools as means to aid designers to more fully consider and communicate user aspects in product development.

Chapter 6 summarises the research carried out (Chapter 2 to 5), and discusses the findings in relation to the two hypotheses established in Chapter 1.

The final chapter (Chapter 7) discusses the methods of research and the relevance and validity of the results and suggestions presented in the thesis. The six studies carried out are each reviewed from a methodological point of view, and the functions of the two hypotheses established. The chapter also includes considerations of further work.

Chapter 2

Reflections on Product Development



This chapter covers issues of product development and the design process in general, as well as a brief coverage of design engineers' use of computer tools and methods. This is followed by a discussion of differences of views of product development between various roles involved in a product development organisation. The aim is to draw attention to possible underlying problems of considering user aspects in product development. The discussions are elaborated with an interview study to build on the topic.

2.1. Context

These days, the development of products generally leads to complex design processes where a multifaceted approach is required to meet and exceed customers' expectations. The competition is tough and global, and it is fair to say that it is the customers' market, i.e. it is the customers who to a large degree set the rules for the companies to act within. The Internet and globalisation has made it easier for customers to get information about alternatives when looking for a product to buy, as well as to find the best offer for the desired product; this being the core of the market economy.

With the term *product* more than the tangible object is implied. A product consists of a bundle of matters included in the offer, such as service, warranty, the way the product is marketed, packaging, brand image etc (Kotler et al., 1996). A customer is likely to perceive a product as a whole, a totality that represents values. The customer does this appraisal more or less consciously, and quantifying a product's value is complex since the value is typically experienced subjectively and individually; it is in the 'senses' of the customer. It is also likely to vary over time. Albeit complex, it is still important for companies to work with these kinds of issues. Not in order to find firm answers, but rather to get keys or indications of what it is with their products that offers value. For example, why does the customer buy the product in the first place and why is it appreciated and kept over a long time.

This also affects the area of ergonomics since ergonomics clearly deals with value increasing properties of products, even though not always clearly expressed by customers, but sometimes rather being taken for granted.

Archer (1963) suggests that design is the art of reconciliation of product matters, and this consideration is often performed in the course of the action known as product development.

2.2. Product Development

Figure 2.1 shows a generic model of the major functions in a product development company: *marketing*, *product design* and *production*, and its typical relation to the market.

The product development activity involves more or less the entire company. Otto and Wood (2001) define product development as: *the entire set of activities required to bring a new concept to a state of market readiness*. This set includes everything from the initial inspiring new product vision, to business case analysis activities, marketing efforts, technical engineering design activities, development of manufacturing plans, and the validation of the product design to conform to these plans (Otto and Wood, 2001). According to this definition, *product design* is a part of *product development.* Product development includes a wide spectrum of activities required to bring a product into reality, but some activities that are quite distant from product design, such as business analysis and promotion efforts. The development of the production system needs to be closely related to the product design activity to enable efficient production, but it is still in essence a separate business since the main task lies in developing the system that is to manufacture the product rather than designing the product.

The given definitions of product development and product design are adopted in this thesis, but since the terms are so close it might in some circumstances be open to question if the most appropriate term has been chosen.

Depending on company culture, opinion or phase in the design process, the product development activity can be considered as centring on the marketing function or on the product design function. The design of the manufacturing system is in general considered as a part of the product development process (Otto and Wood, 2001), and that activity will typically be the responsibility of the production function.

The wide arrows in Figure 2.1 represent the main flows, where black arrows represent information flow (such as market information ❶, product design specifications

❷ and drawings/CAD models ❸), and white arrows represent the delivery of (usually tangible) products (❹ and ❺). Naturally this does not represent reality in detail, but does identify characteristic features of a product developing company. The narrow arrows represent information flow, indicating a large amount of collaboration and involvement among different functions of the company.

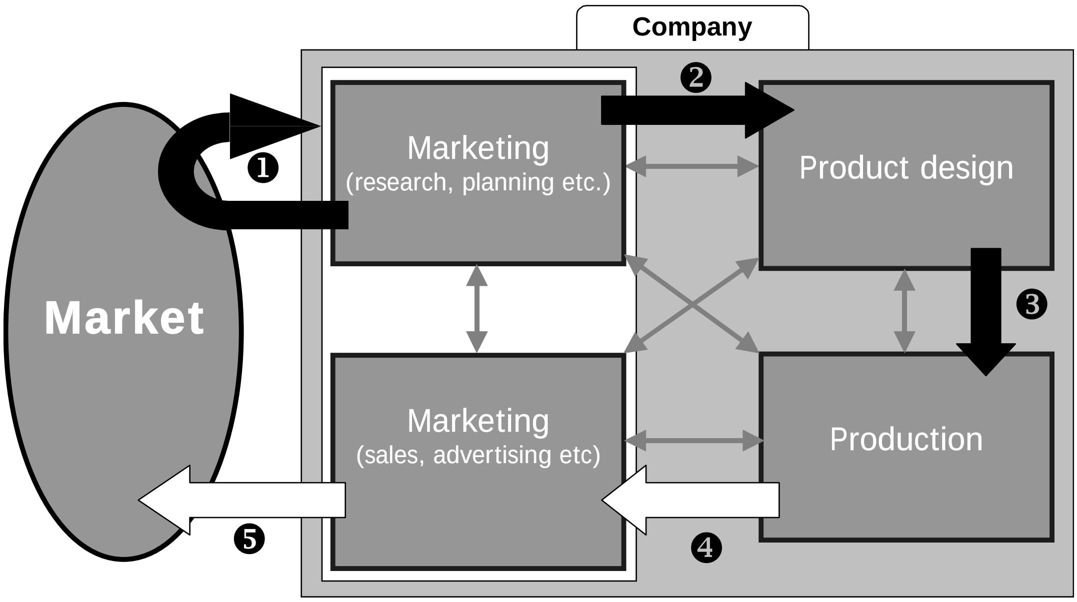


Figure 2.1. Generic model of a product developing company.

It is most likely that the value the customer experiences offered by the product is built up based on many knowledge areas and technologies, e.g. marketing, mechanics, electronics, industrial design, ergonomics, manufacturing and after-sales service. Commonly, these areas are represented by people working in different departments in a company, everyone with their interests, beliefs, backgrounds, roles etc. Essential skills, for management and people working in product development, are therefore the ability to find the best blend of the contributions from all involved, and the ability to cooperate in an efficient and prestige-less way, with a focus on the genuine value of the product. This leads to complex design processes where numerous, often conflicting, requirements have to be treated and balanced.

In addition, time pressure is typically present. This is due to the importance of short time to market, i.e. quick response time from the identification of market opportunity to the day the product is available on the market. This leads to the conclusion that in complex design processes numerous issues have to be handled concurrently, and they have to be handled within time constraints.

One widespread approach to support or enable this is *integrated product development* (Andreasen and Hein, 1987; Andreasen, 1991) or *Concurrent Engineering* (Clausing, 1997), where people are working in an integrated manner, in cross-functional teams, typically involving marketers, design engineers and production engineers, and where activities are performed more or less in parallel. Also, extensive use of design methods (discussed later in the thesis) and computer tools such as CAD, CAE, PDM (Product Data Management), PLM (Product Lifecycle Management), CAM (Computer Aided Manufacturing), VR (Virtual Reality) and simulation software is employed to shorten lead time and assist integrated work. The main objectives promoting the approach are reduced time to market, reduced costs and improved product quality.

2.3. Product Design Process

Otto and Wood (2001) define a design process as the set of technical activities within a product development process that work to meet the marketing and business case vision. Hubka and Eder (1996) define the process of designing as the transformation of information from the condition of needs, demands, requirements and constraints into the description of a structure (a product) which is capable of fulfilling these demands.

There are numerous models, explanations and representations of design processes available in design related literature, all aimed at describing or prescribing the complex process of design (Cross, 2000). Typical design process models are those of (Archer, 1963), (French, 1985), (Pahl and Beitz, 1988), (Hubka and Eder, 1992), (Pugh, 1995), (Ulrich and Eppinger, 2003) and (Ullman, 2003).

Difficulties in portraying design processes spring from the fact that design processes indeed feature linear activities performed at specific stages of the process leading towards a set goal, while at the same time incorporating elements of vagueness, imagination, concepts, creativity, compromises and iterative loops, which are harder to convey. Baxter (1995) mentions that some designers feel uneasy when they see the design process divided into stages, since design, according to them, is "*chaotic in the real world*." This might well be how designers experience design now and then, but may also be an indication of reluctance to structure the design process, or an unwillingness to employ systematic design methods.

Cross (2000) introduces a basic descriptive model of the design process consisting of four stages: *exploration*, *generation*, *evaluation* and *communication* (Figure 2.2).

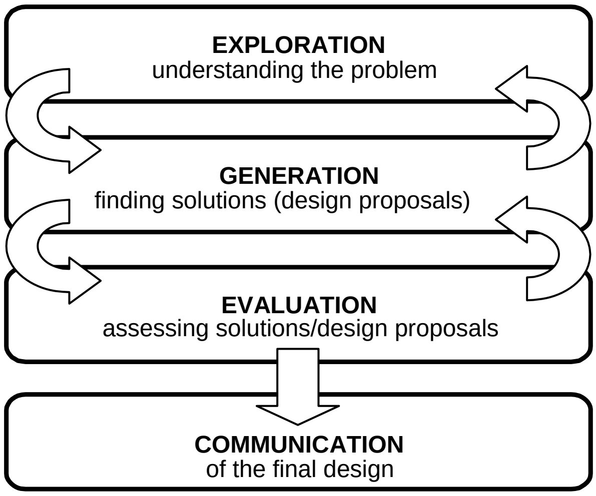


Figure 2.2. A basic four-stage model of the design process (Cross (2000).

The portrayal of a design process in Figure 2.3, inspired by design process descriptions by Cross (2000) and Pahl and Beitz (1988), aims to describe the continuous loop of *exploration* (Ex), *generation* (Gen) and *evaluation* (Ev) carried out, more or less deliberately, when designing something, while at the same time illustrating the typical design process phases: *task clarification*, *concept design*, *embodiment design* and *detail design*. The slope may not be as even and strictly partitioned as indicated in the image, and sometimes even gravity may be defeated when the wheel reverses up the hill (although typically with some resistance), portraying an *iteration*. Iteration can be described as the repetition of tasks in order to refine a design, and may be due to the design failing to meet set requirements, or because of the arrival of new information or understanding.

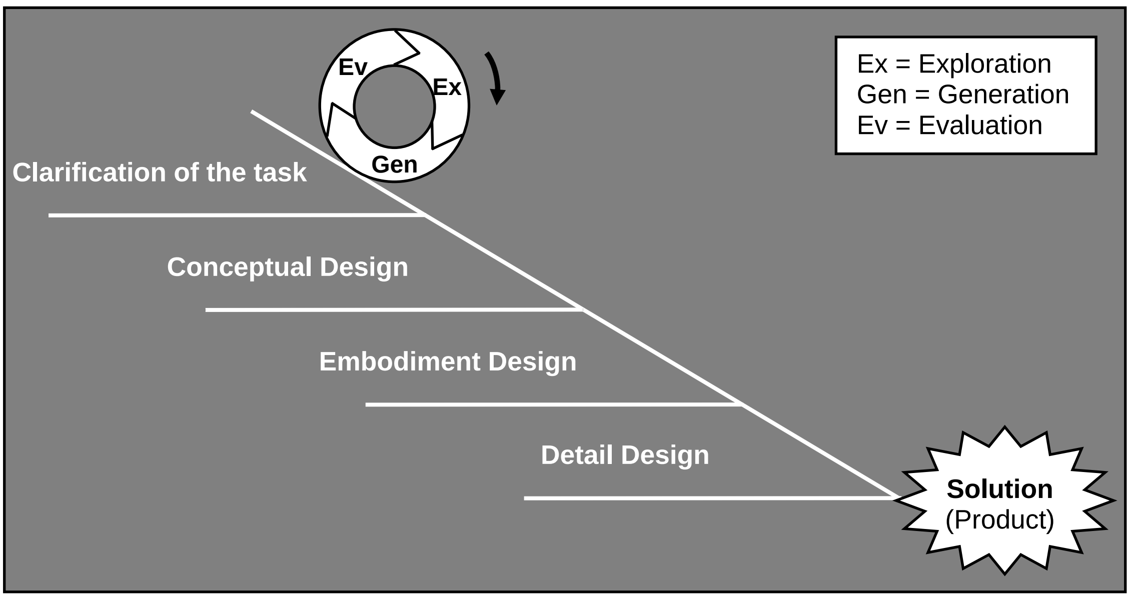


Figure 2.3. Design process representation.

It is apparent that exploration (what is the task/problem about?) and generation (how can we solve the task/problem?) are essential components of designing something. In addition, evaluation (is the task/problem solved?) is a natural component in the act of designing (Cross, 2000). Each section of the 'wheel' in Figure 2.3 is elaborated in following sections.

2.3.1. Exploration

To increase chances for an effective product development (the term effective here means a quick development process resulting in an economically successful product), it is important that all significant requirements are identified at early stages of the design process, i.e. at conceptual stages where multiple variations and alterations can be generated, assessed and modified easily, quickly and cheaply (this is argued later in the thesis). Product design requirements are typically stated in, and communicated through, product design specifications. In general a specification is stated as a quantified short description of the requirement, i.e. a metric and a value (Ulrich and Eppinger, 2003). The job of establishing the product design specification is sometimes done by people other than the designer, e.g. product planners or marketing people. The designer then has the role of translating requirements into concepts and eventually into detailed specifications on how to realise the final product. Therefore, the designers' interpretation of the specifications is crucial. Often requirements are lacking or are badly defined, which means that the designer needs to try to refine the requirements into meaningful information (Ullman, 2003). Often this work includes trying to quantify requirements stated in un-quantified way. Quantified requirements offer richer information to the designer as well as supporting the evaluation of solution proposals. Some design requirement areas are harder to quantify, e.g. aesthetics, semantics and ergonomics. However, this can be done, e.g. by referring to expected outcomes from user trials or focus groups (Wright, 1998). This means that un-quantified specifications can only be seen as objectives rather than constraints since one can never assess if the requirement is met or not, and it will be open to personal opinions and different interpretations. It is important to validate and realise established specifications during the product design process in order to ensure that the design is carried out based on information that is as relevant and current as possible. Product design specifications are one means to communicate products requirements, and methods for enriching the exploration phase are considered later in the thesis.

2.3.2. Generation

Design is about solving problems by generating proposals for solutions, i.e. to change an unwanted state into a wanted state. One key element in the act of designing is the formation of a prescription for a finished work in advance of its realisation (Archer, 1963). Cross (2000) adds that in this design description, almost nothing is left to the discretion of those involved in the process of making the artefact.

In some circumstances designing is a relatively straightforward process where certain inputs generate certain outputs, e.g. when mathematical models exist that transform input data into certain design data, or when the problem is well known and has been tackled previously. In other situations creativity is an essential ingredient to imagine and generate new and promising solution proposals (Navin, 1994). Pahl and Beitz (1988) believe that, even though experience and systematic design procedures are valuable, no real product success is likely without intuition. Cavdar and Babalik (2004) conclude that the mechanism of designer creativity is a subconscious activity that cannot be easily explained. In order to generate ideas the intuitive mind gains from being stimulated by inputs that trigger new and unconventional thinking. Common ways to stimulate creativity, combine sub-solutions and to 'ensure' that the solution space is explored, are methods like brainstorming, brainwriting, analogies and morphology, albeit they are sometimes labelled differently (Pahl and Beitz, 1988; Baxter, 1995; Pugh, 1995; Wright, 1998; Cross, 2000; Otto and Wood, 2001; Ulrich and Eppinger, 2003; Dym and Little, 2004). Additional methods for stimulating creativity in a user context are presented later in the thesis.

2.3.3. Evaluation

Careful evaluation of proposed solutions is important in order to identify and assess feasible solutions that balance all applicable requirements in a good way.

Evaluation can be considered as being performed in the 'small' or 'big'. Evaluation in the 'small' is meant to convey the almost continuous evaluation of generated ideas that are performed by the designer, or the design team, as portrayed by the evaluation segment (Ev) of the 'wheel' in Figure 2.3. An evaluation in the 'big' would represent evaluations carried out more rarely, but possibly more thoroughly, and likely to also involve people other than the design engineers, e.g. specialists and managers. Typically such evaluations are done when progressing from one design process stage to the next, e.g. from conceptual design to embodiment design (Figure 2.3) (Baxter, 1995; Ulrich and

Eppinger, 2003). However, although these 'big' evaluations may discover deficiencies of some sort, time and cost pressures frequently hinder the alteration of the design in any major way. This means that the required design iteration is rejected, but regularly the design process continues.

In an ergonomics context this would represent the situation where ergonomists evaluate a product and detect problems from an ergonomics standpoint, but where these problems are considered too expensive, unimportant or time consuming to resolve. There are several reports of this being a common situation (Simpson and Mason, 1983; Fulton Suri, 1998; Burns and Vicente, 2000).

Some ergonomics issues affect the product design architecture considerably, e.g. overall height, access, maximum forces allowed or vision aspects in vehicles, which means that it is advantageous to consider these issues early at conceptual stages of the design process. Alternatively, the iterative activity to sort out problems later can be very costly and time consuming, or lead to reductions of the final product quality due to the low priority of meeting set ergonomic requirements. As discussed by Porter et al. (1995), ergonomics evaluation often comes late in the design process. This means an increased risk of ergonomics problems not being detected until too late. Often such situations occur when ergonomists are allowed, or prefer, to evaluate the product when the first physical mock-up or prototype is manufactured. Ergonomists sometimes prefer to assess a product after it is realised as a physical object, basically because that makes it easier to make a fair judgment of the design. Ergonomics may be seen as being an inexact science since typically the context of the problem influences the evaluation, i.e. the ergonomist makes a holistic appreciation of the situation since separating and reducing the problem and the analysis of the problem is likely to lead to a sub-optimised solution. Therefore ergonomists' judgment in many cases depends on the circumstances (this also indicates the difficulty of creating ergonomics guidelines that are specific enough to be considered valuable by designers, as discussed later in the thesis). An example would be an evaluation of the appropriateness of the height and width of an armrest in a car, which depends on the distances from the driver position to the armrest, the available adjustments, the diversity of the users etc. This means that it is hard to assess a design properly from an ergonomics point of view when looking at certain details only, i.e. the armrest in the example, and especially if the design of the armrest is only communicated through a separate drawing or CAD model, disconnected from the relevant parts of the environment. If the drawing or CAD model lacks inclusion of human models, or lacks the consideration of user diversity, a proper assessment becomes even harder. A common way to treat this problem is to make physical prototypes or mock-ups where ergonomics can be considered in a more holistic context and in reality. A drawback with this approach is the cost and time to build these prototypes.

Since physical prototypes are expensive and time consuming to produce, and since tools for designing products in virtual environments are continuously improving, it becomes worthwhile for product development companies to delay producing physical prototypes until later in the design process when major modifications of the design are unlikely. This incorporates the risk that ergonomics will be evaluated even later in the design process, enhancing the problem (Porter et al., 1993; Porter et al., 1995). A related difficulty is a bias among designers and engineers to consider the design as almost finished from their point of view when the first full size mock-up or prototype is manufactured (Porter et al., 1995). Methods for supporting ergonomics evaluation in product design are presented later in the thesis.

2.3.4. Design methods

A discussed earlier, experiences of design as being 'chaotic' might well be the occasional perception among members involved in design projects, but may also be an indication of reluctance to structure the design process, or an unwillingness to employ systematic design methods. The grounds for the perception of 'chaos' might be on an individual level, but it is more likely to be due to company traditions and practice; lacking defined processes and routines for the deployment of design methods.

Cross (2000) suggests that, in a sense, any identifiable way of working, within the context of designing, can be considered as a design method. The rationale of design methods is to take advantage of previous experiences and to gain from these by aiding the design work to arrive at better solutions. It is expected that use of experience will result in more easily found solutions.

Wright (1998) notes that one of the greatest benefits to be gained from using design methods is the interaction encouraged between disparate groups within a company, and thereby the encouragement of effective communications between everyone involved in the design of products. The methods provide a 'common forum' for the exchange of ideas and information, e.g. between marketing people, designers and engineers of all disciplines. This also applies to ergonomics integration in product design. Since the achievement from using design methods is linked to effective teamwork in itself, training in working in teams becomes important, both for the individual and for the team as a whole, to fully attain the benefits from the methods (Wright, 1998).

Andreasen (1991) distinguishes between four areas where the theoretical basis of design methodology and models for design activities appear:

- General problem solving
- Product synthesis
- Product development
- Product planning

General problem solving is based on explanations of human thinking and in solving problems. Typical design methods in this area are methods to support creativity, with the aim of finding good solutions to problems, such as *brainstorming* and *brainwriting* (or 6-3-5) methods (Wright, 1998). Another method in this area is *morphology*, which is concerned with the study of the structure or form of things (Wright, 1998). This method supports structured identification of alternative solutions by decomposing the overall problem into sub-problems for which a range of sub-solutions are generated and then combined according to different patterns to generate a range of alternative solutions to the overall problem (Cross, 2000). Pugh's widespread method for *controlled convergence*, also commonly named Pugh's concept evaluation matrix or Pugh's selection charts, is another example of a design method within this area. The method supports the evaluation of solutions, as well as acting as a trigger for the generation of new solutions or combinations of solutions (Pugh, 1995).

Product synthesis is directed towards the design of technical systems and can be described as the sequential determination of product characteristics (Andreasen, 1991). An example is the *theory of technical systems* which is a systemised methodology for engineering design, based on the theoretical framework developed by Hubka in the middle of the 1970s (Hubka and Eder, 1996) where the product is seen as a, or as a part of a, transformation system where inputs are converted by a technical process into outputs. It is hard to make a clear distinction between problem solving methods and synthesis methods, as for example morphology can be seen as belonging to both areas.

Examples of design methods in the area of product development are overall product development models such as *integrated product development* (Andreasen and Hein, 1987) and *total design* (Pugh, 1995). Within this area, several design methods have been developed to support integrated work (Andreasen, 1991; Hein, 1994; Dym and Little, 2004). Examples of this are the so called *Design for X* methods such as *DFM* (Design for Manufacture) and *DFA* (Design for Assembly) for consideration of production related aspects in product development to reduce costs and increase quality (Boothroyd et al., 1994). Other examples of design methods are *DFE* (Design for the Environment) and *Design for Remanufacturing*, where the objective is to reduce the impact of products on the environment and support a sustainable development (Otto and Wood, 2001). Other design methods in this area, which can be seen as *DFQ* (Design for Quality) methods are *FMEA* (Failure Mode and Effects Analysis) to identify, define and eliminate, known or potential failure modes of a product or a system (Wright, 1998; Otto and Wood, 2001), and *QFD* (Quality Function Deployment also called House of Quality, see e.g. (Ullman, 2003)) which supports the linking of customer needs into product characteristics. Marsot (2005) shows how QFD can be applied in the context of integrating ergonomics in hand tool design.

Examples of design methodology related activities in the area of product planning would be methods of identifying needs or product concepts, which match the company's strategies and yield required profits (Andreasen, 1991). More about strategies, product planning and related methods in the context of design can be found in (Kotler and Rath, 1984; Baxter, 1995; Jones, 1997; Ulrich and Eppinger, 2003).

Many sources promote increased employment of design methods in industry (e.g. Andreasen, 1991; Nijssen and Lieshout, 1995; Cross, 2000). Cross (2000) argues that there is a urgent need to improve traditional ways of working in design, and that this need is due to the increasing complexity of design. One particular reason for increased complexity is due to the fact that products become more complex themselves, often consisting of several new technologies integrated more closely than before, e.g. mechatronic products. This calls for systematic design methods to support the design team in considering a range of issues, which they might have little previous experience of from earlier design projects, as well as supporting the collaboration and contribution of people with different competences. Another cause for complexity in design, and hence an argument for using systematic design methods, is related to the context in which modern product development is typically carried out, i.e. in highly competitive markets where huge investments are put into product development, and where the product development organisation is required to deliver high quality products that meet or surpass customers' expectations, carried out within tough time limits. These circumstances involve risks, mainly connected with financial consequences. One risk is that the product becomes unsuccessful in the market by not meeting customers' expectations, e.g. due to lack of customer focus in the design process or due to deficiencies of product quality. Other risks are related to time where a delayed market introduction can cause major economic loss, e.g. due to coming second to competitors, or missing an important milestone (e.g. a fair or a season), or basically due to the fact that the product development activity causes expenses, but yields no income yet. Employing structured design methods has the potential to reduce these risks. Nijssen and Lieshout (1995) believe that, even though the use of design methods in themselves do not guarantee success, the use of design methods can help a company's product development efforts to become more successful. However, many studies show low usage rates of design methods in industry, e.g. (Mahajan and Wind, 1992; Nijssen and Lieshout, 1995; Araujo et al., 1996; Janhager et al., 2002). Reasons for low usage rates may be unawareness or shortcomings of the methods (Nijssen and Lieshout, 1995). Cross (2000) argues that some methods appear to be over-formalised or too systematic to be useful in the rather messy and often hurried world of design, which may cause mistrust among designers of the whole concept of design methods. Another reason for the results drawn from the studies mentioned can be that design methods, or rather the purposes of the design methods, indeed are utilised in industry, but under other terms and with appropriate adaptation of the methods to suit the companies' actions hence making the methods more valuable in the companies' pragmatic interests (Frost, 1999). This makes it hard to distinguish the actual use of design methods in industry, which may cause somewhat incorrect results from surveys. Gill (1990) highlights that much research into design is undertaken by researchers who do not have real insights into or knowledge of its practice, and that may lack understanding of design as an intellectual endeavour; implying a possibility for 'noise' when communicating with practitioners. Eder (1998) considers that, even though intuition, experience, teamwork and the human qualities of designers play a large role in designing, the rationalisation, systematisation and computerisation of parts of the design process is possible and desirable, e.g. to help with conceptualising solutions to design problems, e.g. by opening solution spaces and ensuring consideration of all factors.

The general conclusion is that there are benefits from using structured design methods in modern product development, and it is suggested, at least initially, to uphold a 'keep-it-simple, keep-control' approach towards the methods, and a tolerance of adapting the methods according to the context within which they are applied.

2.3.5. Computer aided design

A widespread tool for today's designers is a CAD system. Typical advantages of such tools are the ability to model, view and easily modify the product in a three dimensional virtual environment. CAD also enables simulation of issues like assembly, manufacturing, packaging, appearance and mechanical properties. CAD also supports rapid prototyping techniques. An obvious advantage would be if ergonomics could be, albeit only roughly, simulated and evaluated in a virtual environment, preferably within the same CAD system used for designing the product. This would support product designers' consideration of ergonomics, together with many other aspects, in product design. Even though such tools, often called *human simulation tools* (term adopted in this thesis), *computer manikin tools* or *human modelling systems*, have existed since the late 1960s (Porter et al., 1993), and their functionality is constantly improving, they are rarely used by 'traditional' design engineers in their day-to-day work, but rather by experts, e.g. specialised ergonomists or simulation engineers. Reasons for the limited use may be high investment costs or skills required for employing human simulation tools properly in product development. The perception may be that the tools give too restricted benefits in relation to the effort of buying, learning and using them. Another reason may be a tradition among design engineers of mainly focussing on the physical product, rather than on circumstances associated with the wider human-product interaction (when that is applicable). According to Hypothesis 2 (Section 1.3.1) it would be advantageous to support designers in evaluating ergonomics in the 'small' as discussed in Section 2.3.3, i.e. within the more or less continuous design loop. The ergonomics evaluation in the 'small' would supplement evaluation of ergonomics issues at specific stages in the project (i.e. in the 'big' as discussed in Section 2.3.3), and thereby reduce the likelihood of identifying major ergonomics drawbacks at phases in the design process where design alterations are harder to consider and often regarded as being identified too late. However, this puts demands on the tools' functionality and usability. A remark is that Hypothesis 2 does not imply that ergonomics experts' input are less required or valuable, neither that evaluations of physical products are redundant since in many cases they are unbeatable in establishing ergonomic conditions.

A parallel to the case where designers would have general access to some sort of human simulation tool, would be the situation where many CAD systems in recent years have begun to add integrated engineering functionality (sometimes referred to as CAE, Computer Aided Engineering), e.g. for FEA (Finite Element Analysis) and MBD (Multi

Body Dynamics) in order to aid the designer to take stress and strain as well as mechanism dynamics into account during product design work. Such software can be considered as being 'designers tools' (in contrast to 'specialists tools'), where the demand of the software is to assist the designer in performing the analysis appropriately by making it 'easy to do it right'. This enables evaluation of products' mechanical properties, in order to assess the design proposal along with other requirements, offering quick response to the need or opportunities for design alterations. The feature of getting quick and 'good enough' feedback from design support tools can stimulate creativity in product design as discussed in (Högberg, 2001), which encourages the designer to generate a larger range of product solutions, which in turn enhances the chance of discovering the 'best' solution (Baxter, 1995). The significance of generating large numbers of ideas in product development is discussed by Stevens and Burley (1997), where they argue that 3000 raw ideas (basically defined as ideas in the head) are required to produce one substantially new commercially successful industrial product.

However, there is still a need for engineers specialised in advanced analysis for more complicated or crucial matters, and for performing concluding evaluations when design proposals are at certain stages in the design process, e.g. as a prerequisite to comply with quality assurance obligations. Seeing this in the ergonomics perspective, the specialist would be represented by the ergonomist.

Although support tools are valuable, the main source of knowledge for designers and engineers is still dialog with other people. This cannot be replaced by any other media, no matter how sophisticated it may be (Henriksen, 2001).

2.4. Views on Product Development

The idea behind this section is that indications of why difficulties of considering user aspects in product development exist could be found by looking at how views on products and product development objectives may differ between roles involved in a product development organisation. Questions are raised such as: what differences of product views and objectives can be recognised as typical? What is driving the product development process? Is it seen as a team effort, or are conflicts the driving force (for example)? How does contact with, and view of, customers vary between roles? The discussion is reasoned by the approach of looking at products and product development from different perspectives. The first model comes from the design community, the next from the area of ergonomics and the third from marketing. The last model is a framework adopted from psychology related to organisational development and change, here used in a discussion of product development objectives.

Of particular interest are objective differences between people in marketing and development functions, related to their view of users' needs of ergonomically sound products. This eventually leads to the carrying out of an interview study for gaining empirical results.

2.4.1. Holistic product view

Monö (1997) describes how a product can be seen as a kind of trinity within the limits of an economical and ecological circumference, and that one involved in design work can speak of a *technical*, *communicative* and an *ergonomic whole*, and still mean the same totality (Figure 2.4). Monö offers the following descriptions of the terms used. The *technical whole* stands for the product's technical function, construction and production. The *communicative whole* designates the product's ability to communicate with humans and its adjustment to human perception and intellect. The *ergonomic whole* includes everything that concerns the adjustment of the design to human physique and behaviour when using the product, e.g. biomechanics, anthropometry and cognitive ergonomics.

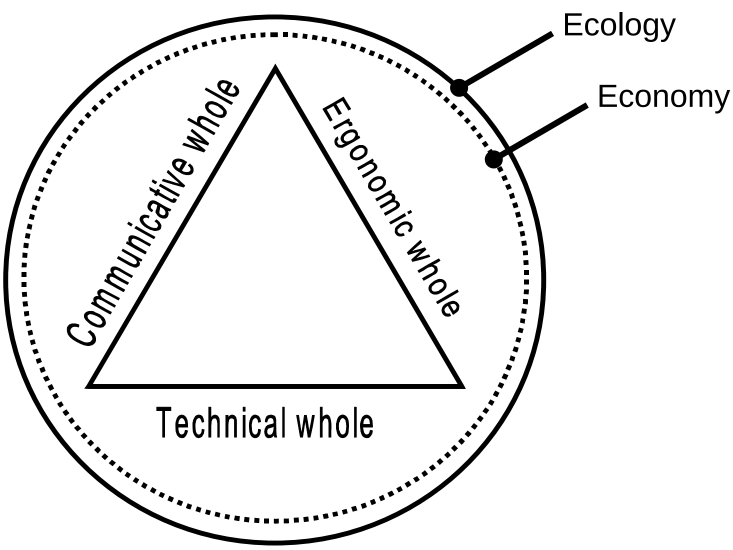


Figure 2.4. Holistic product view (Monö, 1997).

An interpretation of the model is that engineers are likely to see and mean the technical whole, industrial designers the communicative whole and ergonomists the ergonomic whole. This may be a cause for misinterpretation, and a difficulty to communicating and agreeing on what is relevant to consider in product development.

The rationale behind the model is that the whole product must be considered, otherwise the result will be unsatisfactory from one or several perspectives. Warell (2001) adds that the division into three separate views is idealistic, since in reality they are impossible to separate as they are fundamentally interrelated, but that this structure may help focusing when approaching different aspects of the product.

The trinity is surrounded by *economy* and *ecology*. Product development is performed based on the intention of making profit, hence the economic circumference. To keep this activity running in a wider perspective, it becomes essential to perform product development in balance with conditions of nature, i.e. meeting the demands for a sustainable development, hence the ecologic circumference.

2.4.2. Hierarchy of user needs

Jordan (1999a) offers a basic concept for a hierarchy of user needs (Figure 2.5). The foundation of the hierarchy represents products' basic technical functionality. If the customer considers his or her needs at this level as satisfied, the next demand will be related to usability (ease and efficiency of use). For example, for a washing machine this would mean that, at the point where the customer thinks that the machine washes clothes as cleanly, quickly, silently, etc. as expected, the customer will request more and, according to the model, that would be that the machine is easy to use, e.g. that it is easy to load and unload clothes and to operate the control panel. The point is that the customer will want more once a lower step is satisfied. This implies that, when the machine washes well and is easy to use, the customer will expect something more since good functionality and usability may not be enough to satisfy, or that, from a company perspective, there are additional ways to create competitive advantages. According to the model, when the customer wants more, this will be related to affection and emotions of pleasure, such as joy of use and ownership. It also means that pleasure without usability, i.e. fulfilling the needs of the upper but not of the intermediate level, is not likely to satisfy the customer genuinely, especially over time.

Norman (2002) argues that, in order to be truly beautiful, wondrous and pleasurable, a product has to fulfil a useful function, work well, and be usable and understandable. An object that is genuinely beautiful is no better than one that is only pretty if they both lack usability. The design challenge is to make usability and beauty go hand in hand.

Cayol and Bonhoure (2004) believe that, as design is recognised as a key differentiating factor, i.e. an important means of adding value to products, ergonomics becomes an important knowledge provider about users. Jordan (2000) argues that ergonomics in product design needs to more fully take the human being into account by incorporating the consideration of emotional based human factors in addition to the more traditional physical and cognitive aspects. This can be seen as industrial design and ergonomics closing up as knowledge areas; something not too strange since both areas consider human-product interactions (Green, 2002).

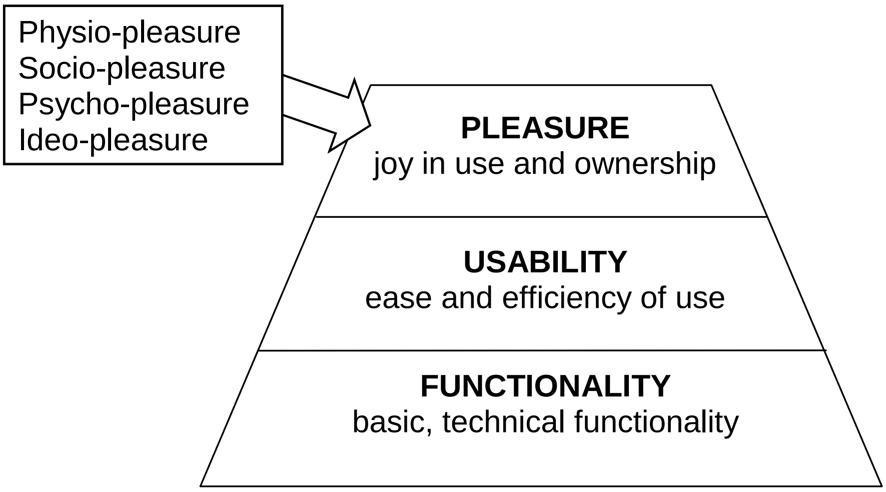


Figure 2.5. Hierarchy of user needs (Jordan, 1999a).

As the model indicates, in order to offer genuine customer satisfaction, usability must not be left out of the business of design since usability is a prerequisite for forming the kind of customer satisfaction that comes above usability on the hierarchy of user needs (Figure 2.5), i.e. aspects relating to affection and emotions, such as pleasure of using and living with the product (see (Jordan, 1999a; Jordan, 2000) for more information of the four types of pleasure noted in Figure 2.5). This indicates that users must at least consider the product's usability as acceptable to be able to appreciate the upper regions of the hierarchy of user needs. Taylor et al. (1999) remark that the three qualities, *functionality*, *usability* and *pleasure*, interact and are not entirely separable but may be regarded as distinguishable, thereby providing a basis for further understanding, discussion and investigation. Not surprisingly, factors related to pleasure are difficult to isolate since they are clearly affected by functionality and usability (Taylor et al., 1999). When the hierarchy of user needs was developed, an analogy was drawn with Maslow's '*hierarchy of human needs*', establishing an order of *physiological* needs, *safety* needs, *belongingness and love* needs, *esteem* needs and *self actualisation* needs (Maslow, 1970; Jordan, 1999a).

When considering ergonomics in product design, the influence of time aspects needs to be considered. In an analogy of physical ergonomics, where the likelihood of getting a permanent injury from performing a particular task is related to frequency and duration, time also influences emotional aspects. Aboulafia and Bannon (2004) distinguish between three feelings related to the time the customer interacts with a product.

1. Affection (short-time). This is the immediate response to a design, and is therefore especially important at the purchasing situation.
2. Emotion (medium time). This is a feeling that lasts several days.
3. Sentiment (long time). This is experienced on a longer term (months/years).

Aboulafia and Bannon (2004) comment that predicting and designing for affection is likely to be the easiest of the three kinds of feelings. For example, by making the product provide a variety of sudden and unexpected changes, affectionate reactions can be evoked in the user that may cause excitement or joy. Affection is indeed influential, e.g. in a purchase situation, but if this would be the sole focal point related to feelings in product design this may be superficial and leave the customer dissatisfied in the longer run, possibly leading to decreased company/brand/product loyalty. A difficulty is however that emotions are harder to predict since they do not depend on the immediate perceptual situation, and may require the entire setting to be designed rather than just the product.

To support the holistic approach described in this section it is important that the hierarchy of user needs and the time aspects of feelings are considered in the design process from the very start. This means that functionality, usability and pleasure are to be taken into account when setting visions for a product development project, when assessing customer needs, when creating the product design specification, and then, through all stages and loops of the core design process (Figure 2.3). Issues of supporting designers to maintain a holistic approach towards user requirements are returned to in Section 3.2 and Section 5.3.

2.4.3. Views of product characteristics

As discussed earlier, three major sections can typically be identified in companies developing products: *marketing*, *product design* and *production* (Figure 2.1). Within these three major sections, people of different backgrounds work with product development. Naturally this is not strict, but in general marketing people have a background from business studies, people working in product design are typically design engineers (mechanical, electrical) or industrial designers, and people in production are normally production engineers. This background, as well the different responsibilities and objectives within each section, is likely to lead to a tendency to look at product development objectives differently.

A description from Kotler et al. (1996) of different levels of a product, coming from the marketing community, is utilised to support discussion of different views of product development objectives (Figure 2.6).

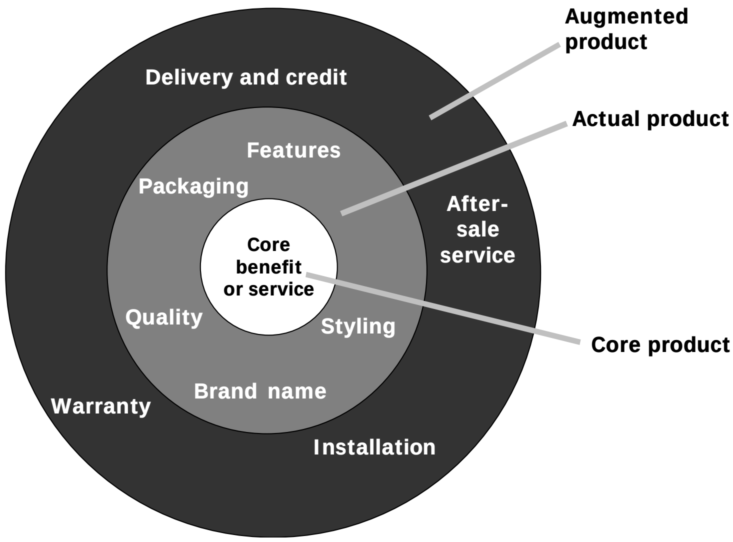


Figure 2.6. Three levels of a product (Kotler et al., 1996).

The first level of a product, according to the model, is the core function of the product, e.g. a drill makes holes but what the customers actually wants is a hole and not necessarily the drill; the drill is just a means of making a hole and there may be other and better ways to offer that function (Kotler et al., 1996). This way of thinking of products might be rewarding by helping people in product development to think in new ways, possibly leading to innovative product solutions. This way of thinking is sometimes promoted in design and engineering education, e.g. by function analysis methods (Pahl and Beitz, 1988; Cross, 2000). If these kinds of methods are not used, designers and engineers can easily think of the product's present design or basic structure as given (this argument is based on the author's own experience in teaching product development methods for undergraduate engineering students). Production staff are unlikely to think in terms of the products' core functions, e.g. since they are rarely involved at the conceptual stages in product development where such issues are typically dealt with. Of course, exceptions exist. As a result of background and focus, marketing people are believed to rather easily think in terms of core benefits.

The second level is the actual product that is to deliver the core benefit, in the model divided into the five characteristics: *quality level*, *features*, *design/styling*, *brand name* and *packaging*. Marketing people are believed to consider all these issues on a general level, where the product is typically seen as one of four parts of the *marketing mix*, also known as the four Ps: *Product*, *Price*, *Place* and *Promotion* (Kotler et al., 1996). However, Kotler and Rath (1984) highlight that one of the few hopes companies have to 'stand out from the crowd' is to produce superiorly designed products to their target markets. This indicates the product as being the nucleus of the marketing mix. Miller (2001) believes that nothing is more fundamental to a company's well being than a meaningfully differentiated product that is valued by a significant set of customers. Design engineers and industrial designers necessarily have to go deeper in detail since their task is to fully define the product's design. Due to tradition and education, a tendency for design engineers to focus on issues related to quality, features and engineering properties is expected, whereas industrial designers (if involved in the project at all) are more likely to focus on styling/design (aesthetics, semantics), and brand identity. Ergonomics related to the product often falls between design engineers' and industrial designers' main areas, which calls for ergonomists to be involved in design projects (Fulton Suri, 1998; Burns and Vicente, 2000). This also indicates the value of including basic ergonomics in the engineering and industrial design curriculum to support the common working manner in today's product development, i.e. integrated project work (Haslegrave and Holmes, 1994; Skepper et al., 2000). Production people are likely to focus on the product's design and quality level from a manufacturing and assembly perspective. They may also be concerned with production related ergonomics.

The third level, the augmented product, is related to issues alongside the actual product, e.g. *delivery*, *warranty* and *installation*. These issues are often the concern of the marketing department and may be very important for creating customer satisfaction in the end as consumers tend to see products as complex bundles of benefits that satisfy their needs (Kotler et al., 1996). Designers mainly consider these kinds of issues when they influence the design of the actual product, e.g. issues related to ease of installation or warranty/product quality. There is an expected gain from encouraging designers to comprehend and consider issues related to the augmented product as important means, in combination with the other levels of the product, for creating value for the customer. Related to this level of the product, production staff may be involved in issues like installation, warranty and after sale service.

2.4.4. Product development from a process theory perspective

A general view of objectives associated with the product development activity can be derived from applying process theories of development and change, where four basic theories have been identified: *life cycle*, *teleology*, *dialectic* and *evolution* (van de Ven and Poole, 1995) (Figure 2.7).

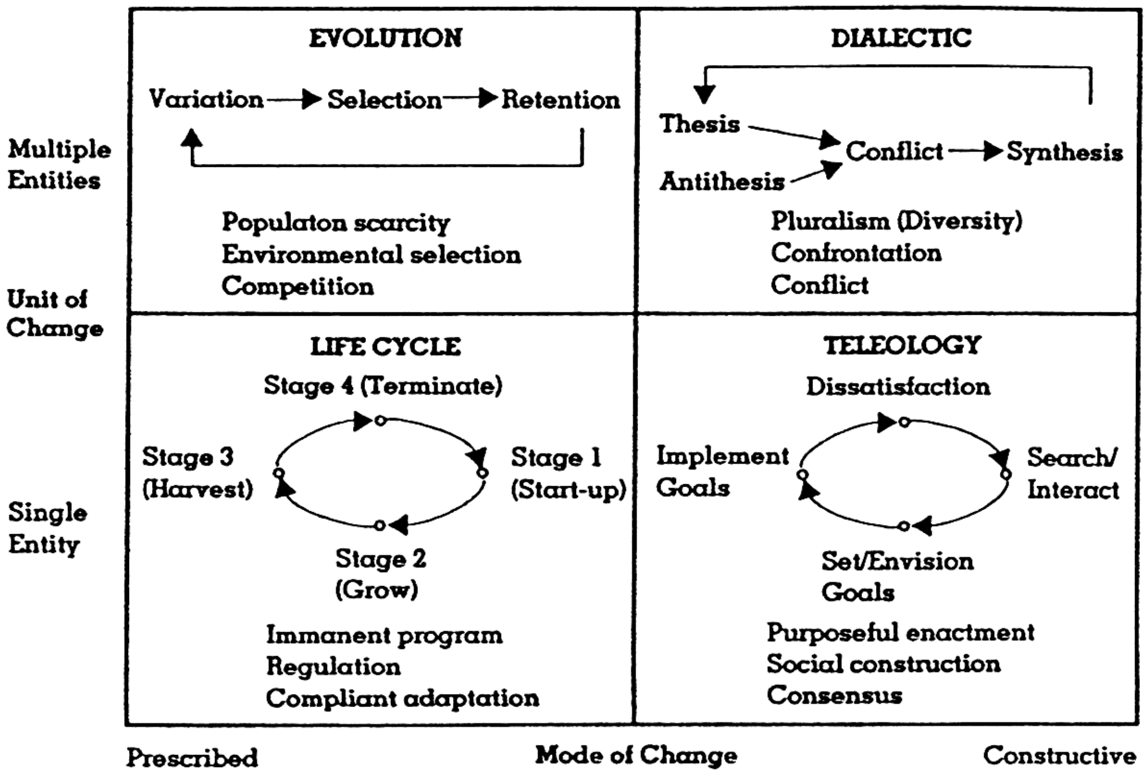


Figure 2.7. Process theories of organisational development and change (van de Ven and Poole, 1995). Comment: arrows on lines represent likely sequences among events, not causation between events.

This theoretical framework was originally introduced to support explanation of development and change in organisations. Here, the framework is applied as a basis for discussing different views of product development, and as an aid to examining what forces might act as conceptual motors in product development organisations.

Product development can be seen from an *evolution* theory perspective, both at a company level and at a project level. At a company level, organisations strive to survive, grow and make profit in the market, competing with other organisations with similar goals. There are normally a variety of alternatives for any type of product available on the market for customers to choose from. Many offers are similar, but still different in some way. Customers choose products they consider, more or less consciously, offer the greatest value, and the companies' objective is hence to offer the greatest value in the eyes of the customer. Fortunately customers' opinions differ, e.g. related to taste, convenience or disposable income, facilitating conditions for multiple companies to survive. The evolutionary theory can also be applied within product planning and product development where market opportunities and ideas can be seen to evolve into concepts, which in turn are assessed according to the degree of fulfilment of visions and set requirements. Out of the approved concept(s), products will eventually be further developed and launched on the market, where only a few (which can be considered as 'the best') compete, survive and gain profit to the company.

Looking at product development using the *dialectic* process theory, the process is explained as being driven by conflicts and confrontations between opposing entities. Such conflicts can stem from disagreements of product development objectives, e.g. between people representing different responsibility areas (marketing/product design/production). Developing products is a matter of finding the best compromise in the eyes of the customer out of an infinite number of possible product variations. Ulrich and Eppinger (2003) remark that one of the most difficult aspects of product development is recognising, understanding and managing such trade-offs in a way that maximises the success of the product. Typical conflicts may be cost to weight or rational production to serviceability. Sometimes aesthetic and usability concerns come into conflict with each other. Norman (2002) believes that often this is not so much related to actual problems of finding a good balance between the two issues, but rather due to designers and ergonomists/usability experts not acknowledging each other's knowledge areas. For example, Olsen (2002) reports that ergonomists and usability experts sometimes do not acknowledge designers' capacity or willingness to consider usability when designing products.

Applying *life cycle* theory to product development is rather straightforward since the product design process consists of defined steps (Figure 2.3), which are more or less exhaustively carried out in product development projects. It is also possible to identify a product type's life on the market as a life cycle, consisting of *introduction*, *growth*, *maturity* and *decline* (Kotler et al., 1996). A unique product also has a life cycle, typically consisting of *premanufacture*, *manufacture*, *product delivery*, *product use* and finally *refurbishment*, *recycling* or *disposal* (e.g. Graedel, 1998).

The *teleology* process theory describes product development as being driven by the objective of performing purposeful activities to meet established goals. Setting goals and searching for ways of meeting these goals are all core characteristics of a product development activity. It is central for management of product development to implement a view of a common objective among people involved in a product development project, preferably established by consensus. Otherwise there is an obvious risk that people aim their efforts in different directions, causing unnecessary conflicts and misleading efforts, leading to inefficient usage of time, money and skills, as well as unfruitful tensions within organisations.

In this thesis the *dialectic* and *teleology* theories are mainly used to support discussions about integration of ergonomics in product design.

2.4.5. Definitions of *users* and related terms

The meaning of words such as *user*, *customer*, *buyer*, *consumer* and *stakeholder* are hard to clearly define. Several sources try to clarify the terms and distinguish their meaning but, albeit a worthwhile endeavour, a common interpretation of the words is still not very distinct. Warell (2001) defines a user as any individual who, for a certain purpose, interacts with the product at any phase of the product life cycle. One advantage of this very broad definition is that when someone is using the term *user* or *user requirements*, it enhances the chances that the product requirements for all relevant people are considered in the design process, at least in theory. On the other hand it means very little, especially to a person who needs to understand what it actually means and who has to consider its consequences, e.g. a design engineer interpreting requirements in a product design specification when the term *user* is used without further explanation.

Karlsson (1996) defines the *user* as the *end user*, who may, but not necessarily, also have been the buyer, and the user may, or may not, own the product. Karlsson connects the term *user* to the actual use of a product, where the product is the mediating object in an activity carried out to reach a distinct goal. As an example: a driver of a motorcycle is a user, but a motorcycle repairman does not use the motorcycle, the motorcycle is the object being repaired, and consequently he or she is not considered to be a user of the motorcycle. However, he or she may be the user of a wrench in order to repair the motorcycle. Karlsson (1996) also treats actions such as misinterpretation and misuse of products as involving users. This definition means that even people using a product wrongly, intentionally or unintentionally, are considered as users, which would have not been the case if the definition were based on the use as being an activity of using a product solely for its main purpose.

Buur and Windum (1994) organise the term *users* into two subgroups: *primary users* and *secondary users*. Primary users include people who use the product for its main purpose, e.g. a musician playing a guitar. Secondary users are those who come in contact with the product and who have to operate it in one way or another, but not using the product for what is was principally intended for, e.g. a guitar assembler, a sales person in a music store, a guitar collector, a guitar repairman or a guitar technician assisting band members on tour. Buur and Windum (1994) suggest that everybody that comes in contact with the product during its life cycle are classified as user types. Examples of user types for each of the five life cycle phases are:

Development - technical writer
Manufacture - quality inspector
Sale - salesperson
Use - repairperson
Destruction - recycling technician

In Karlsson (1996) three different dimensions of use are presented (based on a text from 1956 by Paulsson and Paulsson, originally in Swedish). This framework explains, for example, the guitar collector as being considered a user of a guitar:

- The *practical* use, to make use of or handle the artefact,
- The *social* use, to exist with the artefact,
- The *aesthetic* use, to contemplate the artefact.

Janhager (2003) develops the *primary* and *secondary* user classification system of Buur and Windum (1994) by adding two groups of people who interact with products: *side-users* and *co-users*. Side-users belong to the group of users who are affected, negatively or positively, by the product in their daily life but without using the product (Janhager, 2003). An example of side-users would be people living near a golf course that are negatively affected by the noise of golf players shouting "fore" or by the risk of being hit by a golf ball. The affect may also be positive, like enjoying the troubadour playing at the pub next door. A co-user is a person who co-operates with a primary or secondary user in some way without using his or her product. An example of a co-user would be a car driver that is the co-user of another driver's car in a traffic situation. At the same time both drivers can be considered as primary users of the traffic system.

The term *buyer* is associated with the purchase of the product, which involves activities of decision-making and transactions in order to establish the purchase (Karlsson, 1996). Karlsson defines the term *consumer* as a wider term, representing a general description of the relationships between people/households and goods, typically involving purchase. Elliott (2000) presents the term *customer* as representing anyone who is involved with the product, or influences the buying situation either directly or indirectly, whether they be retailer, buyer, installer, end user or maintainer. Martin (1997) defines *stakeholders* as individuals or organisations that have a need or expectation with respect to products or outcomes of their development and use. Martin gives examples of stakeholders as buyer, user, manufacturer, installer, tester, maintainer, executive manager and project manager. Also the entire company or general public can also be considered as stakeholders of the product. Ulrich and Eppinger (2003) define stakeholders as all of the groups of people who are affected by the product's success or failure, e.g. end user, buyer, internal sales force, service organisation and the production departments. Ulrich and Eppinger propose that a list of stakeholders serves as a reminder for the development team to consider the needs of everyone who will be influenced by the product.

As noted there are many descriptions of the word *user* and related terms. The idea of considering more interest groups than purchasers and/or end users in product development is acknowledged. The concept of structuring users into different groups is believed to be rewarding for the recognition of stakeholders affecting, or being affected by, the product. It may help the design team to consider people that otherwise would not have been identified in product development, and to consider them more appropriately. However, it is still recommended that terms used in product development are clarified to the extent where they actually mean something, and mean the same, to people involved in product development, e.g. on a company or project level. Besides, trying to meet all users' demands is likely to become impossible due to conflicting needs. This calls for a method for prioritising which user demands are the most important to be concerned about in the design process. Buur and Windum (1994) suggest that at least the following three aspects can be considered in such a priority situation:

- **The purchase decision**: Which users/interested parties have the greatest influence on which product is bought?
- **User time**: Which users spend most time operating the product?
- **Total economy**: Which users are 'most expensive to run', or which suffer the greatest consequences from faulty operation/unfortunate strains?

2.4.6. Inclusive design

Even though the above framework for prioritising user demands can certainly make sense in many cases, there are situations where an additional view of the situation can be rewarding; where there may be advantages of considering demands of users that regularly are claimed as being not so important in the design process. Examples of such users are older and disabled people.

The concept of increasing quality of life for more people, typically meeting the demands from both able bodied people alongside elderly and disabled people, has become more widespread in later years, and will be even more important in the future due to demographical changes where the proportion of elderly people is expected to rise considerably (ANEC, 2000). Common terms for this concept are *inclusive design*, *'design for all'*, *transgenerational design* and *universal design* (Vanderheiden, 1997; Coleman, 1999; Freudenthal, 1999). The term *inclusive design* is used in this thesis.

The inclusive design approach promotes products to be designed with consideration of all members of society. In particular, the objective is to consider the needs of old and disabled people alongside the younger and able-bodied population to ensure that products are equally appealing and suited to all users. This is to be contrasted with a 'design for the disabled' approach where the special needs of disabled people are considered in order to provide products that may only be appropriate for that section of society. Jordan (1999b) comments that the inclusive design approach aims to take a holistic view of users. The aspiration behind the concept of inclusive design is ethically sound, and it satisfies the desire for non-stigmatised products. It can also make good commercial sense by extending markets. Jordan (1999b) argues that, in addition to being morally sensible, inclusive design may also lead to market opportunities and financial benefits for companies adopting the concept.

It is recognised that the objective to include all people is ideal rather than totally achievable and there will be relatively small groups that require products that are unattractive to mainstream markets (Case et al., 2001).

Coleman (1999) suggests that with good design it is possible to address the needs of very large numbers of people at present disabled by poor or inconsiderate design, and that future technologies will reduce the need for specialised products. Aging or physical and mental impairments ought to be seen as part of the human condition, which all people will more or less encounter. Kroemer et al. (2001) comment that the use of proper ergonomics measures, carefully selected and applied, is just 'good human engineering', which would help all persons of all age groups, but is of particular importance for the older individual.

As mentioned, the number of older people is increasing, as is their proportion in the total population due to declining birth rates, longer life expectancy and decreasing mortality (Coleman, 1999; ANEC, 2000). The world population over 65 years of age is predicted to grow by 88% over the next 25 years, and approximately 10%, or 800 million people, will be over 65 years of age in 2025 (Smith et al., 2000). This fundamental change in the age structure of modern societies is only just being recognised. The World Health Organisation (WHO) predicts that by 2025, twenty-six countries will have life expectancy of above 80 years of age. These figures emphasise the importance of using data on older adults when designing products for these older customers to avoid poor product usability or lower quality of life for older people (Smith et al., 2000).

Coleman and Harrow (1998) note that perhaps the most important desire of older people is to keep their independence for as long as possible, and car ownership can be important in achieving this. Mobility for people with disabilities is not just a matter of equality; it is also of major importance for health, autonomy and general well-being (Peters, 2001). Mobility is a key factor in life-quality, and meeting friends, visiting relatives, shopping, recreational and educational activities are all essential parts of an active life. Visits to doctors and hospital are likely to increase with age (Coleman and Harrow, 1998). The use of public transport is encouraged by society, e.g. due to the lower environmental impact. However, a private car is still the most common form of travel, offering freedom and independent mobility in a way that public transport does not. In particular, access to private cars can bring a new dimension to the lives of disabled and elderly, who may otherwise have lost, or be starting to lose, their mobility (Nicolle and Peters, 1999). Halkamies-Blomqvist et al. (1999) argue that, for elderly drivers, mobility is important for participation, health and well-being, and can be financially justified with respect to public expenditure. To illustrate how 'soft values' can be transferred into 'hard financial values' they use *the mobility snake* which consists of: *mobility* -> *activity* -> *health* -> *functional capacity* -> *autonomy* -> *small need of public support* -> *saving of public funds*. This indicates that society could gain economically from enabling elderly and disabled people to stay mobile.

So what is the likely response from the automotive industry regarding demographic changes and the call for mobility for all members of the society? Will the industry bother at all? One argument for a commercial response is that, if society can economically gain from keeping its members mobile, it is reasonable for that society to promote those associated with the enabling process, e.g. the automotive industry. Another argument for a response is that increased numbers of older consumers are forming a significant buying force (ANEC, 2000). Also, these customer groups in general are predicted to be relatively wealthy, representing a high buying power, meaning that they are an important target group for companies (Jordan, 1999b).

The rationale behind the inclusive design approach is that one should try to include users rather than exclude when designing products, systems and environments. Inclusive design encourages an attitude of; "*what if we design like this, then we would include these user groups as well, rather than exclude them.*" Fulton Suri (2000b) suggests that the way to develop an appetite for the principles of inclusive design is to focus on methods that allow design team members to make discoveries themselves through observation and experience, rather than just being told about them.

In many cases, younger and able-bodied members of the population benefit from products that originally were designed for people with some kind of disability. Examples of such products are the ball-point pen and the television remote control (Jordan, 1999b). More examples of products designed according to the inclusive design approach are available through Ricability (2001). In some cases this effect can work in reverse, with products particularly designed for the able-bodied bringing benefits to disabled users (Jordan, 1999b). Jordan mentions the hands-free telephone and speech technology as examples of such products. Other examples would be rearward cameras aiding reversing, or cars such as the Bertone Novanta, offering improved vehicle access and driven by the hands only (Figure 2.8). Turning around to look out of the rear window and getting in and out of the car is a common difficulty among older drivers (Herriotts, 2005).

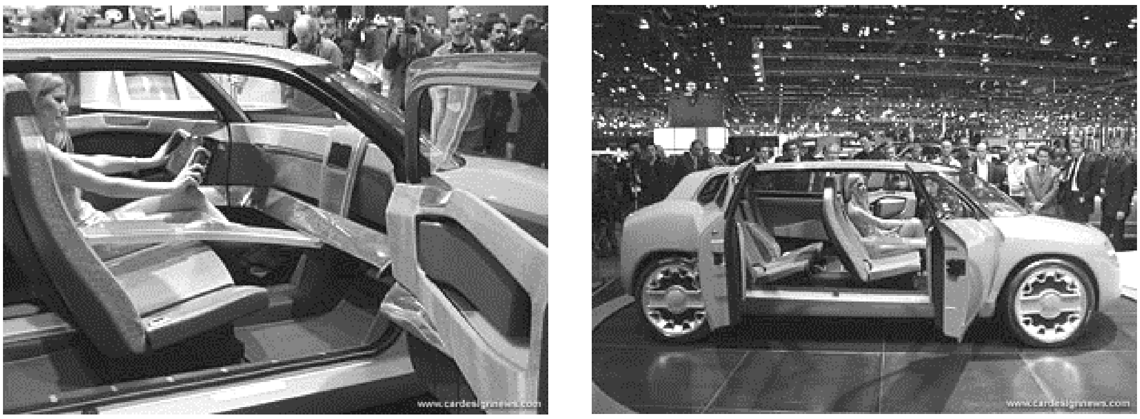


Figure 2.8. Bertone Novanta (image from www.cardesignnews.com).

The *Center for Universal Design* has developed the following seven general principles. More detailed information is available through (Conell et al., 1997).

1. **Equitable use**: The design is useful and marketable to people with diverse abilities.
2. **Flexibility in use**: The design accommodates a wide range of individual preferences and abilities.
3. **Simple and intuitive use**: Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level.
4. **Perceptible information**: The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.
5. **Tolerance for error**: The design minimises hazards and the adverse consequences of accidental or unintended actions.
6. **Low physical effort**: The design can be used efficiently and comfortably and with a minimum of fatigue.
7. **Size and space for approach and use**: Appropriate size and space is provided for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility.

Critics of concepts such as inclusive design claim that it is impossible to profitably make products that suit everyone, and that the contrary is true, where products need to be designed for unique market segments in order to create superior customer value. Cooper (2004) believes that one will have far greater success by designing for a single person than aiming to accommodate a broad audience of users, i.e. trying to please too many different points of view can kill an otherwise good product. Indeed this may be the case. However, products are typically built based on flexible or interchangeable modules or platforms and it is worthwhile to consider how one might meet the demands of 'all' members of the society by an innovative product design, that allows for easy adaptation due to different user requirements and expectations, but is still the same or very similar in the core to facilitate rational production.

If user groups are excluded, that ought to be the result of a conscious decision rather than for example an effect of poor information, knowledge or consideration within the design team. To enable this, designers need support, e.g. tools and methods, since making such considerations is commonly not in the designer's area of expertise. Porter et al. (2002) discuss these issues in the article "*How can we 'design for all' if we do not know who is designed out and why*?" If the title of the article is inverted, it indicates that the approach of inclusive design may be enabled by supporting designers to judge whether people are designed in or out by a particular design. One computer based tool, developed for supporting making such judgements, is HADRIAN (Porter et al., 2004), which is discussed in Section 5.1.6.

2.5. Product Developers' Interaction with Users

As discussed earlier in the thesis, customers choose products they consider offer the greatest value, and the companies' strategy to gain success is hence to offer the greatest value in the eyes of the customer. Customers' expectations of value offered by products, they are supposed to exchange money for in order to possess, are continuously increasing. As a consequence, it is important that product developers become aware of what it is in their products that creates value in the eyes of the customer, and to assess this in an iterative, probe and learn manner during the product development process, e.g. by letting customers test early prototypes to provide rapid feedback to the design team (Cole, 2001). Elliott et al. (1999) believe that many engineering companies fail to design quality products (quality as determined by the customer) since they focus on the purchaser rather than on all of the individuals involved with the use of the product, hence failing to recognise all users' needs.

Hanna et al. (1995) highlight that, in order to be successful, there must be high customer involvement in the design process from beginning to end. Based on their experiences, they report that the perhaps most frustrating aspect associated with their work performed for companies in the product development arena is seeing, over and over again, vast resources being wasted because no one took the time and effort to listen to the customer.

Ulrich and Eppinger (2003) argue that everyone in a product development project that directly controls the details of the product, i.e. including designers and engineers, must interact with their product's users and experience the use environment of the product. The authors maintain that, without this direct experience, design compromises related to the product's design are not likely to be made correctly, innovative solutions to customer needs may never be discovered, and the product development team may never develop a commitment to meet customer needs. Hollins and Pugh (1990) highlight that, in order to be successful and to acquire an understanding of the customer, developers must have access to customers. Fulton Suri (2000a) believes that information becomes more vivid and engaging when it resonates with personal experience. One empathy-based strategy is to encourage designers to participate in field observations and interviews, and thereby gain first-hand appreciation of the context and ergonomics issues and provide a different perspective and interpretation of what was discovered. This prompts a very useful dialog in deciding what is important, useful and possible in terms of design implications, and what remains unknown and deserves another look. Sometimes a simple walkthrough of the process is sufficient for designers to encounter the important issues, but at other times it is helpful to devise and assign specific tasks to ensure that issues are explored (Fulton Suri, 2000a). Margolin (1997) emphasises the importance for designers to know for whom they design. This calls for definition of the intended users in product development projects.

The position of designers defining and meeting the users of their products is acknowledged, but how common is it for design engineers to actually experience interaction with end users and what arguments are behind the ways of working in industry? Another issue is whether or not tools and methods are employed by members in product development teams in order to support successfully consideration of user aspects. An interview study was carried out to get a richer understanding in this area.

2.5.1. Interview study of product developers' interaction with users

The overall objective of the interview study was to investigate how people involved in early stages of product development define their customers, how they communicate about and with the end users of their products and work with user requirements in product development. The overall objective was broken down into the following sub-questions:

1. Are there characteristic differences in working methods, aspirations and views between certain functions involved in product development regarding user aspects?
2. How is user related information collected and communicated between these functions?
3. What tools and methods are used to identify and consider user requirements?

The interview study was carried out in collaboration with a PhD-student at the Royal Institute of Technology as described in Section 1.4, Section 7.1 and Appendix 6. Each investigator had a slightly different research focus, but both were concerned with user consideration in early stages of product development.

2.5.2. Method

An objective was to investigate differences and similarities between companies developing different kind of products. Interviews were conducted at four, to be anonymous, companies where two companies develop hand held power tools for professional use (Company A and B), and the other two develop durable consumer products (Company C and D), see Table 2.1.

Table 2.1. General data of the companies in the study.

	Company A	Company B	Company C	Company D
Products	Professional hand held power tools	Professional hand held power tools	Durable consumer products	Durable consumer products
Number of employees	700	200	1100	600
Interviewed competences	Design engineer Marketing representative PD-manager	Design engineer Marketing and sales manager PD-manager	Design engineer Marketing representative R&D-manager	Design engineer Marketing and sales manager PD-manager

In each company three people, representing three typical functions involved in the early stages of product development, were interviewed: 1) a design engineer, 2) a marketing representative or a marketing manager, 3) a product development manager or research and development manager. None of the companies had any ergonomists employed for product ergonomics; instead the consideration of ergonomics issues was mainly the responsibility of the design engineers, in some cases supported by industrial designers recruited on a consultancy basis. In total 12 interviews were carried out, each 45-75 minutes long. All subjects were male, except one marketing representative. All the companies are located in Sweden and had between 200 and 1100 employees. The chosen method for qualitative information gathering was semi-structured interviews (Lantz, 1993), which were documented using a tape recorder and transcribed before analysis.

The same interview guide was used for each subject in all twelve interviews. The following issues were considered:

- Procedures for defining and describing product users.
- The product developers' contact with the users.
- Communication of user related information to and between functions involved in product development.
- The target group priority in product development.
- The utilisation and opinions of tools and methods that consider user aspects.

2.5.3. Results

Company A

The interviewees had a relatively clear mental picture of their products' users but lacked a formal procedure for user definition. The end users were considered as very important stakeholders that have to be considered in product development. Often the end users have the power to decide which product is to be bought by their employer; "*if the operator does not want to use the product, it is impossible to sell it* [PD-manager]." The marketing representative was the one who had closest contact with end users. The design engineer met end users approximately twice a year, but often due to other circumstances than to actually analyse user requirements of future products. One of the big advantages of meeting end users was considered to be the opportunity to see how the products were actually used; "*it is much more valuable to get the information directly, than to let it get filtered through seller to distributor to our seller and our product manager and then to us. In the end, you do not know which person who wanted the change from the beginning* [Marketing representative]."

The company works with interviews and field studies. Apart from that, the company does not have any formal support methods for working with user aspects. The opinions about the need for more methods considering end user aspects were divided. The marketing representative felt that their routines worked well, while the design engineer requested better methods to learn more about the end users. He believed that formal methods are important in analysing the use of their product in order to highlight the most important design issues and to obtain quantified values; "*otherwise, the decisions are based mainly on subjective judgement* [Design engineer]."

The company does not use any human simulation tools today (such tools are explained in Chapter 4). The common way to evaluate e.g. handgrips is to produce a physical model via rapid prototyping and then to try it within the design team, and perhaps by letting a woman in the reception test it or to go to customers nearby. The interviewees felt that such a tool for evaluating ergonomics, e.g. hand grips, within the CAD system sounded interesting but they had some concerns about ease of use. The design engineer considered that it would be a perfect tool for an ergonomist, or a design engineer with special ergonomics training, rather than for a typical design engineer; "*I have too many 'hats' already; I am supposed to do everything, and each new issue to consider makes it harder to really perform things good enough* [Design engineer]." The design engineer thought that a human simulation tool might encourage a user-centred approach to product development; "*today it is all about fulfilling formal requirements stated in design process directives and it feels that we make products for our own CAD systems and design processes, rather than for customers* [Design engineer]." The design engineer acknowledged that the human simulation tool might make it easier to consider human diversity, e.g. by the feature of inserting hands of different sizes into the CAD-model. However, he was a bit concerned that a human simulation tool might further reinforce the focus on virtual development; "*a clever manager might find out that, due to the introduction of such a tool, it is enough for a design engineer to meet users once a year rather than twice (quiet laugh)* [Design engineer]."

Company B

The interviewees had a generic picture of their diverse set of product users, e.g. related to age, sex, strength and hand size. They do not define or document a description of their end users. Similar to Company A, the main focus is on the end users' requirements during product development, and, as with Company A, the end users often choose which tool their employers are to purchase. The end users' requirements are higher ranked than for example the purchasers' requests. The marketing and sales manager meets end users five to six times every year and the design engineer meets end users three to four times per year. The marketing and sales manager and design engineer visit end users during pre-study and prototype stages, and they always do that accompanied by salesmen. It was a relatively new thing for this company to let design engineers go out and observe and interview end users and they had positive experiences from this new approach. All subjects considered meeting users as being essential in order to learn about the use of

their product in an actual environment. The design engineer felt that it might be more important that he and other design engineers have contact with the end users than the marketing representatives. According to the marketing and sales manager, the design engineers only have a vague understanding of the use of the product and he believed that it is fruitful for them to meet end users and see the applications of their products.
It was agreed that it should be useful with design methods supporting user consideration. The interviewees requested structured methods for analysis, evaluation and valuing of qualities and opinions; "*we build our own methods here and I believe that there are better ways of working with this* [PD-manager]."

The company does not use any human simulation tools today but all interviewees thought that it sounded very interesting if it was easy to use and not too expensive; "*such a tool sounds terrific; since ergonomics is so important to us we want the ability to start working with those issues at very early stages of the design process* [PD-manager]." The present approach for ergonomics evaluation is to produce, e.g. handgrips, with rapid prototyping. The design engineer considered that physical prototypes still would be required to receive formal approval of a design, but that a human simulation tool could reduce the numbers of iterations required before a physical prototype would be manufactured.

Company C

The interviewees had a generic picture of their diverse set of product users. However, the company directs their products towards a more demanding category of customers, who are also prepared to pay a bit extra for the product. They do not employ any procedure for describing the users. However, the company groups' central marketing division has defined market segments, which describe the users' way of life, age, beliefs etc. However, none of the interviewed claimed to consider this when developing products. As indicated by the design engineer, they do not have to care about these market segments since the product requirement specification they receive when commencing a project already contains demands built on them. The research and development manager commented that he does not consider these descriptions too much because he felt that the expression of users offered by the central marketing division did not really represent actual customers. His view was that it is better to try to design a product adapted to all people or to as many as possible due to the diversity of the customer base.

Besides the end user, the product developers have to give priority to the sales organisations' demands on the product. There were also indications that the sales organisations are given the primary focus, i.e. that end user demands are of second priority, and that this is quite in order. It is believed that the sales organisations' demands on the product are the same as the end users' demands; "*since, the sellers receive information about the end customers' wishes* [Design engineer]." Moreover, the brand organisation, which orders the project, has a high influence on the product performance. Even if results from a user clinic points in another direction than the brand organisation's conception, the product developers often have to comply with the brand organisation's demands in order for the product to suit the product family line.

The company does not work actively with meeting end users. None of the interview subjects have formal contact with end users. The marketing division is supposed to feed the product developers with viewpoints and information from the field, through wholesalers, sales companies and distributors. The research and development manager doubted that all the information they receive from the central marketing division is really based on facts, with some information instead being opinions from people in high positions. The design engineer was quite satisfied with the second-hand information. He thought it is better to get the information filtered in a concise form than to get many different impressions; "*it is not interesting to get the opinions from one or a few users, but if many users feel the same thing, then it is important* [Design engineer]." The interviewees considered that it sometimes would be fruitful to get more information about the end user; "*it is always desirable to meet the user, you should not forget who pays in the end* [R&D-manager]."

The design engineer remarked on the fact that the product developers in some way are expert users of their products which could cause difficulties in comprehending 'ordinary' users' thinking; "*you may not see the product in the same way as a 'normal user'. The 'normal user' could complain about something in the product that I think is totally normal, since I know the reason for its performance or design* [Design engineer]."

The company does not use any human simulation tools today and they were all a bit hesitant as to what kind of benefits they would offer. However, the R&D-manager acknowledged the benefits of perhaps performing earlier evaluations; "*today it is first when a prototype is built, when there is something to get a grab of, when one is starting to think about ergonomic aspects* [R&D-manager]." He also felt that drawings and CAD-models, or verbally trying to describe the product, never work well for communicating ideas; "*you need the physical thing so that they get something to touch, that is when the product becomes 'real' for people* [R&D-manager]." The company uses rapid prototyping techniques to manufacture prototypes which they think works well, e.g. for evaluating grips, forces and space required for manoeuvring product components.

Company D

Also in this case the interviewees had a generic picture of their diverse set of product users. The interviewees believed though that their customers are a little more educated and better informed than the general customer. Like the other companies, this company does not have a defined procedure for describing its end users.

The customer focus during product development is split into three, equally important, target groups: *distributors*, *sales organisation* and *end users*. If the distributors are neglected, they do not want to sell the product, and the sales companies must receive sufficient profit margin to be committed to sell the product. According to the marketing and sales manager, the salesman may, in eight out of ten cases, decide which product the customer will eventually buy. Naturally, it is attractive for the seller to propose a product that gives high profit in return.

The design engineer indicated that he is struggling to fulfil the end user demands; "*as a design engineer you try to consider the user and how I would like the product to be if I was the user - that is what I am striving for* [Design engineer]." He mentioned that he feels some ambivalence to the sellers' and distributors' demands.

None of the interview subjects work actively with meeting end users. Instead, the information about the end users reaches the product developers through the marketing division. There were some different opinions about the importance of the product developers' contact with end users. The marketing and sales manager thought that the principal thing is that the product developers receive the information about the end users, and who delivers the information is not very important. The design engineer was of the opinion that it is good to get the information directly, as second hand information is always slightly distorted from the original form. He believed that there would be no disadvantage in having more end user contact. However, he went on to explain that the difficulty was the shortage of resources; "*everybody cannot work with everything* [Design engineer]." The product development manager also thought that it is important that product developers have contact with end users. He added that all people working in the company already have that in one way or another, since the product developers are also users of the products and on a daily basis come in contact with other users, such as relatives and friends.

The product development manager commented that they have more customer requirements methods directed to the sales organisation rather than to end users. The design engineer and the marketing and sales manager thought that they do not need more methods. The sales manager believed that more methods could lead to results rather being based upon a few persons' opinions. The product development manager expressed the view that the use of methods is balanced against the availability of resources.

The company does not use any human simulation tools today and like Company C they were hesitant about the benefits of such a system. They would rather use rapid prototyping to get physical things when evaluating ergonomics. The design engineer commented that they, if they wanted to, could model a range of hand sizes themselves in their own CAD-system and that would be good enough, especially if one considers time and resources available.

Summary of results

The major results of the study are summarised in Table 2.2.

Table 2.2. Summary of results.

	Company A	**Company B**	**Company C**	**Company D**
Products	Professional hand held power tools	Professional hand held power tools	Durable consumer products	Durable consumer products
Primary target groups	End users	End users	End users and sales companies	End users, sales companies and distributors
Formal contact with end users	Yes (all of the subjects)	Yes (all of the subjects)	No (none of the subjects)	No (none of the subjects)
Main attitude towards human simulation tools	Positive if easy to use and not too expensive	Positive if easy to use and not too expensive	Doubtful of benefits	Doubtful of benefits
Comments	Rapid prototyping to evaluate ergonomics at early stages	Rapid prototyping to evaluate ergonomics at early stages	Rapid prototyping to evaluate ergonomics at early stages	Rapid prototyping to evaluate ergonomics at early stages

2.5.4. Discussion of the results of the interview study

The results from the interviews clearly indicate that the companies that develop hand held power tools (Company A and B) were more directed to the end users than the companies developing durable consumer products (Company C and D). The power tool developers have a closer contact with the end users and a different attitude towards the significance of end user contact; they believe to a larger degree that end user contact is very important compared with the opinions in the companies developing durable consumer goods. This is in accordance with Eason (1995), who found that a user participative approach was more appropriate for the design of products where there are identifiable users and where the users are in a position where their views can influence the design; in this situation the user becomes an important stakeholder for the product's success.

Since the power tool developers have little experience of how it is to work with the tools many hours per day they need the operators' opinions and guidance for successful design, while the consumer product developers have a richer understanding of how it is to use the products since they are users themselves. Also, the high workload on the operators using the hand held power tools means that the products' ergonomic properties are crucial. Also, there is information gain from direct communication between the end user and the designer when compared with written documents or interpretation through other persons. The power tools are typically used actively for many hours per day. Poorly designed tools strongly influence the users' performance negatively and may lead to injuries. This is likely to cause economic loss for the operator and the company, as well as pain/injury for the individual. This calls for thoughtful consideration of ergonomics in the power tool design process. For consumer products, poor usability may cause annoyance and disappointment, but other values such as aesthetics may be more important for the purchase decision as well as for long-term appreciation of the product. However, as discussed by Jordan (1999a), in order to create genuine customer satisfaction, usability must not be left out of the business of design since usability is a prerequisite for forming the kind of customer satisfaction that comes above usability on the hierarchy of user needs (Figure 2.5).

Some interviewees argued that the sellers and distributors could communicate end user requirements well, as they "know the end users' needs". However, the sellers' main objective is to make profit by selling products. This may lead to a tendency of short-sightedness by concentrating on design issues influencing the purchase situation, where the possibility to convince a large number of potential customers to buy becomes vital, and perhaps neglecting long-term user satisfaction to a certain extent. Of course, this may be any company's strategy for success, but it is likely to be a short-term one. The end users' interests are more related to positive experiences of using and owning the product. As pointed out, it is not certain that these interests are the same, but they might be more alike if the company follows a user-centred design strategy, based on offering long-term end user satisfaction. Naturally, it is important to consider all stakeholders' interests, and if the company do not have the sellers' support the products may never even reach the end users.

The power tool companies had a more positive attitude towards using human simulation tools in the design process to evaluate ergonomics issues on virtual products, compared to the companies making durable consumer products. The reason is most likely due the importance of meeting ergonomic requirements when developing the power tools. Company A and B see benefits from implementing tools that could assist them in considering ergonomics already from the start of the design process.

Conclusively, identifying customer needs, including end user needs, indeed gives the design team valuable information of the product to be designed, but rather than seeing this information as the sole information source, or as directives, it is believed advantageous for the design team to consider other pieces of the puzzle of creating successful products, and complement the identified customer needs with other design keys such as creativity, innovation, upcoming attractiveness trends, differentiation and the sound use of emerging technologies. Taylor et al. (1999) remark that design has a strongly proactive element, not simply responding to the needs and wishes of the users and buyers.

2.6. Summary

The aim of the chapter was to draw attention to possible general underlying problems of considering user aspects in product development to set the stage for subsequent research activities.

One problem is related to the common complexity of design processes where numerous issues have to be handled concurrently within tough time constraints. Issues not typically dealt with by tradition, obligation, in education or not supported by tools and methods are likely to be assigned low priority by designers or project managers, and hence may be poorly considered. This is likely to apply to ergonomics issues, even when these are considered important for gaining customer satisfaction.

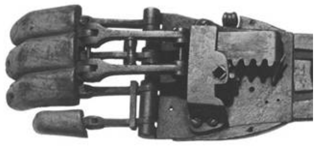
Supportive design tools and methods may reduce this problem by supporting communication about user aspects and aiding the design work to arrive at better solutions quicker, e.g. by facilitating the exchange of ideas and information among members having different backgrounds and roles in product development.

Different views on products and product development objectives among people involved in product development, e.g. based on tradition and education, give reasons for tensions and communication problems. Even though conflicts (being a driving force in the *dialectic* theory) may benefit product development, e.g. by enriching discussions about objectives and compromises, it is believed advantageous to promote views of a common objective among people involved in a product development project (according to the *teleological* theory). This approach is considered better suited in the contemporary highly competitive product development setting.

Ethically justified considerations in product development, such as inclusive design, calls for providing designers with tools and methods to meet these requests in line with other product requirements and within economical and time constraints.

The interview study indicated differences of end user focus depending on type of product developed. It also showed a general low usage of methods for end user consideration. The study also indicated that companies developing products with a clear ergonomics content were more positive towards the outlook of using human simulation tools.

Chapter 2 covered general issues of product development, the design process and designers' use of tools and methods. This was followed by a discussion of differences of views of product development with the aim to draw attention to possible underlying problems of considering user aspects in product development. The next chapter narrows down the discussion towards ergonomics integration in product design.



Chapter 3

Integration of Ergonomics in Product Design

This chapter goes closer into the area of ergonomics integration in product design. It builds on the issues stated in the *Problem Statement* (Section 1.2) and Chapter 2, but with a more prescriptive approach. The literature review for this chapter was directed towards problems and suggestions for improvements in the area, mainly as identified by the design and ergonomics research community. The outcome is elaborated with the author's own discussions and studies. User Characters as a method for aiding designers to consider people different from themselves is presented. The chapter includes the development of a framework for aiding the definition of appropriate timing of ergonomics evaluation in the product development process. The outcome was assessed in a case study at a company.

3.1. Ergonomics and Product Design

To gain an understanding of the implications of the integration of two areas, each area's perspective ought to be highlighted as an important view of the relevant issues. The aim of this section is to accentuate knowledge, opinions and experiences regarding integration of ergonomics in product design, representing both designers' and ergonomists' viewpoints.

Pheasant (1986) presents five common fundamental fallacies among designers, related to their view of ergonomics issues:

1. *The design is satisfactory for me - it will, therefore, be satisfactory for everybody else*. This fallacy highlights the problem that many design proposals are never tested on a representative sample of users, but are typically evaluated subjectively by the design team and management.
2. *The design is satisfactory for the average person - it will, therefore, be satisfactory for everybody else*. This fallacy relates to the first since most people consider themselves to be more or less average. Taking a closer look at the consequences of designing for the so-called average person would soon reveal major reductions in accommodation of people due to human diversity.

Furthermore, Daniels (1952) showed that anthropometrically there is no such thing as an average person when several body dimensions are taken into account, even when using a generous definition of the range considered as being average. These issues will be returned to in Chapter 5.

3. *The variability of human beings is so great that it cannot possibly be catered for in any design - but since people are wonderfully adaptable it does not matter anyway*. People are adaptive, yes, but the issue is at what cost for the user, company or society. And what if competing products require less adaptation?
4. *Ergonomics is expensive and since products are actually purchased on appearance and styling, ergonomics considerations may conveniently be ignored*. As discussed in Section 2.4.2, Jordan (1999a) considers that usability is a prerequisite for creating lasting customer satisfaction from issues like attractiveness to product styling. The challenge for designers is to consider ergonomics along with other design issues (such as appearance and styling) as all being part of a value creating package which is considered from the very start of the design process. Also, a more ergonomic product is not necessarily equal to increased costs.
5. *Ergonomics is an excellent idea. I always design things with ergonomics in mind - but I do it intuitively and rely on my common sense so I do not need tables of data or empirical studies*. As discussed earlier, intuition is inherent in design, but this does not mean that designers' subjective opinions would be enough in order to create successful products. Appropriately devised support systems for ergonomics information as well as communication with ergonomists and user representatives are all important resources for the designer to add objectivity when generating and identifying advantageous design alternatives.

Porter and Porter (1998) add three further fallacies:

6. *The design is not satisfactory for me - it will, therefore, be unsatisfactory for everybody else* (a variation on fallacy 1 above). Porter and Porter provide the example of a motoring journalist strongly criticising a car since the design is not optimised for him or her. However, the car may well be satisfactory for the targeted customers, or a conscious compromise considering the diversity of the targeted customers.

7. *Percentiles are a very clear and simple way to present and use information concerning body size*. Anthropometric data, i.e. measurements of the human body, are typically presented as percentile (%-ile) values assuming a normal (Gaussian) distribution, and hence regular parametric statistics apply in most cases (Kroemer et al., 2001). Percentiles is an easy concept for presenting human dimension distribution for one body dimension for a certain population, but the problem arises when it is assumed that using the data is equally easy, particularly in the common situation where more than one body dimension is involved in the design (Porter and Porter, 1998; Robinette, 1998a). An example of the difficulty of using percentile values is that they are not additive, except the 50th percentile values (Robinette and McConville, 1981).
8. *Designing from 5th percentile female to 95th percentile male dimensions will accommodate 95% of people*. No human has a specific percentile value for all body measurements, but rather a great variability of bodily dimensions (Daniels, 1952; Roebuck et al., 1975). This makes it complicated to define who is accommodated, i.e. designed in or out, by a certain design. The issues related to fallacy 7 and 8 will be returned to in Chapter 5.

3.1.1. Ergonomics in the context of product development

Fulton Suri (1998) gives examples of typical expressions of disappointment among ergonomics professionals working in product development; "*they ignored my advice, they involved me too late, there was not time to do a proper study, the ergonomics input was great, but the product bombed*." To improve this situation Fulton Suri suggests that focus be placed on ways to tailor the ergonomist's contribution to be more relevant in the time and budget constrained, technology centric and market driven world of product development.

Broberg (1997) reports that design engineers considered the following as the three major obstacles to the integration of ergonomics into their work: *customers do not demand products which are ergonomic friendly produced* (manufacturing ergonomics was the focus in Broberg's study), *lack of ergonomics knowledge* and *lack of time*. Regarding prerequisites for integrating ergonomics into work, the design engineers ranked the following three aspects highest: *more time*, *training in ergonomics* and *improved contact with ergonomists*. As can be seen, lack of time to consider ergonomics is a common perception among designers. This should not be misinterpreted as lack of interest or unawareness among designers of ergonomics. Indeed a study by Rouse and Boff (1998) reports the opposite being a common situation. One solution would be to allow designers to spend more time to consider ergonomics. Certainly this consumes time and increases costs, but may be a sensible approach to enable and ensure that the product is of appropriate quality from an ergonomics perspective at market introduction.

A short time to market (time to market is defined as the total time from the identification of a market opportunity to the new product's market introduction), is advantageous in many ways, such as quicker response to market variations, increased chance that the product is up-to-date at market launch, the opportunity to secure market share before competitors introduce their alternatives including the enhanced chance to be seen by customers as originator rather than follower, as well as earlier return from investments in product development (Kotler et al., 1996; Wright, 1998). The time spent on product development naturally affects time to market, which means that, if designers are to spend more time on design, and time to market is not to be prolonged, this has to be carried out in some sort of parallel activity. This is based on the assumption that there are no opportunities for making the design work more efficient, e.g. by introducing useful support tools and methods, reducing time needed for information retrieval or time spent on non-design activities. More time spent on design would require increased resources put into product development (personnel and money). However, investments (allocated resources) in the earlier stages of product development, where important ergonomics issues preferably are dealt with, are well spent according to Baxter (1995) and Ullman (2003). The costs incurred at early stages of the design process are low, especially compared with the total cost of product and production system development, and the costs and effort required for design alterations are moderate at early stages. According to Martin (1997), design changes earlier in the design process are much less expensive to carry out, sometimes by several orders of magnitude.

The costs committed, i.e. associated with the product's eventual manufacturing costs, are to a large degree determined at early stages, and major design modification and cost reduction issues are therefore preferably dealt with at early design stages since the chances for influencing these are lower at later stages due to cost and time penalties. The cost to benefit ratio is better for the early stages of development than for later stages, and the advice is hence to invest time and effort in the early stages of the design process (Figure 3.1) (Baxter, 1995; Ullman, 2003).

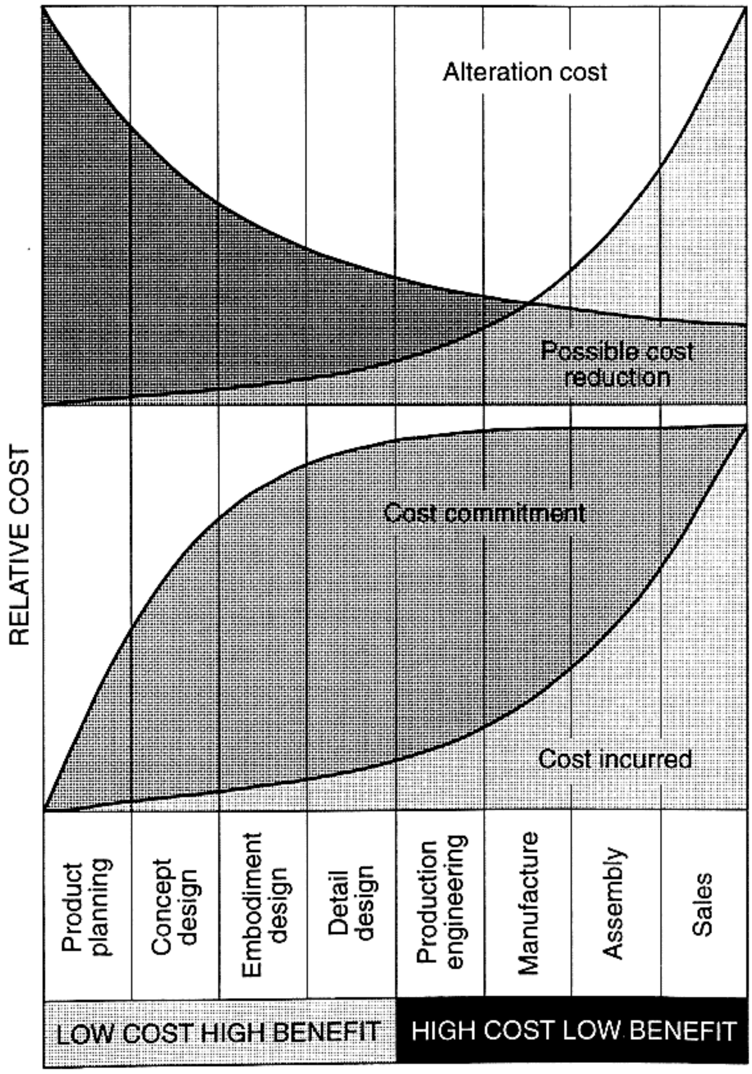


Figure 3.1. Costs and benefits at different design stages (Baxter, 1995).

Design changes, or *iterations*, are essential and natural characteristics of design, e.g. in order to explore design alternatives in a fruitful 'what-if' manner. The objective is not to reduce design changes. Instead, design alterations might well be encouraged, but carried out early in the design process rather than later, due to the moderate time and effort required at earlier conceptual stages. Decreasing late design changes also makes it less problematic to run the project according to plan at later complicated and expensive process stages, e.g. towards quality assurance and manufacture ramp-up activities. Expected benefits from the approach of early design changes are improved product quality as well as reduced costs and reduced time to market. Ullman (2003) points to the Japanese car industry in the early 1980s as a successful example of the employment of this approach (Figure 3.2).

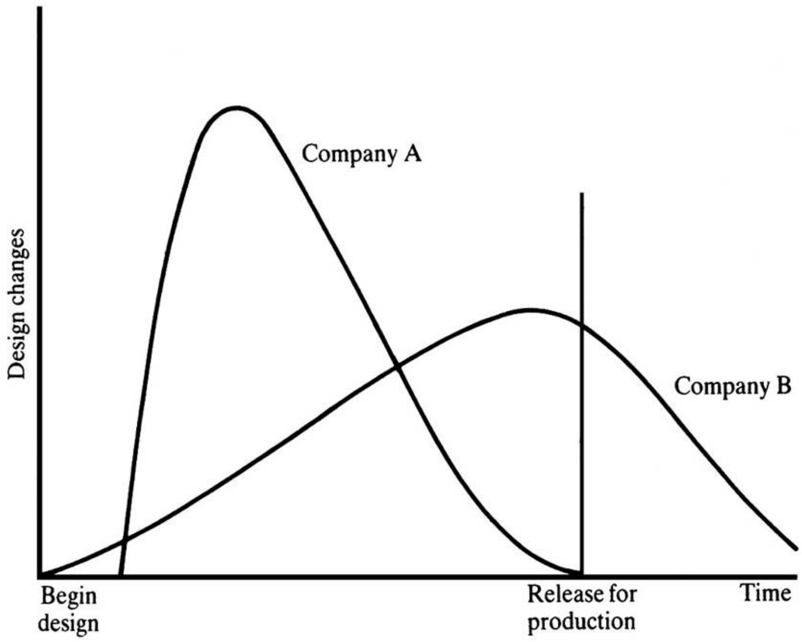


Figure 3.2. Design changes at companies with different design philosophies (Ullman, 2003).

In the context of ergonomics, the characteristics of the contemporary product development approach highlights the importance of treating ergonomics issues at early design stages, and it endorses more resources spent on ergonomics since it is likely to gain product quality, and indeed is a low cost in respect of the entire product development budget. Spending resources on ergonomics may mean a lot of things, e.g. more time for designers to consider ergonomics (e.g. time to interact with representative users of the product being developed), training in ergonomics or enhanced cooperation with ergonomists.

Product development is a sequential process where previous decisions reduce the number of degrees of freedom available at later stages, and this calls for ergonomics to be considered from the very start of the process since ergonomics issues often affect major design issues such as product layout and boundaries, which are hard and expensive to alter later in the design process. Whilst there is little doubt about the desirability of an early involvement of ergonomists in the design process, most ergonomists working in industry will rarely achieve this objective (Simpson and Mason, 1983). Most frequently the ergonomist is faced with a request to evaluate either an already working system or a fully developed operational prototype, forcing a corrective rather than a preventative approach. In both situations the changes necessary to improve the ergonomics considerations are likely to be prohibitively expensive (Simpson and Mason, 1983; Porter and Porter, 1999).

Porter et al. (1993) argue that it is essential that the ergonomics input to a product takes place throughout the design process but nowhere is it more important than at the concept and early development stages of design. Fulton Suri (1998) emphasises the importance of ergonomists being sensitive to what is needed at different stages of the design process. At the earlier conceptual stages a broader approach about issues and possibilities is generally more beneficial than dealing with details, and ergonomists offer the best input by challenging assumptions, proposing alternative ways of tackling the issues and broadening the thinking of the design team. Later in the process, after a product concept has been selected, this kind of fundamental and divergent thinking is less useful than providing specific support to designers in working out the details (Fulton Suri, 1998).

Porter and Porter (1998) propose an inside-out approach for car design, in contrast to the current procedure that in many ways can be seen as an outside-in approach where exterior styling strongly influences the form and volume of the car, for which subsequent design, engineering, ergonomics and other issues are to adhere to. Indeed, cars' styling is important for short and long-time attraction (pleasure) in the senses of the user, but the challenge for the entire design team is to find a balance between function, usability and pleasure as discussed in Section 2.4.2. Naturally, the significance of these issues depends on the type of product, and it would for example be a different blend of functionality, usability and pleasure for the design of a sports car or a family estate car.

According to Liu (2003), issues such as product reliability and physical quality are taken for granted by users. Many ergonomics issues are likely to be considered as such basic factors by product users. Basic factors will not create any pleasure according to the *Kano* model of product quality. However, the experienced customer value may be strongly reduced by not fulfilling expected, but typically not expressed, basic requirements (the *Kano* model invented by Dr. Noriaki Kano is described in Baxter (1995)). Even though it is up to the user to appraise whether he or she is happy and satisfied with the product, it would be risky if a design team did not consider and validate ergonomics issues during early stages of the design process, particularly for creating long lasting customer value.

3.1.2. Nature of ergonomics information directed to design

Meister and Farr (1967) found that the designers in their study appeared to have little or no interest in utilisation of ergonomics information, and seldom even thought of consulting ergonomics handbooks. One reason was that they were looking for specific answers to specific questions and were not interested in trying to extract these from the general guidelines given in the handbooks. Another reason was that they disliked the 'wordiness' of such handbooks; they strongly prefer information in pictorial or graphical form. This lack of familiarity indicates a need to inform designers of what information is readily available, and to develop information sources that encourage designers to explore and grow familiar with the ergonomics information space (Burns et al., 1997).

Simpson and Mason (1983) remark that there is a lack of ergonomics guidelines that are directly applicable in design. A survey by Woodcock and Galer Flyte (1998) indicates the same and found that 60% of the responding automotive designers and engineers did not think their need for ergonomics information was being met. Designers stress that information needs to be in a relevant, concise and usable format, and they also request more graphics in ergonomics references. The latter complaint is connected to the fact that design essentially is a visual activity, and knowledge or data expressed in a graphical format has a subtlety of meaning that cannot be found in a completely textual representation. MacDonald and Jordan (1998) believe that, if ergonomics is to get its message across to the design community, it is essential that it embraces a more visually-oriented approach to communication. One way to achieve this would be to ensure ergonomists had more training in envisioning information and qualitative value judgement during their education.

Burns and Vicente (1994) argue that it is not surprising that in today's competitive and constrained design environments designers may not be accessing ergonomics information. Typically, designers must quickly deal with a rich set of interacting issues that cross many disciplinary boundaries (Rouse and Boff, 1998). This involves accessing and using a wide variety of information sources such as the current state of the design, customers' requirements, past designs, available design components, potential new technologies, failed ideas and, of course, designers' own ideas. This information processing is carried out under tough time constraints. Rouse and Boff (1998) remark that designers must manage all this information in the process of trying to resolve design issues in a few days or couple of weeks at most, which means that there is little time for deeper studies. This puts pressure on ergonomics information to be easily accessible and relevant for current design matters. As discussed, this is a problematic area. For example, if detailed information is required by the design team in order to improve the ergonomics of a product, this request may be impossible to accomplish due to time constraints, if not planned for in advance. This puts emphasise on planning the search for ergonomics information, including interpretation and communication of the ergonomics information to designers. This is especially important for generating so-called primary data, i.e. new information currently not available in a collected form suitable for the specific present purpose, since the search activity may take a long time. Existing information, secondary data, is quicker and cheaper to obtain, but is likely to require time spent on interpretation and validation since the data may be drawn from another context or be more general than ideal for the current design matter. Regarding obtaining primary data, Porter et al. (1993) highlight that detailed information of current designs from user questionnaires and user trials, or of new designs using mock-ups with selected subjects, can take weeks or, more usually months, to acquire.

According to (Meister, 1982), designers are reluctant to accept an input unless the benefits resulting from that input are immediately obvious. This may cause problems in making designers pay attention to ergonomics since it benefits the future use of the product. These benefits may be invisible to the designer since they do not do things to the product directly. Fulton Suri and Marsh (2000) feel that designers are sometimes frustrated by the results from ergonomics analysis as they provide data about peoples' capabilities and their reactions to specific design variables, but generally do not, by themselves, lead to design solutions.

Eason and Harker (1991) argue that it is not sufficient for the ergonomics community to undertake research and generate new primary sources of relevant findings, as it is also necessary to put considerable effort into developing appropriate methods of delivering this information where it is needed. Chapanis (1995) maintains that it is ergonomists', not designers' or engineers', responsibility to translate ergonomics information into project specific design recommendations, i.e. that ergonomists should be the experts in interpreting ergonomics information, e.g. as presented in guidelines, into relevant design information, and to support the employment of the data. This is a challenge since ergonomists have an inclination to point out drawbacks of designs from an ergonomics point of view, but often have difficulty in providing guidance of how something should be designed, e.g. of answering questions such as: "*how could I change the design to improve it*?" (Rouse and Boff, 1998).

Haslegrave and Holms (1994) remark that even the ergonomists themselves found that the guidance given by handbooks was often inapplicable to their own design questions. The authors give the example of design guidelines for the layout for instrument panels (e.g. placements of controls and displays) coming from process industries (e.g. power plant control rooms) not being relevant for the design of a vehicle instrument panel.

To improve the transfer of ergonomics information to designers, ergonomics researchers and intermediaries are faced with two challenges: to reduce the perceived costs of obtaining ergonomics information and, more important, the provision of information which is of high value and matches the needs of designers (Burns and Vicente, 1994). Eason and Harker (1991) comment that the main dilemma in providing an effective ergonomics contribution appears to be the conflict between providing valid inputs and providing usable ones. To be valid the contribution typically has to reflect the specific considerations of task, user, application and technology. However, to be usable to most designers the contribution needs to be simple to understand and to execute.

3.1.3. Ergonomics in product design specifications

A product design specification states the objectives and constraints for a product solution, and it is important that it does so in a way that enables the designers to reach a functionally and commercially acceptable solution in an appropriate period of time (Wright, 1998). The product design specification is an interpretation of customer needs, e.g. a subjective expression drawn from customer needs analysis, into precise descriptions of *what* the product has to do, but not *how* this will be realised (Ulrich and Eppinger, 2003). The level of generality is important so that time is not wasted, or that potentially good solutions are excluded (Wright, 1998). As discussed earlier in this thesis, requirements are preferably expressed in a quantified form, particularly if the requirement is a demand (constraint) rather than a wish (objective), otherwise it is impossible to decide for certain if the demands have been met (Wright, 1998).

Meister and Farr (1967) consider that one way to ensure that ergonomics information will be utilised by designers is to centre on the product design specifications, as the one information source to which designers do respond. Meister (1987b) highlights the problem that criteria used to evaluate product design alternatives rarely cover user aspects, which may result in the selection of an inadequate design alternative from an ergonomics standpoint. Elliott et al. (1999) found that issues that are easier to specify, such as cost and performance, were given a higher customer needs priority by companies than 'soft' attributes and implicit requirements, including ergonomics issues. Eason and Harker (1991) consider that, since task and user needs are very variable, each design process requires an ergonomics specification procedure. Existing specification processes typically highlight business, economic, market and technical criteria and there is a need to develop specification techniques that will support persons creating the product design specification (whether they are from marketing or elsewhere) in adding the role of ergonomics to the requirements for the product, with the same weighting process as technical, economic and other criteria (Eason and Harker, 1991). Meister (1982) argues that one reason for the lack of quantified ergonomic requirements in product design specifications is the inability of the ergonomics discipline to specify such requirements and to demonstrate the need for them. Roussel and Le Coq (1995) discuss the case where the designer has problems in interpreting and valuing the importance of prescribed requirements, especially when the requirements are conceived as blurred or incomplete or deal with an unfamiliar domain, and hence the designer builds his or her own constraints. In an ergonomics context, this calls for requirements to be expressed in a way that is clear and complete for designers, and also underlines the call for ergonomics training for designers. This is in order to reduce the differences between the prescribed requirements and the mentally built requirements (by the designer).

3.1.4. Cooperation and communication of ergonomics in design

Central to product design is working together with other people, with the same or different professions, e.g. product designers collaborating with ergonomists or marketers. MacDonald and Jordan (1998) remark that the two fields of product design and ergonomics share areas of concern; both are concerned with how products, tasks and environments 'fit' people. Kreifeldt and Hill (1976) believe that designers and ergonomists, by combining their separate areas of expertise and refined sensibilities for the different design aspects, form a natural working unit since they are both directed to the same end: true customer satisfaction and thereby a successful product.

Haslegrave and Holmes (1994) advocate normal discussions as the communication pattern between design engineers and ergonomists, rather than ergonomists simply responding to designers' queries on a 'client-consultant' basis. Fulton Suri and Marsh (2000) consider that it is no longer acceptable for ergonomists simply to evaluate what others design and produce, and remark that the role of 'ergonomics police' has won few friends among designers. Eason and Harker (1991) argue that a successful design team has to be built with a multidisciplinary base in which each specialist understands the role to be played and understands, and is sympathetic to, the roles to be played by others. This would resemble a *teleologic* working manner as discussed in Section 2.4.4.

Haslegrave and Holms (1994) comment that the lack of a common language (or terminology) may become a barrier for effective communication between ergonomists and designers. MacDonald and Jordan (1998) describe how poor communication can arise between professions due to limitations in the language each specialism employs, i.e. language used by product designers and ergonomists respectively, and that this communication gap can result in under-optimised products failing to deliver in usability, quality and enjoyment in use. Different disciplines use different jargon in communication, and concepts that are understood by some disciplines are not meaningful to others (MacDonald and Jordan, 1998). Porter and Porter (1999) list three problem areas regarding communication between ergonomists and designers:

1. *Communication of ergonomics information at an inappropriate point in the design process*. Rarely is the ergonomics input planned but rather it occurs when a 'human interaction' problem is identified. This forces a (more time consuming and expensive) corrective approach rather than a preventive approach for managing ergonomics in design.
2. *Communication difficulties between ergonomists and designers/engineering designers caused mainly by educational and practice differences*. Many engineers tend to consider human diversity in a similar manner as they consider other kinds of diversity, e.g. related to product dimensions, manufacturing tolerances or strength of materials. This approach is poor when it comes to humans due to the great diversity, leading to many people being 'designed out' by such an approach. Also, designers and engineers prefer to communicate using visual aids, such as sketches and drawings of the product design, whereas ergonomists commonly communicate information in report format, e.g. about human characteristics or results from evaluations. Commonly this information does not directly influence the design which may cause interpretation and communication difficulties.
3. *Communication of ergonomics information and data in an inappropriate fashion by ergonomists*. A problem is that some ergonomics information is too specific, meaning that the recommendation might not be relevant for the design issue at hand (e.g. a recommendation of enforcing a straight wrist in hand tool design when the context of use is not known, possibly causing another postural shortcoming) or too general, i.e. meaning very little to support the designer's task, or leaving the designer responsible for selecting the relevant data for the current design task, incorporating the risk that it is done wrongly or not at all.

Shackel and Richardson (1991) remark that enhanced complexity of technology sets continually higher demands upon human-product interaction. Complexity also causes designers to need long training and to be busy with technical problems, to the detriment of dealing with ergonomics properly. This highlights the need for designers to obtain some ergonomics training to support the application of ergonomics information in design and to assist in communication about ergonomics with design colleagues and ergonomists (Haslegrave and Holmes, 1994; Porter and Porter, 1999). Eason and Harker (1991) emphasise the need for some understanding of ergonomics by designers since it is hardly likely that a limited number of ergonomics specialists will be able to provide all the inputs that would be desired. It is important that designers at least have sufficient understanding of ergonomics so that they know when to seek the help of a specialist. The required level of ergonomics knowledge can differ depending on the role of the designer, e.g. related to extent of engagement in activities with an ergonomics content (Eason and Harker, 1991). Elliott et al. (1999) found that communication of ergonomics issues relied on informal and unstructured means where information was 'pulled' when there was a problem or a need for information. The authors highlight that this 'information pull' may lead to certain information not being requested since the designer or the design team is not aware that they need it. Offering designers training in ergonomics can reduce this problem by enhancing the awareness of the need for the information.

Haslegrave and Holmes (1994) report a study that showed the importance of the form of communication about ergonomics to designers. In the early stages, it was found that verbal communications were often not sufficient. The information was easily forgotten or not passed on down the chain of communication with all the qualifying factors expressed by the ergonomists. It proved easier to convince design engineers when using three dimensional illustrations or videos of the user trials, and it sometimes helped to let the designers experience user problems at first hand by including them in evaluation trials as if they were subjects.

As discussed earlier, cooperation and communication in design is essential in order to develop successful products that fulfil users' needs and wants. Information about users' needs and wants can be seen as coming from two major, but in many respects often separated, sources: ergonomics research and marketing research (Figure 3.3). It is recognised that the illustration in Figure 3.3 is an over-simplification, but it highlights the importance of cooperation and communication of user related information between ergonomists, marketers and designers (industrial or engineering designers), an area indicated by the dotted grey circle in Figure 3.3. An example of communication would be discussions of the significance of meeting identified particular user needs in relation to other demands on the product's design, i.e. in trade off situations.

Both ergonomics and marketing research may contain ethnographic studies. Taylor et al. (2002) describe ethnography as it concerns observing, documenting and understanding the way of life of people who lie beyond the experience of our own way of life. Taylor et al. (2002) maintain that the method of ethnography can be a valuable tool to enable designers to gain a more holistic picture of potential end users and their product requirements, and they propose the use of video to communicate ethnographic knowledge to designers to gain a rich understanding, and to comply with the 'visual language' of design. Due to the applied nature of design, Ball and Ormerod (2000) argue that it is entirely appropriate for ethnographic studies applied in a design context (named *applied ethnography*) to differ from *pure ethnography* as used in traditional anthropological and sociological research.

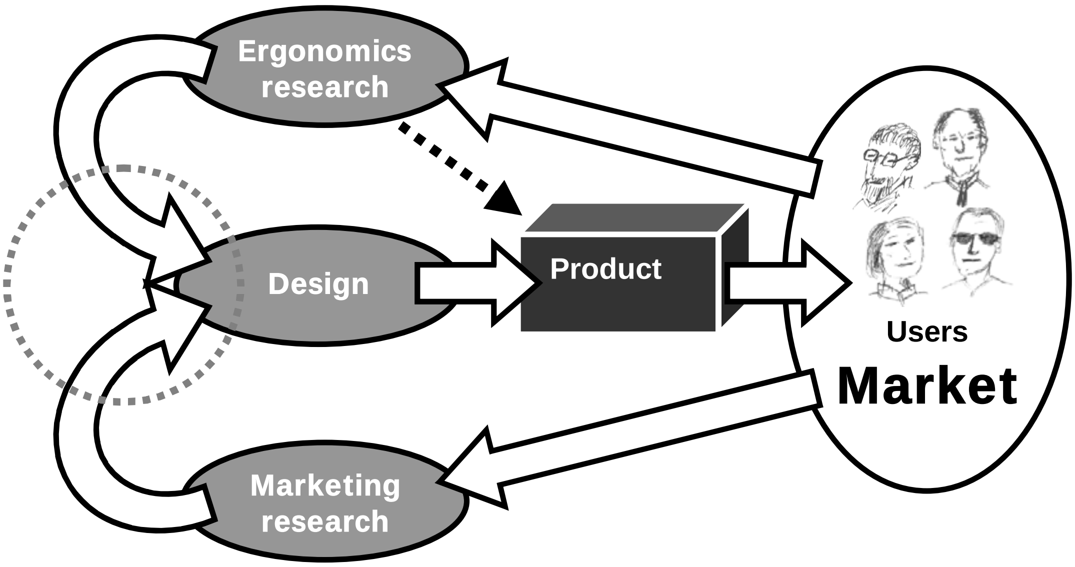


Figure 3.3. Design as information receiver and product realising activity.

The dotted black arrow in Figure 3.3 would represent a *corrective ergonomics* approach, where ergonomics is applied to alter a product that is already designed and manufactured. As discussed earlier, the scope for making major improvements are likely to be small or costly, and the product may already have caused annoyance or suffering, e.g. leading to bad-will for the company, reduced performance or human misery.

Figure 3.3 also illustrates design as receiver of user information as well as a product realising activity, where the design function enables information of users' needs and wants, identified as present on the market, to be channelled into a product, eventually offered on the market. Shackel and Richardson (1991) state that the complexity of modern technology separates designer and user, and thus usually prevents effective feedback from the user to improve the design, and that the ergonomist is an essential link who operates as a sort of preventive and predictive feedback channel.

Rouse and Boff (1998) argue that it is important that ergonomics researchers and educators recognise that their primary influence on the applied world occurs via designers of products and systems. Thompson (1995) comments that, from a product development standpoint, the goal of ergonomics is to design the product to fit the capabilities and limitations of the user in order to address their need for comfort and safety. If this information channel of ergonomics information to designers is ineffective, which indeed is a common conception as previously discussed, this leads to a case where the influence of ergonomics issues on design will be scarce. In Figure 3.3 this would be illustrated by a crack or a restriction in the arrow representing information flow between ergonomics research and design.

The ergonomics and marketing disciplines have different focus and methods, but the human beings studied by the ergonomics researchers are in essence the same human beings as studied by the marketing researchers. Ergonomics research covers characteristics of the human body and mind, whereas marketing research mainly focus on products' commercial success. Still, as it is at present in essence the customer's market, i.e. it is the customers that heavily declare the conditions for competition on the market, customer focus is a key approach for success, and the focus of marketers and ergonomists has much in common in the context of product development. Cayol and Bonhoure (2004) assume that an interdisciplinary approach between design, marketing, ergonomics and sociology will be required in future development of products.

Eason (1995) reflects on two approaches of ergonomics practice when contributing to the design of products. He classifies these as: *design for users* and *design by users*. *Design for users* embodies the case where the person dealing with ergonomics, e.g. a designer or ergonomist, uses theories and findings about human behaviour to act on behalf of users. *Design by users* is when end users themselves can influence the design so that it is compatible with their preferences and objectives. The fundamental point behind this approach is that only those who will be affected by the design can decide what is in their best interest. Applying this approach means that the role of the designer or ergonomist changes from being the expert to becoming the facilitator that helps the user to establish what is in his or her best interests (Eason, 1995). According to Eason the *design for user* approach is appropriate for generic products, whereas *design by users* is the appropriate strategy when significant value judgements have to be taken in a bespoke design setting. Eason suggests a mix of both approaches as a successful strategy, where the ergonomists structure the process by which users engage, as well as support and contribute, e.g. by offering new visions or alternatives, and assist in evaluations. By this approach, the users may be able to make the value judgements that are needed without the loss of any specialist knowledge that might be relevant (Eason, 1995).

Market research may also involve users. An example of direct involvement of users would be focus groups where representatives of the target market are asked to judge early mock-ups/prototypes, or competing products, to elucidate immediate responses, or long-term considerations by asking people to live with the products. Marketing research may be about demographics, economics, lifestyle characteristics and user's preferences, attitudes, thoughts and feelings (Kotler et al., 1996). Adding up both ergonomics and marketing information enhances the picture of users as 'full persons', e.g. in view of both physical and cognitive limitations as well as attitudes and aspirations.

Jordan (1998) considers that, in order to fully represent the user in product development, the ergonomists should look both at and beyond usability. This makes sense since humans are more than physical and cognitive processors, and more than work-performing entities; we have personalities and hopes, fears, dreams, ambitions and beliefs (Bjørn-Andersen, 1988; Eason, 1995; Jordan, 2000). Also, products are more than tools, they are living objects with which people have relationships, and these objects may make us happy or angry, proud or ashamed, secure or anxious (Jordan, 2000).

This view of enhancing the area of ergonomics may assist integration of ergonomics in product development by making ergonomists be considered as an even more valuable competence in the product development team, and may help in integrating the areas of ergonomics, design and marketing (Green, 2002).

Thompson (1995) illustrates how market information gathered for product planning purposes, e.g. characteristics of the targeted customers such as age and gender distribution, educational level, income range and lifestyles is important data from a ergonomics perspective. For example, the anthropometric database software PeopleSize states that people with high income are typically taller than those with low income (PeopleSize, 2004). Liu (2003) believes that marketing research, e.g. 'consumer behaviour', such as how the product design influence purchase decisions, can offer very useful information for product design.

In a product development context, the general objective of ergonomics and marketing research is to get to know more about users' needs and wants in order to provide the design team with proper information to enable the design of a product that will meet or surpass those needs and wants. The overall objective of this enterprise is to benefit users, the company, and ideally also the society. Consideration of all three interests would comply with the Societal Marketing concept (Kotler et al., 1996) as shown in Figure 3.4. This view illustrates that both ergonomics and marketing include the element of being the users' advocate.

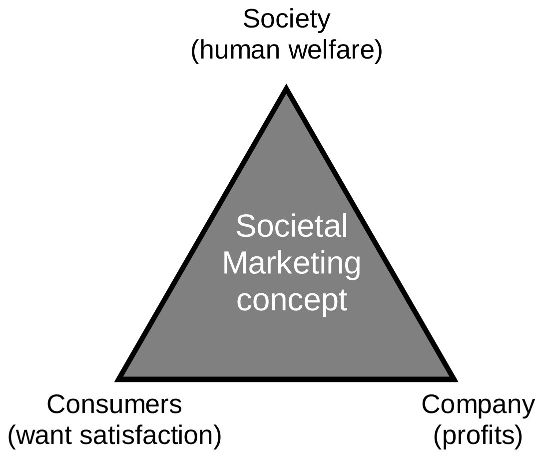


Figure 3.4. Three considerations of the Societal Marketing concept (Kotler et al., 1996).

3.2. User Characters as Supportive Method for User Consideration

Buur and Nielsen (1995) remark that design has changed considerable from the situation where a craftsman made a product for a single user to today's industry where one design addresses a large number of users; it is no longer a question of meeting the needs of *one customer whom you know*, but of *many customers whom you do not know*.

In order to design products that meet or surpass the range of future product users' needs, designers can gain from utilising methods that support the development of a good understanding of these requirements. As discussed in Section 2.5, direct interaction between product developers and users is an acknowledged approach for supporting this understanding. This is complementary to appropriate information about user aspects communicated to designers via ergonomists or marketers, since these are also important sources of information to enhance understanding and support the design task (as discussed in Section 3.1.4).

Direct interaction between designers and users is acknowledged as the preferred situation, but there might be situations where it is hard to achieve. One argument is that today's designers often work at a distance from their widely diverse communities of users (Fulton Suri, 2000b), e.g. as an effect of expanded globalisation (Ekström and Karlsson, 2001). Cost and time constraints put on the design team might not allow for time and cost consuming travel or investigation. Confidentiality can be another reason for making valid user evaluations hard to perform. Alternatively it may simply be due to unfamiliarity or a low priority attitude of the value of direct contact between designers and users among management or project team leaders or members.

Under such circumstances, and indeed as a complement to direct interaction, it is believed that a product development team can gain from applying what might be considered as 'second best' methods. One such method is *User Characters* (Buur and Nielsen, 1995; Kaulio et al., 1996; Nielsen, 2002). It may also be called *User Archetypes* (Mikkelson and Lee, 2000), *Personas* (Head, 2003; Pruitt and Grudin, 2003; Cooper, 2004) or *Fictitious Characters* (Jordan, 2000). The term *User Characters* is used in this thesis. The method is in essence based on the creation of hypothetical characters that describe potential users. These characters then represent real people throughout the design process (Cooper, 2004). The team uses these characters to animate the users in order to perceive, consider and communicate user aspects and user diversity in a richer way, as well as for triggering ideas of how the product may be designed in order to meet the array of user needs.

Employing such a method may appear substandard compared to real interaction with users, but initial studies by the author indicate that engineering design students, carrying out practical product development projects as part of a module in product development methodologies, developed a richer view of users and a better understanding of human diversity by creating and employing user characters in the design process. These experiences are in line other peoples' findings, e.g. (Buur and Nielsen, 1995; Fulton Suri, 2000a; Pruitt and Grudin, 2003). This enhanced understanding of user diversity may support the principles of inclusive design as discussed in Section 2.4.6.

Buur and Nielsen (1995) propose that the characters should be made up from a firm knowledge of real users, and described in a way that makes you feel you 'know' the person, like a character in a novel. The authors suggest the description of the characters be realistic, and that the description is partly about general issues (name, family situation, hobbies etc.) and partly about issues that are especially relevant for operating the product.

Fulton Suri and Marsh (2000) suggest that the characters are detailed with respect to personal characteristics, lifestyle, motivations and circumstances, and that they are based on real users, ideally those observed. The creation of user characters may involve ethnographic studies as discussed in Section 3.1.4 and in (Taylor et al., 2002; Pruitt and Grudin, 2003). Pruitt and Grudin believe that market research and segmentation, field studies, focus groups and interviews all can be used as information sources when creating user characters.

Buur and Nielsen (1995) encourage the generation of characters as distinct examples of users on the borderline of the user population (extremes), rather than representatives of user segments. They base this advice on the hypothesis that, if the needs of the characters are met, then the needs of users with characteristics that place them in-between are met as well. Fulton Suri and Marsh (2000) comment that these characters are usually not intended to be 'typical' of the user population, and that the set is created to personify the range of critical characteristics, e.g. young and elderly, novice and expert, owner and renter, in a similar way as extreme values normally are used for anthropometric fit rather than average values. Djajadiningrat et al. (2000) argue for making the characters extreme rather than shallow to expose character traits which, though common, may remain hidden when considered antisocial or in conflict with a person's status. The opinion of Pruitt and Grudin (2003) is that user characters do not need to be extreme or stereotyped characters; "*the team engages with them over a long enough time to absorb nuances, as we do with real people*." Greaney and Riordan (2003) comment that, while extreme characters may be more memorable, the downside is that they are less realistic.

Pruitt and Grudin (2003) report on the possibility of creating full-international or disabled characters as well as 'anti-personas' (in their terminology), i.e. user characters intended to identify people that are specifically not being designed for.

Buur and Nielsen (1995) feel that the suitable number of characters depends on the variability of the user group, but their experience is that a set of between three and seven characters seems to work well. Pruitt and Grudin (2003) report that they try to keep the set of characters down to a manageable number: three to six characters depending on the breath of product use.

Pictures and drawings are helpful in visualising and communicating the personality and features of the characters (Buur and Nielsen, 1995). Pruitt and Grudin (2003) report that when a user character description is written, they find local people to serve as models for photographs to get visual material to help illustrate and communicate each character.

As discussed in Section 3.1, a common fallacy among designers is to consider themselves as being, in many respects, an average user. Eason and Harker (1991) argue that, when designing products aimed at a wide market there is commonly no specific user population to participate in the design process and there is a danger that the ergonomics needs that are considered are based on a 'model' or 'metaphor' of the user that the designers carry, and if this is not well founded the result may not be very successful. The User Characters method has the potential to reduce the effect of these fallacies. Pruitt and Grudin (2003) believe that the greatest value of user characters is in providing a shared basis for communication, and that the act of creating user characters has helped to make assumptions about the target audience more explicit. Buur and Nielsen (1995) describe how working with average users and general types easily leads one to ignore details specific for task and environment, and that usability often lies in the detail. The experience of Buur and Nielsen (1995) of utilising user characters was that "*suddenly users' needs weren't abstract clichés or personal preferences any longer and the 'user feeling' became possible to communicate*." Nielsen (2002) recommends that users should be presented as vivid characters rather than as anonymous or unbelievable stereotypes or existing as names only, as she feels that it is important to know and be conscious of the user; "*without this it will be much harder to engage, understand and be involved with the user, especially when the user's experiences are far from ones own*." Nielsen draws parallels between writing a film script and creating user characters and scenarios for design purposes. However, one difference is that the description of user characters for design purposes must be based on knowledge of actual users, on how they perceive the world, on how they act and where they act; user characters for design are based on fact and not on fiction (Nielsen, 2002). Nielsen highlights that the user should be described in such a way that it becomes clear how and why the model-user behaves the way he or she does, and she recommends that the description considers three dimensions of a human being: the person's *physiology*, *sociology* and *psychology*.

- Physiology includes: sex, age, height and weight, colour of hair/eyes/skin, posture, appearance, defects and heredity.
- Sociology includes: class, occupation, education, home life, religion, race/nationality, place in community, political affiliations and amusements/hobbies.

- Psychology includes: sex life, ambitions, frustrations, temperament, attitude towards life, complexes, extrovert/introvert/ambivert, abilities and IQ.

These three dimensions can include present and past, and both self and relations to others (Nielsen, 2002). In addition to physiological, sociological and psychological aspects, Nielsen recommends the consideration of the person's inner needs and goals, interpersonal desires and professional ambitions and well as the user's surroundings. Nielsen feels that describing users as vivid characters brings a focus on the user into the design process, and that it helps the design team to engage with the user with empathy, thereby keeping the user in mind all the way through the design process, and remembering that the design is for a user.

User characters can be seen as parts of a transitional system, as discussed in Klein (1994), where the characters may support discussions within a product development team about user aspects that would be harder to discuss if it was about real users rather than characters. Even in cases when there has been direct interaction between project members and users, the characters can be a way to gain from, and store, real experiences and to support understanding and communication, e.g. with other project members who have not met users, and to evoke empathy for the users throughout the project. Figure 3.5 tries to describe the transitional system, portraying the fictional 'direct' contact between designers and users. Small grey arrows within the company represent common information flows, making it possible to read that designers' contact with product users commonly goes through the marketing function, indicating the possible cause for misconception when marketers communicate user information to designers.

Buur and Nielsen (1995) remark that the User Characters method serves a dual purpose in relation to design; it can be used both to innovate and evaluate designs. Pruitt and Grudin (2003) found that user characters enhanced user testing and other evaluation methods, field research, scenario generation, design exploration and solution brainstorming. Pruitt and Grudin give an example of an evaluation, using a weighted priority matrix, where each character was used to evaluate product features (the product was software in this case). They used the following scoring: -1 (the character is confused, annoyed or in some way harmed by the feature), 0 (the character doesn't care about the feature one way or the other), +1 (the feature provides some value to the character), +2 (the character loves this feature or the feature does something wonderful for the character even if they don't realise it).

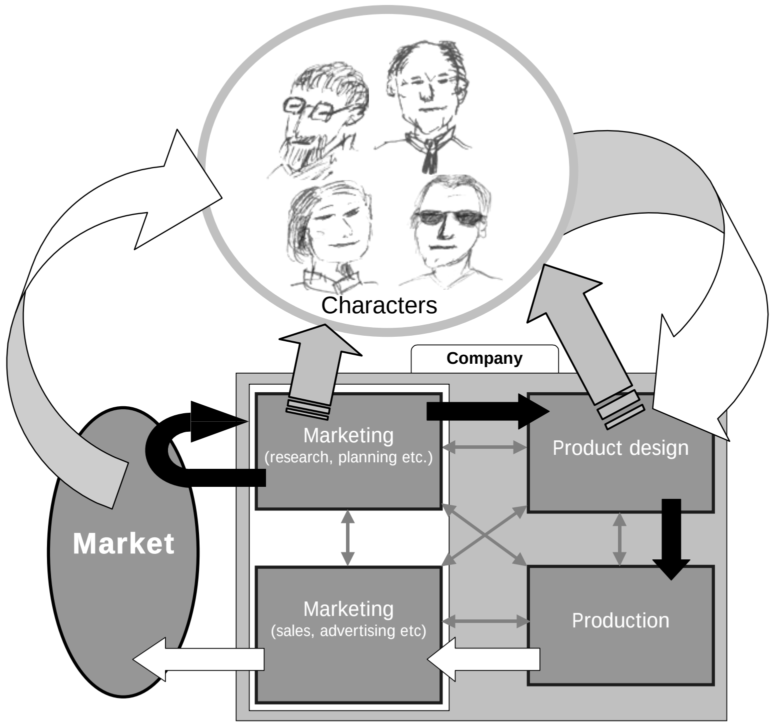


Figure 3.5. User characters as a transitional system in product development.

Although the superlatives and good examples of the employment of the User Characters method, it should not be seen as a miracle cure-all method, but rather as a complement to other user-centred methods. Pruitt and Grudin (2003) comment that the method rather should augment and enhance; *augment existing design processes* and *enhance user focus*.

Albeit reported successfully utilised today, Pruitt and Grudin share previous problems of using methods resembling the User Characters method:

1. *The characters were not believable*. Either they were obviously not based on data, or the relationship to data was not clear.
2. *The characters were not communicated well*. Often the main communication method was a resume-like document blown up to poster size and posted around hallways.
3. *There was no real understanding about how to use the characters*. In particular, there was typically nothing that spoke to all disciplines or all stages of the development cycle.
4. *The projects were often grass-roots efforts with little or no high-level support*. Typically there was shortage of people resources for creating and promoting the characters, or for making posters or other material to make the characters visible, or lack of encouragement among team leaders that the team should use the characters.

It is recommended that the characters are created and refined jointly by people from marketing and product design departments (hence the grey thick arrows from the marketing and product design departments in Figure 3.5), as well as with the involvement of ergonomists (Mikkelson and Lee, 2000). Pruitt and Grudin (2003) give an example from Microsoft where character creation teams consisted of members representing product designers, technical writers, usability engineers, product planners and market researchers. Pruitt and Grudin report that the characters are used to aid communication of information associated with market research, ethnographic studies, prototypes and usability tests to all project participants, such as designers, testers, writers, managers and marketers. The joint creation and agreement of the user characters' characteristics to be used in the design project can act as a trigger for effective communication between members of the project team or other stakeholders, leading to enhanced understanding and consensus of important aspects to accomplish by the design in order to meet different users' needs. Pruitt and Grudin (2003) report that when the user characters' documents and materials are in place, they hold a kick-off meeting to introduce the user characters to the development team.

Commonly user characters are parts of scenarios. Scenarios are stories involving specific characters, events, products and environments, which allow for exploring product ideas or issues in the context of a realistic future (Fulton Suri and Marsh, 2000). Such story telling can promote a very fruitful discussion of ergonomics issues between ergonomists and designers (Fulton Suri, 2000a). Fulton Suri and Marsh (2000) promote scenario building, involving the creation of user characters, as a method for ergonomists to enhance and better communicate their contributions to designers, as well as to raise the importance of the user at all stages of the design process. They consider scenarios as a powerful exploration, prototyping and communication tool, and that it is particularly useful at early stages of design process.

The following section describes an example of the employment of user characters in a real design project: the design of a future gearshift system for automobiles. The example is included in the thesis to demonstrate the methodology and to aid discussions about the potentials of the methodology.

3.2.1. Example of the employment of User Characters

The User Characters method was used to assist the designer in getting a notion of possible customer responses when interacting with different types of gearshift systems aimed at future automobiles. The point behind the approach was to get a view of peoples' responses without the need for exhaustive market research and user studies, which often is both time consuming and expensive. A version of this text was published in (Högberg, 2003).

3.2.2. Method

Four fabricated characters were created aimed at being representative of most types of new car buyers in Sweden (a restriction in the project). The development of the characters and scenarios was discussed with representatives from the cooperating automobile component supplier. The characters were designed to represent a range of critical user types, in accordance with the recommendations of (Buur and Nielsen, 1995; Fulton Suri and Marsh, 2000), in contrast with any attempt to represent the average user. The characters were used for discussing alternative design scenarios (vague product concepts).

3.2.3. Characters

Torbjörn is 30 years old and currently drives a BMW with a manual gearbox. He appreciates high-tech, electronic features, performance and car driving in general. Torbjörn does not care too much about fuel consumption or environmental issues. The car is an important status symbol. He may accept a new type of gearshift, but only if the car's performance is improved and gears can be shifted quicker.

Jenny is 35 years old and currently drives a Renault with a manual gearbox. She prefers not having to shift manually but she thinks cars with automatic shift are too expensive and consume too much petrol. She considers the car mainly as a means for transportation. Fuel consumption and environmental issues are important. Performance and luxury are uninteresting.

Bror is 45 years old and currently drives a Volvo with a manual gearbox. He appreciates basic cars and has the opinion that "*new cars just cause trouble*." Bror is not interested in having an automatic since that means higher fuel consumption, causes trouble and is unnecessary. His opinion is that a 'real' car is equipped with a manual gearbox and a clutch pedal. He does not care too much about performance. He has recently started to care somewhat about the environment and he thinks fuel efficiency is important but not crucial. A safe and secure car is more important than status.

Frans is 55 years old and currently drives a Mercedes with an automatic gearbox. He appreciates electronic features if they offer a feeling of comfort and luxury. Frans sometimes misses the possibility of changing gear manually, mostly for nostalgic reasons, but he appreciates not having to press the clutch pedal. He does not care too much about fuel consumption or performance and has only just started to consider environmental issues. Frans' opinion is that the right choice of car shows class.

3.2.4. Design scenarios

Six technologically based design scenarios were created for common transmission types existing today or to be expected in cars approximately by the year 2008.

Design scenario 1: Traditional manual transmission, including a clutch pedal.
Design scenario 2: Traditional automatic transmission.
Design scenario 3: Automatic transmission based on a continuously variable transmission (CVT).
Design scenario 4: Automatic transmission with the feature of manual gear shift. Technically based on a robotized manual gearbox, including an automatic clutch.
Design scenario 5: Automatic transmission with the feature of manual gear shift. Technically based on an automatic gearbox.
Design scenario 6: Automatic transmission with the feature of manual gear shift. Technically based on a robotized CVT enabling an unlimited number of gears and gear ratios.

3.2.5. Results

The likely response of each character for each design scenario is shown in Table 3.1. The table was completed without thorough investigation and is merely to be seen as a way for the designer or the project team to reason, structure and communicate thoughts and ideas. Gearshift systems expected to be appreciated by the different characters are marked with an √, whereas an (√) means that the system might be accepted but with some reservations. As can be seen, design scenario 4 is considered as the best general solution.

Table 3.1. Likely responses to design scenarios for each character: appreciation √and acceptance (√).

Characters	Design scenarios					
	1	2	3	4	5	6
Torbjörn	√			√		(√)
Jenny	√		√	√		(√)
Bror	√			(√)	(√)	(√)
Frans		√	√	√	√	√

Arguments for Table 3.1 are presented below.

Column 1. Torbjörn, Jenny and Bror accept manual gears; that is how their car works today. Frans is not interested in a manual gear system though.

Column 2. Torbjörn does not want automatic gears since it takes too much power and is boring. Jenny and Bror think that cars with automatic gears are too expensive and consume too much fuel. Frans accepts the automatic gears as that is how his car works today.

Column 3. Torbjörn does not want a car with CVT; it takes power and is boring. Jenny might consider the CVT since she appreciates not having to change gears and manoeuvre the clutch, and the CVT consumes less fuel than a car with automatic gears. Bror does not want a CVT since a 'real' car has manual gears, and he is hesitant about the CVT technology. Frans may consider the CVT if the technology is developed to the degree that it feels like a traditional automatic.

Column 4. Torbjörn appreciates the feature of manual gears, but also that the automatic can be enabled when preferred, e.g. during city driving. He also likes the system since it does not take more power than the manual gear. He is very impressed by the fact that the automatic changes gear quicker than he does. Jenny thinks it would be great to not have to shift gear herself, and that the fuel consumption will be even less than with manual gears since the automatic will change gear more optimally than she does. She will probably use the automatic most of the time and will not bother with the manual feature. However, the system must not cost too much, or else she would buy a car with ordinary transmission. Bror accepts the system but with doubts. He does not see any particular reason why he should buy a car with this system. He is afraid that the system will cause difficulty, especially in the long run. Frans accepts the system as long as it acts as a traditional automatic transmission.

Column 5. Torbjörn does not accept this system since it takes too much power. Jenny does not accept this system either due to too high fuel consumption. Bror accepts the system with doubts. But he sees no real purpose of buying a car with such a system. If he did buy a car with such a system, it would be important that the fuel consumption does not increase, compared to a manual, and that it will not cause any trouble. He considers this system as simpler and more robust that the robotized system in Scenario 4. Frans appreciates this system since it works as his car works today, but with the feature of manual gears.

Column 6. Torbjörn accepts this system with doubts and with the conditions that CVT takes less power and is more responsive at take off. He is very attracted by the feature of personal programming of the number of gears and gear ratios. Jenny thinks the system seams fine, but she sees no real benefits from the option of manual gears; she would rather buy a car with traditional CVT, like the one in Scenario 3. Bror accepts the system with doubts, and, similar to Scenario 4 and 5, he sees no major reasons for him to buy car with such a system. Frans appreciates this system on the same grounds as for Scenario 5.

3.2.6. Discussion of the User Characters method

Frequently, design engineers not only consider technically related issues when developing products, but also issues associated with user information retrieval, ergonomics, design for use etc (Janhager et al., 2002); activities typically associated with ergonomics and industrial design. This calls for methods that support design engineers in handling these kinds of 'soft' issues in the design process, even without the valuable support from ergonomists or industrial designers. Since issues of users' emotional responses to products are becoming more important in gaining customer satisfaction (Jordan, 2000), it is expected that design engineers will increasingly become involved in dealing with such issues, in addition to functionality and usability. The use of the User Characters method is believed to assist the designer(s) in considering possible user responses and user diversity, e.g. related to emotional responses, when generating and evaluating design proposals. Inherent in the approach is the risk that the designer(s) will bias the results. However, the approach is a way to assist reasoning about user responses and diversity, e.g. when time and money for more thorough studies are lacking, and to support internal communication within an organisation, e.g. between designers, ergonomists and marketers in a design project group. The developed characters can be iteratively refined by applying experiences gained from completed projects or by obtaining new user information.

Based on the findings from the literature review, the case study as well as the author's experiences from inspiring engineering students to use the method in design projects, the employment of user characters in a product development context are recognised as being useful for:

1. *Exploration of the user-product interaction*. The User Characters method supports the examination of the user-product interaction among a diversity of users, both related to mental and physical interaction, and the recognition of how this puts demand on the product's design.
2. *The involvement of user aspects in product design specifications*. It is often difficult to describe and quantify user related requirements in product design specifications in a way that develops understanding of user needs among project members. User characters ease that problem and enrich the description of such requirements.
3. *The generation of product design solutions*. The user characters act as triggers for discussions and creativity of how to meet the needs of diverse users. The likely outcome is a product design that suits more people, or at least that user diversity has been considered by the designers but deemed not possible to fully satisfy due to recognised reasons.
4. *The evaluation of product design proposals*. The User Characters method offers a structure of likely responses from different users when interacting with products in certain situations, and therefore improves the evaluation of design proposals by enriching the assessment.

3.3. Overlapping Ergonomics Evaluation in the Design Process

As discussed earlier in the thesis, ergonomics evaluation typically comes late in the design process, often not performed until physical mock-ups are produced. This may lead to expensive and cumbersome iterations, or to reductions of the final product quality due to low priority of meeting set ergonomic requirements.

This section discusses possibilities of moving ergonomics evaluation earlier in the design process by implementing planned Overlapping strategies. It also shows initial results of applying the method at an automotive company. The method is believed to be applicable both for evaluations made in a virtual environment (this will be further discussed in Chapter 4) or evaluations performed in the real world. The context is automotive design processes, but the conclusions are expected to be relevant for other products and design processes as well. A version of this text was published in (Högberg et al., 2002).

3.3.1. Design and ergonomics evaluation

As discussed in Section 3.1.4, good communication between those involved in the design process is essential for increasing the probability of ending up with a competitive product on the market. This incorporates communication within design teams but also, and often more difficult, communication between different actors and teams involved in the product development process. This is especially true in larger projects, e.g. in the design of automobiles or aircraft (Eppinger et al., 1994).

Figure 3.6 shows a general model of the core design activity (*exploration-generation-evaluation* as discussed in Section 2.3) surrounded by a 'communicative environment'. The aim with the model is in particular to highlight the *in-design-communication*, which is important for facilitating conditions for successful design, but is sometimes not obvious in design process models. With 'in-design' is meant: 'whilst the design activity is carried out', in contrast to stages before and after the design work. Broberg (1997) believes that the dialog between people involved in the design process is the most important tool in their work compared to written materials and databases. Communication can be encouraged through invitations to workshops, or by the establishment of a shared language to reduce communication barriers (Woodcock and Galer Flyte, 1998).

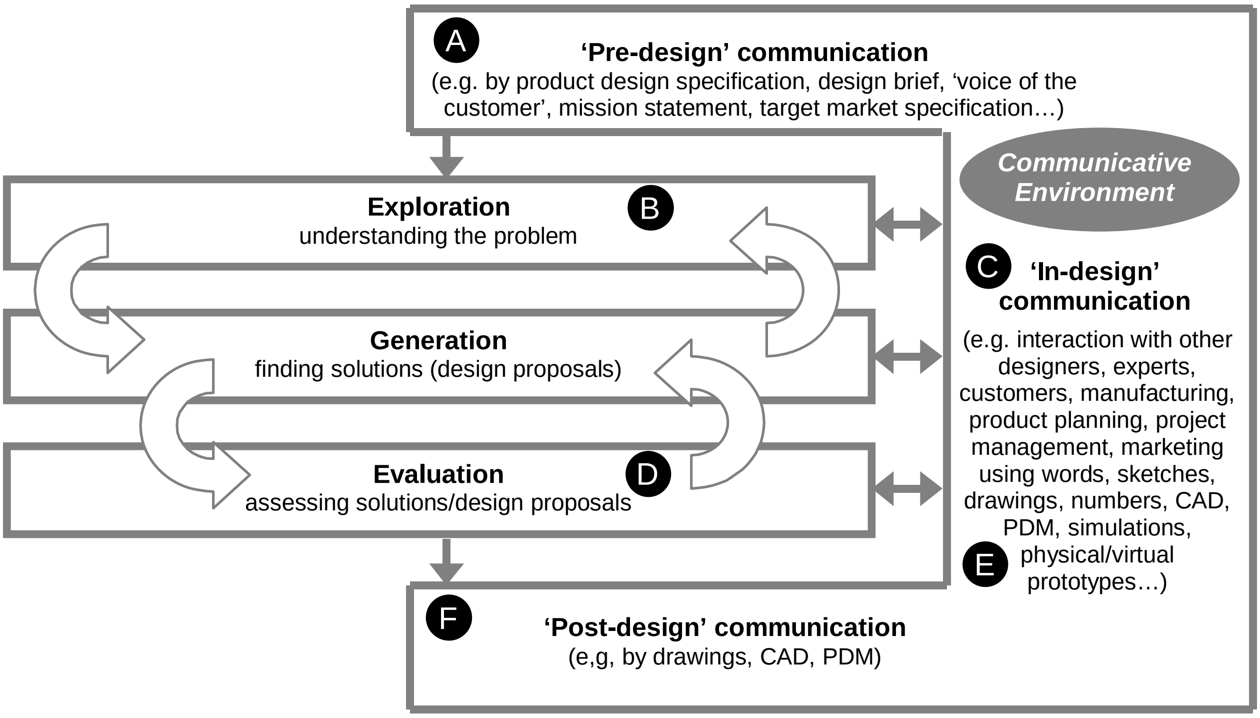


Figure 3.6. The design core activity and a 'communicative environment'.

Communication between people involved in product development can involve many roles and professions. Here the focus is on communication between designers and ergonomists, in order to identifying potential for improvements. The following typical communication patterns have been identified (also see Figure 3.6).

A Ergonomists are involved in setting ergonomic requirements for the product to be developed. Preferably these requirements are integrated into the product design specification as discussed in Section 3.1.3.

B Designers interpret the ergonomic requirements and try to find a solution (a design proposal) that balances the ergonomic requirements with other types of requirements.

C Designers and ergonomists have formal/informal contact, (e.g. direct communication via discussions and project meetings or indirect communication via CAD and PDM systems).

D Designers evaluate the design proposal, considering ergonomics amongst other issues. This would represent an evaluation in the 'small' as discussed in Section 2.3.3.

E Ergonomists evaluate the design proposal before it is frozen. This would closest represent an evaluation in the 'small' as discussed in Section 2.3.3.

F Ergonomists evaluate the design after it is frozen (or when it is about to be frozen). This would represent an evaluation in the 'big' as discussed in Section 2.3.3.

As discussed earlier, the 'in-design communication' (C) is important, also between designers and ergonomists. Haslegrave and Holmes (1994) argue that regular contacts and exchange of information between designers and ergonomists are vital; that there must be an ongoing dialogue between ergonomists and others involved in the design.

Another important element of the design activity is evaluation. Ideally this should be the straight forward process of identifying if set requirements are met or not, but in reality it is often about finding the best solution from a holistic view point, i.e. to assess design proposals in order to find the best balance between, often conflicting, requirements (such as safety, appearance, ergonomics, costs, performance and manufacturability), that build up the best totality. Here the focus is on evaluation done by ergonomists, i.e. section E and F in the list above, the centre of attention being the timing of the evaluation in the product design process.

3.3.2. Timing of evaluation

Ha and Porteus (1995) remark that if a design is evaluated too often, too much time is spent on evaluation, time that instead could be spent on other elements of the design work. However, infrequent evaluations increase the risk of design mistakes going undetected for too long (Ha and Porteus, 1995). A difficulty is to find the appropriate amount and timing of evaluations. Ideally there would be continuous ergonomics input in design projects, but, as Eason and Harker (1991) note, it is likely that there is a limited supply of qualified ergonomics staff available (which indicates the need for basic knowledge of ergonomics among designers as discussed in Section 3.1.4).

Ideally, the design would need to be evaluated only once by the ergonomics expert(s). Accepting this hypothetical view, it is interesting to discuss when the evaluation ought to be performed. Should it be done as early as possible or as late as possible? There are clearly pros and cons with both approaches. The advantages of evaluating something late in the design process, e.g. when functional prototypes of the product (e.g. a vehicle) are built, is that it is easy to assess the design properly because 'this is it'. The obvious disadvantage is that any redesign (iteration) actions would be time and cost consuming to carry out; "*if only you informed me/us earlier*" would be an understandable response from the designer(s), indicating lack of communication at earlier stages of the design process. This being the situation, there is a risk that time and cost pressure affect priorities so that the iteration is cancelled, leading to the final outcome not meeting the set ergonomic requirements. The opposite, evaluating things very early in the design process, i.e. at the conceptual or embodiment stage, means that redesign is easy and relatively inexpensive to handle (as discussed in Section 3.1.1). The drawback is that there is a risk of the assessment not being valid if the design is altered afterwards, i.e. the evaluation is performed on something that 'is probably not it'.

3.3.3. Overlapping strategies

Rapid time to market, i.e. a quick product planning and development process, is a goal for many companies in order to quickly respond to, and gain from, opened market opportunities (as discussed earlier in the thesis). One approach to enable this is to perform product development activities more concurrently, meaning that tasks are overlapped to some degree. However, not all tasks are appropriate to overlap. Krishnan et al. (1997) highlight that without careful management of task overlapping, the development effort and cost may even increase and product quality decrease. In the same article a conceptual framework is presented which supports the identification of how and when to overlap tasks by using qualitative inputs; a more sophisticated approach than the common, but often shown to be false, recommendation to simply overlap tasks as much as possible (Krishnan et al., 1997).

The Overlapping approach is employed here in an attempt to enable identification of when and how the vehicle design activity and ergonomics expert evaluation activity can be overlapped (Figure 3.7), i.e. when is the appropriate timing for the transfer of design information to the ergonomist(s)? Must the design be frozen to be worthwhile to evaluate, or can it be done or begun earlier?

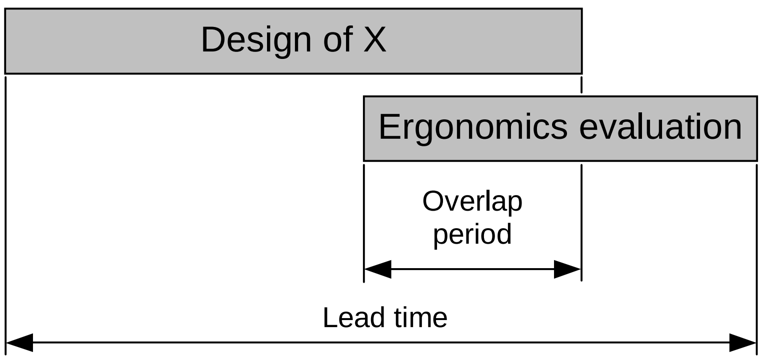


Figure 3.7. Overlapping design of X and ergonomics evaluation.

To clarify, *Design of X* stands for the design of components or sub-systems related to what is about to be evaluated, e.g. the design of parts affecting the adjustability possibilities for the driver position or the text messages presented to the driver by an in-vehicle computer system.

By being able to perform valid ergonomics evaluations earlier, the intention is to reduce total lead time and to ease iterations by giving feedback earlier in the design process, e.g. towards conceptual or embodiment stages where alterations of the design are easier and less costly to manage.

Another objective is to enable 'ticking-off' issues, as early as possible to facilitate time and focus being spent at complex cases and to reduce the likelihood of an overload situation at the end of the product design process by spreading out activities. Figure 3.8 illustrates this, where the objective is to move from curve A towards curve B.

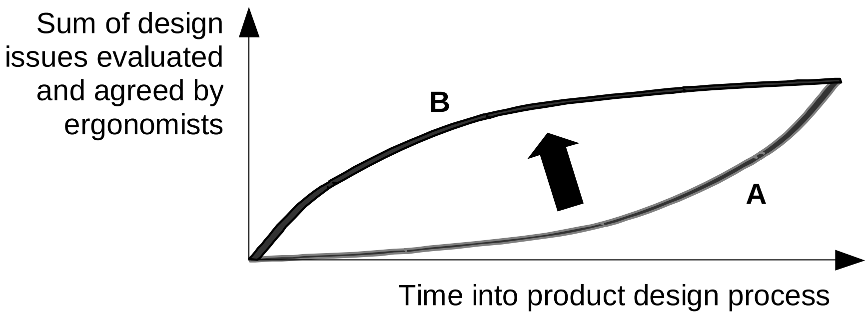


Figure 3.8. Strive towards earlier evaluations.

According to the Overlapping Framework, developed by Krishnan et al. (1997), it is possible to recognise when the evaluation can be valid or worthwhile, even though the design is still not frozen, by looking at the characteristics of the two related activities, in this case: *Design of X* and *Ergonomics evaluation of X*. This is done by looking at the extremes of upstream information evolution (*slow – fast*) as well as the extremes of downstream iteration sensitivity (*low – high*) (Figure 3.9).

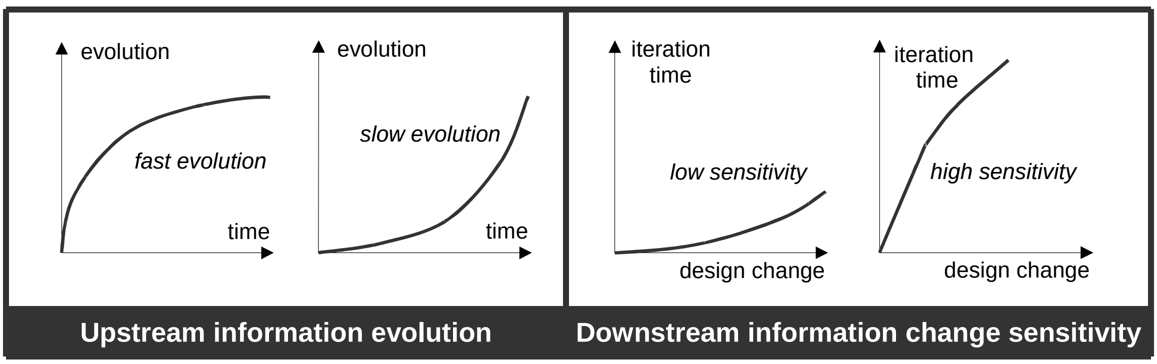


Figure 3.9. Information evolution and change sensibility (Krishnan et al., 1997).

The Overlapping Framework proposed by Krishnan et al. is general purpose, i.e. it can be applied to the evaluation of a variety of design tasks when aiming to optimise parallelism in product development processes. The Overlapping Framework has not previously been used in the context of ergonomics evaluation and the study that follows was devised to determine the suitability of the method for the application of ergonomics within the established design processes of the automobile industry.

To explain, upstream activity equates here to *Design of X* and downstream activity equates to *Ergonomics evaluation of X*. The term *evolution* relates to how quickly the designer(s) come(s) close to final results or 'good guesses' which can be considered worthwhile to evaluate from an ergonomics perspective. Thus, *fast evolution* means that the design is rather quickly developed to a stage where it may be evaluated by ergonomists. Contrary, *slow evolution* means that the design is slowly developed in the sense of ergonomics evaluation, i.e. it is hard to perform a valid ergonomics evaluation until late in the design activity. The term *sensitivity* relates to what degree later design alterations affect evaluation activities in duration, e.g. "*is it a good idea to start with preliminary results*?", "*is it a big deal if the design is changed after the evaluation; do we have to do the evaluation all over again*?" Accordingly, *low sensitivity* means that a later design alteration, i.e. a design change after the evaluation was performed, is relatively easy to manage; everything does not need to be done all over again. *High sensitivity* means that major work has to be done all over again if design changes occur.

3.3.4. Method

Based on the co-operating company's method for ergonomics evaluation, a list of 39 'issues' (or tasks), were identified, e.g. loading/unloading of luggage compartment or cruise control functionality. These 39 issues are considered to be a representative selection of tasks that are evaluated by ergonomists in a car development project. In order to associate the tasks to the Overlapping Framework, i.e. to identify the most appropriate evolution (*fast* - *slow*) and sensitivity (*low* - *high*) types, a product development professional was interviewed, as recommended by Krishnan et al. (1997). The interviewed person was a manager of the ergonomics department at the co-operating company and had many years' experience from several car development projects.

To get a notion of the possibilities of evaluating some ergonomics issues when the product only exists virtually (in computer systems), brief interviews were also conducted with two persons at the ergonomics department that use computer tools to assist some of the tasks performed in their daily activities. One person mainly works with physical ergonomics using a human simulation system (further discussed in Chapter 4) that assists visualisation and evaluation of ergonomics issues such as fit, reach, posture and visual field. The other person mainly works with cognitive ergonomics using a human-product interface simulation system, which assists visualisation and evaluation of interface logics. The same issues were used for the interview structure as for the interview considering Overlapping. The persons were asked to indicate if computer tools assisted the related 'issue' today. If not, they were asked to indicate their opinion of any potential to utilise computer tools for that task in the future. The result of this, somewhat separate, study is available in Table 3.2.

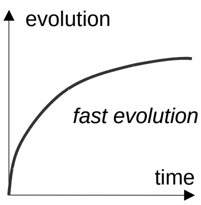
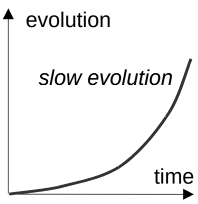
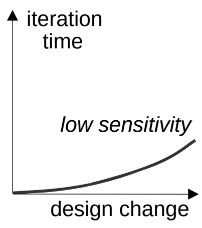
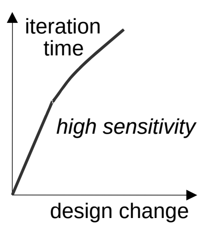
3.3.5. Results

The identification of combinations of upstream information evolution and downstream sensitivity of the 39 issues considered in this survey gave the following result.

Fast evolution – Low sensitivity	16	(41.0%)
Fast evolution – High sensitivity	6	(15.4%)
Slow evolution – Low sensitivity	4	(10.3%)
Slow evolution – High sensitivity	13	(33.3%)

Four illustrative examples of evolution and sensitivity combinations are selected to demonstrate the method (Table 3.2).

Table 3.2. Four examples of evolution and sensitivity combinations.

	Upstream Evolution		**Downstream Sensitivity**		
Issue to evaluate					**Computer tool** U=used P=potential
Driver position Adjustability	√		√		U
Comfort controls Cruise control		√		√	P
Information system Text messages		√	√		U
Luggage compartment Load/unload	√			√	P

The Overlapping Framework recommends different overlapping strategies for different combinations of evolution and sensitivity. The issue *Driver position – Adjustability* was identified by the ergonomics manager to be closest to the combination *fast evolution – low sensitivity*. This means that the design of components related to the seating and steering wheel adjustability develops quickly to a stage where it can be evaluated by ergonomists, and if any alterations of the design occur it is easily reconsidered by ergonomists without having to perform the evaluation all over again. In this case, *distributive overlapping* is the recommended overlapping type (Krishnan et al., 1997) (Figure 3.10). This means that the overlapping starts with preliminary information exchange (since the sensitivity is low) and when information gets finalised it is distributed to the downstream task. In this case, there are good conditions for effective overlapping.

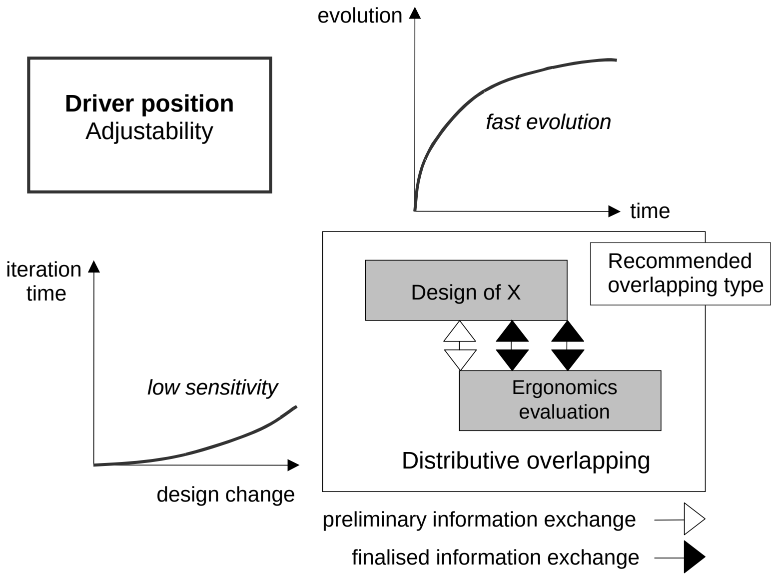


Figure 3.10. Distributive overlapping for 'Driver position - Adjustability'.

The issue *Comfort controls – Cruise control* was identified by the ergonomics manager to be closest to the combination *slow evolution – high sensitivity*. This means that the design of the cruise controls develops slowly to a stage where it can be evaluated from an ergonomics viewpoint, and that any subsequent design alterations will cause the ergonomics evaluation to be redone all over again. In this case, *divisive overlapping*, or no overlapping, is recommended (Krishnan et al., 1997) (Figure 3.11). This means that it is not a good idea to exchange preliminary information (since the sensitivity is high), hence information is exchanged when it is finalised. In this case it is hard to overlap. Either the tasks are done serially or the tasks are divided into sub-projects. It might be worthwhile to search for elements that are evolving faster and/or for elements that have a lower sensitivity.

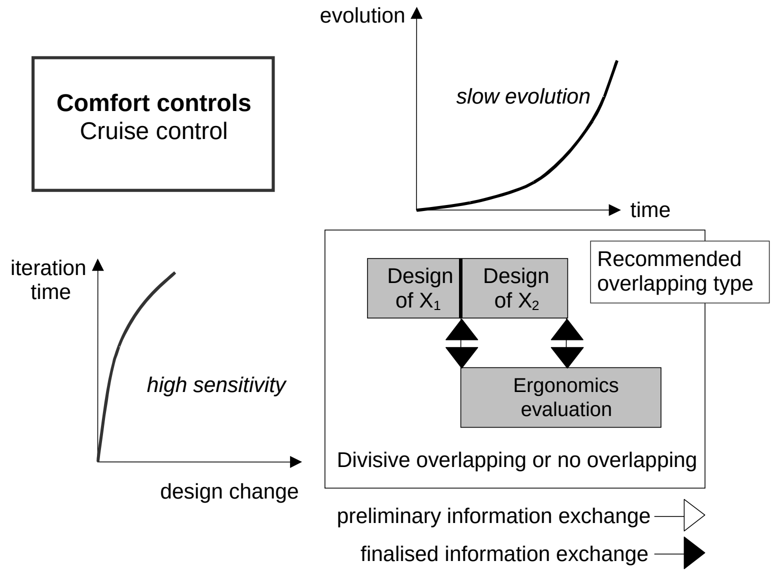


Figure 3.11. Divisive or no overlapping for 'Comfort controls - Cruise control'.

The issue *Information system – Text messages* was identified by the ergonomics manager to be closest to the combination *slow evolution – low sensitivity*. This means that the text messages used in the car's information system are developed slowly, i.e. the final version of all text messages is not available until late in the design task, but a previously evaluated design that change can be re-evaluated rather effortlessly by ergonomists. In this case, *iterative overlapping* is recommended (Krishnan et al., 1997) (Figure 3.12). This means that the overlapping starts with preliminary information exchange and when information is finalised it is exchanged to the downstream task. In this case there can be effective overlapping. Ergonomics evaluation can start by using preliminary information. If the final information is altered, little effort is required to reconsider the evaluation.

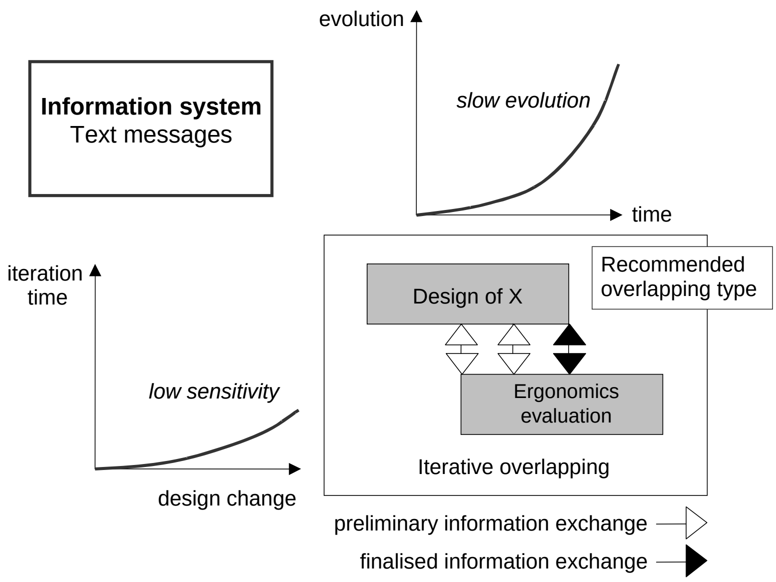


Figure 3.12. Iterative overlapping for 'Information system – Text messages'.

The issue *Luggage compartment – Load/unload* was identified by the ergonomics manager to be closest to the combination *fast evolution – high sensitivity*. This means that the design of issues related to ergonomic conditions for loading and unloading the luggage compartment develop fast, but any later design changes will cause the ergonomics evaluation to be redone thoroughly. In this case, *pre-emptive overlapping* is recommended (Krishnan et al., 1997) (Figure 3.13). This means that finalised information, or very good guesses that are most likely to be correct, is exchanged even though the design activity is not actually closed. However, exchanging preliminary information it is not recommended due to the high sensitivity.

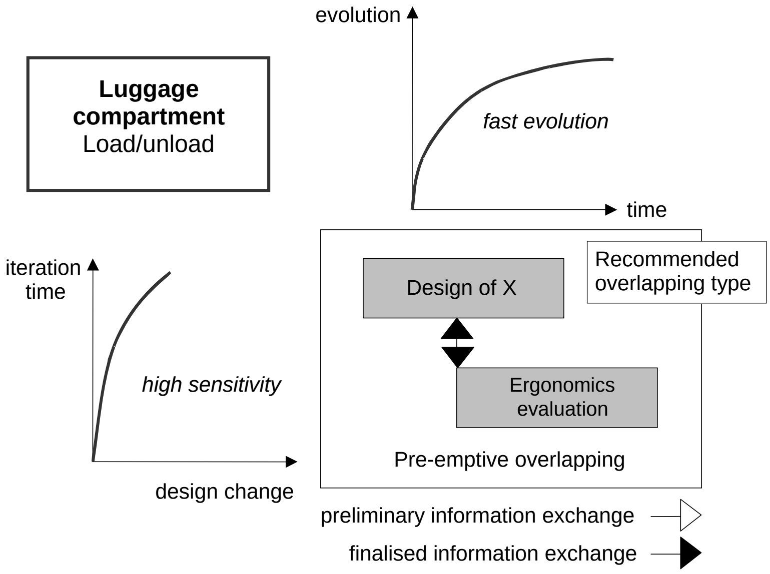


Figure 3.13. Pre-emptive overlapping for 'Luggage compartment – Load/unload'.

3.3.6. Discussion of the Overlapping method

In the process of defining the timing of evaluations, this initial study indicates that the principle of studying upstream information evolution and downstream sensitivity of related tasks looks feasible in the context of ergonomics integration. It might improve work by making iterations easier and help in managing design projects so that time it is spent on doing the 'right things', in addition to doing 'things right'. As a complement to the important ongoing dialogue between designers and ergonomists there also needs to be a defined structure of activities carried out, such as the formal approval of design proposals by ergonomists. For this the Overlapping strategies are believed to be of assistance.

However, it is arguable how correct the identification of evolution and sensitivity are when looking at extremes only. There might be small differences that influence what extreme to choose, which have large influences on recommended overlapping type. More studies need to be done of what these overlapping recommendations actually consist of in a real car development project. Additional suggested studies would be to identify characteristics of the different evolution and sensitivity types, i.e. to try to see if there are typical conditions that make evolution of information fast or slow, or sensitivity to this information high or low. Another issue would be to look into the ways in which computer tools such as human modelling systems can support the aim to move evaluations earlier in the development process (Figure 3.14). For example, to identify what kind evaluations can be done adequately in a computer model. This would be essential for cases where the car only exists as a computer model. This is further discussed in Chapter 4 and 5.

Figure 3.14. Human modelling system used in automotive design (image from SAMMIE CAD Limited).

3.4. Summary

The aim of the chapter was to investigate problems and opportunities for integrating ergonomics in product design and using this information to propose ways for improvements in this and later chapters.

Studies show that product design and ergonomics both have similarities and dissimilarities. Both areas are concerned with how to design products or environments to make them 'fit' peoples' capabilities and expectations. But whereas ergonomists typically focus on thorough evaluation of design proposals, the designer's focal point is on developing the product, often adopting a pragmatic approach to make all ends meet. The design function can be seen as the receiver of user information as well as the product realising activity, i.e. the design function enables information of users' needs and wants to be channelled into a product. One dilemma in this context is how to provide designers with both valid and usable ergonomics input. To be valid it needs to be relevant for the design problem at hand, and to be usable the input has to be simple to understand and use. Another issue is the timing of the ergonomics input, where input at early conceptual stages is particularly important. A third issue is communication difficulties between designers and ergonomists due to a lack of a common language and knowledge about each other's competences.

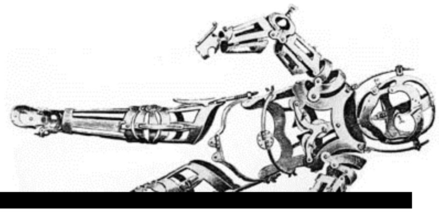
The User Characters method can gain input of and communication about user aspects and support the consideration of user diversity and the recognition of how this puts demands on the product's design. The method can also encourage discussions and ideas of how to meet the needs, e.g. support the generation of design proposals, as well as offer a structure when evaluating design alternatives.

With focus on timing of ergonomics input, the Overlapping Framework can aid the scheduling of ergonomics evaluation in product design processes, thereby supporting an integrated and teleological working manner among ergonomists and designers. It may also enhance the efficiency of the design process by making iterations easier and help in managing design projects.

The next chapter builds on previous chapters but concentrates the discussion of ergonomics integration in product design on how the usage of computer based tools can aid the consideration of ergonomics in product design processes. It also introduces human simulation tools into the discussion.

Chapter 4

Computer Aided Ergonomics



This chapter goes into the area of computer aided ergonomics. Clearly, in an ergonomics context, one can be supported by computer based tools in many ways due the wide subject area of ergonomics. Here the focus is on physical ergonomics, and anthropometrics specifically, where human simulation tools are employed to support ergonomics considerations during product design processes. Rather than trying to portray such tools in detail, or the development history of the tools, this chapter discusses the tools on a general level, and the focus lies on implications of implementing the tools in design processes, as a means for improved integration of ergonomics in design.

4.1. Ergonomics Integration in Design through CAD Tools

One of Hein's (1994) general experiences from working with industry to encourage companies to employ an integrated working manner in product development was that teamwork has a beneficial effect in product development, but only if the team members have a common approach to professional procedures and tools for product development. This indicates that there are benefits from enabling and promoting design team members to utilise common methods and tools since this supports integrated work. It is expected that this will also be valid for ergonomics integration in design and hence human simulation tools can act as a communicator of ergonomics issues in design teams.

Modern product development methods promote an integrated work manner (as discussed in Section 2.2) and this also applies to ergonomics. The next section elaborates this discussion, in the particular context of the automotive industry.

4.1.1. Pressure from modern product development

It makes sense to look at the automotive industry as an example of an industry with very complex design processes, where ergonomics is an obvious element. Car companies invest huge amounts of money in product development. Also, in many cases, they struggle to make profit in the end. Customers want better and cheaper cars, a hard equation to solve. This means that marketing, development and production activities must be performed efficiently and the money put where it is most beneficial. In development work, two things cause large costs in the design process. One is the actual product development activity itself, strongly influenced by the development time. The other major expenditure is the cost of building physical mock-ups. Hence, virtual product development is intensively used in the automotive industry to uphold profitability and competitiveness by reducing development time and cost and by promoting product quality. This means that the development activity is moved towards being performed in a virtual environment, assisted by powerful computers and software. This involves both the generation of product design solutions and the evaluation of the design. Examples of approaches are the simulation and assessment of road handling, crash safety and driver/passenger ergonomics before the car is even made in the real world. This encourages a digital design process where expensive, inflexible and time-consuming physical mock-ups are only built towards the end of the design process. As a consequence, CAD as well as other computer tools such as CAE, FEA, MBD (see Section 2.3.5) are intensively used in the automotive industry. As performance and usability of computers and software are improving, these tools will be employed even more intensively in modern product development.

4.1.2. Human simulation tools

The approach of moving the development work towards being performed in virtual environments affects ergonomics in that it incorporates the risk that ergonomics evaluation (with the use of physical mock-ups) will be put even further back. This can lead to time consuming and expensive iterations, or products that do not meet the full ergonomics specification. Thus, the ability to evaluate the design from an ergonomics point of view in a virtual product has become vital (Porter et al., 1995). Chaffin (2001) considers that an important ability in modern product development is the efficient employment of virtual tools such as human simulation tools. One way to address this problem is to enable ergonomics evaluation in a virtual product using software featuring digital humans, often called *human modelling systems* or *human simulation tools* (latter term adopted in this thesis). Examples of software appropriate in the context of this research include SAMMIE (Case et al., 1990), JACK (Badler et al., 1993) and SAFEWORK (Fortin et al., 1990). The system actually used is RAMSIS (Seidl, 1997), which was mainly developed for human accommodation in car interior design (Figure

4.1). There are many other systems available which have a different focus in terms of application area or industry. For example MADYMO can be used for simulating dynamic behaviour in relation to vibration and occupant safety analysis (Verver and van Hoof, 2002), COSYMAN for evaluating seat comfort in cars (Schmale et al., 2002) and BHMS for human simulation in the aircraft industry (Chaffin, 2001).

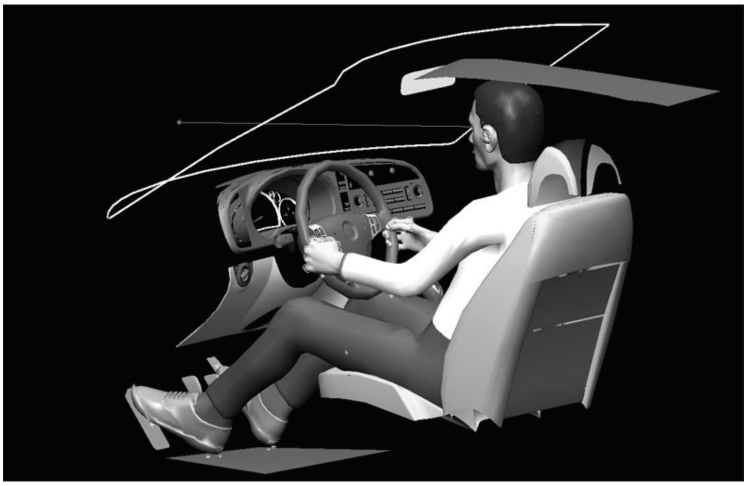


Figure 4.1. The human simulation tool RAMSIS.

The tools include a *computer manikin* (*soft-dummy, digital man model* and *human figure model* are other terms), an advanced computer model of the human body, typically with modifiable size, shape and posture. The Comité Européen de Normalisation define a computer manikin as a: *2D or 3D graphical computer representation of the human body based on anthropometric measurements, link and joint structure, and movement characteristics* (CEN/TC122WG1, 2001).

The functionality of human simulation tools differs but common features are fit, clearance and reach verification, collision detection, posture and motion prediction, reach envelope, vision (e.g. modelled as cones or as seen through the eyes of the manikin, as seen in Figure 4.2), comfort and ergonomics evaluation and biomechanical analysis such as NIOSH (Waters et al., 1993), OWAS (Karhu et al., 1977) and RULA (McAtamney and Corlett, 1993). The human simulation tools can for example be used to analyse and expose the ergonomic conditions of workstations or human-vehicle interactions.

Today's human simulation tools enable, with varying effort, CAD modelling of both the user/human as well as the product; an ergonomics-design integrating feature in itself. Porter et al. (1995) argue that the optimum solution is to provide a means of supplying the ergonomics input in a complementary fashion to the engineering input, and that the logical conclusion is to develop CAD systems with facilities to model both equipment and people.

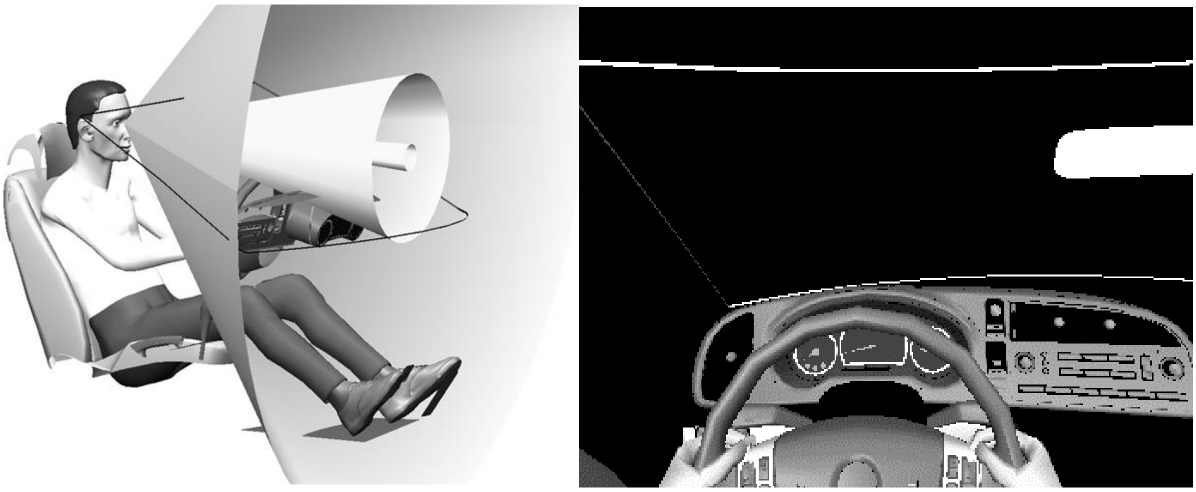


Figure 4.2. Example of evaluation functionality in human simulation tools.

Most human simulation tools offer some basic CAD modelling functionality but the limitations are likely to make anyone who is used to the functionality of modern CAD systems feel too frustrated to model the product within the human simulation system. One alternative is to import CAD geometry into the human simulation tool, through some kind of CAD geometry standard format (e.g. IGES or STEP). The drawback of that approach is the struggle in itself, the risk that not the latest geometry is used and the complexity of modifying and returning the updated geometry back to the original CAD system (if possible at all). These are all negative aspects of a common working method and employment of common tools, as prerequisites for effective integration as discussed earlier. The logical approach would be to have the human simulation tool integrated in the CAD system, in a similar way as FEA and MBD functionality is often integrated in CAD systems today. An effort in that direction is the possibility to run RAMSIS and SAFEWORK within the CAD system CATIA V5. This enables human simulation tools to become 'designers tools' as argued in Hypothesis 2.

4.1.3. Validity of ergonomics evaluation

Hasdogan (1996) concludes that one clear benefit from human simulation tools is that the tools quicken the design process by providing evaluation facilities at the drafting stage, making it a valuable tool for designers. Bowman (2001) suggests that human simulation tools provide the possibility to do quick and dirty testing, something designers and engineers requested in a study by Haslegrave and Holmes (1994).

The possibility of evaluating a product at early virtual stages is indeed beneficial, e.g. to support strong arguments for ergonomics considerations in design and to identify design defects early on. However, in many cases, evaluation of a physical prototype is unbeatable in establishing ergonomic conditions due to the complexity of influencing matters, e.g. holistic implications and user diversity; making it difficult to perform realistic simulations in virtual environments. So, evaluation validity is a concern. However, there are also concerns for the validity of an evaluation made in a physical prototype. Porter et al. (1993) argue that the greatest validity will usually be provided when real people are asked to perform real tasks with a real product for realistic durations in a real environment, but that this information is often only available, if at all, after the production and sale of the product. Eason and Harker (1991) recognise that the evaluation of how a given target group of users would respond to a product is ideally done by running real trials with real users, but add that this can be expensive, time consuming and difficult to undertake. Hence commonly, real trials are replaced with experimental evaluations with representative users in a laboratory, incorporating the risk that the artificial conditions of the experiment may not be a reliable indication of what would happen in practice. Eason and Harker highlight that another problem is that it is very difficult for prospective users to evaluate the adequacy of a product at the conceptual design stage. They can make a much more realistic assessment when they have a finished working product to examine, but, unfortunately, (as discussed in Section 3.1.1) at this stage it is likely to be too late to make major design changes if problems are revealed.

This indicates the general difficulties of performing valid ergonomics evaluations, and it shows that the employment of human simulations tools for evaluating ergonomic conditions is not the only approach where there are concerns of validity. Hence, based on considerations such as time, cost and quality, an issue is to define how and when to evaluate the ergonomic conditions of a design, e.g. what issues can be evaluated adequately in a virtual environment, and when is the evaluation of prototypes performed by user representatives better? These difficult issues are believed to be largely context dependent and hence hard to answer. An indication of what kind of issues that currently are evaluated in virtual environments in an automotive company is given in Table 3.2 (right column).

4.1.4. Means for communicating ergonomics in design

Fallon and Dillon (1988) give the following reasons for using computer based ergonomics tools to optimise the ergonomics input in the design process:

- There exists a diverse and disparate knowledge base within the ergonomics community, which needs to be organised and coded to make it easily accessible to the world at large.
- Given the general shortage of adequately qualified ergonomists, the concept of a local ergonomics expert needs to be supplemented by tools, which will enable designers to put ergonomics into the design process.
- Because of the multidisciplinary nature of the design activity, there is an increasing need to communicate at an operational level with other disciplines which make extensive use of computers.
- There is the expectation that the ergonomist's input will be better received as a consequence of using computer based tools.

Porter and Porter (1999) report from a design project where a human simulation tool (SAMMIE in this case) was successfully employed; "*it provided information for the designers in a visual form that they could relate to, it provided dimensioned data for both engineering and design purposes and was able to cross language barriers and computer systems*."

Designers require support systems to be able to consider the wide range of requirements that are typically current in product development, e.g. in order to find advantageous design compromises, as discussed earlier in the thesis. This demand increases as time pressure and product complexity increase. By offering human simulation tools as part of the designers' package of CAD tools it becomes 'their' tool and it signals the importance of integrating ergonomics, and as being a 'normal' issue to consider when designing products. This approach involves risks of misuse though, and it puts pressure on human simulation tool developers to adapt the tools to the designers' conditions. Similarly to the use of other analysis tools (such as FEA or MBD) on a general level, the designer requires basic knowledge of the functionality of human simulation tools. It is important that human simulation tool users understand fundamental characteristics of the tools' evaluation methods and the limitations of generated results (Rönnäng et al., 2002; Ziolek and Nebel, 2003).

This knowledge requirement may mean that it is not relevant for all designers to employ human simulation tools, but rather a section of designers, especially those directed towards human-product interaction issues. In spite of this, there are expected benefits beyond human simulation tools being a specialist's tool, e.g. since that approach would not gain from the advantages of integrated work.

Adapting and implementing human simulation tools to design processes can guide designers into tackling design issues in a proper way from an ergonomics viewpoint. Rouse and Boff (1998) give examples where the users of a tool (software) follow good ergonomics practice, but where the users are seldom aware that they have adopted human-centred design; they use the tool because it helps them to formulate and address critical design trade-offs. Porter et al. (1993) believe that human simulation tools can act as interactive guidelines that meet designers' and engineers' needs, and have the potential of offering more accuracy than conventional recommendations and guidelines. Bowman (2001) proposes that human simulation tools provide a means for the development of a standardised evaluation methodology.

Rouse and Boff (1998) argue the importance for the ergonomics discipline to move beyond simply compiling and archiving data and then leaving potential users to figure out how to use the data. In order for ergonomics to have an influence through design, there is a need to embed data, methods and principles of ergonomics in tools so that good ergonomics practice is intrinsic to the use of the tools. Rouse and Boff comment that it is easy for ergonomics researchers to dwell on pilots, drivers, computer users and other end users; these people are clearly the beneficiaries of ergonomics effort. However, they will not fully benefit unless designers become the agents of ergonomics best practice (Rouse and Boff, 1998). Human simulation tools have the potential to be a means to convey ergonomics best practice through design, hence making designers the 'agents', eventually to the benefit of product users, as illustrated in Figure 3.3.

As human simulation tools potentially can become 'designers tools', the tools are equally relevant for use by ergonomists, not least to support integrated work by using the same tools as the designers. Porter et al. (1995) remark that the tools are designed to supplement an ergonomist's skill, not replace them. Brennan and Fallon (1990) believe that computer aided ergonomics design tools enhance the abilities of the ergonomist and have the potential to place him or her in a more directive, as opposed to supportive, role in the design process. Simpson and Mason (1983) argue that if the ergonomist is to be involved in early stages of product development, he or she must either influence the organisation to ensure involvement in design teams, or provide carefully designed aids to those specialists already involved in the design process. While most ergonomists would choose the first alternative as preferable, it may not be the best choice from the company viewpoint (Simpson and Mason, 1983). Indeed it could be argued that the most efficient role for an ergonomist in a research and development function is to make himself or herself 'redundant' as soon as possible on each particular problem, by ensuring that his or her conclusions and recommendations are scientifically sound, practical and presented in a way which allows other specialists to implement them. This then releases the ergonomists to research the next problem (Simpson and Mason, 1983).

To support an integrated work arrangement, e.g. collaborative and decentralised work involving designers and ergonomists, human simulation tools need to be networked versions with added functionality to support group work (Rouse and Boff, 1998).

One clear advantage of human simulation tools, such as RAMSIS shown in Figure 4.1, is the visual attribute. Porter et al. (1995) state that computer graphics provide an excellent means of presenting ergonomics input to designers; the visual impact of the ergonomics specifications is far stronger and easier to grasp than numerous recommendations in a report. Porter (2000) comments that designers prefer to use visual information which is readily accessible and can be incorporated into their sketches or 3D CAD models.

4.1.5. Demands on human simulation tools to suit designers

A move towards making human simulation tools to a greater extent 'designers tools' puts pressure on the tools to adapt to the way designers work, or indeed need to work in contemporary product development. This not only applies to human simulation tools but to CAD tools in general. Ullman (2002) discusses the implications associated with the development of '*the ideal mechanical engineering design support system*' (however explicitly not incorporating design aids for ergonomics consideration in his discussion). Ullman argues that, although the evidence of CAD's ability to support the design process is evidenced by its wide use, CAD systems are weak in their ability to support many activities of the designer in product development. Design is more than making drawings; it is a complex human/computer undertaking, and, to date, the computer has only filled a very small segment of its potential (Ullman, 2002). Ullman believes that future development of CAD systems needs to be driven from the 'D' and not from the 'C' in CAD, where the 'D' stands for *design*, or even more appropriately, stands for *designer*. This will require focused studies of human designers and their interactions with mechanical design support systems.

This is a complex subject area with many dimensions. One dimension is the call for enhanced functionality in CAD systems to support designers in collaborative working. One advance in that direction is the development of a real-time collaborative 3D CAD system to enhance the usefulness of 3D CAD tools in team design projects, in both co-located and distributed situations (Nam and Wright, 2001). Another dimension is the call for CAD systems to better support designers at early conceptual stages, where it is important for the designer to be able to quickly sketch rough ideas in order to stimulate creativity and gain understanding, as well as to document and communicate ideas (Schütze et al., 2003). Commonly sketching is done on paper, as conventional CAD systems require complete, concrete and precise definitions of the geometry, which are only available at the end of the design process (Qin et al., 2003). An additional issue with CAD systems is the increased cognitive load that they impose when compared with sketching (Ullman, 2002). However, there are benefits from enabling sketching in CAD systems. One advantage is that it eases reuse of the sketches when developing the idea further in the CAD system, e.g. into 3D CAD models. Another benefit is that it facilitates the distribution of sketches and the receipt of quick feedback on the design from others involved in the development of the product, e.g. feedback via the Internet from manufacturers situated on the other side of the world (Qin et al., 2003; Lim et al., 2004).

There are many interesting dimensions of future CAD systems. However, in this thesis the discussion is directed towards the implications for computer based design support systems in the context of ergonomics.

Brennan and Fallon (1990) state that the process by which a designer arrives at a solution is not well understood, but methods used in the process include:

- A leap of the imagination (creative approach)
- Analogy with previously encountered solutions (pattern recognition)
- Following a set of rules based on experience (heuristic approach)
- Guessing (random search)
- Reducing the solution space to a finite number of possibilities and exploring each one in turn
- Transforming the design problem into a mathematical problem and obtaining a solution

Brennan and Fallon (1990) argue that computers excel in analysis and computation and may support or replace the human to some degree in some of the areas listed above. However, the human strengths are in pattern recognition and creative ability. Brennan and Fallon's view is that the human is a necessary component in the design process, and will remain so in the long term, and that creativity seams to be the hardest area to automate. Baxter (1995) believes that creativity is one of the most mysterious of human abilities, and is at the heart of design, at all stages throughout the design process.

Norman (1994) shows how the relative strengths and weaknesses of humans and machines depends on the viewpoint taken (Table 4.1).

Table 4.1. Different views of characteristics of people and machines (Norman, 1994).

The human-centred view		**The machine-centred view**	
People	***Machine*s**	***People***	***Machine*s**
Creative	Dumb	Vague	Precise
Compliant	Rigid	Disorganised	Orderly
Attentive to change	Insensitive to change	Distractible	Undistractible
Resourceful	Unimaginative	Emotional	Unemotional
Decisions are flexible because they are based upon qualitative as well as quantitative assessment, modified by the special circumstances and context	Decisions are consistent because they are based upon quantitative evaluation of numerically specified, context-free variables	Illogical	Logical

Hence it is important for design support systems to facilitate conditions for areas where human is seen as being superior to the computer (the machine) in the design process, e.g. in creativity. Ullman (2002) highlights that the ideal engineering design support system should support the management of different types of information and match the speed of the short-term memory during information development and add no cognitive burden while supporting information development. Hasdogan (1996) reports that, in the development of design methodologies, notably in CAD, it is often observed that in the early stages of design, designers need to retain in their mind the basic idea, making them impatient with any method that endangers their ability to maintain a grasp of their original concept. Ullman (2002) argues that engineers/designers spend a great percentage of their time recreating prior work or looking for prior information, and one of the greatest potentials for future design support systems is the ability to capture, archive and query the full range of design information.

4.1.6. Demands on implementing human simulation tools

As the human simulation tools' functionality and usability develop, the skills to properly implement the tool in the design process, as well as in the organisation, become central, in addition to running the tools properly. Relevant questions are for example: when is the tool to be used in the process, for what matters and by whom? Is it to become the expert's tool or the designer's tool, or perhaps both? Is a CAD trained designer with basic ergonomics knowledge less suited to using the human simulation tool than an ergonomist with basic CAD or computer simulation knowledge, or do we need 'simulation ergonomists' specially trained in running the tools, and if so, what would the advantages and disadvantages of such an approach be?

Today many companies lack an established methodology for ergonomics evaluation in a virtual environment, which easily results in the tools' advantages not being fully utilised, thus being a cause for poorer efficiency in the design process and late design modifications.

4.2. Simulation of Human-Vehicle Interaction

This case study based section focuses on the employment of human simulation tools in vehicle design in different departments at a specific car developing company. The aims of the case study were to identify which departments at the cooperating company currently use human simulation tools to simulate human-vehicle interaction, and to identify each use procedure. The rationale behind the search for this information is that it forms the foundation for later proposals for improved human simulation employment at the company. The case study was performed within the VERDI project and the author contributed to the formulation of the objectives and methods of the study, the collection of data and in writing the article based on the results from the study, as described in Section 1.4, Section 7.1 and Appendix 6.

4.2.1. Background for the case study

Throughout the vehicle development process, people in different departments use a variety of tools to represent users such as drivers, passengers and vehicle assemblers. The tools are meant to assist designers and engineers when considering different aspects of human-vehicle interaction. As discussed earlier in the thesis, traditionally, human-vehicle interactions have been evaluated relatively late in the development process by using physical mock-ups (Porter et al., 1993). Since the 1980s, the utilisation of human simulation tools has supported ergonomics evaluations in virtual environments, hence reducing the need for physical tests.

Human simulation tool developers, reviewers (Porter et al., 1993; Chaffin, 2001) and users (Bowman, 2001) claim that the tools may reduce development time and costs. However, there are some barriers to be overcome before such benefits can be realised. For example, a formal working process is needed for the proper use of human simulation tools (Ziolek and Kruithof, 2000). Green (2000) suggests a generic process for human model analysis including the following major steps:

- Understanding the task
- Understanding the work environment
- Understanding the worker population
- Understanding the limits of the software used
- Performing the analysis
- Analysing and applying judgments to the results
- Reporting the results of the analysis

As discussed in Section 4.1.4, issues related to understanding of the tools by the users needs to be considered when implementing human simulation tools. Also, the documentation of analysis results needs to be structured as a natural part of the human simulation process (Sundin, 2001). This is in accordance with Ullman's (2002) requirements of an ideal mechanical engineering design system that supports the capture, archive and query of information. Ziolek and Nebel (2003) highlight the importance of documentation in order to control misuse of the tools. Reason (1997) comments that, in order to reduce risks of human error and to store gained experiences, it is preferable to save knowledge physically, for instance in guidelines, instead of in peoples' minds.

4.2.2. Method

The survey was performed at Saab Technical Development Centre. An investigation in the company telephone book was completed to identify which departments could possibly be working with human-vehicle interaction. All identified departments were contacted and asked if they used simulation to some extent for human-vehicle analysis. They were also asked if they knew of any other department using such systems. Semi-structured interviews of about one and a half hours were conducted with eight male subjects, representing departments using human simulation tools to handle human-vehicle interaction issues. Subjects represented the following departments: *crash safety* (1), *packaging* (occupant packaging/vehicle architecture) (4), *production planning* (2), and *vehicle ergonomics* (1). Questions focused on four areas: subjects' backgrounds, tools used, information flow and working methodology for human simulation. Green's (2000) generic process for human simulation was used to structure and support the methodology discussion. All subjects were engineers (design, mechanical or civil) at master, bachelor or high school levels. They had been working at the company for one to fifteen years. Subjects received the interview protocol afterwards to enable them to complete and/or correct information.

4.2.3. Results

HUMAN SIMULATION TOOLS

The four departments indicated above use virtual human models, or parts of virtual human models, in their daily work in order to perform analysis of the interaction of drivers, passengers or assembly workers with the vehicle. These analyses include matters such as accelerations, clearance, force, penetration, posture, reach and vision. Vibration, noise and temperature are other parameters affecting human interaction with the vehicle. At the time of the case study, these parameters were analysed without virtual human models employed in the simulation. The simulation results are compared to physical and psychological limitations of the human. Those limitations are in general available within the software or in guidelines. No department uses virtual human models in order to analyse the interaction of service personnel or dismantlers with the vehicle. Several other departments, e.g. *interior* and *complete test*, analyse human-vehicle interaction but use physical tests rather than simulation tools. The *crash safety* department uses finite element (FE) software including FE models of the crash dummies used in real crash tests. The finite element approach was introduced at Saab in the middle of the 1980s. The *packaging* department uses the SAE (Society of Automotive Engineers) human model, (Roe, 1993) including eye ellipse, recommended seat position and head contour (Figure 4.3). The reach envelope is not used. SAE guidelines have been used since 1990 and the guidelines are integrated in the CAD system UNIGRAPHICS (UG), which was introduced in the middle of the 1990s, replacing CATIA. Today UG is connected to a product data management system where files are stored and organised.

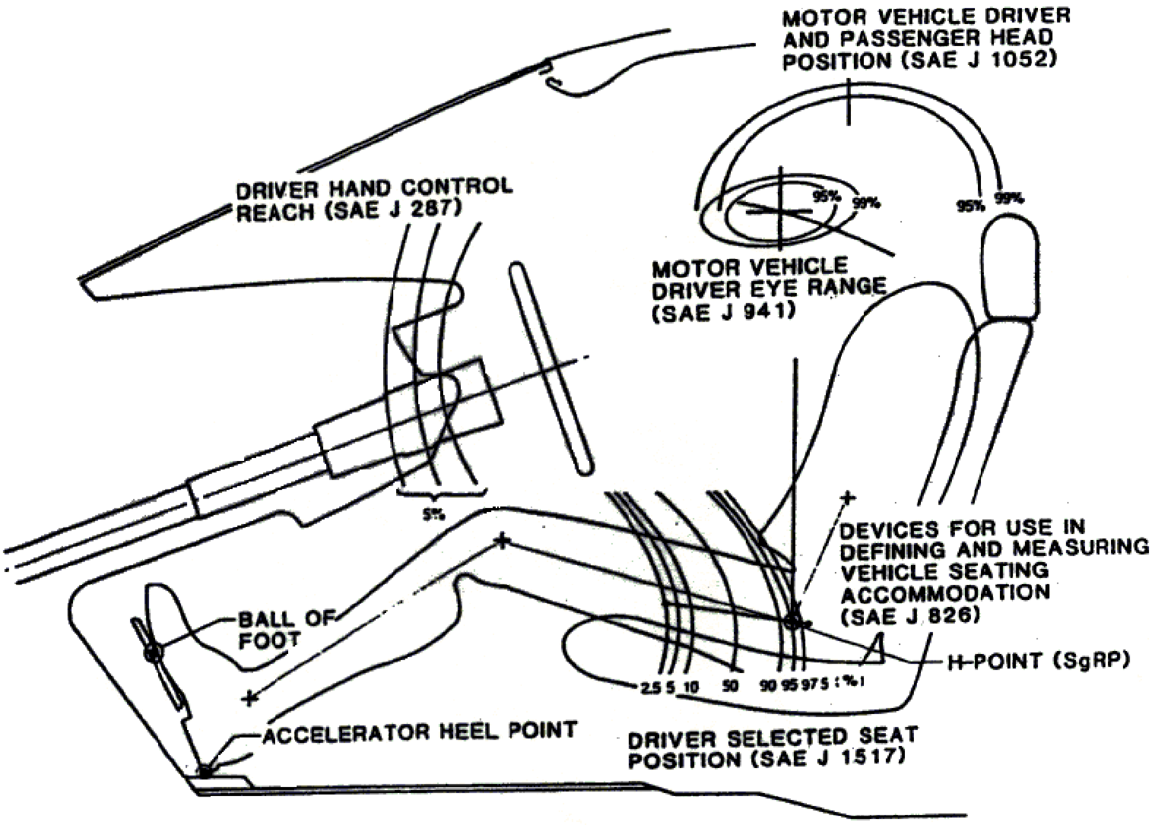


Figure 4.3. SAE accommodation design tools (Roe, 1993).

The *production planning* department uses the CAD systems UG and PRODUCT VISION to perform simulations for geometry, dimensions and product planning. PRODUCT VISION could also be used to verify, or more to visualise, simple ergonomics problems. More extensive ergonomics analyses are performed with the SAFEWORK manikin integrated in ENVISION/IGRIP. The SAFEWORK manikin replaced the previously used ENVISION/ERGO manikin. Human simulation was introduced at the beginning of the 1990s. Considerable work has gone into implementing the company specific ergonomic manufacturing guidelines inside ENVISION/IGRIP, which makes it possible to automatically perform an evaluation according to Saab's own recommendations in a virtual environment (Bäckstrand and Jonasson, 2001). The incompatibility between software used by design engineers for product design (UG) and that used by simulation engineers for production simulation (ENVISION/IGRIP), leads to extensive file converting and the risk that simulation is done using outdated files.

The *vehicle ergonomics* department has used human simulation tools since the middle of the 1990s, and from the late 1990s a standalone version of RAMSIS has been used. RAMSIS and UG exchange files via a neutral file format. The *vehicle ergonomics* department also uses the SAE human model for benchmarking.

For future development, *packaging* and *vehicle ergonomics* departments request a three-dimensional SAE manikin making it possible to visualise two legs instead of just one. They would also like to work with PRODUCT VISION, the visualisation software used by the *production planning* department. The *production planning* department requests a simulation software that is able to treat soft material and elasticity. *Vehicle ergonomics* ask for tools for simulating ingress/egress and for manikins with detailed hands, facilitating grasp simulation. Users who are working with standalone tools want easier file exchange between programs, or the tools to be integrated in the CAD environment. The *packaging* department, which uses the SAE tools within UG and therefore does not need to perform any file exchange, asks instead for more powerful computers that can load geometric models faster.

The *packaging*, *production planning* and *vehicle ergonomics* departments all believe that human simulation tools reduce development time and reduce development cost. *Production planning* is more positive compared to the other two departments. The *packaging* department restricts its interest to the possibility of performing quick and dirty tests, whereas the other departments do not. To be beneficial they all stress the importance of tools being integrated early in the design process and the ability to understand results from the tools. None of the departments think that human simulation can replace all physical tests. *Packaging*, *production planning* and *vehicle ergonomics*, all agree that human simulation tools are suitable for validation. In addition, *packaging* and *vehicle ergonomics* think that human simulation tools are useful for benchmarking human-vehicle interaction issues.

INFORMATION FLOW

Project management is the information exchange centre at the company. *Project management* distributes information and arranges connections between the main areas of economics, engineering design, industrial design and marketing. All four human simulation departments, *crash safety*, *packaging*, *production planning* and *vehicle ergonomics*, are within the engineering design area. Within engineering design, the *packaging* department is a key player. The *packaging* department has contact with *crash safety*, *production planning* and *vehicle ergonomics*, i.e. the three other human simulation tool users. No direct connections exist between *production planning* and *vehicle ergonomics* or between *crash safety* and *production planning*. In vehicle projects, human simulation tool users in *production planning* cooperate with internal physiotherapists and medical doctors working with production ergonomics. *Crash safety* cooperates with external medical doctors. *Packaging* and *vehicle ergonomics* do not discuss project-related vehicle design issues with other internal or external ergonomics experts.

The information flow between the departments is supported by the exchange of text documents and by verbal communication. The departments also exchange information using drawings and animations, where drawings are most common. Digital photos and videos are used when employing other tools or methods such as mock-ups and user tests. Animations and video techniques are mainly used by *production planning* and *crash safety*, respectively. The information exchange is today restricted to concepts and details about specific products, mainly concerning geometries. Limited information is exchanged concerning human simulation processes and tools.

Ergonomics information is available in guidelines accessible from the intranet and in printouts spread over the company. Internal training courses are held to inform designers and engineers how to design user related products and manufacturing processes. The *packaging* and *vehicle ergonomics* departments agreed that there is a lack of ergonomics guidelines and that the need for guidelines will increase in the future. The *production planning* department could not see any lack of guidelines and could only, to some extent, see an increase in the need for more guidelines in the future. All the departments thought human simulation tools could be used and seen as interactive guidelines. However, they stressed the importance of the adaptation of human simulation tools to earlier company experiences and tools.

For integration of the human simulation tool into the design process, the *packaging*, *production planning* and *vehicle ergonomics* departments highlighted the importance of relating human simulation results to key measurements used by management such as cost, stars in Euro NCAP (European New Car Assessment program, provides consumers with an independent assessment of the safety performance of cars sold in Europe) and points in J.D. Powers (J.D. Powers and Associates is a global marketing information firm that investigates customer satisfaction). They also pointed out risk as an important factor for acceptance within the company. Crash safety is considered important because of the important consequences, for instance death, if something is not correct with the design and an accident occurs. If something is not correct with the vehicle according to responsibility for the vehicle ergonomics area, it may just lead to some discomfort for the driver or passengers. Furthermore, they found vehicle ergonomics is an area where almost everybody has their own experiences to relate to and their own opinion.

Therefore, it is an easy topic to discuss and argue about. Crash, packaging and production planning issues are to a greater extent measurable, and everybody does not have their own experiences, therefore these topics are less discussed. For human simulation tool integration in the design process and acceptance within the company, the *packaging* department mentioned the importance that leaders with authority advocate the tools.

WORKING METHODOLOGY

The *crash safety* and *packaging* departments have formal descriptions of the human simulation process, whereas the *production planning* and *vehicle ergonomics* departments have no formal process descriptions. The *crash safety* department uses its process description to support new employees, and the process is regularly discussed within the department. Human simulation users in the *packaging*, *production planning* and *vehicle ergonomics* department discuss the formal or informal processes with colleagues or nearest manager sporadically. The following sections are structured according to Green's generic process for human model analysis (Green, 2000).

Formulating analysis question(s) and evaluation criteria

All human simulation tool users are trained to handle computers and have extensive knowledge of the capabilities and limitations of their tools. They discuss analysis questions with their manager or have a supervisor to consult. The tool users are engineers and have limited formal education in anatomy, physiology, psychology and ergonomics. However, one of the subjects had studied these topics for more than six months. The others had a five-week course in the engineering training program and/or in-service day courses at the company. Competence in ergonomics was normally obtained by working with more experienced colleagues and/or by consulting ergonomics experts in or outside the company. The *crash safety* and *production planning* departments are aware of their limited expertise and consult medical and ergonomics experts when difficult questions arise. The *vehicle ergonomics* department is also aware of their medical and psychological limitations but have no internal or external consultants.

Several departments perform analyses within their area of responsibility, without being assigned to do so from project management or other departments, in order to be prepared when questions arise and to generate guidelines for coming projects. Analysis is also performed on request from different projects in order to evaluate the design status in respect to the vehicle requirement specification. Essentially all car brands on the market fulfil legal requirements and therefore departments stress that it is more relevant to compare with competitors' data in order to stay competitive. They also compare with previous Saab models and the company's brand profile.

Defining users

Basic information about drivers and passengers to consider in the design of the vehicle is included in the vehicle technical specification and the assembly personnel are described in a risk and health production document. The *vehicle ergonomics* department uses a small manikin family as the user representation in analysis. The family is a combination of manikins of different statures, nationalities, genders, waist circumferences and torso/stature ratios. The *packaging* department uses the SAE human model together with its own designed arms and head. The SAE model is scaled up and down to represent humans of different statures. The *crash safety* department uses finite element models of the actual crash dummies used in real crash tests. The *production planning* department uses manikins representing 50th percentile persons and sometimes the 95th percentile, but without more extensive knowledge about what population and anthropometric variables they are referring to.

Describing tasks

No department performs any structured task analysis before simulation. All tool users in *vehicle ergonomics* and *packaging* are expected to have a picture of the driving tasks that the driver performs. Engineers in the *production planning* department have seen the tasks they simulate, but they have rarely performed them themselves. The tool users in the *crash safety* department have seen videotapes of crash dummies.

Describing physical environments

The *vehicle ergonomics* and *production planning* departments spend most of the total simulation time in preparing the environment, e.g. the car interior or the assembly station and working tools (Table 4.2). Tool users in these departments use standalone tools and spend time to import and export geometries from different systems. Crash safety also uses a stand-alone tool, but does not spend as much time as *vehicle ergonomics* and *production planning* in describing the physical environment. The *packaging* department uses the SAE human model within UG and has all information and tools within one system.

Performing the analysis

Result generation is considered to be a rather straightforward process, whereas the interpretation of the results, considering limitations of the software and input data, is a more complex task.

Judging results and making presentation material

The status of projects and contradictory results are presented and discussed at formal meetings where supervisors make compromises and agree on action plans. Colour codes are used to clearly communicate the status of different issues, i.e. approved or not approved. Commonly the results are quantified in some way. These figures are compared to what is stated in the vehicle requirement specification and with competitors' corresponding figures. Results from the tools are also illustrated with drawings, pictures and animations to support communication and arguments.

Documenting analysis

The *packaging* department saves all their SAE analyses in drawings on the computer network. The biggest difficulty is the file structure and name convention. The *vehicle ergonomics* department also saves analyses, drawings and written reports on the computer network. Written reports are numbered and accessible for all human factors engineers from a searchable index page. The reports tend to include elaborated results descriptions and recommendations. The aim and background of the analysis as well as a description of how the analysis was performed, e.g. geometries and manikins used, is covered very briefly, if mentioned at all. The report does not mention project consequences and project actions taken from the analysis. The *production planning* department has a standard routine for documentation. Simulations are saved, together with links to machine and tool libraries. Problems arise when the libraries are updated without adjusting the simulations due to changed prerequisites.

The ratings of time spent in each process step show that describing the physical environment is the most time consuming part (Table 4.2). The *crash safety* department has a relatively even distribution of time spent in each process step compared to *packaging, production planning* and *vehicle ergonomics*.

Table 4.2. Percentage of total time spent on the different steps of the generic simulation process in different departments.

	Departments			
Generic process	*Crash safety*	*Packaging*	*Production planning*	*Vehicle ergonomics*
Formulating analysis question(s)	15%	5%	5%	5%
Defining evaluation criteria(s)	10%	5%	10%	5%
Defining user and representation	15%	15%	5%	5%
Defining task	15%	5%	10%	5%
Describing environment(s)	15%	40%	45%	40%
Performing analysis and judging result	20%	20%	10%	30%
Presenting result(s)	5%	5%	10%	5%
Documenting	5%	5%	5%	5%

4.2.4. Discussion of the results of the case study

The study shows that it is mainly engineers (including design engineers) who are involved in the vehicle design process and it is engineers who handle the human simulation tools. An initial reflection from the case study is the lack of communication between tool users. Creating a forum for human simulation tool users where problems and solutions can be discussed may be useful (this is discussed further in Section 4.3.4).

The study shows methodological heterogeneity between departments working with human simulation. The heterogeneity may be due to the number of years the tools have been established in the vehicle development process. Tools such as the SAE and FE human models are well established in the vehicle development process compared to RAMSIS and SAFEWORK/IGRIP, which were introduced to the company a couple of years ago. The *crash safety* department's time distribution in the different process steps indicates a process that is working well, with large amounts of time spent in the early stages for formulating analysis questions as well as for defining the user, task and environment. The *packaging*, *product planning* and *vehicle ergonomics* departments have a more imbalanced time distribution over process steps. The major time is spent in the middle stages, i.e. describing the physical environment and performing the analysis.

The picture of the time distribution over the process stages may need to be changed in order to achieve an efficient simulation process. Today too much time is spent on physical environment description due to compatibility difficulties between software applications. Thompson (2001) and Bowman (2001) have also identified the large amount of time spent on exchanging data between systems. A future solution may be the integration of human simulation tools in the main CAD software used, i.e. working within one CAD platform using common master models and data formats.

Sundin (2001) highlights the importance of task analysis and documentation. The people in the study seemed to document their work quite well. However, the documentation is often not complete, making results hard to reuse. Improvements in describing the aim, method used and project consequences may support the reuse of previous work by making it easier to understand the results and trace prerequisites of the analysis. Furthermore, proper documentation leads to knowledge that stays within the company when employees leave.

Task analysis is rarely performed before simulation. This incorporates the risk of an inadequate process where communication with and understanding of real users is limited. This is because human tool users often have little experience of the task analysed, especially when concerned with assembly simulation.

The survey found that not all users interacting with the vehicle during its lifecycle are analysed with human simulation tools. Human simulation was mainly used for drivers, passengers and assemblers and not for servicemen and dismantlers, a result in agreement with Sundin's (2001) findings.

One suggestion for improving the simulation process is to look at advantages of introducing manikin families in order to represent targeted customer groups and assembly workers (this subject is developed in Chapter 5).

Finally, to increase the benefits from using human simulation tools, companies need to implement and adapt the tools into their design processes. However, the human simulation tools are not to be used in isolation (Porter et al., 1993), a fact that tool users are aware of when they comment that simulation can never replace all prototype testing.

4.3. Web-Based Support System for Human Simulation Process

The aim of this study was to build on the experiences from the previous case study (Section 4.2) and to give suggestions for improvements. The results from the previous study indicated four general shortcomings at the company: 1) lack of a formal process for human simulation, 2) limited human simulation tool understanding 3) insufficient documentation and 4) acceptance problems. The origin of this study was the objective of the associated company to overcome these shortcomings.

The study involves the design and evaluation of a prototype of a web-based human simulation support system for the formalisation and documentation of a human simulation process in order to improve the process quality and documentation. Besides a formalised process and a database, the complete system also consists of a human simulation tool, which itself is not developed or evaluated in this study.

This study was performed within the VERDI project and the author was involved in the formulation of the objectives and methods of the study and contributed to the writing of the article based on the results from the study, as described in Section 1.4, Section 7.1 and Appendix 6.

4.3.1. Method

A participatory approach inspired by Wilson and Haines (1997) was used to design the prototype of a human simulation support system. Three prototypes were developed and evaluated in an iterative manner (further details and discussions of methodological issues of this study are given in Section 7.1). The final prototype was individually evaluated by eleven subjects, who were divided into four groups: *industry users* (3), *industry manager and project leader* (2), *university users* (4) and *interface experts at universities* (2). The evaluations were performed as semi-structured interviews with the prototype as a stimulus. The interviews contained open questions and ratings of the usability components: *Acceptance*, *Attitude*, *Effectiveness*, *Efficiency*, *Learnability*, *Relevance*, *Understanding* and *Usage*, which were taken from Löwgren (1993) and the guidance of usability in ISO 9241-11 (ISO, 1998). The rating scales had five grades ranging from negative to positive with a middle neutral choice, and were described depending on the usability component, for example: *very difficult*, *difficult*, *neutral*, *easy* and *very easy*.

4.3.2. The final prototype

The web-based human simulation support system displays a formalised process divided into three major sections: *Background/Order*, *Method*, and *Results/Discussion*. Furthermore, the system is connected to a database that has search and print capabilities.

During the *Background/Order* stage the tool user preferably collaborates closely with the requester of the analysis. The requester can be a person without tool experience, for instance, project managers or design engineers from other departments. It can also be a person with tool experience, such as an ergonomics manager planning activities in a project, or the tool user himself or herself coming across an issue suitable for analysis with a human simulation tool. Figure 4.4 shows the Background/Order section of the prototype, which has the three headings: *Identification*, *Background and aim* and *Output*.

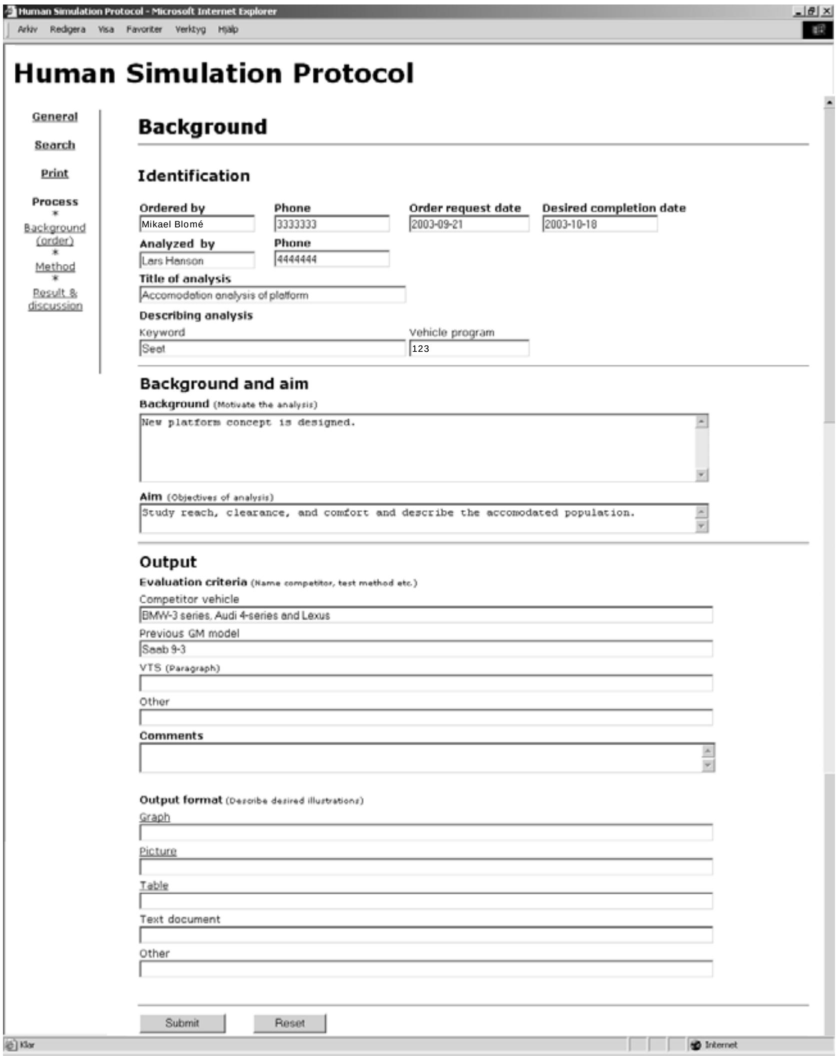


Figure 4.4. Background/Order section.

- **Identification**. The title of the analysis has to be filled in, as well as keywords, which are used when searching for information later on. Thus the keywords should represent the type of analysis and associated parts of the vehicle, e.g. accelerator. The date and analysis identification number are generated automatically when the information is submitted.
- **Background and aim**. The background provides a motivation for the analysis. The aim is formulated and agreed on in one or two sentences.
- **Output**. The evaluation criteria, such as the vehicle's technical specification (VTS, including legal and brand requirements), comparisons with previous car models or competitors' models, are entered. The preferred output format of the human simulation is also stipulated. Common output formats are graphs, pictures and text documents. Finally, the completion date is agreed upon.

Section two, *Method*, formalises the usage of the tool and includes three major steps that have to be considered (Figure 4.5 and Figure 4.6).

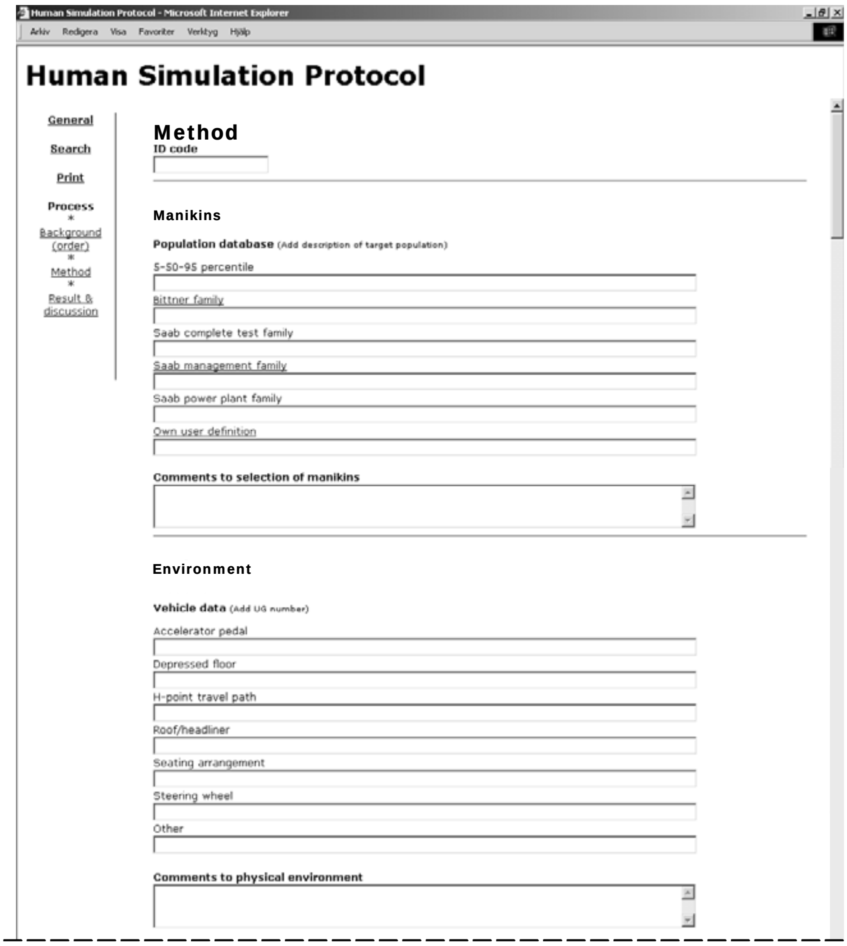


Figure 4.5. Method section (upper part).

The steps can be performed by the tool user alone, or together with the requester thereby promoting participation and understanding of the constraints used as well as the tool's limitations. The *Method* section has the three headings: *Manikins*, *Physical environment* and *Task*.

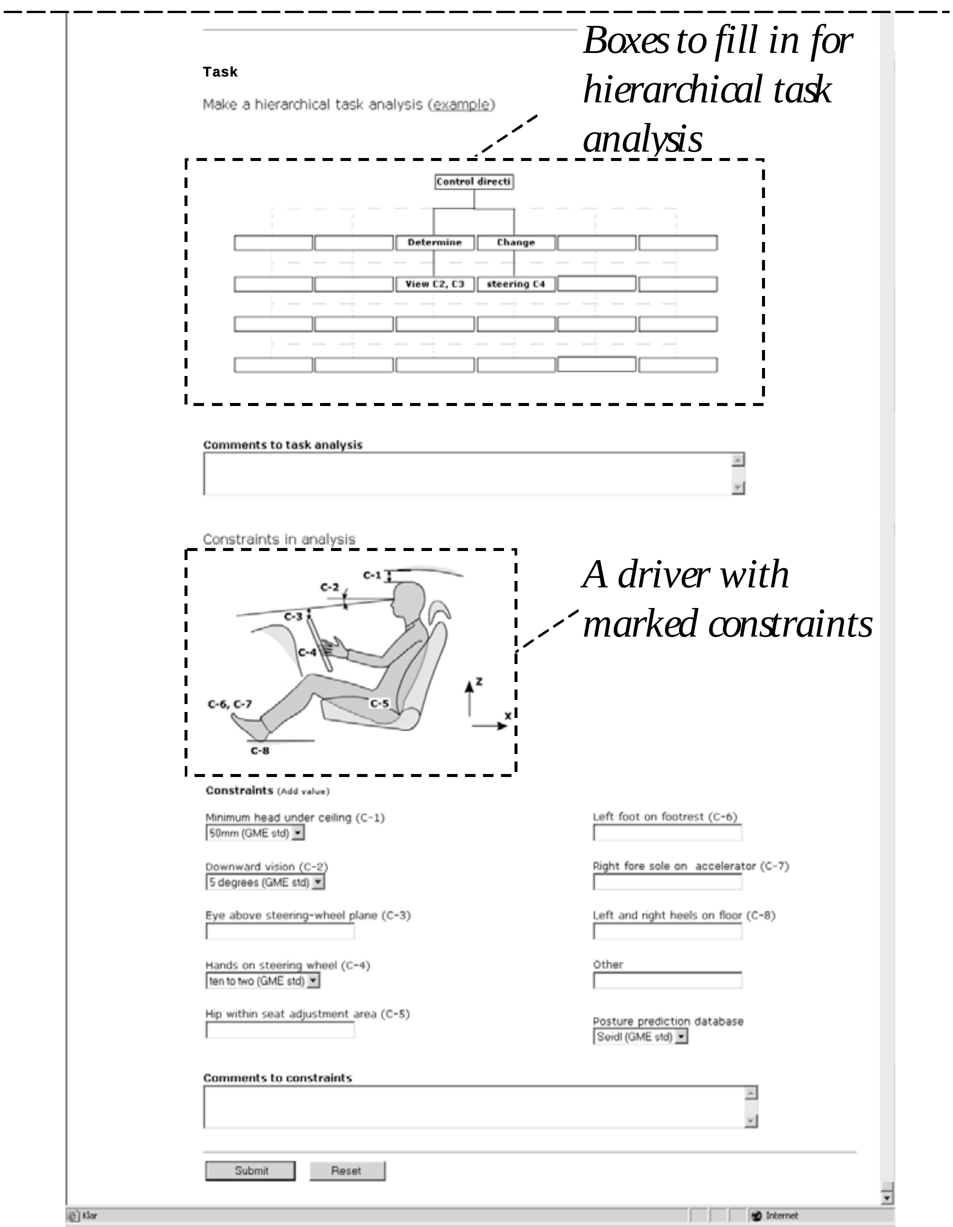


Figure 4.6. Method section (lower part).

- **Manikins**. The manikins, representing the humans who are interacting with the vehicle, are specified. Standard set-ups could be made available, e.g. *European customer family*, *power plant family* and *manager family*. The feature to specify a unique family of manikins could be added, which then would be generated in the human simulation tool by defining for example nationality, age, gender, percent of target population considered and key anthropometrical variables.

- **Physical environment**. The physical environment refers to descriptions of vehicle parts through which a human interacts with the vehicle by performing tasks. The environment is described in the detail that the analysis requires. Relevant information is entered, such as size in a clearance analysis and weight in a force/torque analysis. The numbers of the drawings used to create the simulated environment are stored. Furthermore, simplifications as well as limitations of the environment descriptions are explained.
- **Task**. The task is the action that the human will perform. Initially, the task is divided into subtasks using hierarchical task analysis in order to retrieve simple tasks that are possible to handle and simulate. Secondly, constraints for performing the task are defined. Standard constraints for different tasks are available and visualised in the process with an illustration of a driver with marked constraints (Figure 4.6). Furthermore, it is possible to provide the motivation for any constraints used and explain any deviation from standard constraints.

Upon completion of the *Method* section the analyses are performed and visualisations are generated by running the human simulation tool.

In section three, *Results and Discussion*, the results are presented and discussed, taking into consideration reflections from interested parties such as the tool user, the requester and the manager (Figure 4.7). Finally, the requester and the analyser approve the work. This section has the three headings: *Results*, *Discussion* and *Approval*.

- **Results**. In the results it is possible to attach generated animations, pictures and tables of the analysis to the documentation. It is also possible to write text with illustrations or to just describe results in text.
- **Discussion**. The interested parties select important results from the analysis to compare with the evaluation criteria decided upon in the *Background/Order* section. Comments and reflections on the analysis output are entered. Suggestions and recommendations for vehicle or workstation design and further analysis are given. The limitations of the analysis are entered, the delivery date is set and the analysis is permanently saved in a database. The requesters can automatically be notified when the analysis is available in the database. The analysis process can be cleared or preliminarily results saved whenever the user wants.
- **Approval**. The requester or manager approves, using their name and the date, to verify that the work has been done according to the order specification.

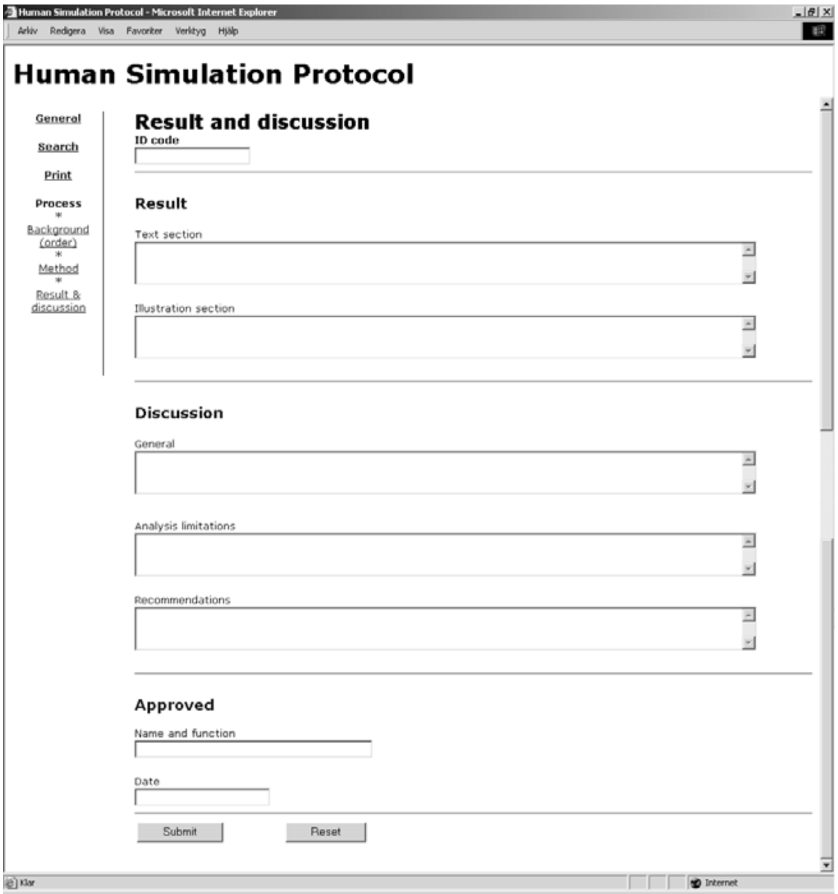


Figure 4.7. Results and Discussion section.

The information about the web-based human simulation process is stored in a database that can be searched using keywords and the number of a specific vehicle program (Figure 4.8). The search results are listed according to identification number, requester, title, analyser and vehicle program. Furthermore, it is possible to print information from the database by entering the identification number and selecting a compact or a complete report format for the desired output (Figure 4.9).

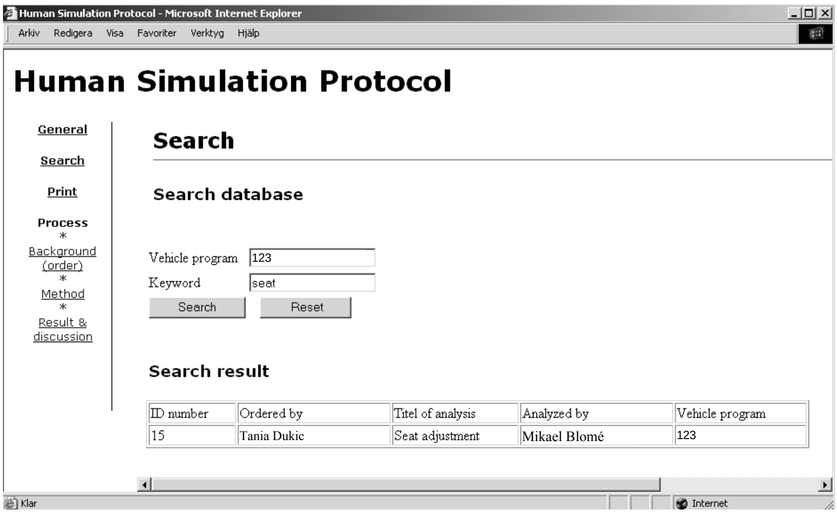


Figure 4.8. Search section.

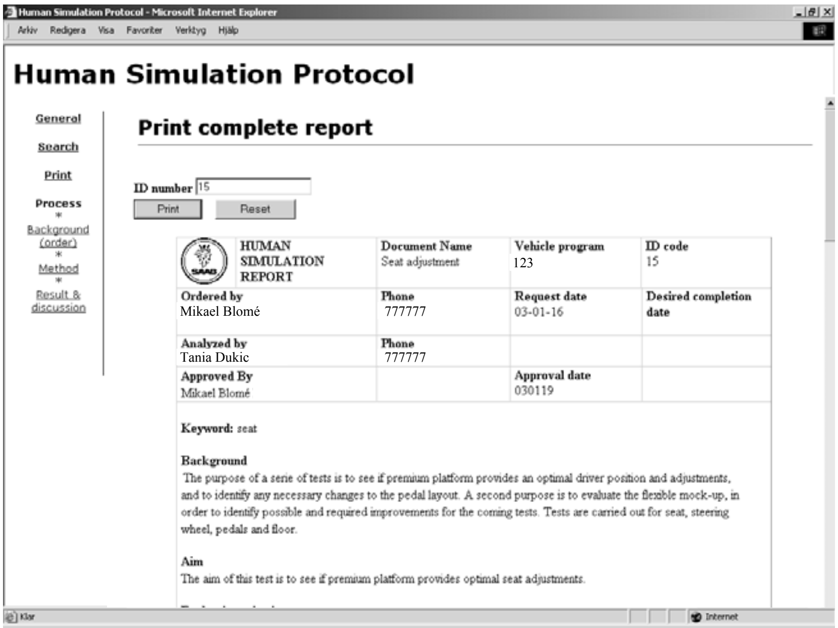


Figure 4.9. Print section.

The layout of the generated document matches the General Motors Group's standard format. The report is available in two versions: *complete* and *compact*. The complete report includes all the information available in the database. The compact report includes only aims, results and recommendations.

4.3.3. Evaluation of the prototype

Subjects representing industry and university users as well as the manager appreciated the formalisation of the human simulation process. This was indicated by the high ratings in *Acceptance*, *Attitude* and *Relevance* in Table 4.3 (the manager rated relevance at 5, while the project leader gave it a 1). A reason frequently mentioned was that the formalised process provided a structured guide for how to work with human simulation tools that decreased confusion. Some described the process as a cookbook for human simulation usage with clear steps for what to do, and used expressions like "*extensive checklist*" and "*good overview*". The interface experts particularly commented on the graphical layout and suggested changes which took into consideration cognitive design recommendations such as coding with colour and size, using empty spaces instead of lines to separate sections and excluding redundant information in headings and subsections.

Table 4.3. Ratings of the support system prototype's usability characteristics performed by four groups of subjects using a five-graded scale, 5 being the most positive. n.a.= not applicable.

Subject group	*n*	*Acceptance*	*Attitude*	*Effectiveness*	*Efficiency*	*Learnability*	*Relevance*	*Understanding*	*Usage*
Industry users	3	4.0	4.0	3.7	4.0	3.7	4.7	4.0	4.0
Manager and project leader	2	4.5	4.5	3.5	4.0	3.0	3.0	3.0	3.0
University users	4	4.0	4.3	4.3	4.0	4.3	4.7	4.0	4.0
Interface experts	2	n.a.	n.a.	n.a.	n.a.	4.0	n.a.	3.5	2.0
All	11	4.1	4.3	3.9	4.0	3.5	4.3	3.6	3.2

Most of the subjects were positive about the need to begin with a definition of the aims and background in the *Background/Order* section, thereby forcing the requester and tool user to think through the human simulation analysis together. The subjects also mentioned the importance of a clear and common goal for the analysis and hoped that the order formula and cooperation would reduce misunderstandings. The managerial representative and one industry user considered the definition of output formats to be unnecessary in this section.

The subjects were positive towards the task analysis and the user representation with manikin families in the *Method* section, and assumed that it would improve the quality of the analysis. However, according to some industry users, the task analysis should preferably be presented as a selection from a set of standard cases instead of requesting the whole task analysis scheme from scratch.

There were few comments about the *Results/Discussion* section, but the subjects were generally positive towards the use of a mixture of pictures and text. Additionally, some wanted to have a text editor to be able to comment the results as well as the capability of integrating attached graphics in the text instead of having them separated, as was the case with the system presented in this study. The most relevant feature of the web-based human simulation support system was, according to most subjects, the database. The subjects saw the likelihood that such organised information would facilitate search and reuse of results or methods from previous studies performed by themselves and other human simulation users within the company. Furthermore, the database could provide information about the progress of the human simulation work. However, a precondition among the subjects for considering the relevance, effectiveness and efficiency of the human simulation support system was that it could be used by more than one industry user and that the database would include results from the whole GM Group, or at least those simulations performed at GM Europe, i.e. at Saab and Opel.

The university and industry users, as well as the manager, agreed that a formal process like the one presented in this study would be needed in extensive analyses and in companies with several users. However, for smaller analyses and for single users they perceived the formalised process as being too lengthy and too time consuming. To increase flexibility, the subjects asked for shortcuts and a more general process that could be used for all types of ergonomics analysis. Furthermore, the subjects asked for hyperlinks, e.g. to descriptions of methods, vehicle technical specification paragraphs and geometrical drawings. The opportunity to choose a printout of either a compact or a complete report of the analysis was appreciated, but some industry users and the manager also requested a PowerPoint presentation feature to summarise the results.

4.3.4. Discussion of the results of the support system

The system developed in this study can be regarded as an interactive guideline for human simulation analyses, since it presents the methodology of using human simulation tools and guides the user through the process as well as documenting the simulation results in a database. This corresponds to the need identified by Green (2000) for a structured human simulation process and the system assists the tool user to follow an appropriate process without necessarily recognising it, as discussed by Rouse and Boff (1998).

University users tended to be more positive than industry users, and the industry users tended to be more positive than the managers. However, some of the university users had been involved in researching these kinds of issues themselves, which could explain their more positive attitude to the formalised process.

The acceptance rating of the human simulation support system is lower than the ratings for all other usability characteristics. This could be explained by the subjects' comments on rather extensive documentation, and also that some found it difficult to fill in the requested information. The use of the formalised process is likely to reduce differences in results, both within and between tool users, as well as document the employed process and deliver well-founded and consistent results.

Today, human simulation tool users tend to have a vague picture of the tasks that the driver or assembler performs (as discussed in Section 4.2). In many cases the tool users have neither performed the tasks they simulate nor seen them being performed. It is recommended that human simulation tool users should gain their own experience and understanding of the tasks they are simulating. This could be arranged by such activities as simulation engineering days at assembly plants or days for test-driving concept cars, which would prepare the tool users for theoretical task analyses. Furthermore, for effective use, understanding of a human simulation tool's capabilities and limitations are important. The system developed may not enhance tool users' understanding; therefore prior knowledge of the tool is essential. However, the use of the system may establish and increase confidence in human simulation tools within the company group and be one way of changing the negative attitudes towards ergonomics which, according to the study by Helander (1999), frequently is considered to be simply a matter of common sense.

A formal process description can also support new tool users when performing analyses and in speeding up the learning process. Competence and awareness of tool limitations may increase with a formal process, leading to a reduced number of misuses. Furthermore, with a formal process it may be possible to let non-experts, e.g. 'ordinary' designers, perform simple standard analyses, i.e. a move towards making human simulation tools become 'designers tools' (in line with Hypothesis 2), and to let the tool experts act as supervisors and/or consultants. An increase in the number of users is likely to spread awareness and knowledge about ergonomics and usability. The information documented in a database could support professionals as well as beginners and maintain the knowledge as a common resource instead of as an individual one. This is important, e.g. since the automotive industry frequently applies job rotation to promote career advancement, either inside or outside the organisation.

Today, human simulation tools are used by a few users working in isolated departments within a company, with a limited dialogue between departments. The previous case study (Section 4.2) showed that this particularly was the case between product and production development departments. However, there are great similarities between the issues analysed with human simulation tools. By bringing the people working with human simulation together in the organisation, a critical mass can be achieved; something that was also requested in the evaluation of the system. A forum could be established as a channel for sharing tools, experience and knowledge, which is likely to increase the aggregate human simulation competence in the organisation. At a higher level, this is likely to improve product quality and reduce product development time. The formal process may be a common interest that is needed to start a forum where human simulation tool users can discuss findings, problems and possibilities. The system could also facilitate exchanges of experiences and information between users within the company as well as between companies in the company group. The use of a common human simulation process and cooperation between company group members may lead to efficient cooperative human simulation work. European tool users can analyse a request sent late in the afternoon from the US and vice versa. Such a process may facilitate fast replies and reduce work peaks for human simulation tool users, thus facilitating a smooth and efficient vehicle design process.

Development and use of a database that keeps track of previous and ongoing analyses facilitates the tracing and reuse of analyses. With experienced and educated tool users and a complete human simulation system, consisting of a process, a tool and a database, it may be possible to reduce the number of physical prototypes required in the development process, something which is very attractive from time and cost perspectives, particularly in vehicle development companies.

4.4. Summary

The aim of the chapter was to analyse how computer aided ergonomics may support integration of ergonomics in design processes.

Since human simulation tools enable ergonomics evaluation of a design during virtual stages, ergonomics can be considered in a way that is similar to the way that other product requirements are assessed and it is possible to reduce the ergonomics deficiencies when the product is eventually physically realised.

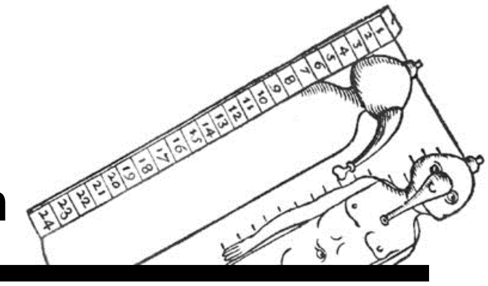
Since CAD is a widespread tool for today's designers it is sensible to see CAD as a means for supporting user aspects consideration, i.e. in making the CAD system the vehicle for ergonomics input. By aiding designers to see the entire human-product interaction, human simulation tools, ideally integrated in a CAD system, can be a common tool as well as acting as a communicator of ergonomics issues within design teams, thereby supporting integrated work. By offering human simulation tools as part of the designers' package of CAD tools it becomes 'their' tool and it signals the importance of integrating ergonomics, and as being a 'normal' issue to consider when designing products. This approach involves risks of misuse though, and it puts pressure on human simulation tool developers to adapt the tools to designers' requirements.

The developed support system for human simulation can act as an interactive guideline for human simulation analyses, both for requesting, performing and interpreting simulations. Since the system presents the methodology of using human simulation tools and guides the user through the process, as well as documenting the simulation results in a database, it becomes easier for the tool user to follow an approved process as well as take advantage of experiences of previous simulations, even though not familiar with all methodological details behind the system and the proposed process. As a result, the support system backs up Hypothesis 2 since it encourages the outlook of 'normal' designers utilising human simulation tools. By supporting communication among members in a product development team and acting as a vehicle for discussing findings, problems and possibilities about ergonomics and human simulation, the support system also backs up Hypothesis 1.

As discussed, it is important that the manikins used in human simulation represent the targeted product users. Since humans show large variations in body size and proportions, this area is not as straightforward as one may assume. The next chapter focuses on how to handle this complexity in product design by the use of manikin families in human simulation tools.

Chapter 5

User Diversity Consideration



This chapter focuses on user diversity in product design. The discussion is in many respects holistic but the concentration is on the complexity of considering anthropometric diversity in multivariate design problems, and particularly on how human simulation tools can aid designers to consider human body dimension variety in product design, using automobile interiors as an example. The view is that the employment of human simulation tools during product design should support the difficulty of anthropometric diversity and judgement of anthropometric accommodation, and hence benefit the design process by making it easier for the designer to assess who is designed in our out by a certain design.

The chapter begins with an explanation of some of the difficulties of anthropometric diversity and an appraisal of accommodation. The chapter also presents the basic ideas behind, and some of the functionality of the human simulation tool RAMSIS (Seidl, 1997). RAMSIS was utilised in this empirical research to gain knowledge and hands-on experience from using human simulation tools, as well as for performing simulation experiments. No development of the actual tool is carried out but rather development of methods for getting more valuable results from using the tool in product design. At the end of Chapter 5, ideas for expanded assessment are presented, i.e. how future human simulation tools may develop to become an even more valuable 'designers tool'.

5.1. Human anthropometric diversity

Daniels (1952) showed over 50 years ago that the tendency to think in terms of the 'average man', "*is a pitfall into which many persons blunder when attempting to apply human body size data to design problems*." Daniels concludes that it is virtually impossible to find an 'average man' due to the great variability of bodily dimensions, which is a human characteristic. Therefore the concept of the 'average man' is a illusionary concept as a basis for design criteria, and especially so when more than one dimension is considered (Daniels, 1952). In the study (which consisted of 4063 air force male personnel) Daniels showed that, even with a generous definition of average, no one in his study proved to be average when 10 dimensions were considered. Daniels defined average as the mean ± 0.3 standard deviations (SD), i.e. approximately the middle 30% of the total population in the study, called the 'approximately average' (Daniels, 1952; Annis and McConville, 1990).

Figure 5.1 shows a common way to present anthropometric data for a certain population, i.e. as normal (Gaussian) distributions (in this case of stature). The assumption that most anthropometrical variables conform quite closely to the normal distribution is empirically true (Pheasant, 1986). However, weight is usually 'positively skewed', indicating a disproportionate number of people who are heavier (Smith et al., 2000). The concept of using percentiles to define specific body dimensions is straightforward. For example, a person with a 65th percentile (p) stature will be taller than 65% of the related population, and smaller than 35% (100-p) of the same population. However, as will be developed later, when several body dimensions need to be considered simultaneously it becomes problematic to use percentiles.

Figure 5.1 also shows how the 'approximate average' was defined for each dimension in Daniel's study.

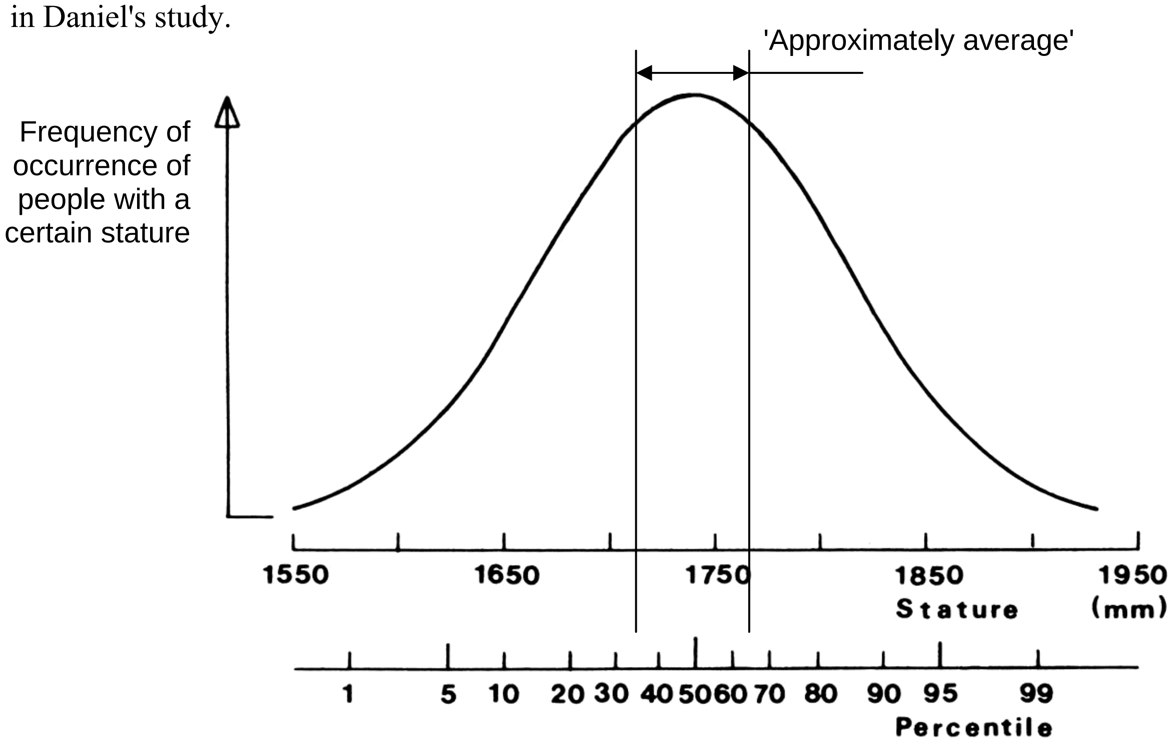


Figure 5.1. Normal distribution of anthropometric data (stature in this case) (Pheasant, 1986).

Figure 5.2 illustrates the findings of Daniels' study, i.e. that the number of individuals being 'average' reduced remarkably for each additional dimension considered. Annis and McConville (1990) duplicated Daniels' study, using up-to-date anthropometric data as well as dividing the study into men and women, revealing similar findings. The variables selected in Daniel's study were chosen as being useful for clothing, but a similar result would have been given if other dimensions had been selected, e.g. for cockpit layout or seat design (Daniels, 1952).

Even if average persons exist for the dimension(s) relevant for the design, the concept of designing for the average person has clear shortcomings. For example, designing a doorway for a person with average stature (50th percentile) would require people above that stature, i.e. about 50% of the population, to bend to avoid hitting their heads on top of the doorway (Daniels, 1952). However, for non-critical work where it is not appropriate to design for an extreme and where adjustability is not feasible, it may, after careful consideration of the situation, be acceptable to use an average value in design, e.g. when designing a checkout counter at a supermarket (Sanders and McCormick, 1993).

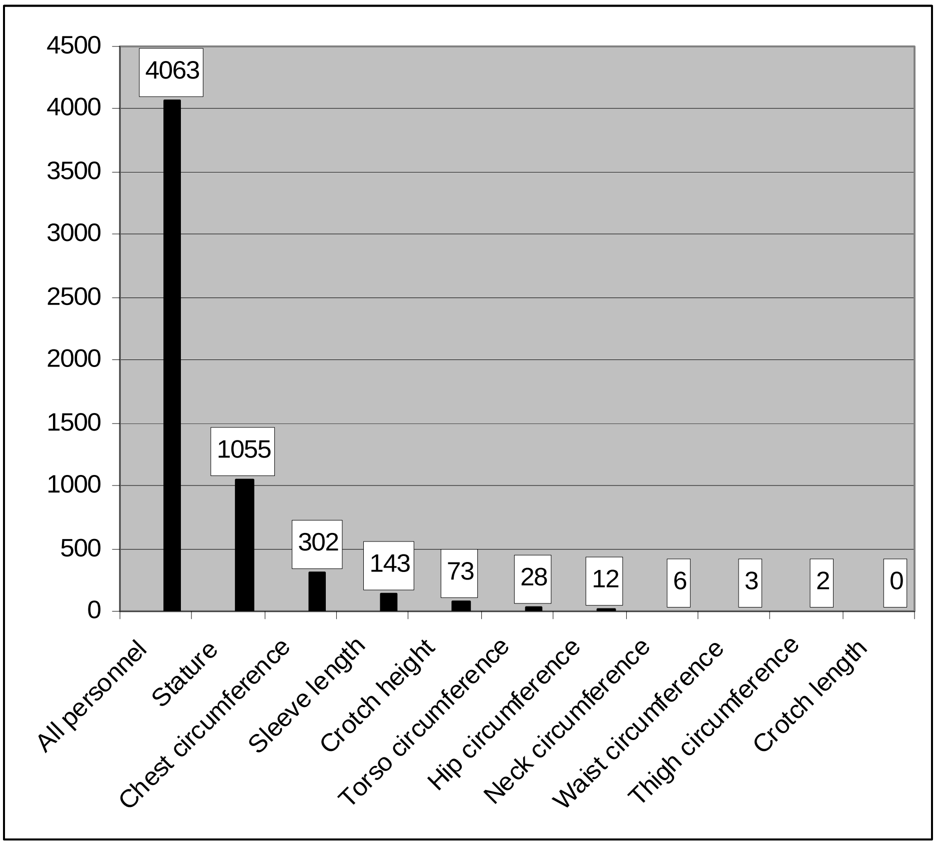


Figure 5.2. Reduction of persons considered 'average' in the study by Daniels (1952).

A similar reduction of accommodation, as in Figure 5.2, but declining less quickly, would be achieved if the 'average' range was enlarged from 30%, as in Daniels' study, e.g. up to 90%. This would represent a common situation in design, i.e. aiming to design for 90% of the population, typically from the 5th percentile to the 95th percentile. This would exclude 10% of the population, which may be relevant or required due to economic or practical reasons. However, Porter and Porter (2001) consider 90% accommodation as somewhat out-of-date given the concern for quality of life, high productivity and safety and recommend the use of the 1st percentile female to the 99th percentile male values wherever possible.

Also, when several dimensions affect the design, i.e. being a multivariate problem, the aim of accommodating 90% is often reduced considerably due to human variability. This is a major issue, since the design will accommodate a smaller proportion of the population than was the objective. More people are excluded by the design than intended, basically due to the complexity for the designer in considering human diversity in multivariate problems when designing the product. The scope for aiding this situation by supporting the designer with appropriate tools and methods will be returned to later in this chapter. This would in itself be a contribution to the concept of *inclusive design* as discussed in Section 2.4.6.

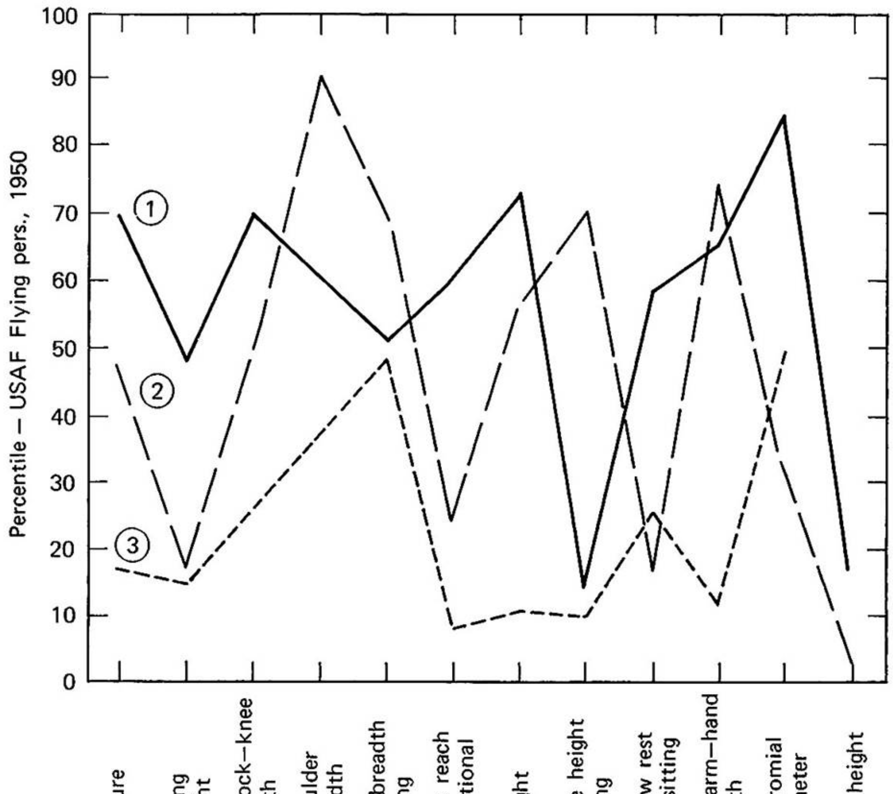


Figure 5.3. Example of three individuals' percentile values (Roebuck et al., 1975).

As no average persons (50th percentile) exist when several body dimensions are considered, there similarly exist no 5th percentile or 95th percentile persons, or no 'constant percentile man' at all for that matter (Roebuck et al., 1975). Figure 5.3 illustrates that great deviations of percentiles among individuals' body dimensions and proportions are commonplace, in this case showing how percentile values of three individuals vary (Roebuck et al., 1975).

Figure 5.4 illustrates how human diversity causes accommodation reductions in multivariate problems even though one aims to accommodate 90%, 70% and 45% respectively of the population (Roebuck et al., 1975). For each dimension considered accommodation is reduced, but less rapidly than in Daniels' study (Figure 5.2) due to the wider range of accommodation from the outset. As Figure 5.4 shows, attempting to accommodate 90% causes lower reduction in accommodation (compared with 70% and 45%), but still, after 15 dimensions considered the accommodation is down to approximately 53%. A study by Moroney and Smith (1972) showed that the original attempt to accommodate 95% (3rd percentile to 98th percentile) was reduced to approximately 67% after 13 dimensions were considered.

The gradually reduction in accommodation is caused by the fact that, for each new dimension considered, different individuals are excluded than the ones already excluded.

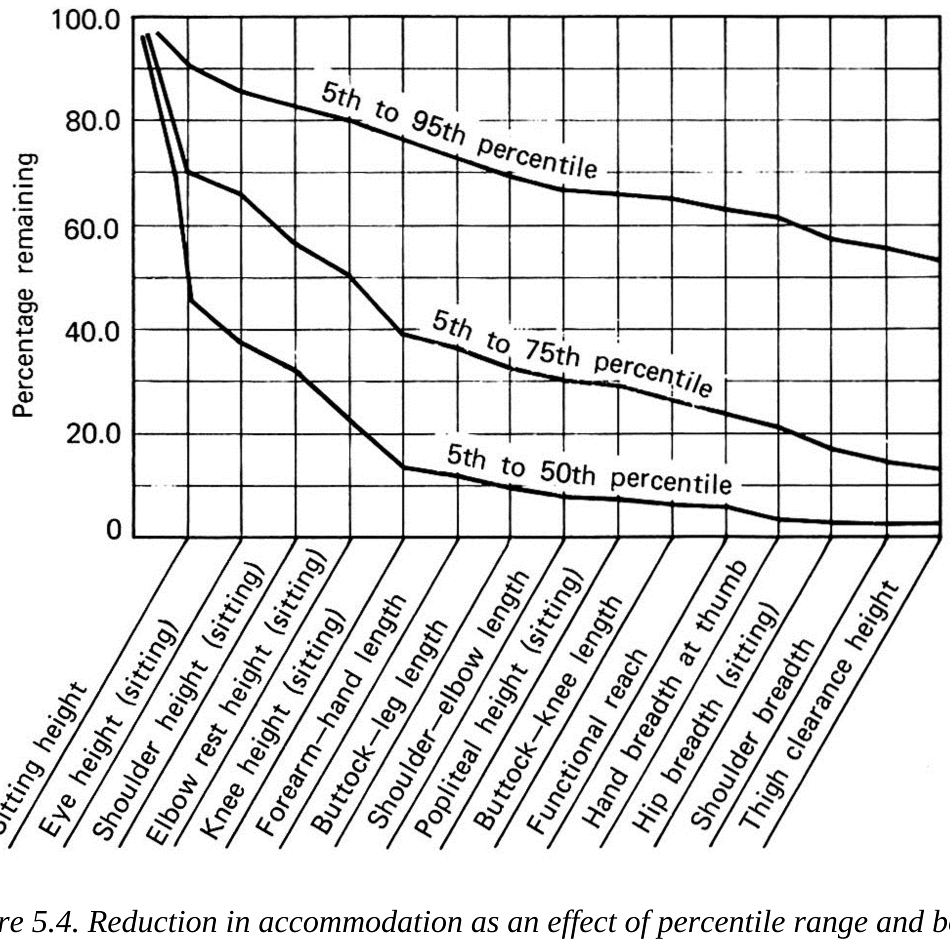
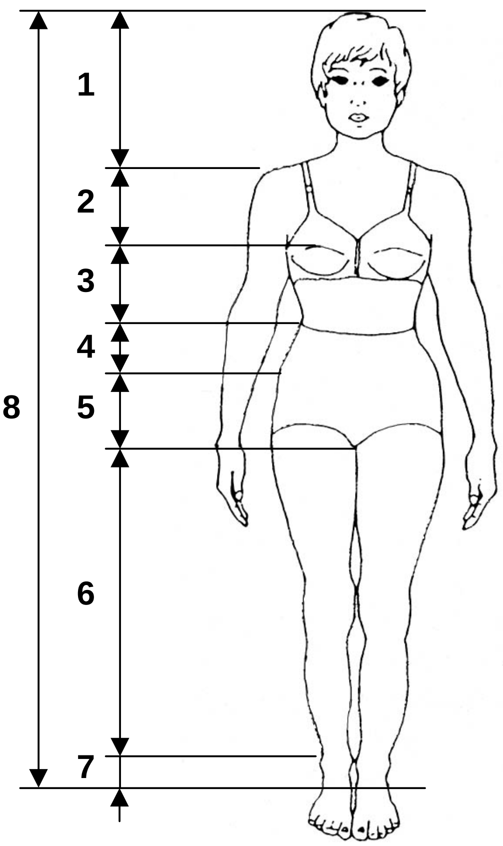


Figure 5.4. Reduction in accommodation as an effect of percentile range and body dimensions considered (Roebuck et al., 1975).

Correlations between different dimensions have a strong effect on the results in Figure 5.4; the lower the correlation coefficient the greater the reduction in percentage remaining (Roebuck et al., 1975). If the dimensions are closely related (high correlation), so that people who are big in one dimension tend to be big in the other as well (e.g. stature and eye height) the same people tend to be excluded, so that the second dimension does not add much to the total number of exclusions (PeopleSize, 2004). However, some other dimensions vary independently, for example elbow height and nose breadth, so in that case different people tend to be excluded each time, and the exclusions add up (PeopleSize, 2004).

5.1.1. Problems of using anthropometric data

As stated in Section 3.1, percentiles is an easy concept for presenting human dimension distribution for one body dimension for a certain population, but the problems arise when it is assumed that using the data is equally easy. This is particularly true in the common situation where more than one body dimension affects the design (Porter and Porter, 1998; Robinette, 1998a).



Variable	Measurement	5 %-ile	95 %-ile
1	Shoulder to vertex	270,5	327,9
2	Bust to shoulder	107,9	177,7
3	Waist to bust	134,2	217,8
4	Buttock to waist	137,8	216,7
5	Crotch to buttock	47,8	104,2
6	Ankle to crotch	578,4	710,9
7	Ankle height	92,3	132,9
	TOTAL (mm)	**1368,9**	**1888,1**
8	Stature	**1525,0**	**1730,6**

Figure 5.5. Illustration of how percentile values are not additive (Robinette and McConville, 1981).

One aspect of the difficulty of using percentile values is that they are not additive, except the 50th percentile values (Robinette and McConville, 1981; Annis and McConville, 1990). This consequence is illustrated in Figure 5.5. This phenomenon is caused by the one-dimensional and non-linear nature of percentiles, and the relationships between statistical variables not being preserved when calculating percentiles (Speyer, 1996).

Percentiles do not represent individuals but rather probability distribution data for certain body dimensions within a certain population (e.g. Sitting height, British male, 18-64 years old). According to Robinette (1998a), the source of the problem is that percentiles are univariate (one-dimensional) statistics applied to multivariate (many dimensional) situations. Robinette argues that it is common, e.g. for designers and engineers, to make assumptions about the relationships between the variables that are not true. Since many anthropometric databases present data for male and female as 5th percentile, 50th percentile and 95th percentile values, it is reasonable for a non-specialist to assume that such 'constant percentile people' exist, and that by designing from the 5th percentile female to 95th percentile male, the product would accommodate 95% of the population, due to the overlap of the two distributions (Haslegrave, 1986). This may be true for design based on one dimension, e.g. defining proper headroom in a doorway, but will not be true for multivariate problems, such as vehicle occupant accommodation or workstation design (Roebuck et al., 1975; Porter et al., 2004). Besides, the assumption that the dimension of the 95th percentile male always will be larger than the 95th percentile female will in some circumstances not be true, e.g. hip breath and chest depth (Annis and McConville, 1990; Smith et al., 2000).

The anthropometric software PeopleSize distinguishes between '*Dimension percentiles*' and '*People percentiles*' (PeopleSize, 2004). *Dimension percentiles* refer to 'common' percentiles as discussed previously, i.e. probability distribution data for one certain body dimension within a certain population. *People percentiles* indicate which *Dimension percentiles* would be required to meet the required level of accommodation. This functionality may be of great assistance for a designer. The *People percentile* is calculated using advanced (Monte Carlo) statistics, which will be further discussed in later sections. The *People percentile* function can also be used to calculate the actual accommodation based on a set of predetermined *Dimension percentiles*, similar to the case in Figure 5.4.

Annis and McConville (1990) highlight the fact that gender, race/ethnicity, age and occupation are sources of anthropometric variation, which can have significant effects on anthropometric data. They give following four examples: 1) Women can with some reliability be rendered as scaled down males for height and weight dimensions, whereas for many other dimensions, particularly those involving body tissue and dimensions of the hands, feet and head, this is not possible. For some dimensions, women are rather scaled up versions of men, such as for buttock circumference and hip breadth dimensions. 2) White people on the average have shorter legs and arms than blacks, and longer legs and arms than Asians. 3) Stature starts to decline at an accelerating rate after the age of approximately 65. 4) Certain occupations, e.g. airline stewardesses, are typically taller than average women.

Marras and Kim (1993) found significant differences in weight and abdominal dimensions between industry and the US Army populations, the latter often used as the basis for anthropometric surveys. Abeysekera and Shahnavaz (1989) found large differences in body sizes, in almost every part of the body, of people living in different countries. As an effect of this, a product designed to accommodate 90% of the British population (according to stature) would fit only 35% of Sri Lankans and 13% of Vietnamese (Abeysekera and Shahnavaz, 1989). Income also affects anthropometric data and people with high income are typically taller than people with low income (PeopleSize, 2004). Also, secular (historical) trends affect the relevance of the anthropometric data, i.e. changes in body size and rate of growth over time (Peebles and Norris, 2000). The average secular increase in height in Europe and North America is thought to be around 1 cm per decade (Peebles and Norris, 2000). More information about human diversity, related to gender differences, ethnic differences, growth and development, secular trends, social class and occupation as well as aging, is available in Pheasant (1986).

Consequently, when using anthropometric data, it is important to make sure that the data is valid for the design issue at hand, and to know for example from what population the sample was drawn, how big the sample was and how old the study is.

One method that has been used to approximate a percentile person (e.g. to construct 'small' and 'large' crash test dummies) while avoiding some of the pitfalls noted with percentiles, is regression analysis (Zehner et al., 1993). This approach begins with one or two 'key dimensions' such as *Stature* and *Weight*, and predicts values for a number of other measurements statistically. Zehner et al. highlight that, while the use of regression predictions provides additive values that can be assembled into a person, the results may not be as uniformly extreme as are usually desired when the intention is to look at the ends of the body size distributions. Furthermore, in practical applications the regression approach does not take into account the fact that humans show considerable variation in the combinations of dimensions, e.g. that there are numbers of individuals who combine short torsos with long limbs or tall heavy bodies with small heads (Zehner et al., 1993).

Bubb (2004) describes how recent body scanning technologies, enabling three dimensional descriptions of the body surface, are really new forms of anthropometric measurement and application, and that these scanning methods will gain in importance in the future. Advantages of the methods are the fast collection of entire body geometry descriptions and the compilation of measurements for individuals rather than as disintegrated body segment measurements as with the one-dimensional percentile approach.

5.1.2. Anthropometric accommodation in multivariate design

If one or two body dimensions affect the design, or in the case of a bespoke design, it is relatively easy for the designer to assess and achieve the expected accommodation level of the product. However, when the product should fit a population of users and several body dimensions affect the design, the design task becomes very complicated due to human anthropometric diversity.

Roebuck et al. (1975) state that, although body dimensions for given individuals are not simply related by common percentiles nor by simple ratios, populations as a whole do show observable tendencies for proportional relationships between some dimensions. For example, tall persons tend to have relatively long legs and long arms, while shorter persons tend to have relatively short legs and arms (Roebuck et al., 1975).

The correlation coefficient is a measure of closeness of the linear relationship between two variables, such as body dimensions, defined by a value between -1 and +1. For anthropometric data the coefficients are usually positive (i.e. large values of one variable tend to accompany large values of the other variable), and consequently the correlation coefficient is normally a number between 0 and +1 (Roebuck et al., 1975). A correlation of 0 means that if someone is big in one dimension it is not possible to predict how big they may be in the other dimension. Equally, a correlation of 1 means that everyone who is big in one dimension is proportionally big in the other dimension (PeopleSize, 2004). Haslegrave (1986) remarks that correlations between body dimensions are generally very low when the whole male or female population is considered, normally less than 0.5. In general terms, vertical body dimensions are more closely related to stature, while horizontal body dimensions are more closely related to weight, there is however very little correlation between a person's weight and stature; 0.44 for men and 0.29 for women (Haslegrave, 1986).

Table 5.1 shows examples of correlation coefficients between six variables (body segments) from a study of 1774 males (Hudson et al., 1998).

Table 5.1. Example of correlation coefficients (Hudson et al., 1998).

	Shoulder height	**Butt-knee length**	**Eye height**	**Knee height**	**Sitting height**	**Thumb tip reach**
Shoulder height	**1.00**	0.34	0.86	0.41	0.87	0.34
Butt-knee length	0.34	**1.00**	0.34	0.84	0.35	0.79
Eye height	0.86	0.34	**1.00**	0.42	0.98	0.36
Knee height	0.41	0.84	0.42	**1.00**	0.43	0.84
Sitting height	0.87	0.35	0.98	0.43	**1.00**	0.36
Thumb tip reach	0.34	0.79	0.36	0.84	0.36	**1.00**

A scatter diagram is a way to graphically illustrate relations between two dimensions (i.e. bivariate distribution). Figure 5.6 illustrates scatter diagrams for correlation coefficients (r) of 0.00, 0.75 and 1.00 respectively.

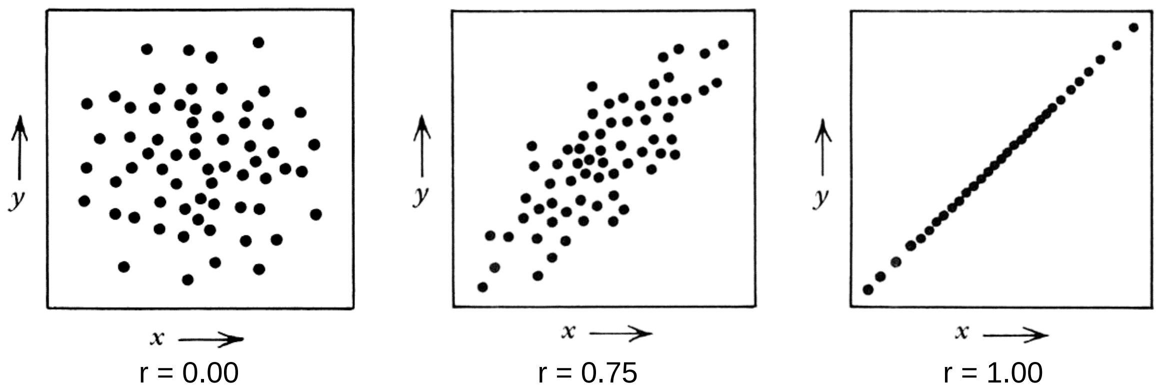


Figure 5.6. Bivariate scatter diagrams for three correlation coefficients (r). (Roebuck et al., 1975).

Roebuck et al. (1975) highlight two advantages of scatter diagrams. Firstly, they enable quick observation of whether the bivariate distribution gives promise of some possible adjustment mode that can fit more persons for minimum expense or space requirement. Secondly, the diagrams provide a relatively simple method of determining approximately how many or what percentage of the individuals in the population are likely to fit within given limits of clearance or adjustments, merely by counting the number of subjects within defined regions and dividing by the total number (Roebuck et al., 1975).

Figure 5.7 (Zehner et al., 1993) shows a scatter diagram over a bivariate distribution, in this case the distribution of *Stature* and *Weight*. Each individual (pilots in this example) is plotted at the point where his or her stature and weight intersect. Using the mean value for both *Stature* and *Weight* as a starting point (X), an ellipse can be imposed on the plot which includes any desired percentage of the population (Zehner et al., 1993).

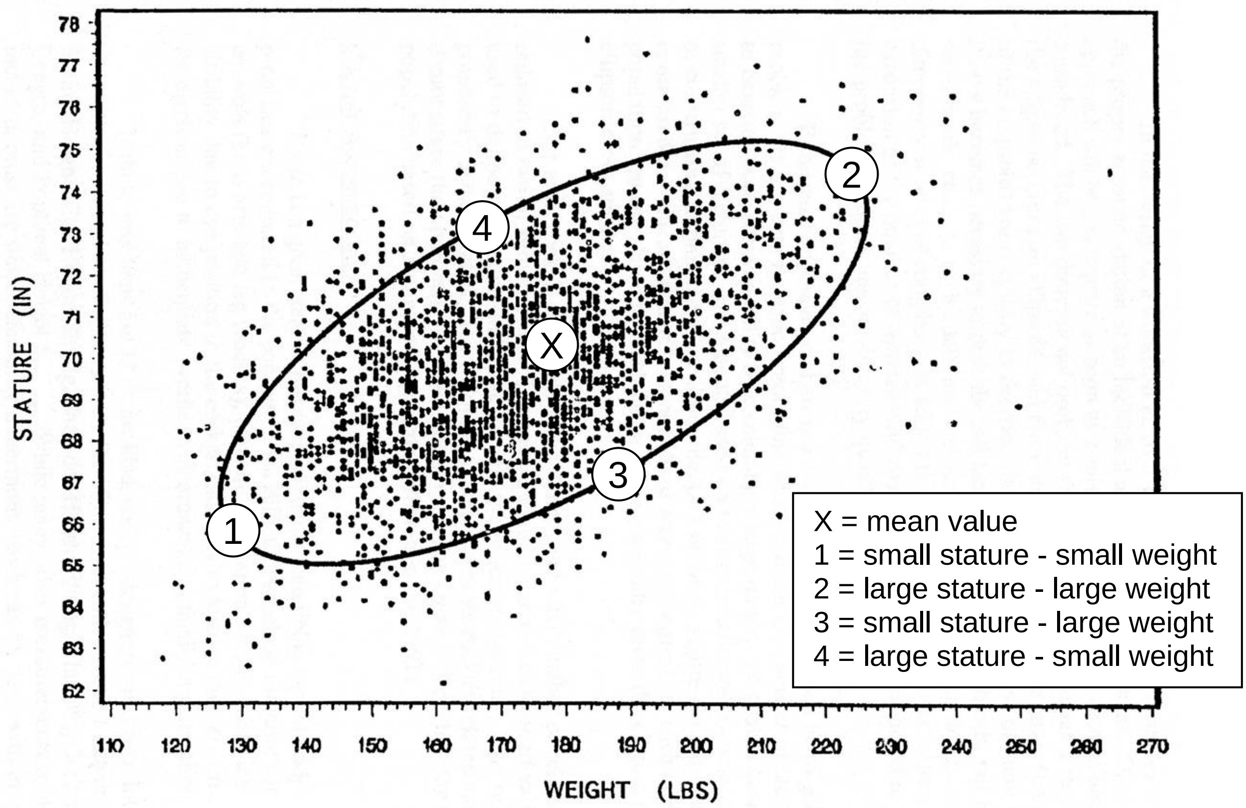


Figure 5.7. Stature/Weight bivariate scatter diagram, 90% accommodation model (Zehner et al., 1993).

The ellipse in Figure 5.7 includes approximately 90% of the dots, hence representing about 90% accommodation if these where considered in the design. The ellipse passes near point (1) and (2), which represent individuals who are small or large for both values. However, since selecting only the individuals who are small or large in both dimensions does not describe all the body dimension variability that must be considered in a design, the ellipse also intersects those points representing a short-heavy person (3) and a tall-thin person (4) who are just as likely to occur in the population as any other individual along the boundary of the ellipse (Zehner et al., 1993). The rationale is that several points (representing several individuals) spread along the edge of an ellipse, which may be called *representative cases*, better represent the variety of extreme body types to be accommodated, than does the use of only two points in the distribution (Zehner et al., 1993).

When designing complex products such as car interiors, that are to accommodate drivers and passengers of a variety of sizes and shapes, the problem becomes more complicated, since more than two variables need to be considered. This means that more *representative cases* are required to describe the various combinations of these measures, and as each additional measurement is added to the design, an additional dimension of complexity is added to the analysis (Zehner et al., 1993). The problem becomes unworkable very quickly. Consequently, approaches have been developed that permit the power of computers to be applied in a way that more realistically represents the wide diversity of possible percentiles that can occur in a population (Roebuck, 1995). It is beyond the scope of this research to develop or describe these methods in detail, but a short general description of common mathematical methods used in this context is given. Roebuck believes that these methods permit ergonomists, designers and engineers to move from the evaluation of what specific percentiles are accommodated to the evaluation of what percentage of persons in a sample (and thus, by implication, the percentage of a entire population) will be accommodated. This is really what the use of percentiles was intended to accomplish in design practice (Roebuck, 1995).

Principal Component Analysis

Principal component analysis (PCA) is a statistical method which reduces the number of measurements needed to describe body size variability by combining a large number of related measurements into a smaller set of factors or components based on their correlation or co-variance (Zehner et al., 1993). Roebuck (1995) describes PCA as an approach to calculate certain statistically feasible worst-case examples. The method develops a set of boundary conditions for a multidimensional distribution of human measurements, which are much better able to guarantee a given percentage of accommodation in a design than common-percentile manikins are (Roebuck, 1995). Hudson et al. (1998) state that the multivariate accommodation method corrects deficiencies of percentile and regression approaches while retaining the concept of accommodating a specific percentage of the population in the design. The method takes into account not only size variance but proportional variability as well, i.e. not only individuals who are uniformly large or small, but those whose measurements combine, for example, small torsos with long limbs, or vice versa (Hudson et al., 1998). The method works well when the measurements form groups of highly correlated components (as in cockpit related measurements), but for measurements that show poor inter-correlation (such as facial dimensions) the method does not work so well (Hudson et al., 1998).

For most cockpit or workstation design the total number of relevant measures can be reduced to two or three factors, which means that a bivariate circle or tri-variate sphere (this procedure turns ellipses into circles and the ellipsoids into spheres) can be used to define population limits and identify *representative cases* (Zehner et al., 1993). Figure 5.8 shows a two-dimensional principal components solution where eight *representative cases* have been selected on the border of a circle that represents 99.5% accommodation.

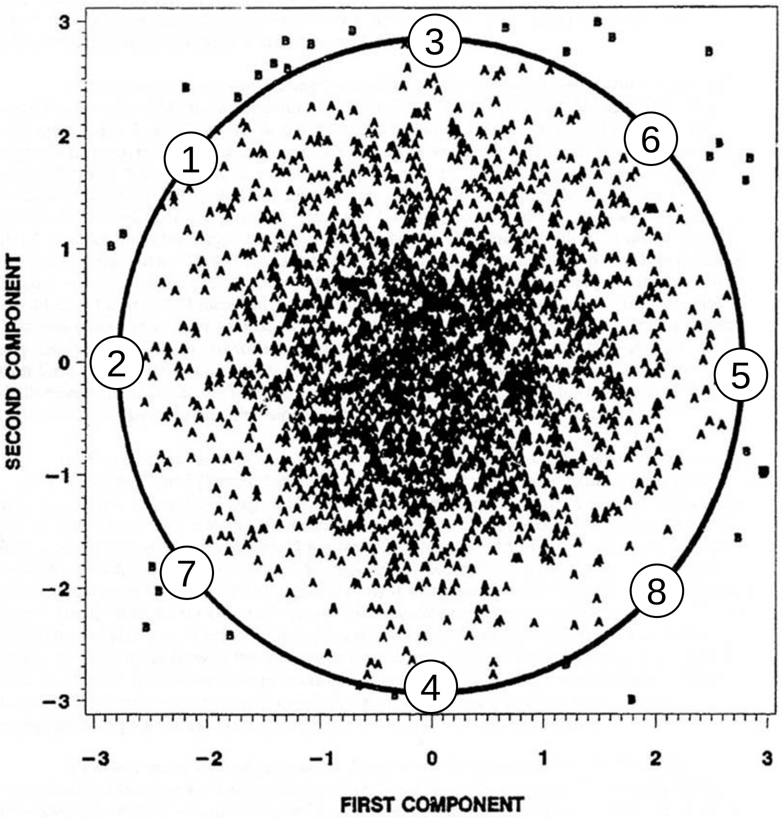


Figure 5.8. Two-dimensional principal components solution, 99.5% accommodation (Zehner et al., 1993).

The following six variables were included in the study by Zehner et al.: *Thumb tip reach*, *Buttock-knee length*, *Popliteal height sitting*, *Sitting height*, *Eye height sitting* and *Shoulder height sitting*, all considered critical for pilot accommodation in airplane cockpits. Zehner et al. (1993) remark that, while many other measurements could arguably be included, most are simple clearance dimensions that can be dealt with in terms of minimum and maximum values. Porter and Porter (2001) consider that the situation is less critical in an automobile than in an airplane, where e.g. ejecting and frequent exposure to very high g-forces (acceleration due to changing direction or increase/decrease of speed) do not need to be considered. Porter and Porter believe that it is, however, more than likely that poor vision from a vehicle, due to a driver's sitting eye height being too low/high or too far forward/rearwards, will have contributed to many accidents over the years.

Table 5.2 shows the two-component factor correlation matrix in the study by Zehner et al. (1993), where the two factors (Factor 1 and Factor 2) explain the variations among the six variables. The values of Factor I are relatively high positive values of about the same magnitude, thus being a good predictor of general *overall body size*. Factor II shows a marked contrast between the three first measures and the second three (positive for the torso dimensions and negative for the limb dimensions), and this allows individuals to be classified based upon the relative sizes of these two body components, and is the basis for discriminating between individuals with varying *body proportions*.

Table 5.2. Two-component factor correlation matrix (Zehner et al., 1993).

Variable	**Factor I**	**Factor II**
Thumb tip reach	0.69451	0.51817
Buttock-knee length	0.69608	0.51063
Popliteal height sitting	0.74656	0.46231
Sitting height	0.88639	-0.39995
Eye height sitting	0.86122	-0.41069
Shoulder height sitting	0.80865	-0.43561

Table 5.3 shows the percentile values obtained for the eight *representative cases* for the six critical variables (Zehner et al., 1993). These values can then be used to model *representative manikins* to be used in human simulation to aid the design task. Examples of the application of PCA to develop a set of representative manikins, which may be

defined as a *manikin family*, can be found in (Kim and Whang, 1997), (Tarzia and Eynard, 2000) and (Hsiao et al., 2005).

Table 5.3. Percentile values for eight representative cases (Zehner et al., 1993).

Variable	1	2	3	4	5	6	7	8
Thumb tip reach	34	1	96	4	99	100	0	66
Buttock-knee length	33	1	96	4	99	100	0	67
Popliteal height sitting	25	1	94	6	99	100	0	75
Sitting height	0	0	9	91	100	87	13	100
Eye height sitting	0	0	9	91	100	86	14	100
Shoulder height sitting	0	0	7	93	100	81	19	100

More detailed information about the multivariate anthropometric method used by Zehner et al. is available in (Zehner et al., 1993). In addition to this study, a more complex example with 11 variables is included, where three-component factors were used to describe body size variability, leading to the identification of 14 *representative cases* on a three dimensional spheroid. Table 5.4 shows how the amount of variance explained expands when using from 1 to 6 factor components in a six variable study by Hudson et al. (1998). As can be seen in this example, a two-component model would explain 90.9% of the total variation. The addition of a component increases the variance explained but also greatly increases the number of *representative cases* required to adequately represent the accommodation boundary. Ignoring the 9.1% of the variation is considered as acceptable given the simplicity of the two-component model, rendering few (8 in this case) *representative cases* on an accommodation circle (Figure 5.8) rather than a large set of *representative cases* on a three-dimensional sphere or a multi-dimensional hypersphere (for more than three factor components).

Table 5.4. Cumulative variance explained from using different numbers of factor components (Hudson et al., 1998).

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Cumulative variance explained	64.1%	90.9%	94.5%	97.4%	99.6%	100.0%

Monte Carlo generation

Monte Carlo generation (or modelling) is another method to deal with multivariate problems. This technique was invented for predicting the behaviour of atomic particles, and it is named after the casinos of Monte Carlo because it uses probability theory in random samples; if you play long enough, you can discover the probability of winning without having to calculate it predictively. In this way the Monte Carlo method answers the question hypothetically, but on a very large sample. The method generates large sets of numbers, each of which is random, but which collectively are 'normally' distributed, in the same way that human dimensions are distributed. The distribution is then examined to determine the proportion of data points which meet all the dimension percentile criteria (PeopleSize, 2004).

Monte Carlo methods were used in the CAPE (Computerised Accommodated Percentage Evaluation) model to determine the accommodated proportion of a user population (Bittner, 1976). Originally developed for pilot accommodation in aircraft cockpits, the model was developed to suit the development of automotive interiors (Bittner, 1978). In these models the user (ergonomist, designer, engineer) can ask the program to generate, by Monte Carlo methods, a set of synthetic human models (manikins) that have different percentiles for each dimension (Roebuck, 1995). The selection of percentiles is governed by software that generates random multipliers of the standard deviation that are constrained by the correlation coefficients between all pairs of dimensions and by means and standard deviations of each dimension's distribution. Although no single synthetic human model is guaranteed to match an actual individual, each model represents one possible case that could occur in a population of people without violating any of the underlying statistics. These manikins are then used in human simulation to assess human activity (e.g. fit, vision and reach) within a workspace geometry (e.g. in an car interior).

5.1.3. A-CADRE manikin family

Bittner and his colleagues report the development and validation of a family (limited set) of manikins, called CADRE, to be used in workstation design to assure population accommodation (Bittner et al., 1987). This CADRE family was later developed into A-CADRE (Advanced-CADRE), using a similar approach as when developing CADRE, but with variations designed to assure greater reach accommodation within a tighter percentile boundary envelope (Bittner, 2000). A-CADRE was developed using a procedure consisting of four stages.

1. **Identification of variables** - the selection of 19 workstation related anthropometric variables, as shown in Table 5.5.
2. **Development of intercorrelations** - the estimation of the correlations between the 19 variables.
3. **Factor analysis** - three steps: 1) Principal Factor Analysis, 2) Varimax rotation and 3) Division of the resulting rows of factor loadings by the square root of the variable communalities for those rows.
4. **Manikin descriptions** - the development of the percentile descriptions for the 19 variables for the manikin family (see (Bittner, 2000) for detailed information of how this was done). This resulted in descriptions for the 17 manikins; 16 systematically located on the surface of a four dimensional hyper-ellipsoid, plus one manikin at the centroid of the ellipse (Table 5.5).

The A-CADRE family was eventually evaluated for process and outcome validity in the context of the redesign of a (cockpit) workstation, showing good results (Bittner, 2000). This evaluation revealed that the process validity of the 17-member family was virtually equivalent to that for a 400-member random sample.

Bittner et al. (1987) remark that the actual accommodation obtained when using the manikin family (CADRE in this case, but is also expected to apply to A-CADRE) depends on number of dimensions that are ultimately limiting. A likely accommodation range is about 90-95%.

Bittner et al. suggest that the 17-member manikin family also can be used to guide the selection of real humans when performing evaluations in mock-ups and at later stages of the design process. Subject selection can be directed at obtaining human representatives who are anthropometrically comparable to the suggested manikin family on two or perhaps three significant dimensions (Bittner et al., 1987).

Percentile descriptions according to the A-CADRE will be utilised in human simulations later in the thesis.

Table 5.5. A-CADRE manikin family percentile descriptions (Bittner, 2000).
(Variable names according to Adultdata (Peebles and Norris, 2000) when possible)

Workstation related	A-CADRE manikins																
variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Stature	99,0	91,0	82,7	95,4	75,6	52,0	24,4	38,3	61,7	75,6	48,0	9,0	17,3	4,6	24,4	1,0	50,0
Chest height (ilial)	98,7	84,8	90,4	96,0	63,4	45,1	28,6	20,1	79,9	71,4	54,9	15,2	9,6	4,0	36,6	1,3	50,0
Sitting height	96,6	89,7	31,5	91,0	93,6	85,0	21,6	83,2	16,8	78,4	15,0	10,3	68,5	9,0	6,4	3,4	50,0
Eye height sitting	96,5	92,7	29,6	89,8	92,3	81,3	18,0	85,7	14,3	82,0	18,7	7,3	70,4	10,2	7,7	3,5	50,0
Back of knee height	98,1	67,5	91,8	97,3	64,4	59,0	37,7	10,6	89,4	62,3	41,0	32,5	8,2	2,7	35,6	1,9	50,0
Buttock-knee length	98,6	92,6	95,7	81,6	61,8	16,3	43,5	33,1	66,9	56,5	83,7	7,4	4,3	18,4	38,2	1,4	50,0
Shoulder-elbow length	99,0	78,4	93,2	94,0	79,3	51,9	49,4	23,5	76,5	50,6	48,1	21,6	6,8	6,0	20,7	1,0	50,0
Forearm-hand length	98,5	57,9	93,7	94,1	85,3	67,0	66,0	17,9	82,1	34,0	33,0	42,1	6,3	5,9	14,7	1,5	50,0
Shoulder breadth (deltoid)	93,6	87,4	89,6	18,9	93,6	18,9	89,6	87,4	12,6	10,4	81,1	12,6	10,4	81,1	6,4	6,4	50,0
Hip breadth	96,9	96,1	89,6	34,4	86,4	12,3	69,2	84,1	15,9	30,8	87,7	3,9	10,4	65,6	13,6	3,1	50,0
Foot length	98,9	65,7	92,5	92,9	89,3	66,9	65,7	26,4	73,6	34,3	33,1	34,3	7,5	7,1	10,7	1,1	50,0
Hand length	98,0	45,9	90,6	92,5	92,9	80,1	76,6	24,3	75,7	23,4	19,9	54,1	9,4	7,5	7,1	2,0	50,0
Functional reach	98,8	71,1	95,3	93,0	80,0	51,9	59,4	19,1	80,9	40,6	48,1	28,9	4,7	7,0	20,0	1,2	50,0
Functional leg throw	99,0	82,4	93,3	94,6	72,3	45,5	41,1	21,5	78,5	58,9	54,5	17,6	6,7	5,4	27,7	1,0	50,0
Shoulder height sitting	97,1	93,4	35,8	88,9	92,2	77,3	20,1	84,9	15,1	79,9	22,7	6,6	64,2	11,1	7,8	2,9	50,0
Neck height	99,0	90,0	84,9	95,4	75,2	51,0	26,4	35,3	64,7	73,6	49,0	10,0	15,1	4,6	24,8	1,0	50,0
Ear height	98,9	91,0	81,4	95,4	75,6	52,9	23,6	39,3	60,7	76,4	47,1	9,0	18,6	4,6	24,4	1,1	50,0
Weight	96,9	95,5	89,9	34,1	87,4	13,2	71,5	83,8	16,2	28,5	86,8	4,5	10,1	65,9	12,6	3,1	50,0
Shoulder breadth (acromion)	97,1	76,0	88,3	45,6	97,8	50,0	90,4	79,4	20,6	9,6	50,0	24,0	11,7	54,4	2,2	2,9	50,0

5.1.4. RAMSIS anthropometric typology

This section describes the anthropometric typology feature in the human simulation tool RAMSIS (Seidl, 1997). Later in the thesis (Section 5.2), RAMSIS will be used as the 'laboratory' to compare manikin families' functionality according to the *A-CADRE* versus the *RAMSIS Typology* human dimension descriptions.

Unique features in RAMSIS are posture prediction and comfort evaluation functionality for vehicle interior design, and the software is utilised by more than 70% of the car industry worldwide (Human-Solutions, 2005). The software is continually developed, e.g. bringing in force prediction, linked to posture and comfort prediction, as well as movement simulations (Bubb, 2004). The application area is also expanding, e.g. towards production ergonomics in the partner software eM-Human (Human-Solutions, 2005).

The model structure of RAMSIS is divided into two linked models: an interior model (skeleton) for motion simulation, and an exterior model (skin) for body contour modelling (Figure 5.9) (Human-Solutions, 2003a).

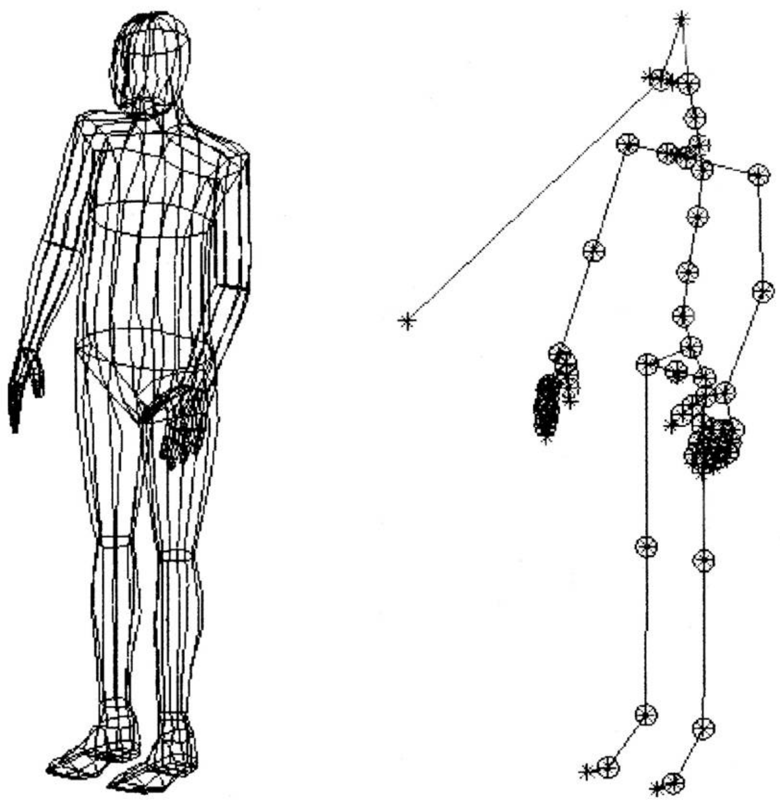


Figure 5.9. RAMSIS external model (left) and internal model (right) (Human-Solutions, 2003a).

The RAMSIS typology is used for manikin dimension definitions and supports the human simulation tool user (ergonomist, designer or engineer) to select manikins to be used in the simulation. The objective behind RAMSIS typology is that it should aid the tool user in selecting manikins that represent user diversity 'good enough' for most design problems. The typology is the standard functionality in RAMSIS for manikin selection and it is based on data that were obtained by physical measurement of statistically correct human test samples.

According to Professor Holle Greil (who defined and calculated the RAMSIS typology), the idea behind the typology is that single measurements vary differently due to different correlation coefficients; length measurements of long bones are highly correlated; length measurements of the spinal column are highly correlated, but correlation between these measurements is not so high. Measurements of corpulence are only lowly correlated (independent from, or even negatively correlated) to measurements of length (Greil, 2004).

As a result, RAMSIS typology is based on the knowledge that the definition of the characterising property of *length*, *proportion* (ratio of sitting height over body height) and *corpulence* of an individual is sufficient to give an excellent prognosis of all other body dimensions for this person (Speyer, 1996). These three properties are defined by the key measurements of *stature*, *sitting height* and *waist circumference* (Figure 5.10). Based on these three key measurements, RAMSIS then derives statistically likely dimensions for the other measurements of the body (if not specified by the tool user).

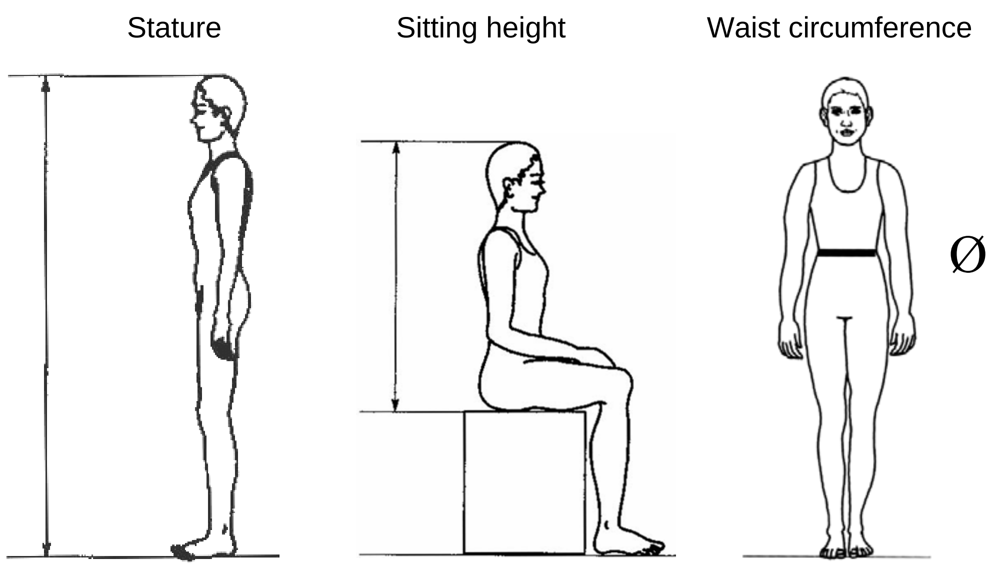


Figure 5.10. The three key dimensions stature, sitting height and waist circumference used in RAMSIS typology. Images from (Peebles and Norris, 2000).

Speyer (1996) states that statistical analysis of anthropometric survey data by several research groups have found the independence and characterising property of *stature*, *sitting height* and *waist circumference* (or weight) to hold true, not only for European populations but also for North American and Korean populations.

To support the definition of manikins, the RAMSIS user can select from the following predetermined categories of length, proportion and corpulence.

- **Length**: very short - short - medium - tall - very tall
- **Proportion**: short torso - medium torso - long torso
- **Corpulence**: slim waist - medium waist - large waist

The 5 categories of height, 3 categories of proportion and 3 categories of corpulence mean that 45 manikin types can be generated, per gender, i.e. in total 90 possible combinations. In addition, there are four age groups in RAMSIS: 18-70, 18-29, 30-49 and 50-70, which all have separate typologies. The two-step procedure to define the RAMSIS typology types is described in (Speyer, 1996), and is here reported in abbreviated form.

Step 1: All subjects in a survey, male and female separated, are classified as belonging to one of the following five stature groups:

- **very tall** lower limit of stature = 87th %-ile (average approx. 95th %-ile)
- **tall** lower limit of stature = 80th %-ile
- **medium** lower limit of stature = 20th %-ile (average approx. 50th %-ile)
- **short** lower limit of stature = 13th %-ile
- **very short** no lower limit (average approx. 5th %-ile)

Step 2: Each of the five *stature* groups is further divided according to a 3 x 3 type scheme with respect to *sitting height* and *waist circumference* (Figure 5.11). The greyscale in Figure 5.11 illustrates the probability density, i.e. the dark central region shows a high extent of occurrence of the combination of medium waist and medium torso. The radius of the inner region of the circle (the normalised probability distribution has an approximate circular shape) is chosen so that it represents 60% of all persons, and the outer region is divided into 8 congruent sections (45°), each representing 5% (Speyer, 1996).

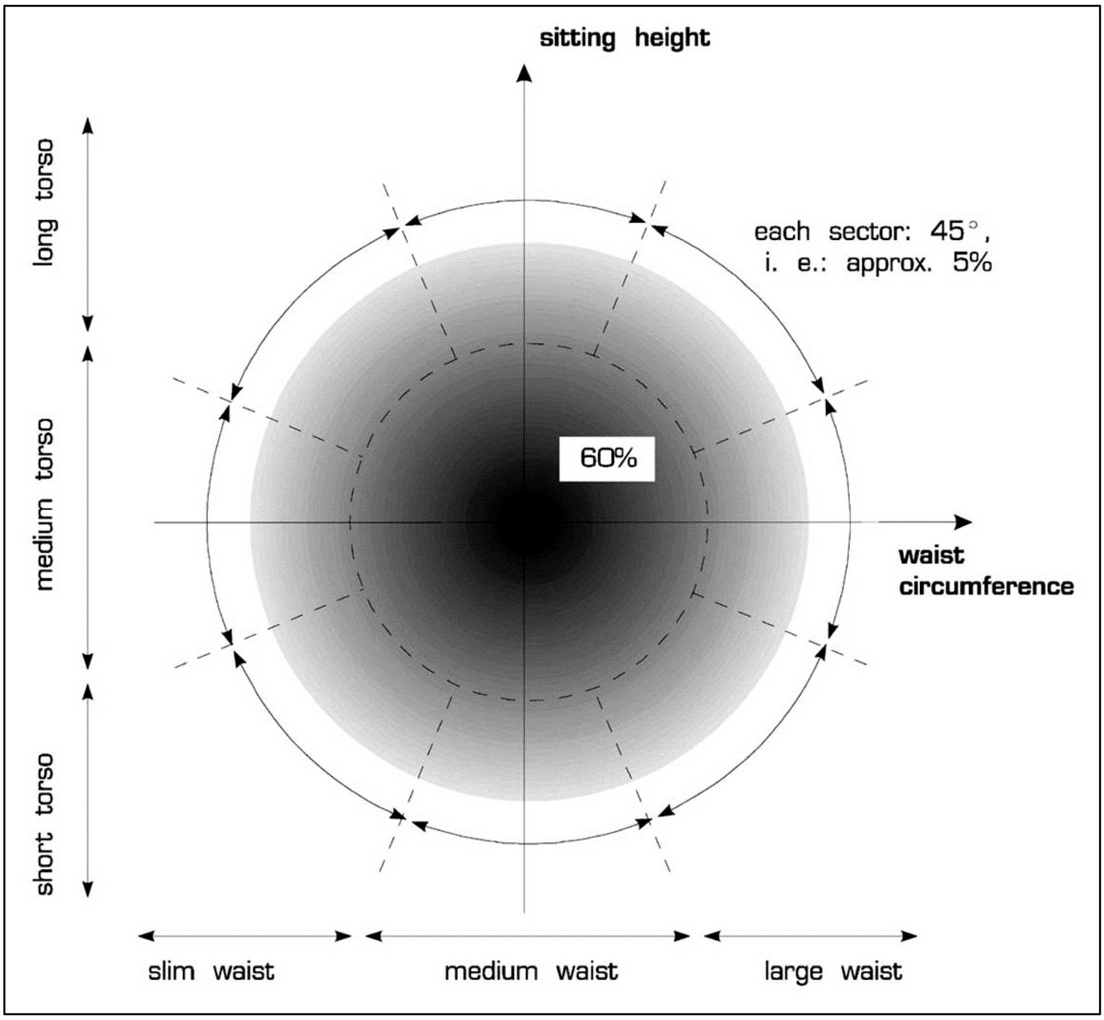


Figure 5.11. Definition of 9 RAMSIS types for sitting height and waist circumference, as done for each of the 5 stature groups (Speyer, 1996).

Finally, a certain RAMSIS type is defined to be the average manikin calculated from all individuals belonging to a fixed sub-section. For any of the 5 stature types, the corresponding 9 types of sitting height and waist circumference combinations cover 82% of the entire population (Speyer, 1996).

Depending on the design problem the human simulation tool user determines if all manikins are useful to include in the simulation or if a subset is sufficient. To illustrate this issue: to define appropriate height of a doorway so that 90% of the target population will be able to pass in a fully erect posture would require a test sample of only *one* manikin (90th percentile in stature of the targeted population), whereas to define appropriate height adjustment range of an adjustable office chair to accommodate 90% would require a test sample of *two* manikins (typically the 5th percentile and 95th percentile in seated thigh height of the targeted population). The conclusion is that it is not enough to know only the critical body dimension(s) to be able to define an optimal test sample, but also the characteristics of the design problem (Speyer, 1996).

The position that the selection of numbers and configurations of relevant manikins to use in simulation relates to the design problem at hand makes sense, but also, this approach leaves it to the tool user (ergonomist, designer or engineer) to carry out the frequently complex selection of appropriate manikins for the design problem at hand. For an expert tool user this might be straightforward, but for a 'normal' tool user this is a difficulty and a source of error, especially in multivariate design problems. One approach to this problem is to perform simulations including *all* members of the manikin family. The downside is the amount of simulations to be performed and analysed. As functionality for automatic simulation of several manikins is available in RAMSIS, and computing time per manikin is a matter of seconds (for a typical static posture simulation) the actual performance of the simulations is not a limiting factor. This approach would be supported by a predetermined set of manikins, e.g. as a company or project standard family of manikins that is established to correctly represent the targeted product users. Even though several simulations can easily be performed automatically, if the number of members in the manikin family can be kept reasonably low, but still give valid results, this is believed to ease the analysis of the simulation results. With this as the rationale, a comparison between the 17 manikins of the A-CADRE family and the 45 members of the RAMSIS typology is performed later in the thesis.

5.1.5. Level of accommodation

The definition of accommodation it is not only a matter of representing user diversity appropriately; there are more aspects to consider. Expressed simply, the level of accommodation can be defined by analysing: *who* can do *what* with *what where*? Consequently, a statement in a product design specification of an objective to accommodate 90% of a population would mean very little if not specified in more detail. Firstly, the population in question needs to be clarified. Secondly, what criteria apply? As discussed earlier, if one is designing a doorway the criteria would be related to users' height and width, where the users' task would be to enter the doorway. This is easy to specify, interpret and achieve in design. However, this will be very different for different kind of products, meaning that an important issue is to define the criteria that apply to the design problem at hand and that need to be considered to fulfil the set objective, i.e. to really accommodate the targeted population. Criteria for door or chair design are quite straightforward to define, whereas defining criteria for the design of a car cockpit is more complicated since more body dimensions affect the problem, and more tasks are performed within the environment. You pass through a door opening. You sit in a chair. In a car cockpit you sit, you steer, you use the foot pedals, you use the gearshift, you look through the window, you look in the mirrors etc. In theory, all targeted users should be able to perform all these tasks to be truly accommodated.

Pheasant (1986) believes that the objective of user-centred design (and hence ergonomics) is to achieve the best possible match between the *product* and its *users*, in the context of the *task* that is to be performed. Archer (1963) portrays a *man - tool - work - environment* systems view (Figure 5.12). Shackel (1991) defines *user - task - tool - environment* as the four principal components of a human-machine system.

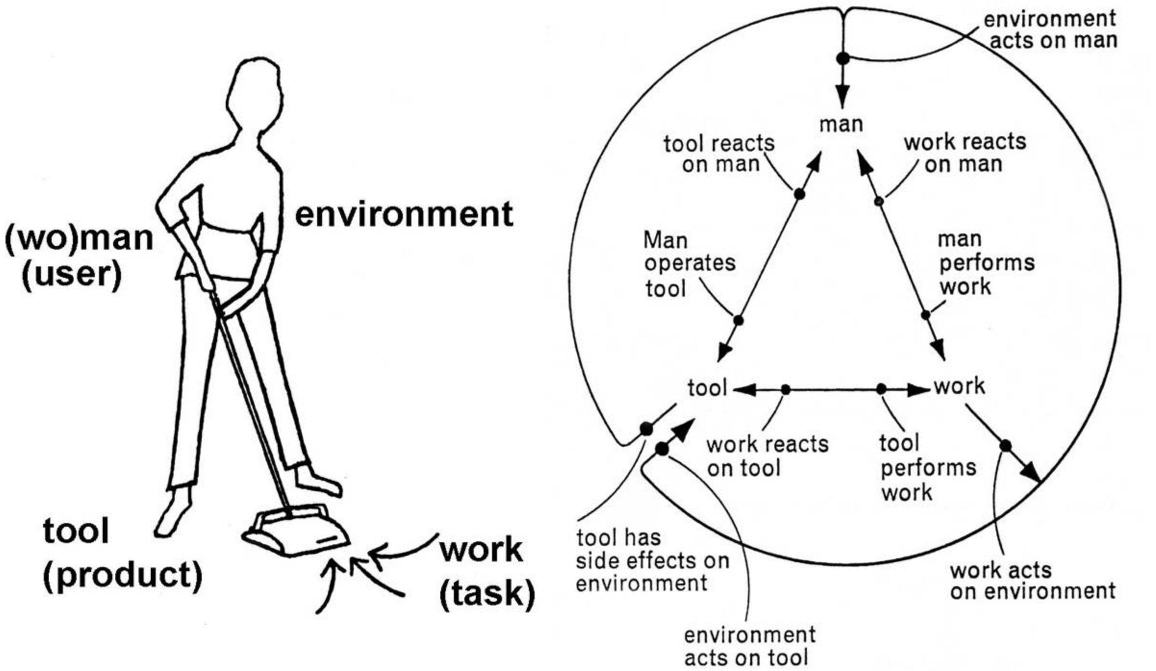


Figure 5.12. Systems view of man-tool-work-environment (Archer, 1963).

According to Shackel (1991), there are three general types of measurements available for evaluation (here in the context of usability): *dimension*, *performance* and *attitude*. *Dimensional criteria* (analytic) is the most familiar and simplest, relying on physical measurements and is primarily relevant to the size, shape and other characteristics of the tool (product) in relation to the user(s). The problem with analytical dimensional criteria is that they do not enable judgement that something is better or worse, but rather give results of pass/fail, if not related to performance and attitude criteria. *Performance criteria* (objective) involve an objective statement of some achievement against which human performance can be measured, and can be used to assess the operational capability that can be achieved by the user. *Attitude criteria* (subjective) are relevant to assess the user's view of the cost and relative difficulty in achieving the performance and can be gathered by various forms of scaling techniques. Shackel emphasises that these three types of criteria and measurement should not be regarded as alternatives, but as complementary, each being equally valid.

Consequently, assessing accommodation properly is complicated since many factors influence the evaluation. In this thesis, aspects of accommodation are primarily associated to *dimensional criteria*, and in later in this chapter the *user* is the car driver, the *task* is driving and the *product* is a car interior.

5.1.6. HADRIAN

One interesting approach to support designers in assessing the level of accommodation is the software HADRIAN (Porter et al., 2004) (Figure 5.13).

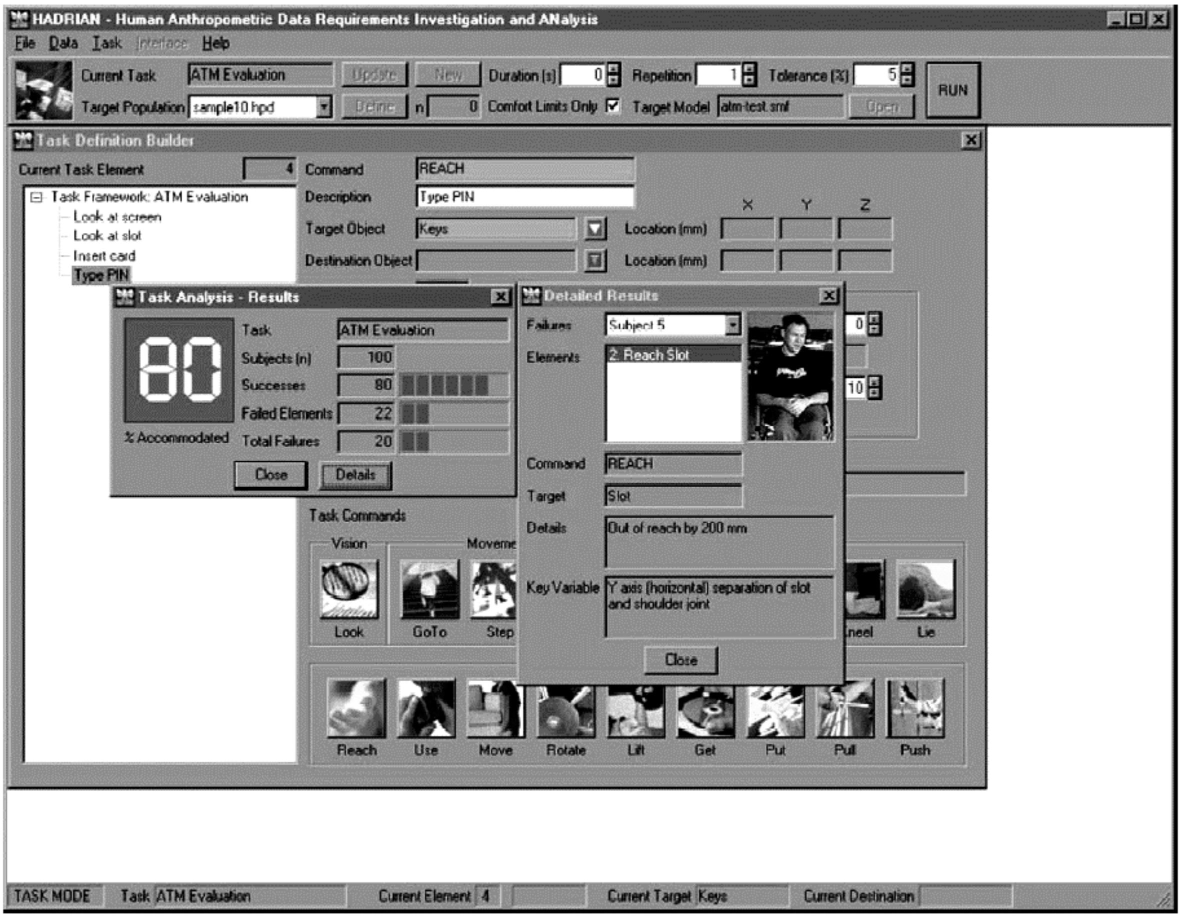


Figure 5.13. HADRIAN. Task analysis results showing 80% accommodation and descriptions of why Subject 5 was 'designed out' (Porter et al., 2004).

HADRIAN, based on the human simulation tool SAMMIE (Figure 3.14), is directed to support *inclusive design* (Section 2.4.6), which promotes the idea that all users in society should be considered when designing products, systems and environments. HADRIAN consists of anthropometric and functional ability data of individuals (rather than being based on disintegrated percentiles) of a wide range of people, and hence multivariate analysis can be conducted on a wide range of people of all ages, abilities, shapes and sizes (Porter et al., 2004). The 'individuals approach' also has the benefit that it 'puts faces' to the data, and may generate empathy among designers for the people they are designing for (Porter et al., 2004). This resembles the ideas behind using *User Characters* as discussed in Section 3.2.

HADRIAN aids the designer to assess which individuals in the database are able to perform certain tasks within certain environments (with certain products), and hence defines the percentage accommodated. The idea is that it should be clear to the designer *who* are designed out and *why*, and as an effect, problems that may be solvable by modifying the design are highlighted. Hence HADRIAN acts as a 'designers tool' by bringing problems to light and stimulating the generation of improved design solutions.

The prototype database in HADRIAN consists of 100 individuals, including a large proportion (75%) who are older and/or disabled (Porter et al., 2004). Statistically these 100 individuals are not accurately representative of the entire population (which was not the intention when developing this prototype tool), but provide a useful measure of the extent of variation in physical characteristics and capabilities for the development and validation of the predictive tool (Porter et al., 2004). The large numbers of individuals, and hence manikins, required, especially if aiming to be statistically representative, is believed to be a downside of this approach.

Later in the thesis (Section 5.2), results from employing manikin families in human simulation are discussed. The manikin families consist of *representative cases* (see Section 5.1.2) derived from applying statistics on anthropometrical data, i.e. a different approach towards creating individual manikins compared to the one used in HADRIAN.

Before discussing the use of manikin families, the next section briefly reviews and discusses aspects of human simulation tools' functionality being expanded to consider user aspects in a richer sense, both concerning physical and cognitive ergonomics, and hence becoming ever more valuable aids for designers.

5.1.7. Bringing physical and cognitive human models together

Ideally, human simulation tools should represent the human more fully than is the case today. This is of course extremely complicated, not at least since humans are extremely complicated, e.g. the way that we perceive, think and operate our body. Hertzberg (1960) argued a long time ago that sound workspace design involves both objective factors (body size, muscle force capability) and subjective factors (individual preferences, pain, fatigue etc.), all of which must be understood to ensure long-term occupant comfort. To a degree, it is possible to evaluate subjective factors in today's human simulation tools, e.g. comfort evaluation in RAMSIS (Bubb, 2004). However, cognitive issues such as how the human acts as an information sensor and processor, including issues such as information processing, perception, memory, decision-making, attention, mental workload etc. (Sanders and McCormick, 1993) are currently not integrated in the types of human simulation tools presented in this thesis. Bubb (2004) believes that, in a human simulation context, a very important step in the future will be to combine both physical and cognitive models (also called *human performance process models*). This is to enable the assessment of both physical and cognitive ergonomic conditions, particularly at early virtual design stages, with the objective that first prototypes will require fewer major modifications than would be the case without the aid of the tools. Figure 5.14 illustrates the ideas of combining computer manikins and cognitive models (Bubb, 2002).

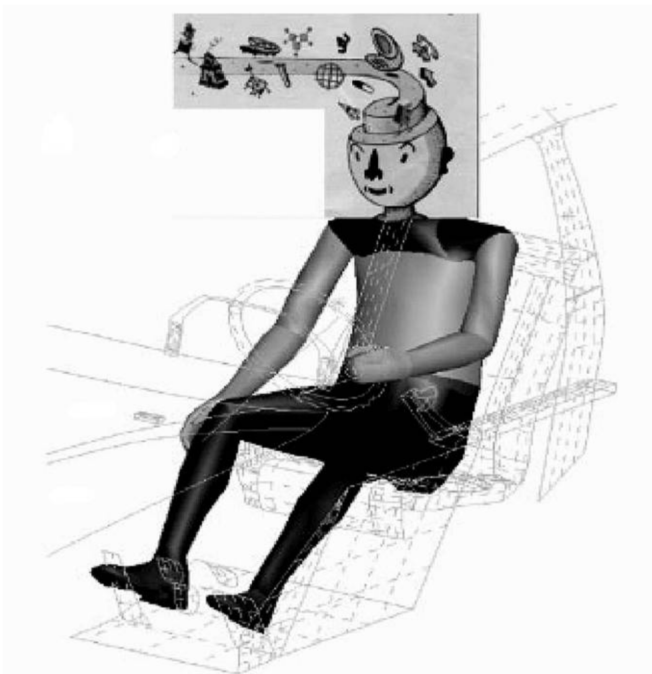


Figure 5.14. Illustration of the combination of computer manikin and cognitive model (Bubb, 2002).

Ianni (1999) proposes the term *virtual humans* to be used to describe the combination of models of the physical human and the cognitive human. Ianni exemplifies physical human functionality as being able to accurately represent human anthropometry and biomechanics, and cognitive functionality as fatigue, anger, mental overload and decision-making based on beliefs, experiences and heuristics over its 'life'. Ianni concludes that many applications can greatly benefit through a marriage of mind and body models, e.g. by virtual humans being able to perform tasks autonomously. Plott et al. (2003) present accomplishments of merging the human simulation tool Jack (Badler et al., 1993) and the cognitive model Micro Saint (Plott et al., 2003) stating that, albeit being powerful in their own right, bringing the two models together could significantly augment human representation in simulations, to designers' benefit.

Badler's (1997) view of what makes a virtual human *human* is not just a well-executed exterior design (such as in cartoons and games) but movements, reactions and decision-making which appear 'natural', appropriate and contextually sensitive. Ziolek and Kruithof (2000) distinguish between virtual humans used for illustrative purposes and humans used for analysis and product development, stating that humans used for the purpose of illustration represent an 'idealistic' representation of human form, whereas humans used for simulation strive to develop a more 'realistic' representation.

In a general and future context, Badler (2002) gives his view of the outlook of virtual humans (within a time span of approximately 10 years) applied in a wide sense, including applications in movies, e.g. where virtual humans perform dangerous stunts, or applications in education/training, e.g. where virtual co workers instruct someone on how to repair an aircraft. Badler sees virtual humans as being developed into extremely realistic characters, which not only look real but also have a real behaviour, and intelligence enough to allow interactions such as discussions. Badler also sees cloning of real people into virtual ones as a realistic outlook. These views require extensive knowledge of human behaviour, e.g. models of motion, emotion, mood, personality, decision-making and thought to be developed, and the elusive task of establishing individuality.

The next section in the thesis is narrower in its approach and focuses on the use of manikin families to aid designers to reach a high level of human accommodation in vehicle interior design.

5.2. Computer Manikin Family Usage for Human Accommodation

A car interior is designed to meet a large number of requirements, e.g. related to comfort, customer appeal and safety. Obviously, car drivers' ergonomic requirements are very important aspects to consider (indeed car passengers' ergonomic requirements are also important, but not as critical as for the driver due to the task of driving). This means that an appropriate user representation is crucial; a representation that encompasses the anthropometric diversity of targeted users.

5.2.1. Issues of human accommodation in vehicles

A car is a high technology product where issues such as branding, styling, ergonomics and safety all are variables in a very complicated optimisation activity. The challenge for the car industry is to find the most competitive balance of all aspects. Consequently, the complex car development process involves many people and competences, all making numerous large and small decisions on the car's final design.

The ergonomists in a car design project can be seen as the users' advocates. This concerns both users' physical and cognitive/mental limitations and abilities. The ergonomists' responsibility can for example be to ensure that the car is suited for drivers of different sizes, or making sure that a navigation panel is readable, understandable and manoeuvrable.

Technical aspects of products as well as product styling are easy to model in computers, especially if compared to modelling of humans. As discussed earlier in the thesis, it is possible, to a degree, to model humans, and particularly physical aspects using human simulation tools. These tools are extensively used in the car industry, since they enable ergonomists to provide designers with geometric data associated with human accommodation in the car, e.g. digital data coordinates for minimum headroom required to accommodate the tallest users, and to perform ergonomics evaluations on design proposals at virtual stages. Human simulation tools introduce both possibilities and problems for ergonomists, e.g. the possibility to actually assess ergonomics when the product is only CAD-data, and the problem of how to represent users, and to appreciate the validity of the results obtained (as discussed in Section 4.1.3).

A pragmatic approach towards user representation in human simulations would be for a company to have a standardised manikin family that would always represent the targeted customers. This would be similar to, and indeed a complement to, having a group of real test persons within a company that would always be recruited to assess products being developed. One difference between virtual and real test persons is that the virtual test group will always be available, even concurrently at different places. A concern is that the virtual test group will only do what they are told to do, putting pressure on the tool user to set up the study properly (Ziolek and Kruithof, 2000). Such a virtual test group (or manikin family) would most probably be continuously refined, e.g. based on marketing issues, management decisions and on lessons learned from the employment of the virtual test group, e.g. linked to feedback from real customers from real markets. This is similar in a way to the refinement of user characters as discussed in Section 3.2.

As discussed earlier, possible reduction in the number of simulations required (i.e. number of members in manikin family) to obtain valid results is attractive for an efficient simulation process, and would support analysis and communication of the results obtained. The following study, carried out in the context of human accommodation in cars, compares results of seat adjustment ranges obtained when using two different approaches for user (driver) representation: the RAMSIS typology and A-CADRE (as described in Section 5.1).

5.2.2. Method

USER REPRESENTATION

The RAMSIS typology approach renders a manikin family consisting of 45 members in each gender, in total 90 members. In this study *all* members are included. The rationale for this decision is that it is hard for the human simulation tool user to know in advance which manikins will limit the design problem, especially if the tool user has little knowledge or experience of the complexity of the design issues at hand. Therefore the inclusion of *all* members is a sensible approach if RAMSIS is to be used as a 'designers tool'.

The A-CADRE family consists of 17 members in each gender, 34 in total. Since not all of the 19 body variables in the A-CADRE definition (see Table 5.5) are possible to enter in RAMSIS, the decision was made to just use the three key variables *stature*, *sitting height* and *waist circumference* as used in the RAMSIS typology to predict other dimensions of the body (as described in Section 5.1.4). As waist circumference is not present in the A-CADRE definition, values for weight were used instead. This assumption is believed to be adequate due to the relatively high correlation between the two dimensions. Kroemer et al. (2001) report the correlation coefficient between weight and waist circumference (for US Army personnel) as 0.767 for women and 0.849 for men. These values are above the '0.7 convention', which states that a correlation of at least 0.7 is required for design decisions to be able to explain at least 50% of the variance of the predicted value from the predictor variable (Kroemer et al., 2001).

The anthropometric database incorporated in RAMSIS was used in the study, with Germany as the selected nationality (the database at hand) and age group selected as 18-70 years (considered as the relevant age group for car drivers).

To roughly illustrate the anthropometric diversity represented, Figure 5.15 shows the A-CADRE manikin family for each gender as modelled in RAMSIS. Detailed values of stature, sitting height and waist circumference for all members in the RAMSIS Typology and A-CADRE families, for each gender, are available in Appendix 1, both as percentile values and in millimetres.

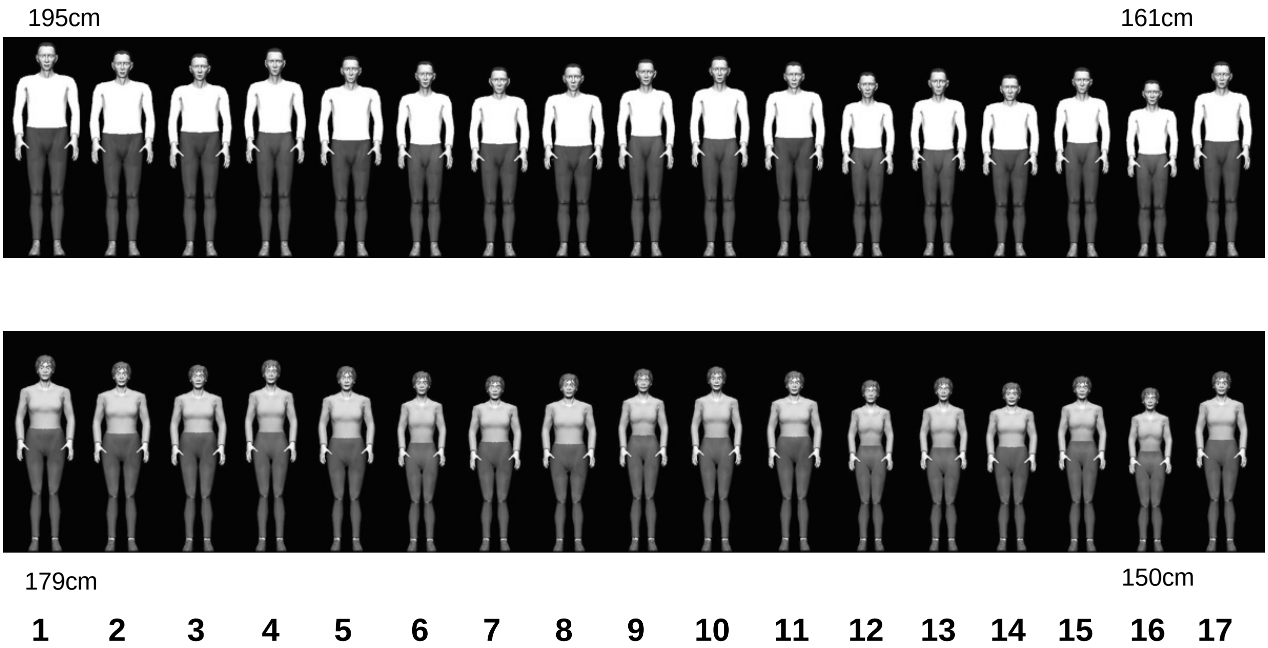


Figure 5.15. A-CADRE modelled as male and female manikins in RAMSIS.

Tables 5.6 and 5.7 show the minimum and maximum percentile value of each variable for each family approach, for female and male populations respectively. The accommodation level that these value ranges answer to was calculated using the multidimensional analysis functionality in two separate anthropometric software: 1) PeopleSize 2000 Professional Version 2.06c (PeopleSize, 2004) and 2) BodyBuilder Version 1.4 (with statistics license) delivered with RAMSIS (Human-Solutions, 2003b).

Table 5.6. Minimum and maximum values for females used in RAMSIS Typology and A-CADRE families, and calculated level of accommodation.

FEMALE		**RAMSIS Typology**	**A-CADRE**
Stature	min	4.6%-ile	1%-ile
	max	97.5%-ile	99%-ile
	coverage	92.9%	98%
Sitting height	min	1%-ile	3.4%-ile
	max	99.1%-ile	96.6%-ile
	coverage	98.1%	93.2%
Waist circumference	min	5.3%-ile	3.1%-ile
	max	99.4%-ile	96.9%-ile
	coverage	94.1%	93.8%
Accommodation	PeopleSize	86.8%	86.7%
	BodyBuilder	86%	86%

Table 5.7. Minimum and maximum values for males used in RAMSIS Typology and A-CADRE families, and calculated level of accommodation.

MALE		**RAMSIS Typology**	**A-CADRE**
Stature	min	3%-ile	1%-ile
	max	96.4%-ile	99%-ile
	coverage	93.4%	98%
Sitting height	min	0.9%-ile	3.4%-ile
	max	98.8%-ile	96.6%-ile
	coverage	97.9%	93.2%
Waist circumference	min	4%-ile	3.1%-ile
	max	97.6%-ile	96.9%-ile
	coverage	93.6%	93.8%
Accommodation	PeopleSize	86.8%	87.0%
	BodyBuilder	86%	86%

Tables 5.6 and 5.7 show that A-CADRE has greater percentile coverage than RAMSIS Typology in stature, but smaller in sitting height and very similar for waist circumference. Even though different percentile ranges are covered, the two approaches result in approximately the same accommodation level, i.e. approximately 86%.

However, this level of accommodation is linked to the population used in the analysis (Germany, 18-70 years) and can decrease considerably if the design is to fit other user groups, e.g. other nationalities (as discussed in Section 5.1.1). The PeopleSize software enables the creation of *composite populations* where it is possible to define proportions of two or more populations, which enables a mix of gender, age and nationality to more correctly represent targeted product users (PeopleSize, 2004). If a product is to fit a diverse collection of users, e.g. related to nationalities and age groups, this is an approach to obtain appropriate anthropometric data and accommodation levels.

Further reduction in accommodation will happen if more body dimensions limit the design problem. However, this reduction is likely to be moderate due to relatively high correlation of the added dimension with either stature, sitting height or waist circumference (which between themselves have low correlation), i.e. the major reduction has already been made. To test this, the two dimensions *shoulder (acromion) to underside of elbow* and *back of elbow to tip of middle finger* was added with a 95% coverage (2.5th percentile to 97.5th percentile) to the RAMSIS Typology and A-CADRE data as shown in Table 5.6 and 5.7, by which PeopleSize gave an accommodation level of 82.2% (RAMSIS Typology Female), 83.1% (RAMSIS Typology Male), 81.6% (A-CADRE, Female) and 82.2% (A-CADRE, Male).

TOOL AND PROCEDURE

RAMSIS was utilised as the human simulation tool to predict car-driving postures of all members in the manikin families. RAMSIS uses 'comfort angles' as the basis for posture prediction, i.e. values of angles for various joints that have been identified as the most preferred through empirical car-driving posture studies (Seidl, 1997; Vogt et al., 2005) (Figure 5.16). As the RAMSIS posture functionality is constraint (or task) driven, the tool user defines the driver's task (in this case), and the software generates the most likely position and posture considering the present constraints, as determined by vehicle geometry, anthropometry and task definitions (Loczi et al., 1999). For driving this may be: *both hands on steering wheel*, *right foot on the accelerator*, *both heels on the floor* etc. (Geuss, 1998). The software uses extensive optimisation algorithms to correctly and repeatably calculate postures (Seidl, 1997). The capability of RAMSIS to correctly predict position and posture in vehicle CAD environments has been tested by Loczi et al. (1999) showing good results.

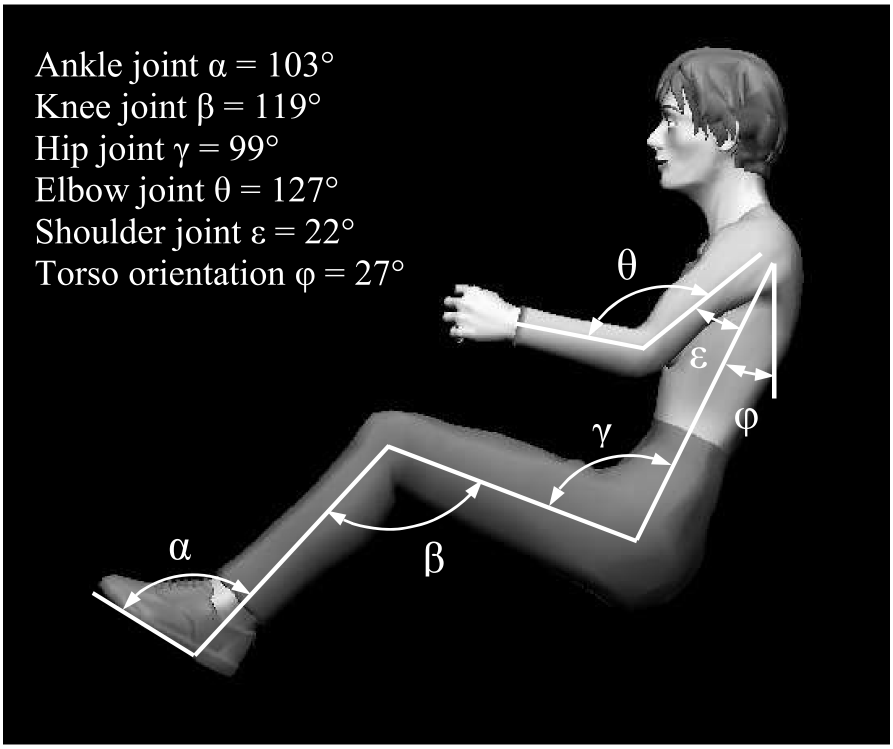


Figure 5.16. Posture defining joints and preferred angles (Vogt et al., 2005).

The objective of this study was to see where each manikin would prefer to locate his or her H-point within present constraints, thereby getting indications of the characteristics of each manikin family formation approach. The H-point is a point that simulates the pivot centre of the human torso and thigh, and provides a landmark reflecting where people sit in a seat (Roe, 1993). RAMSIS offsets the H-point relative to the hip centre depending on waist circumference and characteristics of the seat. The H-point location is defined by linear correlation to the waist circumference and since the waist circumference indicates corpulence, the assumed volume of the buttocks and thighs is accounted for (Human-Solutions, 2003a). A corpulent person will sit higher in the seat than a slim person and hence the offset is larger for a corpulent person than for a slim person, as shown in Figure 5.17.

This current functionality of RAMSIS is more correct than simply assuming that the manikin's hip-point is identical with the H-point (Bubb, 2004). In the future RAMSIS will be able to simulate the contact behaviour between the manikin and the seat as if a real person was sitting there, and in that manner simulate influences on posture and comfort (Bubb, 2004).

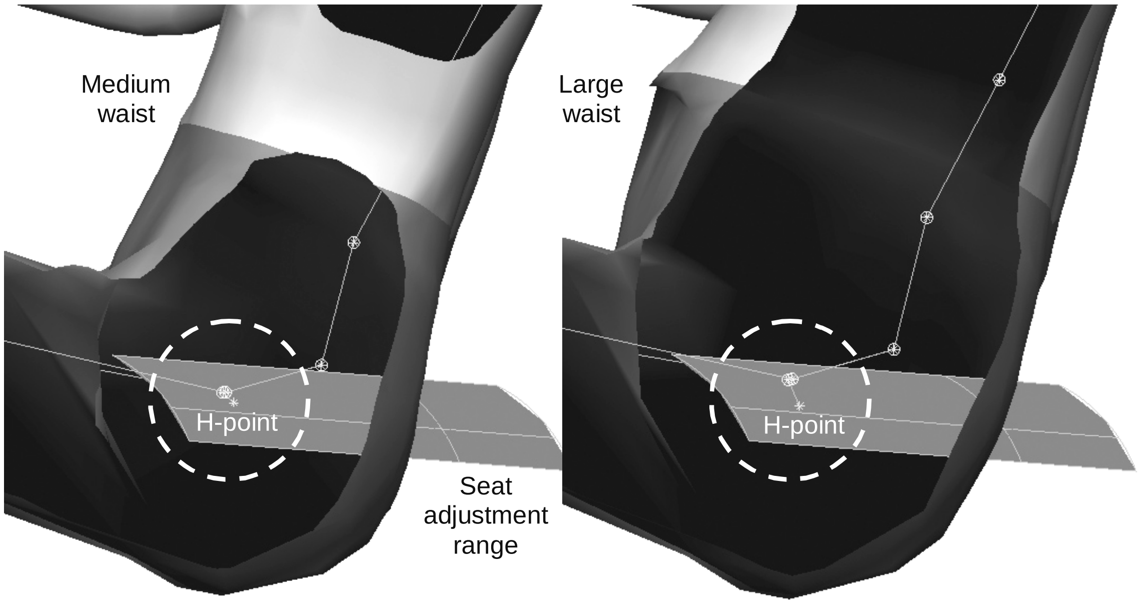


Figure 5.17. Illustration of H-point offset as a function of corpulence.

A car interior, obtained from the cooperating company, was imported into RAMSIS as CAD geometry in the study, representing a 'typical' car. Figure 5.18 shows the coordinate system as used in vehicle design (Roe, 1993).

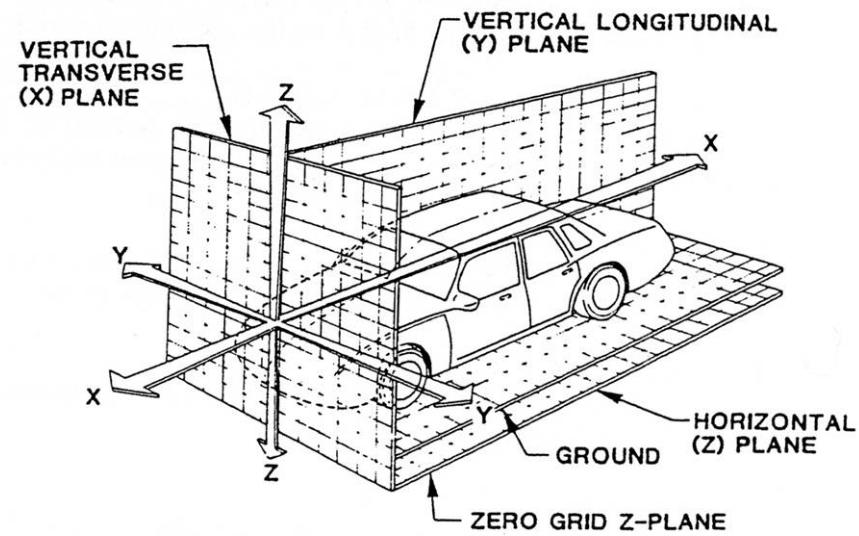


Figure 5.18. Coordinate system used in vehicle design (Roe, 1993).

The following constraints were present in the study (Figure 5.19).

C-1 Head clearance. Minimum 20 mm vertical distance between head top (vertex) and inner roof.

C-2 Right pedal-point on accelerator, pressed down halfway.

C-3 Right heel point on floor.

C-4 Left pedal-point on foot support.

C-5 Left heel point on floor.

C-6 Line of sight. 5 degrees down from horizontal line.

C-7 Line of sight clearance. Minimum 70 mm vertically between line of sight and top of instrument panel.

C-8 Right grasp point within steering wheel adjustment area.

C-9 Left grasp point within steering wheel adjustment area.

C-10 H-point within greatly extended seating adjustment area (non-constraining in x and z direction).

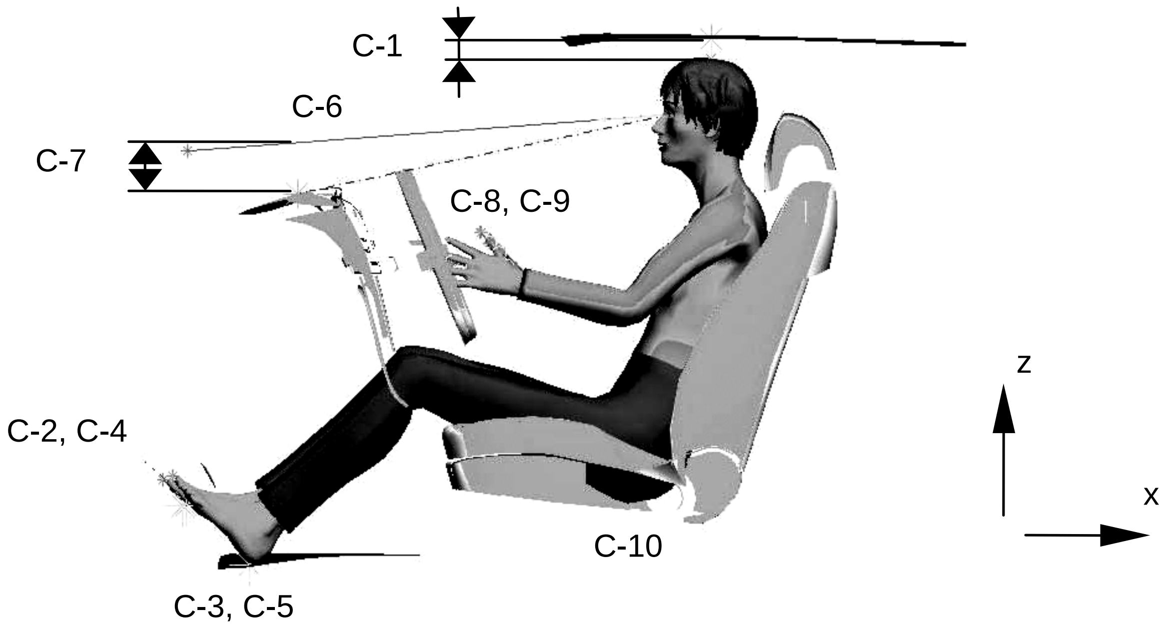


Figure 5.19. Constraints used in RAMSIS simulations.

5.2.3. Results

The H-point locations obtained from simulation of each manikin family are shown in Figures 5.20 to 5.23, where each manikin's H-point location is labelled with the manikin number as specified in Appendix 1. All H-point positions in x and z directions are available in Appendix 2. Grasping point locations selected by each manikin within the steering wheel adjustment area are shown in plotted form in Appendix 3. As a reference area, Figures 5.20 to 5.23 contain the seat adjustment range of the 'typical' car used in simulations, as an indication of reasonable match. The figures also contain SAE driver seat position curves described at 2.5, 5, 95 and 97.5% accommodation levels, which are based on a 50/50 male/female US driving population mix (Roe, 1993). To explain, the 95% curve does not represent where a 95th percentile male would sit, but a location forward of which 95% of the population would sit. A seat track travel that extends the H-point rearward from the 2.5% curve to the 97.5% curve would predict accommodation for the middle 95% of the population (Roe, 1993).

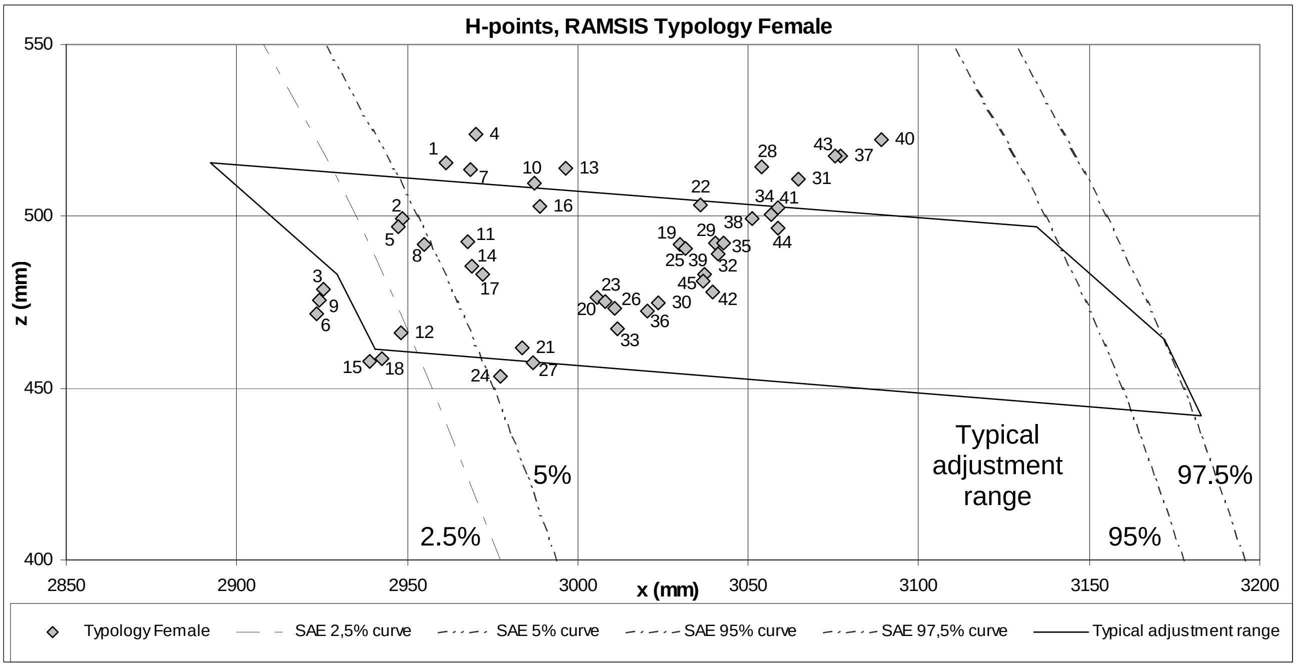


Figure 5.20. H-point locations of RAMSIS Typology female manikin family.

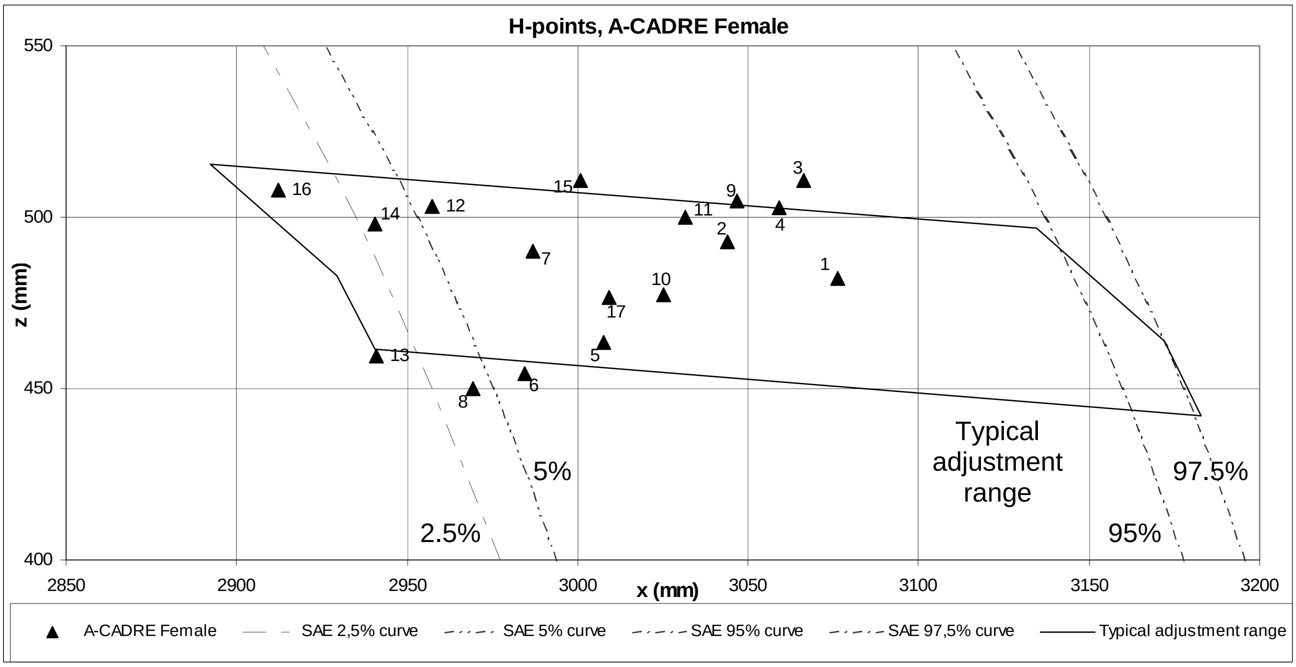


Figure 5.21. H-point locations of A-CADRE female manikin family.

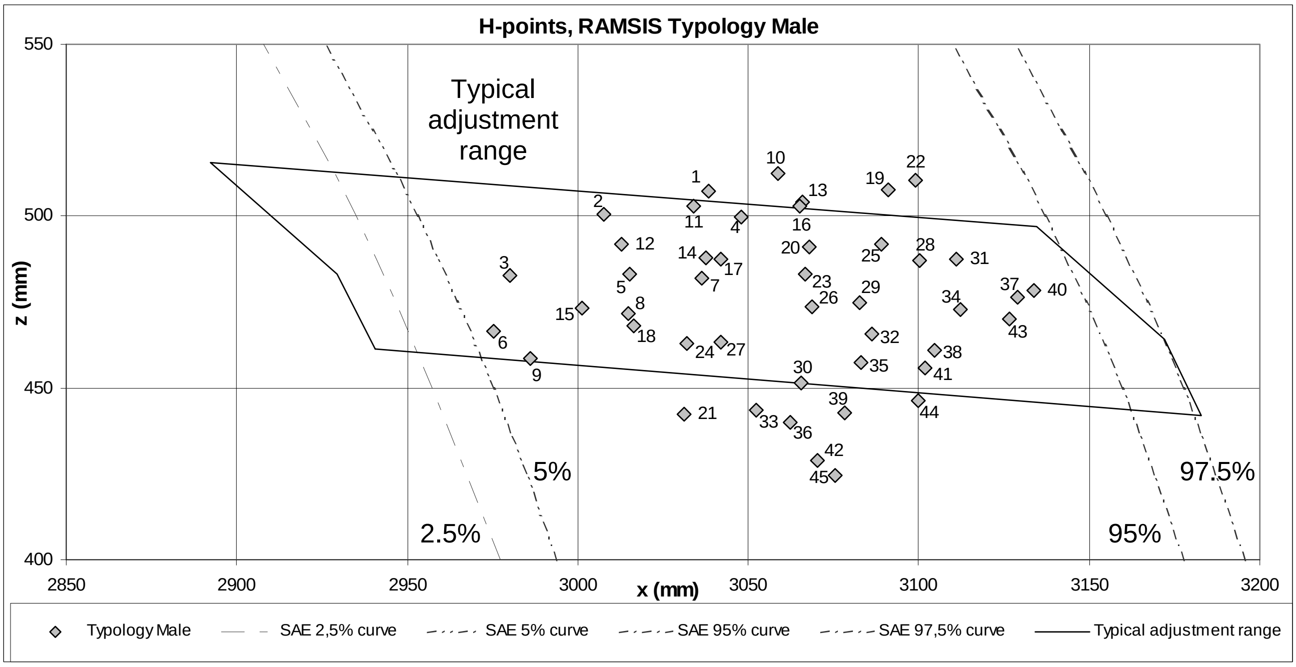


Figure 5.22. H-point locations of RAMSIS Typology male manikin family.

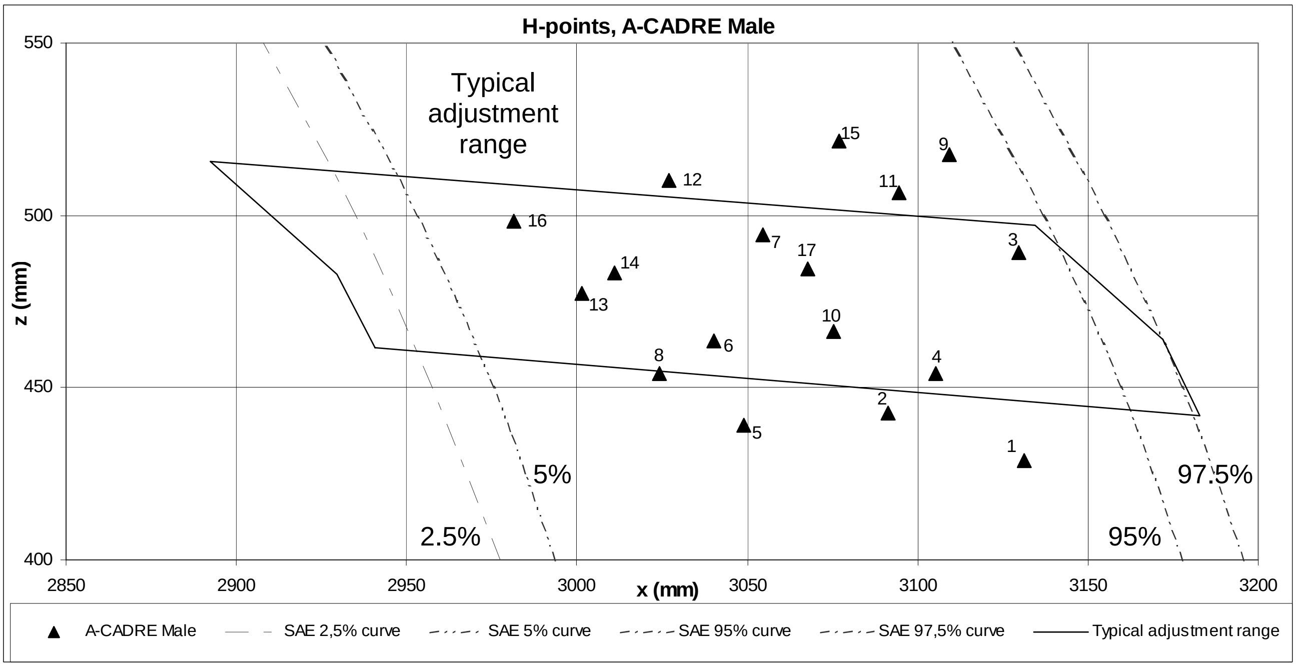


Figure 5.23. H-point locations of A-CADRE male manikin family.

Figure 5.24 shows H-point locations and approximate seat adjustment area indicated by the entire RAMSIS Typology manikin family, i.e. both female and male manikins, representing 90 simulations. Figure 5.25 shows the same for the entire A-CADRE family, representing 34 simulations.

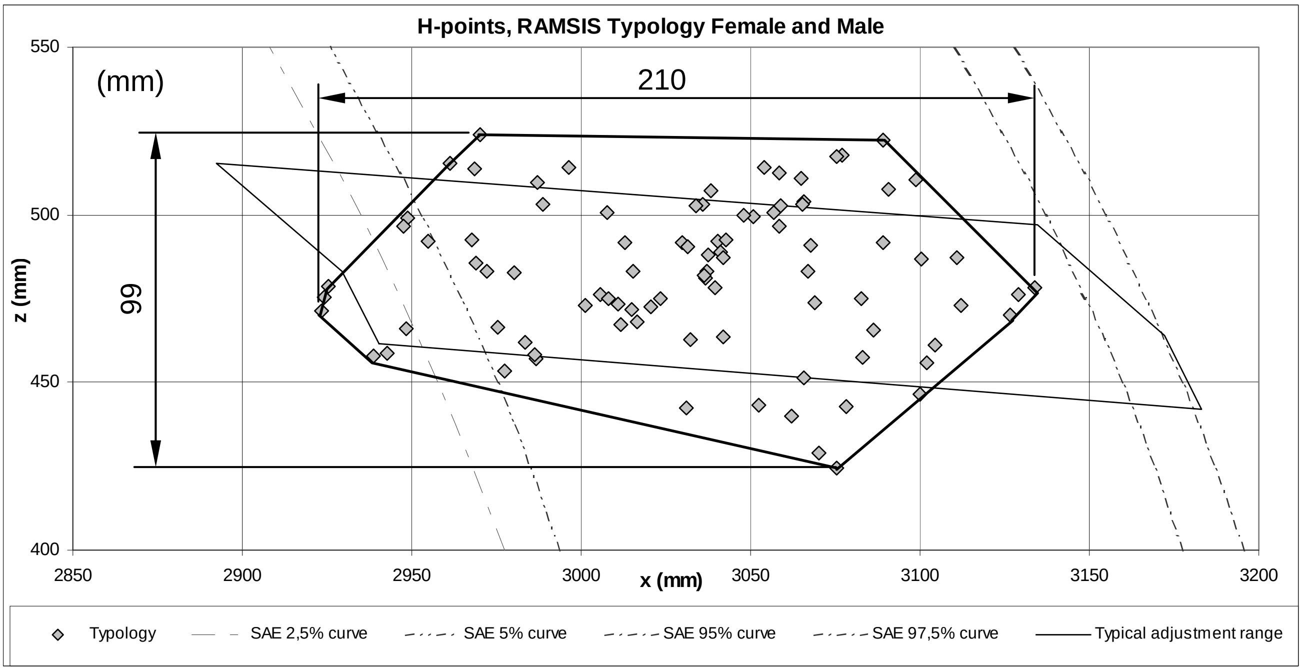


Figure 5.24. H-point locations and approximate seat adjustment area indicated by entire RAMSIS Typology manikin family.

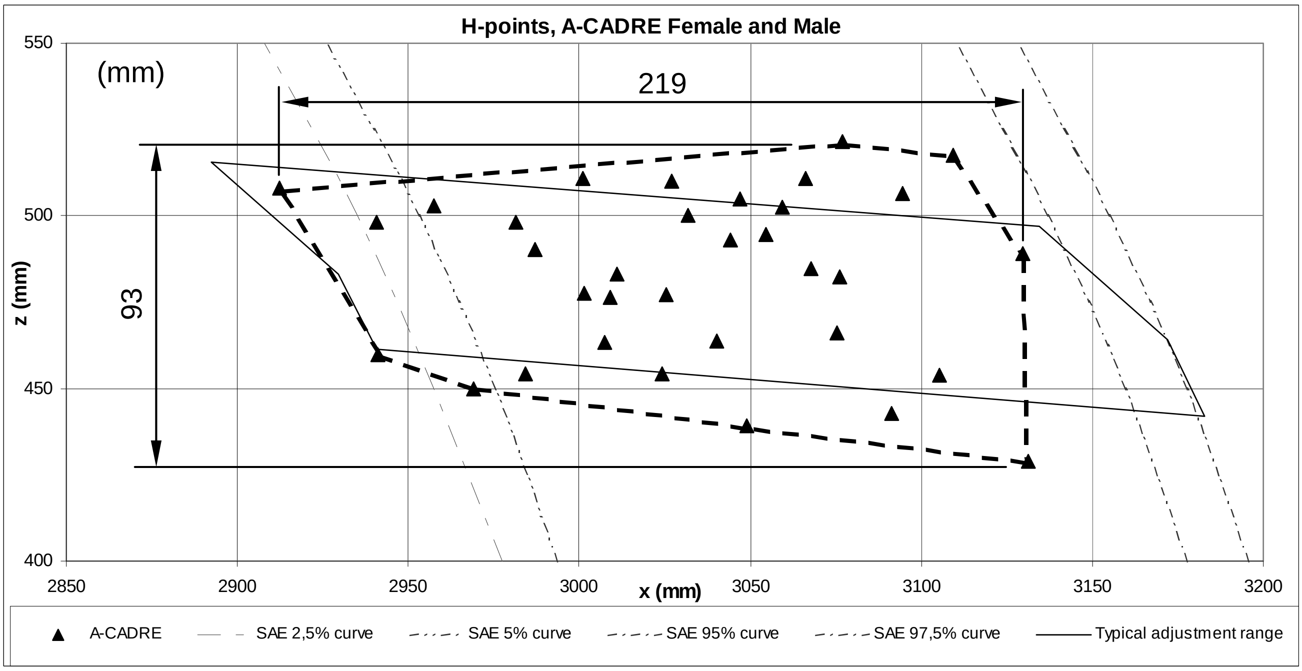


Figure 5.25. H-point locations and approximate seat adjustment area indicated by entire A-CADRE manikin family.

5.2.4. Discussion

In general, when comparing the simulation results with the present seat adjustment range, both manikin family approaches embody human diversity in a credible way (Figures 5.24 and 5.25). The manikin family results in an adjustment *area*, whereas the use of a small (e.g. 5th percentile woman) and large (e.g. 95th percentile man) manikin would only indicate a *line*. Of course, the selection of any two manikins would indicate a line (or a dot), but the careful selection of manikins in the families span an adjustment area that offers the designer valuable information of the adjustment area required to accommodate targeted users. The A-CADRE manikin family render results closer to the current adjustment range than RAMSIS Typology (Figures 5.24 and 5.25). Even though it is hard to draw major conclusions from this study, it is worth emphasising that A-CADRE gave these results by 62% fewer simulations required (34 compared to 90).

Simulation results show that the manikins were seated more forward than the current seat adjustment range enables, and the SAE accommodation curves indicate. When compared to the SAE curves, one possible reason would be body size differences due to different nationalities used in the simulations (German) and used in the development of the SAE curves (US). Indeed PeopleSize indicates that US populations on average are taller than Germans (PeopleSize, 2004). However, since the SAE curves were developed in the 1960s with 1960s anthropometry data, secular growth effects cause average stature of Germans of 2005 to exceed 1960s figures of US stature (Roe, 1993; PeopleSize, 2004). One possible cause for manikins to select positions more forward is the effect of the clutch pedal, which causes some drivers to select a posture that enables them to operate the clutch properly, while sitting more forward than otherwise preferred (Schneider and Vogel, 1988). The posture prediction functionality of RAMSIS is based on drivers sitting in German car mock-ups (Seidl, 1997), and most cars in Europe have a clutch pedal. The SAE curves are developed in the US (Roe, 1993), where automatic transmission is more common, enabling drivers to select a more rearward driving position.

The human simulation tool RAMSIS predicts posture fairly accurately (Loczi et al., 1999). Still, the tool predicts a mean posture based on empirical data obtained from studying a number of people. This means that if a test group, selected to be representative of the target population (hence being similar to the virtual test group), carried out the equivalent tasks as the virtual test group they are not likely to come to exactly the same results as the virtual test group. Ranking of the validity of each group's results is a complex issue and is likely to be a concern for the design team to agree upon and gain experience from.

Figure 5.26 show skin compositions of all members in the RAMSIS Typology (black) and the A-CADRE (grey) merged into one (monstrous looking) CAD geometry, separated per gender. Additional views and postures are included in Appendix 4.

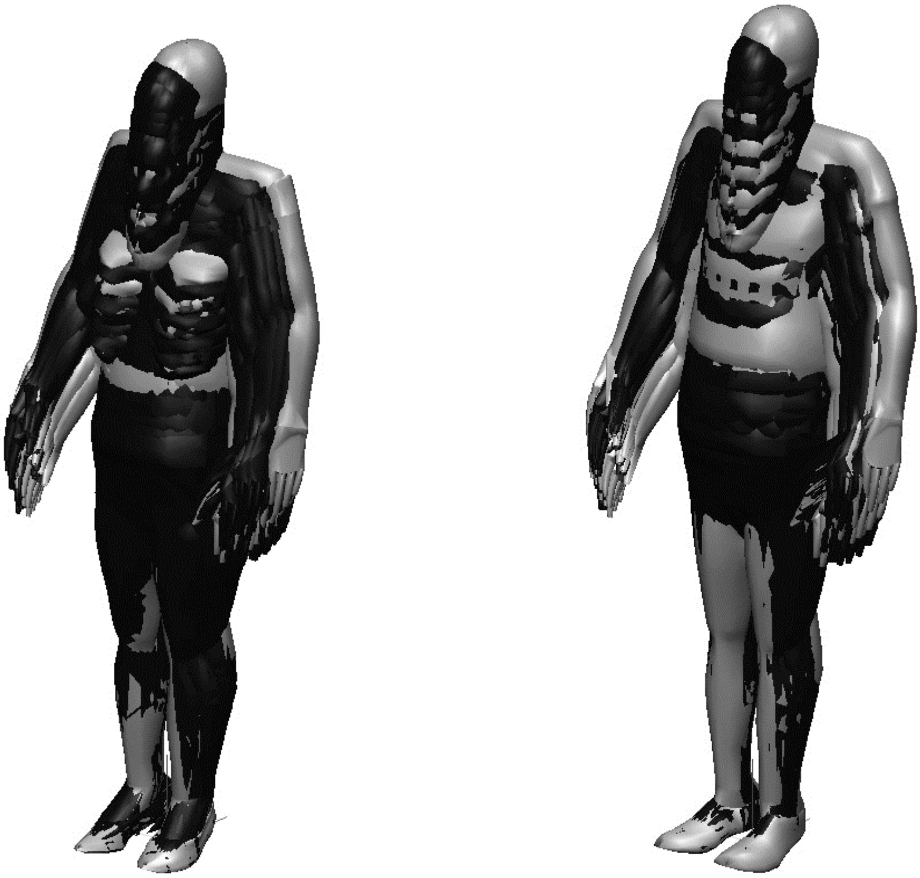


Figure 5.26. Skin compositions of RAMSIS Typology (black) and A-CADRE (grey) families for women (left) and men (right).

Not surprisingly, considering the larger coverage of stature of A-CADRE (Tables 5.6. and 5.7), the A-CADRE family represents taller manikins (grey geometry in Figure 5.26). More interesting is that the RAMSIS Typology seems to represent corpulence differently than A-CADRE. Tables 5.6 and 5.7 show similar numbers of coverage of corpulence but Figure 5.26 indicates that the RAMSIS Typology represents corpulence to a higher degree (hence the black abdomen), particularly for shorter persons. This may be an effect of sources of anthropometric data when creating the manikin families, and particularly of correlations between body measurements. The RAMSIS Typology is largely based on large anthropometric surveys done in Germany by measuring civilians (Flügel et al., 1986; Human-Solutions, 2004), whereas the A-CADRE is mainly based on

US Army personnel data (Bittner et al., 1987; Bittner, 2000). It is likely that people represented in the US study are on average more fit than people in the German study, and hence that the RAMSIS Typology manikin family more accurately represents corpulence of common people, which in turn better corresponds to the anthropometric diversity of typical car drivers. This effect is also noticeable when comparing values of corpulence for shorter manikins in the RAMSIS Typology and A-CADRE families in Appendix 1, where small manikins in the A-CADRE family are comparatively slim whereas the RAMSIS Typology family represents short people with both slim and large waists.

Figure 5.27 illustrates the effect discussed in Section 5.1.1 that women cannot be modelled as scaled down men since in some respects they are rather scaled up versions compared to men, e.g. in buttock circumference, hip breath and chest depth dimensions. Figure 5.27 shows men modelled in white colour and women in grey. The left model in Figure 5.27 shows this effect in the entire RAMSIS Typology family and the right model the effect in the entire A-CADRE family. The constraint in this simulation was that each manikin should keep its centre heel points at a fixed location and the line of sight 15 degrees down from the horizontal line. The posture taken by the manikins affects the results of this study, but the grey areas indicate that the female manikin families represent areas outside the boundary embodied by male manikin families.

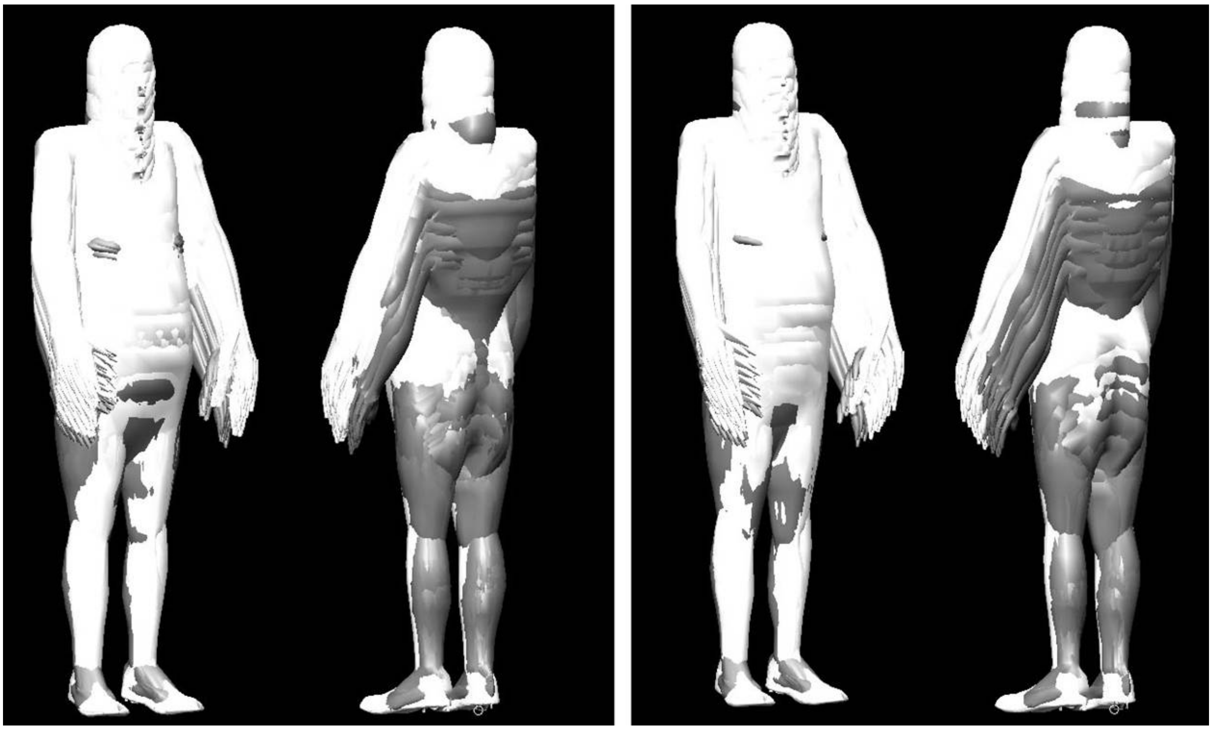


Figure 5.27. Effects of largest male (white) and female (grey) manikin dimensions for RAMSIS Typology family (left) and A-CADRE family (right).

The H-point study is not greatly affected by corpulence (as e.g. a seat design study would be), but an effect could have been that the RAMSIS Typology would result in manikins indicating a lower adjustment range than A-CADRE, particularly for shorter persons, but that is however not noticeable in Figures 5.24 and 5.25.

The constraints used in simulations affect the results obtained. For example, if the constraint C-1 (Figure 5.19), i.e. head clearance of minimum 20 mm vertical distance between head top (vertex) and inner roof, was set to 50 mm this would tend to make taller drivers select a different posture in order to fit within the constraints. How close to the inner roof an actual person would choose to sit is an open question, and is likely to be individual as well as being influenced by the car's design, e.g. by front window design.

The use of human simulation to predict H-point locations seems to be a more careful user consideration approach compared with the SAE occupant packaging guidelines (Figure 4.3). The human simulation tool generates realistic looking human pictures and might be considered as a more human centred approach compared to the more technical SAE method when performing adjustment range analysis. However, the human simulation and the SAE method complement each other and may act as benchmarking methods for each other.

An additional study is presented in Appendix 5 to further compare simulation results between the RAMSIS Typology and the A-CADRE family, and to compare results with a similar study by Vogt et al. (2005) that uses a variant of the RAMSIS Typology family (that does not consider diversity in corpulence). The study in Appendix 5 only utilises two constraints: a fixed mid eye point (a point right between the eyes) and a line of sight 5 degrees down from the horizontal line. The approach of starting the accommodation task from a fixed eye point is common in aircraft cockpit design (Roebuck, 1995) and has been used in some concept cars. This is a sensible and likely approach for future cars and requires adjustable pedals/floor, steering wheel and seat. Even this study shows that the two families render quite similar results, and that A-CADRE covers a larger range in height whereas the RAMSIS Typology covers corpulence to a larger degree (Appendix 5). The study by Vogt et al. (2005) gives somewhat different results but this is reasonable when considering the design of their family (this is elaborated in Appendix 5). Figure 5.28 shows A-CADRE manikin *Number 1* (tallest) and *Number 16* (shortest) to illustrate the span of anthropometry and posture. Since the only constraints are related to eye position and line of sight, the manikin will position itself in the most comfortable position according to the posture prediction functionality in RAMSIS. To accommodate these postures would require large adjustment ranges, which may not be feasible for economic or other reasons. However, the level of comfort experienced is not very distinct and a small variance from an ideal posture is unlikely to result in major variations of comfort level, i.e. comfort level is not as firm a constraint as for example reach or fit. It is likely that a small reduction of comfort level would enable adjustment ranges to be reduced a great deal. This would require a deeper study that is outside the scope of this thesis. A conclusion is that careful interpretation of simulation results is needed since the level of importance of following the results differs depending on how the study is set up and what is to be considered.

Figure 5.28. Fixed eye position. Tallest male and shortest female in A-CADRE shown.

If basing major decisions on postures predicted by RAMSIS, particularly when there are few constraints and the posture is largely based on optimised comfort, it might be relevant for a car company to develop their own data for posture prediction since it might be that the targeted customers differ from the ones used for developing the data in RAMSIS. This may also be an approach to differentiate the car in relation to competitors' cars. Hanson et al. (2004) describe an example of such a posture study.

There is a risk associated with the realistic appearance of manikins. Albeit a nice feature at presentations, the 'good look' might bias the human simulation tool user to comprehend the man model as 'real' and therefore accurate (Ruiter, 2000; Alexander and Conradi, 2001). It is important not to see human simulation results as truth, but rather as indications. If the human simulation tool has high functionality and usability, and the simulation is carefully carried out, the results can be seen as realistic indications. Ziolek and Nevel (2003) highlight issues related to misuse and misinterpretation of human modelling, and remark that model validation should be viewed in the context of a continuous process not an end goal.

Rönnäng et al. (2003) suggest a collaborative approach, involving people with different backgrounds and knowledge (production engineers and ergonomists in the study), when interpreting human simulation results, since they tend to interpret results differently. Ruiter (2000) highlights the importance for human simulation tool developers to provide the tool users with information of the shortcomings and accuracy of the tools. While expert human simulation tool users are likely to be familiar with the drawbacks of the specific software he or she uses, it is not realistic to assume that an occasional user, such as a designer, will be as familiar with the tool's limitations (Ruiter, 2000). The expected growth of human simulation tool usage among designers (and others), without special training, reinforces the need to inform the tool users of the tools' limitations, and to evoke careful handling (Ruiter, 2000). This puts pressure on the tool developer to adapt the tools to the 'new' way of usage. Ruiter argues that, rather than solely aiming efforts at improving the actual human model, human simulation tool developers need to find out what designers require from the tools, what they use them for and how they use the tools, and thereby enhance the usability of the tools and reduce the likelihood of misuse. In a sense one can consider human simulation tools as being on the lower section of the hierarchy of user needs, i.e. at the functionality level, as discussed in Section 2.4.2 (Figure 2.5). The next demand will, according to the model, be related to the usability of the tools, particularly if the aim is to develop human simulation tools to become a 'designers tool'.

5.3. Concepts for Expanded Assessment

It would be advantageous if human simulation tools could represent the human more fully than is the case today (as discussed in section 5.1.7). This would make the tools even more valuable for simulating humans at virtual stages of the design process. Simulating fully realistic human behaviour is extremely complicated, basically since humans are extremely complicated, e.g. in the way that we perceive, think and operate our body. Thus, considerable research and development is required to achieve this objective.

The next section describes the author's ideas of a different approach towards enhancing human simulation tool functionality, mainly in the sense of making human simulation tools become valuable 'designers tools'.

5.3.1. Applying User Characters to computer manikins

A more low-tech approach, compared to combined physical and cognitive human models as described on Section 5.1.7, to enhance the functionality of human simulation tools would be to apply the User Characters method (as described in Section 3.2) on computer manikins, i.e. to develop each or some of the manikins in a manikin family into a character. This means that the manikin would represent both physical and psychological diversity, indirectly implying behavioural processes. In a design context this could be an approach to support designers to consider human diversity in the design process, particularly at early virtual and conceptual design stages. In essence, such a computer manikin family can potentially be the means to inform and inspire the designer regarding all kinds of user related aspects, both connected to utilitarian and emotional issues, i.e. all levels in the hierarchy of user needs (Section 2.4.2). Guidelines, facts and figures, e.g. related to communicative and ergonomics aspects (as discussed in Section 2.4.1) can be supplied in the same package as the manikin family. This information should be supplied in a way that is adapted to designers' need, e.g. in a similar way as ergonomics guidelines are presented to designers (Blomé, 2004), which eliminates some of the common problems of ergonomics reference handbooks in meeting designers' needs, as identified by (Vicente et al., 1998). As discussed earlier, User Characters is no miracle method, but usage shows that the method aids designers to develop a richer view of users and a better understanding of human diversity (Buur and Nielsen, 1995; Fulton Suri, 2000a; Pruitt and Grudin, 2003). The amalgamation of computer manikins and User Characters, which we may call *Manikin Characters* to support discussion, can act as a complement to other tools and methods at the designers' disposal such as design methods, CAD, databases and reports.

Differently to virtual humans as discussed in Section 5.1.7, assuming they would be available to common designers, Manikin Characters would leave a greater part of the design task in the hands of the designer. This may not be bad. All people, even designers of course, meet and interact with people, have opinions about people, recognise 'types' of people and are able to imagine how people will probably respond to certain situations and inputs. Grudin and Pruitt (2002) comment that, from birth or soon thereafter, every day in our lives, we use partial knowledge to draw inferences, make predictions and form expectations about the people around us. We are not always right, but we learn from experience. We continue to extrapolate, and user characters evoke this universal capability and bring it into the design process (Grudin and Pruitt, 2002). Mikkelson and

Lee (2000) report that research in understanding designers and the design process shows that designers often create mental images of users, particularly within simulation of solutions, in order to experience the design from the user's view. Manikin Characters can be a way to support and evoke this kind of empathy for the users by the designer. Figure 5.29 give some abstract illustration of Manikin Characters.

Figure 5.29. Abstract illustration of Manikin Characters.

The concept behind Manikin Characters resembles the ideas behind the knowledge system GAMAK as presented in (Cavdar and Babalik, 2004), but whereas GAMAK assists engineers and designers to consider machine acoustics, Manikin Characters would assist consideration of human aspects in product design. Both concepts have in common the aim to support the designer with appropriate information as well as to stimulate the designer's creativity, rather than aiming to offer direct design solutions. The author's ideas of Manikin Characters are further developed in Section 7.3, *Considerations of Further Work*.

Finally, although human simulation tools, User Characters and other tools and methods that support designers to consider requirements and desires of people that differ in many ways are valuable, they should not be applied in isolation; designers interacting with real users still is a superior approach in many ways.

5.4. Summary

The aim of the chapter was to study how human simulation tools can aid designers to consider human body dimension variety in product design to assess and maximise accommodation of users of diverse anthropometric characteristics.

Since the issue of human anthropometric diversity is not straightforward to consider in product design the possibility of modelling humans and realistically simulating and visualising outcomes make human simulation tools valuable aids for ergonomists and designers.

One problem facing the tool user is to know how to select or dimension appropriate manikins to be used in simulations. The number and characteristics of appropriate manikins depend on the design problem at hand. Although an experienced human simulation tool user may regard this issue as straightforward, this problem needs to be managed in order to enable human simulation tools to become 'designers tools'. It is not realistic to assume that an occasional tool user will be able or have time to analyse appropriate manikins to use in simulation. One approach to solve this problem is to always use a particular set of manikins in simulations, which would ensure that all bodily characteristics are included in the study. Even though this might sometimes mean unnecessary simulations, that detail is believed to be a minor disadvantage.

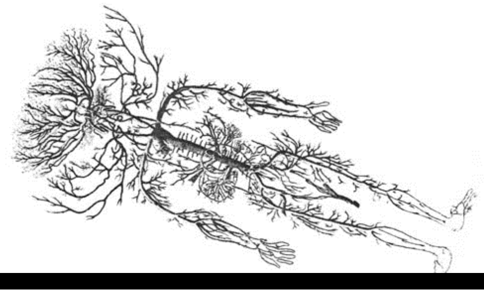
The studies carried out indicate that both manikin families, RAMSIS Typology (45 members) and A-CADRE (17 members), gave rather similar results. It is hard to claim that one manikin family is better in all respects than the other but A-CADRE shows promising functionality especially bearing in mind the limited number of members.

By using a distinct manikin family, a high level of accommodation can be reached even though based on a limited number of simulations. This approach is time effective and relieves the designer from the complex task of selecting appropriate manikins for each design problem, which is particularly difficult in multivariate problems such as vehicle interior design. The inclusion of a manikin family in the human simulation tool supports Hypothesis 2 by enhancing the functionality for non-expert users (particularly).

Future developments of human simulation tools with expanded functionality to represent the product user realistically from a holistic perspective, both related to physical and psychological characteristics, will make the tools even more valuable for designers. The concept of *Manikin Characters* has the benefit of potentially being relatively easy to put into practice since it is largely based on existing tools and methods. The aim of the *Manikin Characters* concept would be to support designers with appropriate ergonomics information, simulate physical ergonomics in a realistic way as well as to stimulate and evoke designers' creativity and empathy for users, rather than trying to realistically simulate the 'entire' user, or aiming to offer direct design solutions.

Chapter 6

Discussion



This chapter summarises the research carried out (Chapter 2 to 5), and discusses the findings in relation to the two hypotheses established in Chapter 1. Since the hypotheses are somewhat intertwined some discussion relates to both hypotheses, but in general, arguments related to communication of ergonomics between the designer and other people (e.g. ergonomists or other designers) relate to Hypothesis 1, and discussions about designers' employment of tools and methods for the consideration of ergonomics simultaneously with affected and affecting design issues (e.g. safety, aesthetics, strengths, manufacturing) relate to Hypothesis 2.

6.1. General reflections

The research demonstrates a general shortage in considering user aspects in product development, which also covers ergonomics considerations since, in this context, the objective of ergonomics is to make products compatible with the needs, abilities and limitations of the users. To remedy this situation product designers need methods that support the consideration of ergonomics. However, methods not adapted to designers' working methods and conditions are likely to give poor results. Several reports show low usage of design methods in industry, and trying to bring in another method focusing on ergonomics is a challenge. Albeit a relevant area for product designers, ergonomics is still quite remote from many designers' speciality or deep interest, making acceptance and use even more demanding.

Since CAD is a major tool for designers, and since more functionality is continuously being implemented in the tools, it seems promising to use the CAD system as a vehicle for ergonomics input. To a degree that is offered today but there is still much to do before human simulation tools can reach the level where they have the chance of becoming a 'designers tool' in the same sense as CAD systems today enable the designer to easily model and modify geometries, simulate assembly or analyse stress and strain. Current human simulation tools are still too complex to use, making it 'too easy to do things wrong'. However, some characteristics of the tools indicate opportunities for being of great assistance in the task of developing products that are ergonomically sound for the targeted users. This argument will be discussed further in following sections.

6.2. Hypothesis 1

According to Hypothesis 1 - '*means for ergonomics communication*'

Human simulation tools act as a means to support communication of ergonomics with other members of a product development team, particularly between designers and ergonomists.

As noted in Chapter 1, this hypothesis is based on the assumption that the tool will support communication of ergonomics to and among members of the product development team. In particular, it helps in packaging ergonomics information in a way that is compatible with designers' working methods and conditions. The information may be obtained directly from an ergonomist, or indirectly through ergonomics information, where both approaches involve a human simulation tool.

The following text aims to delineate what conclusions can be drawn on the basis of the research in respect to Hypothesis 1.

Since human simulation tools enable ergonomics evaluation of a design at virtual stages, ergonomics issues can be dealt with at these early stages. The alternative of postponing the evaluation until mock-ups or prototypes are manufactured would put tension on the communication, particularly if major deficiencies are identified (Section 3.1.1, 4.1.1 and 4.1.2).

The human simulation tool offers ergonomics information to be adapted to the design problem at hand, i.e. not being static and generic data in a handbook or similar, thereby giving more valid and interesting results to the designer. This feature supports interpretation and communication of ergonomics information among designers and ergonomists (Section 3.1.2 and 3.1.4).

The human simulation tool supports communication and integrated work among designers and ergonomists by offering a common approach towards ergonomics integration in product design, i.e. a common tool, method, language (or terminology) and forum (Section 3.1.4, 4.1 and 4.3.4).

The opportunity to visually convey ergonomics information in human simulation tools is valued by designers since it matches their typical manner of thinking and communicating visually, making the ergonomics information easier to comprehend and put in context (Section 3.1.2, 3.1.4 and 4.1.4).

Further developed, human simulation functionality integrated in a CAD system can be a valuable channel for providing designers with ergonomics information. This can involve functionality for anthropometric and biomechanical analyses, as well as functionality to evoke understanding and considerations of diverse users from a more holistic perspective, e.g. as offered by the *Manikin Characters* method (Section 5.3.1). Thus, the tools can act as a channel for conveying ergonomics and indeed also marketing information about targeted users to designers (Figure 6.1).

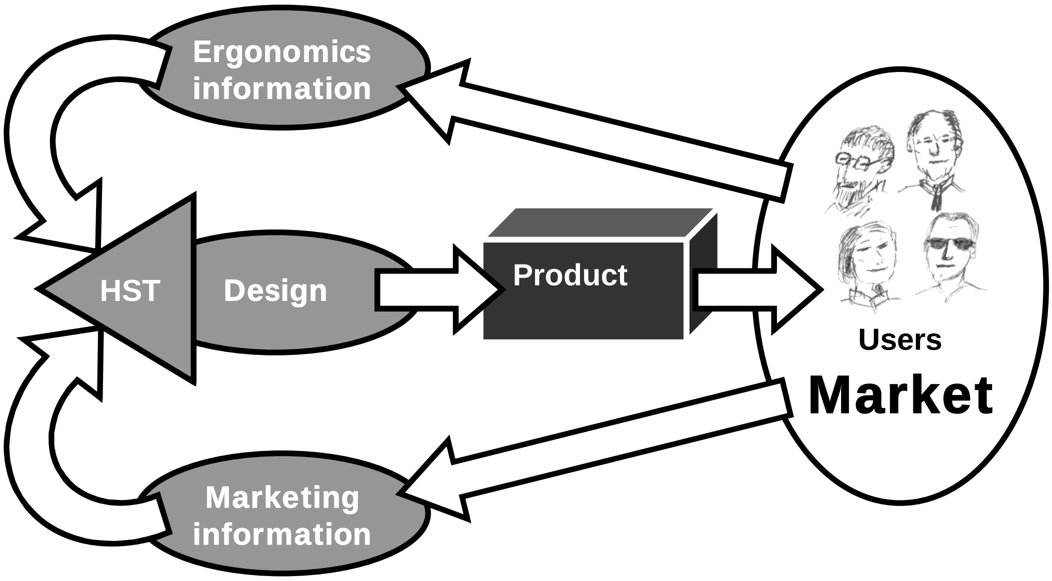


Figure 6.1. Human simulation tool (HST) as a channel for conveying ergonomics and marketing information to designers.

Using the same tool naturally forms a common forum for ergonomists and designers when discussing ergonomics issues. The ergonomist is likely to be more knowledgeable about the ergonomics issues applying to the design problem at hand and the tool's limitations, whereas the designer is more familiar with the product being developed and the opportunities for successful modification. Together they form a powerful unit. In cases where the ergonomist is not available, or for familiar types of design problems, the tool acts as a substitute for the ergonomist. In a sense this may cause increased risk of misuse but compared to the alternatives, e.g. to base design decisions to a greater extent on assumptions or having to delay product development, this is regarded as a better alternative. In cases where an ergonomist's evaluation and approval is essential in order to proceed in the product development process, the Overlapping Framework can aid the scheduling of ergonomics evaluation. This is regardless of whether the evaluation is done in a virtual or physical environment. However, since human simulation tools enable evaluations in virtual environments the identified appropriate timing can be followed regardless of whether a physical product exists or not.

6.3. Hypothesis 2

According to Hypothesis 2 - '*designers tool*'

Human simulation tools assist designers in considering ergonomics issues in product design concurrently with other design requirements.

This hypothesis is based on the assumption that the designer himself or herself uses the human simulation tool, in a similar way as he or she uses other tools, e.g. CAD and CAE tools. The human simulation tools' capacity to offer the designer quick feedback of the product's ergonomic qualities supports generation and evaluation of design alternatives, where ergonomics is reconciled with other product qualities.

The following text aims to outline what conclusions can be drawn on the basis of the research in respect to Hypothesis 2.

By offering human simulation tools as part of the designers' package of CAD tools it becomes 'their' tool and it signals the importance of integrating ergonomics, and as being a 'normal' issue to consider when designing products (Section 4.1.4).

Enhanced functionality and usability of human simulation tools means that the tools have the potential to become 'designers tools'. An example of enhanced functionality and usability is the formal human simulation process provided by the developed web-based support system since it makes it easier for tool users to 'do things right' by guiding the user through the process, i.e. it encourages the user to follow, from an ergonomics point of view, an appropriate working method (Section 4.1.4 and 4.3.4).

Another example of enhanced functionality and usability is the implementation of pre-defined manikin families in the tool. In this way the designer can consider anthropometric diversity rather straightforwardly even though not being required to know the problems in detail or the theory behind the manikin family, but rather putting his or her design efforts into making sure that all manikins are accommodated by the design. One great advantage is that this approach relieves the designer from the complex task of selecting appropriate manikins for each design problem, which is particularly difficult in multivariate problems such as vehicle interior design (Chapter 5).

By enabling the designer to see and operate the user as well as the product modelled in the same virtual environment, human-product interaction issues are more easily considered concurrently with other design issues, thereby supporting the synthesis work that is characteristic of design (Figure 6.2). The opportunity to quickly and easily modify geometry and operate the human model, and to observe what result this leads to, is expected to improve the designer's creativity and hence result in better final product solutions (Section 2.3 and 4.1.5).

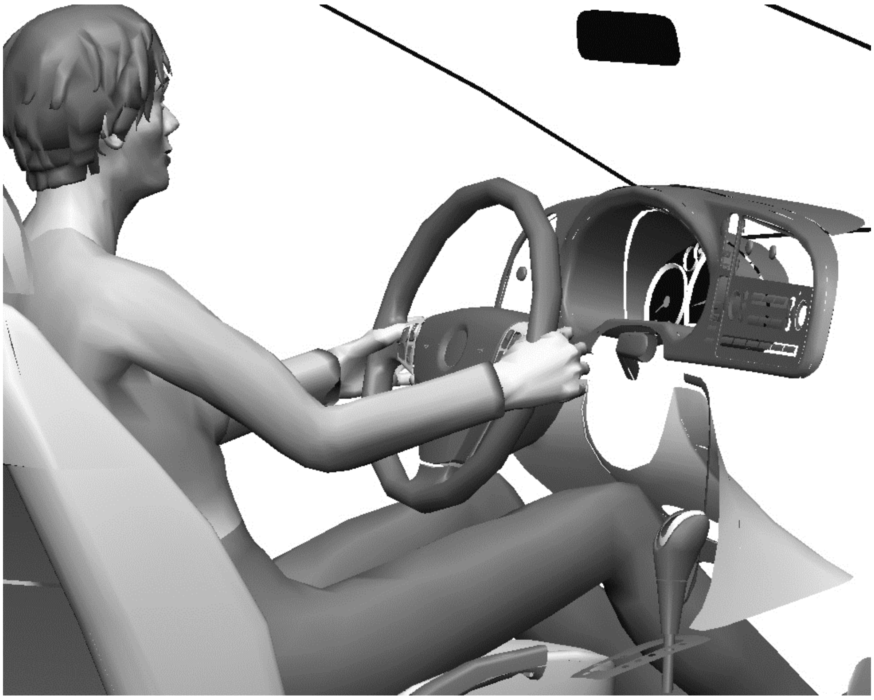


Figure 6.2. Geometry revision and human model operation within one system.

Finally, if future human simulation tools combine physical and cognitive models where the product user can be considered in a more all-compassing sense, e.g. both related to anthropometrical, biomechanical and psychological characteristics, this would enhance the tools' value for designers to reconcile ergonomics issues along with other product requirements, particularly at early virtual stages of the design process (Section 5.1.7 and 5.3). Even the more basic concept of *Manikin Characters* (Section 5.3.1) would assist in turning human simulation tools into 'designers tools' by the features of supporting designers with appropriate ergonomics information, simulating physical ergonomics in a realistic way as well as stimulating and evoking designers' creativity and empathy for users.

Chapter 7
Conclusions and Further Work

This final chapter discusses the research layout and the relevance and validity of the results and suggestions presented in the thesis. The six studies that were carried out are each reviewed from a methodological point of view, as is the function of the two hypotheses established. The chapter also includes considerations of further work.

7.1. Reflections on Research Methods Used

This research can be distinguished as encompassing a wide research area where several foci, levels of detail and perspectives could have been taken by the researcher. The structure of the research and the choice of research methods employed to acquire knowledge in the area is arguable. The wide area of ergonomics integration in product design could have been studied in a range of ways. One deep study in a sub-area would perhaps have been a more usual research approach, likely to lead to more distinct results although perhaps somewhat isolated. Two reasons can be identified that affected this decision to employ a wide encompassing format. The first is the author's bias towards synthesis and looking at things holistically, possibly a consequence of an educational and professional background in product and engineering design. The second is due to the conditions for this research, where a research subject area in integrated product development is to be established at the author's home university, meaning that a wide spanning research enables a research field to be investigated in which a narrower relevant and interesting research area can evolve. Also a range of other factors influenced the arrangement of the research and eventual choice of methods. One factor is the author's initial comprehension of the research area and research in general which built up throughout the research project meaning that the author's developed knowledge and view of things affected the research agenda established at the outset. Another factor that influenced the research project and methods used was the collaboration with other researchers and involvement in research projects. The opportunities for these fruitful and educational collaborations came up during the project and meant that the author's research activities had to be tailored somewhat in content and time in order to fit with collaborators' intentions and plans.

The following section discusses the relevance and validity of the research methods employed in the six studies carried out at different phases of the research. Each phase also included a literature review to consider other researchers' findings and to put the research in context.

7.1.1. Study of product developers' interaction with users (Section 2.5)

The objective of the interview study was to increase comprehension of how people working within product development organisations communicate with and about users of their products, and the general need for methods to support communication of user aspects in product development (*Research objective 1*). Semi-structured interviews with people involved in product development (design engineers, product development managers and marketing representatives), performed according to interview methodology recommendations in (Lantz, 1993), were used to gather qualitative information. An interview guide was developed and used for each subject in all interviews. In total 12 interviews were carried out, each 45-75 minutes long. Each interview was documented using a tape recorder and transcribed before analysis. Each company received the outcome of the study afterwards to enable them to comment on the results.

The two researchers performing this study (Janhager and Högberg) agreed on performing interviews rather than sending out questionnaires due to the enhanced opportunity to develop a proper comprehension of the issues studied. The opportunity to meet and talk to people directly and having the chance of explaining and asking further questions meant that the interview method was considered appropriate for this study. The interview guide gave structure to the interview and conformity between interviews.

Criticisms of the study could include the low number of interviews carried out, at only four companies, representing only two industry sectors, which restricts the reliability of the study. This criticism is acknowledged but the approach was considered adequate for this study basically due to both researchers' time limitations.

7.1.2. User Characters study (Section 3.2)

The User Characters method was included in the thesis as a potential method to support ergonomics integration and user diversity consideration in product design (*Research objective 2*). In a sense the user characters study can be considered as being limited in research weight since it involves little formal gathering of external data, apart from the literature review. The employment of the method was carried out by the author in another context than for research purposes. The example was considered meaningful to illustrate the application and to support reflections and discussions about the method. In addition, the author has experiences of teaching the User Characters method to different types of engineering students (mostly mechanical engineers). By informal studies of the outcome of student projects and exam answers the author had the opportunity to get a notion of the benefits of using the method. An argument for including the User Characters method in the thesis was the author's earlier positive but basic experiences of the method for enhancing user consideration in product design, making the method relevant to study further in the context of the overall theme of ergonomics integration in product design and user diversity consideration. Another argument was the author's idea of combining the User Characters method with computer manikins, described as *Manikin Characters* in Section 5.3.1. This could be an important future direction for more comprehensive human simulation tools.

7.1.3. Overlapping Framework study (Section 3.3)

The existing Overlapping Framework by Krishnan et al. (1997) was modified and implemented in the context of ergonomics evaluation in product design with the intention that it would support the scheduling of ergonomics evaluation in design processes and thereby ease collaboration and communication between product designers, project managers and ergonomists (*Research objective 3*). The evaluation of the developed framework was done by implementing the method into a car developing company's current procedure for ergonomics evaluation and then studying the outcome and relevance. The implementation and assessment of the method was done by consulting a product development professional, i.e. the manager of the ergonomics department at Saab Automobile, who has many years' experience of ergonomics evaluations in several car development projects. The discussion began with explaining the framework and then 39 evaluation tasks were organised according to the framework, using a prepared enquiry guide to support the discussion. Finally the subject was asked to give his initial opinions of the method, giving positive results. A full implementation and a period of using the method would give a much better view of the relevance of the method, but this would require the method to be authorised by the company since it would significantly affect the car development process, not only the ergonomics department.

A common problem with design research is to find relevant measurable criteria (Blessing and Chakrabarti, 2002). Profit would be relevant since that is the driving force in most companies, but it is considered impossible to measure in a way that could be linked to the research carried out. In this study the criterion was professional judgment, obtained from experienced people working within product development. The approach of evaluating a method by using professional judgment conforms to 'the authorisation model' (Westlander, 1999).

7.1.4. Simulation of human-vehicle interaction study (Section 4.2)

This study was done to enhance understanding of the current procedures for using human simulation tools in vehicle design in different departments at Saab Technical Development Centre (*Research objective 4*). Eight semi-structured interviews of about 90 minutes were conducted, supported by an interview guide to give structure to the interview and conformity between interviews. Green's (2000) generic process for human simulation was used to structure the simulation methodology discussion. The results were transcribed before analysis and subjects received the interview protocol afterwards to enable them to complete and/or correct information.

One criticism of this study is the low number of interviews carried out, which restricts the reliability of the study. However, the amount of people using or having some kind of professional relation to human simulation tools is still low, particularly when considering companies in a wider perspective (the vehicle industry is a major user of human simulation tools compared to other types of industries). This restricts the number of people that is possible to interview in this kind of study.

7.1.5. Web-based support system study (Section 4.3)

The objective with this study was to build on the experiences from the previous study as well as to exploit proposals and findings from other researchers, and from this knowledge foundation develop a prototype of a web-based support system for a human simulation process that would remedy many of problems identified (*Research objective 5*). Since the support system to a large degree is a bespoke application, it was considered beneficial to employ a participative design approach inspired by Wilson and Haines (1997). Three prototypes were developed and evaluated in an iterative manner. The first two prototypes were presented with demonstrations to a group of subjects consisting of industry human simulation tool users and industry project leaders and managers. The subjects evaluated the prototypes in a walk-through discussion of the contents and features. Ideas and requests were documented by taking notes and used to update forthcoming prototypes.

The first prototype was evaluated by human factors engineers at the Usability/Ergonomics Centre at Saab Automobile. The second prototype was evaluated by human factors engineers at Harmony and Human Factors at General Motors, USA and at the Usability/Ergonomics Centre at Saab Automobile. The third and final prototype was a modification based on opinions of the second prototype and existing documentation at General Motors gathered in the second evaluation round. This prototype was individually evaluated by eleven subjects, who were divided into four groups: *industry users* (3), *industry manager and project leader* (2), *university users* (4), and *interface experts at universities* (2).

A criticism of this study could be the low number of subjects evaluating the prototype system, which affects the reliability of the study negatively. Preferably it would have been a larger group of subjects, but human simulation users are rare at present and since it was considered important that the subjects were representative of the intended system users, the quantity of subjects relevant to appoint in the study was heavily reduced. However, a strength of the study is the attempt to include both development and evaluation of the support system. An approach of developing a system which benefits would have been supported by some untested superlatives would have been weaker from a reliability point of view.

According to Wilson and Haines (1997), participatory ergonomics is a process that frequently leads to the development of effective, efficient, usable and accepted tools and products. However, participation sometimes slows the process down due to lack of motivation among participants, e.g. because of an already high workload or limited interest on an individual or organisational level. Furthermore, participants may have difficulties seeing problems in a wider perspective, such as consideration of future changes or the concerns of other affected parties. In this study the development process was not always smooth and several of the negative sides of participatory ergonomics mentioned above were apparent. This is thought of as being an effect of the considerable impact that the suggested process would have on work process and organisation.

7.1.6. Computer manikin family study (Section 5.2)

The objective of this study was to investigate how the implementation of computer manikin families in human simulation tools can support designers in considering human anthropometric diversity when aiming to accommodate targeted users in multivariate problems such as automobile cockpits (*Research objective 6*). This was done in a technology-centred way by comparing results from the included manikin family in the human simulation tool RAMSIS, which is used for human accommodation in vehicle design by more than 70% of the car industry worldwide (Human-Solutions, 2005), with results from the A-CADRE manikin family (Bittner, 2000), for this study implemented in RAMSIS. This study is by its nature dependent of the functionality of the human simulation tool RAMSIS. The posture prediction and comfort assessment functionality in RAMSIS has been evaluated with largely reliable outcomes by Loczi et al. (1999). The results from the study depend also on the way the tool user, i.e. the author in this case, designs the study. To assess the reliability of the study the results were compared to the current vehicle design and SAE vehicle accommodation guidelines (as shown in Figure 5.24 and 5.25). The results were also informally discussed with people at Saab Automobile who had experience of human accommodation in vehicles both from real test group evaluations as well as through feedback from Saab customers on the market. Another benchmark was the comparison of results from a similar vehicle accommodation study in RAMSIS by Vogt et al. (2005). The comparison of the results with all these benchmarks indicated that the results were truthful. Still it is acknowledged that there is a range of factors influencing the reliability of the study.

7.1.7. Reflection of the hypotheses' function in the thesis

The two hypotheses that were established in Section 1.3.1 had the main function to convey the overall incentive of the research, and to unite the research activities carried out and to place them in a common context, even though the proximity to the hypotheses varies for different phases of the research. For this purpose the hypotheses are constructive. However, even though the hypotheses are considered in discussions throughout the thesis and at some places supported by strong coherent arguments it is arguable how strongly the hypotheses have been really tested for their accuracy. It is also debatable whether an appropriate research approach has been utilised when aiming to test the hypotheses. Nevertheless, the hypotheses are thought of as being important and valid for the development of designers' tools and methods for integrating ergonomics in product design, the latter an important objective in itself. The hypotheses may well be developed further and act as inspiration in future research.

7.2. Contribution

The contribution of this research can be looked at from different perspectives. One contribution is the relatively uncommon way of viewing, discussing and studying human simulation tools as being design tools used by 'common' product designers to support creativity and synthesis. In general, research about human simulation tools is related to the optimisation of the tools' functionality to accurately represent human beings, or about the application of the tools by specialist users, typically in a production ergonomics context or applied in the design of complex products such as airplanes, vehicles or military equipment. A reason why this approach is uncommon can be due to human simulation tools still being in their early days where aspects of widespread use by designers and the implications for usability in occasional use by non-experts are still not identified as significant research areas.

On a more concrete level the Overlapping Framework for aiding the scheduling of ergonomics evaluations is a contribution albeit still being considered as a 'draft' method that needs to implemented and evaluated in a realistic industrial setting to be tested for validity.

Another contribution is the web-based support system for the human simulation process. Even though still a prototype, the system's conceptual design is well thought out. The design evolved through review of the relevant research literature, several deep discussions at research project gatherings, use of current experiences at the company and evaluations of design concepts by representative users in a participative and iterative manner.

A final contribution is related to the use of manikin families in human simulation tools in product design processes to assess and optimise the accommodation of users of diverse anthropometric characteristics. By using a distinct manikin family, a high level of accommodation can be reached even though based on a limited number of simulations. This approach is time effective and relieves the designer from the complex task of selecting appropriate manikins for each design problem, which is particularly difficult in multivariate problems such as vehicle interior design.

7.3. Considerations of Further Work

Due to the wide spanning characteristics of this research there is wide scope for further work.

The Overlapping Framework needs to be developed and tested further in order to assess its value. This is thought of as requiring an implementation in an actual product development setting in a company developing products with a clear ergonomics content.

Also the User Characters method would be interesting to study further. Today the method is mostly used in software design, e.g. as illustrated by (Pruitt and Grudin, 2003) and it would be interesting to study how the method can inspire designers and engineers of physical products to evoke user diversity consideration. An assumption is that the method is rather easily adopted by designers working with conceptual design, e.g. industrial designers, whereas the method may be harder to implement among design engineers essentially occupied by detail design. This might be due to educational and habitual differences but also because the method may be of less value in those design stages. Methods for the actual development of the user characters can be further developed. An interesting approach is shown in (Greaney and Riordan, 2003) where they demonstrate how statistics can be used to derive user characters, based on empirical data rather than on intuition or shallow surveys. By applying Principal Component Analysis (PCA) (discussed in Section 5.1.2) to questionnaire responses a large set of data could be simplified and their relationships explained, thereby uncovering patterns that can be embodied in user characters representing the targeted population (Greaney and Riordan, 2003).

A related area is the author's ideas of the development of *Manikin Characters* as discussed in Section 5.3.1. The validity of the ideas behind Manikin Characters is a challenging research question, as is how Manikin Characters might best be created, communicated to, and used by designers. One area to investigate would be if, and if so how, the user characters should be linked to computer manikins, i.e. should the anthropometric models and character descriptions be separate features or combined in some way. A related issue would be manikin character family structure. The number of members in a manikin family in order to represent anthropometric diversity is not likely to be the same number as to represent personal diversity, i.e. number of user characters. It would be nice if it were, but there could be risks of sub-optimising if it was an objective to make the numbers match. Assuming that a company chose to employ the A-CADRE approach to represent anthropometric diversity, which includes 17 manikins for each gender, this would mean 34 manikin characters. That number is likely to be unmanageable when it comes to user characters. A number of three to seven user characters is advised (Buur and Nielsen, 1995; Pruitt and Grudin, 2003). In addition, further research is suggested on creating refined manikin families where the latest anthropometrical data is utilised, e.g. data from the CEASAR project (Robinette, 1998b), as well as a methodology for the quick creation of project specific manikin families.

A natural future development of CAD/CAE/PDM/PLM systems and human simulation tools is the development of a kind of a multi-purpose tool primarily used by product designers to aid the synthesis work. The fundamental concept is that the tool would enable the tool user to consider both the product and the user within one system and thereby facilitate consideration of both product and product-user interaction issues. We may call this kind of tool a *PAUS* (Product And User Simulation) tool. The 'And' is the key in this concept. One may argue that such tools already exist through human simulation tools being implemented in CAD systems supported by PDM/PLM systems. Indeed, the functionality may be there through technical aggregation of existing systems but it is questionable if the systems have been developed with designers' requirements of such a tool in focus. It is believed that there is still a lot of work to be done before today's systems fulfil designers' requirements for usability. When the tools reach the usability level (as discussed in Section 2.4.2) they would fulfil the requirements of the PAUS tool concept. Janhager's (2005) six design methods for user consideration in product development could possibly be employed in the PAUS tool to support the integration of product and user aspects. Primary users of such a tool would be designers, and secondary users would be others involved in product development such as managers, marketing people, ergonomists and production people. In a wider perspective beneficiaries would also be end users, companies and society as illustrated in Figure 3.4. Within the PAUS tool concept there are many possibilities for future research. However, rather than to go into details the concept is described in overall terms in Figure 7.1, which is partly a development of the ideas behind Figure 6.1 and 6.2. The illustration of the PAUS tool in Figure 7.1 does not attempt to be precise but is rather a representation of the author's ideas for a future design tool.

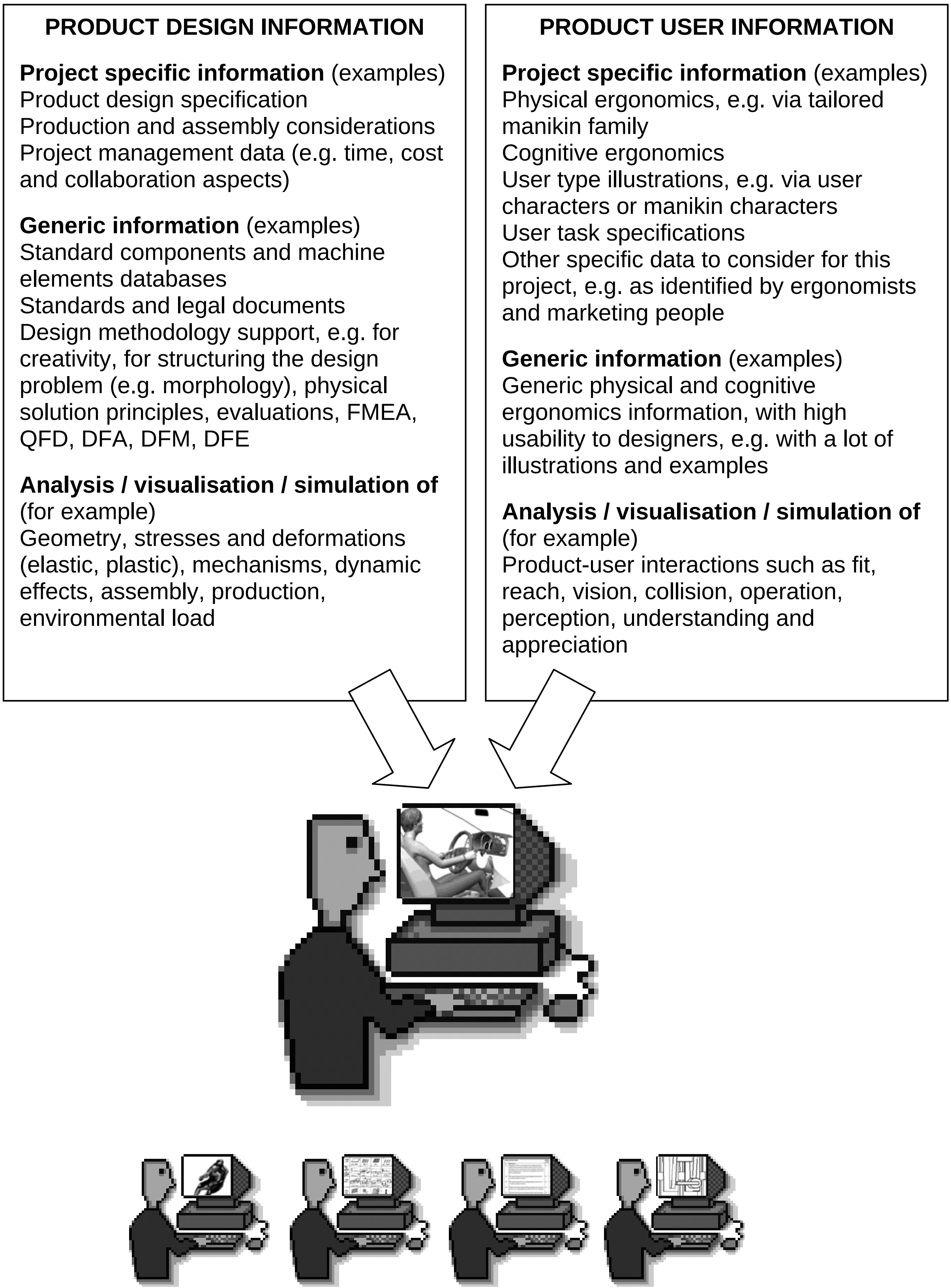


Figure 7.1. Conceptual illustration of the Product And User Simulation (PAUS) tool. Several PAUS tool users to illustrate design as a collaborative work.

7.4. Personal Closing Remarks

Although being proud and pleased with the outcome of this PhD thesis it has been very different from my previous experiences of carrying out, studying and teaching engineering and product design. A similarity with design though is the common feeling of wanting to start a project all over again when it is finished since the experiences gained during the project mean that one believes that the project should have been carried out differently and hence much better; "*if I knew what I know today*." I guess that reaction is intrinsic in learning something. For me, learning research has to a large degree been the development of seeing things differently; seeing things from a kind of a curious-critical perspective. No matter what I do later on I feel that this PhD journey has enriched me in many ways. Finally, the suggested abbreviation PAUS fittingly means 'pause' in Swedish. After writing a thesis pause sounds nice to me.

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Appendix 1

Manikin dimensions

A1.1. RAMSIS Typology Manikin Family, Female

Gender:	Female	Age group:	18-70
Nation:	Germany	Reference year:	2005

Manikin	Typology	Stature		Typology	Sitting height		Typology	Waist circumference	
	Length	Value (mm)	%-ile	Proportion	Value (mm)	%-ile	Corpulence	Value (mm)	%-ile
1	Very short	1550,1	6,3	Short torso	810,0	2,5	Slim waist	685,0	15,1
2	Very short	1554,8	7,3	Medium torso	835,0	11,3	Slim waist	642,1	7,6
3	Very short	1546,5	5,7	Long torso	858,1	30,3	Slim waist	665,8	11,3
4	Very short	1549,7	6,3	Short torso	797,9	1,0	Medium waist	802,2	52,7
5	Very short	1551,2	6,6	Medium torso	834,3	10,9	Medium waist	790,3	48,2
6	Very short	1546,6	5,7	Long torso	868,2	41,7	Medium waist	801,3	52,4
7	Very short	1550,3	6,4	Short torso	804,5	1,6	Large waist	958,8	93,8
8	Very short	1557,1	7,8	Medium torso	837,5	12,8	Large waist	1060,5	99,4
9	Very short	1540,2	4,6	Long torso	857,6	29,8	Large waist	962,9	94,2
10	Short	1585,8	16,8	Short torso	820,3	4,9	Slim waist	698,3	18,2
11	Short	1586,7	17,2	Medium torso	849,2	21,6	Slim waist	622,7	5,3
12	Short	1587,4	17,4	Long torso	881,5	57,6	Slim waist	692,3	16,8
13	Short	1587,9	17,6	Short torso	812,7	3,0	Medium waist	840,4	66,5
14	Short	1587,6	17,5	Medium torso	853,2	25,3	Medium waist	793,9	49,6
15	Short	1584,9	16,4	Long torso	893,1	70,6	Medium waist	808,4	55,0
16	Short	1588,0	17,7	Short torso	827,1	7,3	Large waist	982,4	96,0
17	Short	1587,4	17,4	Medium torso	853,6	25,8	Large waist	1030,9	98,6
18	Short	1583,5	15,9	Long torso	886,2	63,0	Large waist	926,1	89,0
19	Medium	1658,9	57,7	Short torso	857,1	29,3	Slim waist	683,0	14,7
20	Medium	1650,1	52,2	Medium torso	878,9	54,5	Slim waist	633,5	6,5
21	Medium	1637,5	44,2	Long torso	896,2	73,7	Slim waist	675,8	13,2
22	Medium	1650,5	52,4	Short torso	839,9	14,4	Medium waist	793,0	49,3
23	Medium	1647,9	50,8	Medium torso	877,7	53,0	Medium waist	777,4	43,4
24	Medium	1637,6	44,3	Long torso	908,2	84,1	Medium waist	786,9	47,0
25	Medium	1652,1	53,4	Short torso	852,3	24,5	Large waist	949,9	92,7
26	Medium	1646,0	49,6	Medium torso	875,4	50,3	Large waist	1024,9	98,4
27	Medium	1637,6	44,3	Long torso	898,9	76,3	Large waist	945,9	92,1
28	Tall	1709,9	84,1	Short torso	876,3	51,3	Slim waist	687,8	15,7
29	Tall	1713,6	85,5	Medium torso	903,1	80,0	Slim waist	639,3	7,2
30	Tall	1712,5	85,1	Long torso	928,0	94,5	Slim waist	679,0	13,8
31	Tall	1710,2	84,2	Short torso	863,7	36,5	Medium waist	779,9	44,3
32	Tall	1711,0	84,5	Medium torso	902,3	79,4	Medium waist	773,1	41,9
33	Tall	1710,6	84,4	Long torso	941,8	97,8	Medium waist	744,3	31,7
34	Tall	1710,8	84,5	Short torso	877,8	53,1	Large waist	956,1	93,4
35	Tall	1712,4	85,0	Medium torso	899,6	76,9	Large waist	1004,5	97,5
36	Tall	1710,7	84,4	Long torso	931,7	95,6	Large waist	979,7	95,8
37	Very tall	1755,4	95,7	Short torso	895,4	72,9	Slim waist	690,5	16,4
38	Very tall	1734,5	91,7	Medium torso	911,5	86,3	Slim waist	651,3	8,9
39	Very tall	1740,1	93,0	Long torso	939,7	97,4	Slim waist	679,6	14,0
40	Very tall	1770,3	97,5	Short torso	894,9	72,4	Medium waist	774,2	42,3
41	Very tall	1751,7	95,1	Medium torso	920,0	91,2	Medium waist	762,6	38,0
42	Very tall	1756,1	95,8	Long torso	953,9	99,1	Medium waist	763,4	38,4
43	Very tall	1752,9	95,3	Short torso	892,6	70,0	Large waist	928,8	89,5
44	Very tall	1749,1	94,7	Medium torso	919,0	90,7	Large waist	987,7	96,4
45	Very tall	1743,8	93,7	Long torso	942,8	97,9	Large waist	926,1	89,0
	min	1540,2	4,6	min	797,9	1,0	min	622,7	5,3
	max	1770,3	97,5	max	953,9	99,1	max	1060,5	99,4
	coverage		92,9%	coverage		98,1%	coverage		94,1%

Multidimensional accommodation: 86.8 % (PeopleSize software)
86% (BodyBuilder software)

A1.2. RAMSIS Typology Manikin Family, Male

Gender:	Male	Age group:	18-70
Nation:	Germany	Reference year:	2005

Manikin	Typology	Stature		Typology	Sitting height		Typology	Waist circumference	
	Length	Value (mm)	%-ile	Proportion	Value (mm)	%-ile	Corpulence	Value (mm)	%-ile
1	Very short	1664,2	5,6	Short torso	857,9	1,8	Slim waist	785,3	12,2
2	Very short	1658,5	4,8	Medium torso	885,0	8,8	Slim waist	742,2	6,0
3	Very short	1642,7	3,0	Long torso	901,5	18,3	Slim waist	799,5	15,0
4	Very short	1668,0	6,2	Short torso	847,6	0,9	Medium waist	943,4	60,3
5	Very short	1664,6	5,7	Medium torso	887,0	9,7	Medium waist	943,0	60,2
6	Very short	1648,0	3,5	Long torso	916,6	31,2	Medium waist	951,8	63,2
7	Very short	1665,1	5,8	Short torso	863,7	2,7	Large waist	1079,9	93,3
8	Very short	1667,2	6,1	Medium torso	891,6	12,1	Large waist	1131,0	97,5
9	Very short	1650,9	3,8	Long torso	912,2	27,0	Large waist	1078,8	93,1
10	Short	1710,6	17,2	Short torso	879,6	6,7	Slim waist	803,5	15,8
11	Short	1711,2	17,4	Medium torso	909,7	24,9	Slim waist	752,3	7,2
12	Short	1707,7	16,2	Long torso	934,0	49,2	Slim waist	769,5	9,5
13	Short	1709,3	16,8	Short torso	869,2	3,7	Medium waist	950,0	62,6
14	Short	1710,3	17,1	Medium torso	907,1	22.6	Medium waist	935,8	57,7
15	Short	1707,9	16,3	Long torso	951,6	67,7	Medium waist	924,1	53,5
16	Short	1714,7	18,7	Short torso	874,4	5,0	Large waist	1105.8	95,8
17	Short	1711,7	17,6	Medium torso	905,5	21,4	Large waist	1124,8	97,1
18	Short	1708,7	16,6	Long torso	933,3	48,5	Large waist	1064,8	91,3
19	Medium	1787,8	54,8	Short torso	913,4	28,1	Slim waist	772,3	10,0
20	Medium	1782,3	51,8	Medium torso	939,7	55,4	Slim waist	728,4	4,6
21	Medium	1774,9	47,7	Long torso	962,5	77,5	Slim waist	765,6	8,9
22	Medium	1782,2	51,8	Short torso	897,8	15,8	Medium waist	925,0	53,8
23	Medium	1780,3	50,7	Medium torso	937,0	52,5	Medium waist	907,7	47,6
24	Medium	1761,3	40,3	Long torso	965,8	80,1	Medium waist	920,5	52,2
25	Medium	1789,3	55,7	Short torso	913,6	28,3	Large waist	1067,3	91,7
26	Medium	1777,4	49,1	Medium torso	934,2	49,4	Large waist	1133,2	97,6
27	Medium	1763,4	41,5	Long torso	955,3	71,3	Large waist	1060,1	90,6
28	Tall	1846,4	82,4	Short torso	941,3	57,1	Slim waist	753,2	7,3
29	Tall	1843,1	81,2	Medium torso	963,8	78,6	Slim waist	720,4	4,0
30	Tall	1845,8	82,2	Long torso	991,2	93,8	Slim waist	772,1	9,9
31	Tall	1846,5	82,5	Short torso	931,1	46,1	Medium waist	888,4	40,7
32	Tall	1844,1	81,6	Medium torso	961,8	76,9	Medium waist	886,9	40,2
33	Tall	1844,5	81,7	Long torso	998,2	95,8	Medium waist	919,8	52,0
34	Tall	1843,1	81,2	Short torso	937,8	53,4	Large waist	1063,3	91,1
35	Tall	1844,0	81,5	Medium torso	964,5	79,1	Large waist	1106,3	95,9
36	Tall	1844,3	81,6	Long torso	989,8	93,3	Large waist	1049,9	89,0
37	Very tall	1909,1	96,4	Short torso	960,6	76,0	Slim waist	762,5	8,5
38	Very tall	1898,0	95,0	Medium torso	984,6	91,3	Slim waist	729,4	4,7
39	Very tall	1885,0	92,8	Long torso	1005,3	97,3	Slim waist	764,9	8,8
40	Very tall	1900,5	95,3	Short torso	944,6	60,6	Medium waist	891,1	41,7
41	Very tall	1891,5	94,0	Medium torso	981,1	89,7	Medium waist	873,8	35,7
42	Very tall	1883,1	92,5	Long torso	1017,3	98,8	Medium waist	878,6	37,3
43	Very tall	1892,9	94,2	Short torso	948,2	64,3	Large waist	1025,2	84,2
44	Very tall	1883,0	92,5	Medium torso	977,9	88,0	Large waist	1097,0	95,1
45	Very tall	1893,4	94,3	Long torso	1017,5	98,8	Large waist	1014,1	81,6
	min	1642,7	3,0	min	847,6	0,9	min	720,4	4,0
	max	1909,1	96,4	max	1017,5	98,8	max	1133,2	97,6
	coverage		93,4%	coverage		97,9%	coverage		93,6%

Multidimensional accommodation: 86.8 % (PeopleSize software)
86% (BodyBuilder software)

A1.3. A-CADRE Manikin Family, Female

Gender:	Female	Age group:	18-70
Nation:	Germany	Reference year:	2005

Manikin	Stature		Sitting height		Waist circumference	
	Value (mm)	%-ile	Value (mm)	%-ile	Value (mm)	%-ile
1	1793,9	99,0	935,7	96,6	994,2	96,9
2	1731,6	91,0	917,1	89,7	976,0	95,5
3	1706,4	82,7	859,2	31,5	931,2	89,9
4	1753.3	95,4	919,6	91,0	751,3	34,1
5	1690,6	75,6	925,6	93,6	917,3	87,4
6	1649,9	52,0	909,5	85,0	675,8	13,2
7	1602,8	24,4	849,1	21,6	855,7	71,5
8	1627,9	38,3	907,1	83,2	900,3	83,8
9	1665,5	61,7	843,3	16,8	689,8	16,2
10	1690,6	75,6	901,2	78,4	734,4	28,5
11	1643,5	48,0	840,8	15,0	914,2	86,8
12	1561,9	9,0	833,3	10,3	614,1	4,5
13	1587,1	17,3	891,1	68,5	658,9	10,1
14	1540,1	4,6	830,7	9,0	838,8	65,9
15	1602,8	24,4	824,7	6,4	672,8	12,6
16	1499,5	1,0	814,7	3,4	595,9	3,1
17	1646,7	50,0	875,2	50,0	795,0	50,0
min	1499,5	1,0	814,7	3,4	595,9	3,1
max	1793,9	99,0	935,7	96,6	994,2	96,9
coverage		98,0%		93,2%		93,8%

Multidimensional accommodation: 86.7 % (PeopleSize software)
86% (BodyBuilder software)

A1.4. A-CADRE Manikin Family, Male

Gender:	Male	Age group:	18-70
Nation:	Germany	Reference year:	2005

Manikin	Stature		Sitting height		Waist circumference	
	Value (mm)	%-ile	Value (mm)	%-ile	Value (mm)	%-ile
1	1947,4	99,0	1001,7	96,6	1120,9	96,9
2	1876,0	91,0	981,2	89,7	1102,0	95,5
3	1847,2	82,7	917,0	31,5	1055,6	89,9
4	1900,9	95,4	984,0	91,0	869,0	34,1
5	1829,2	75,6	990,6	93,6	1041,2	87,4
6	1782,6	52,0	972,8	85,0	790,8	13,2
7	1728,8	24,4	905,8	21,6	977,3	71,5
8	1757,5	38,3	970,0	83,2	1023,5	83,8
9	1800,5	61,7	899,3	16,8	805,2	16,2
10	1829,2	75,6	963,6	78,4	851,5	28,5
11	1775,4	48,0	896,6	15,0	1038,0	86,8
12	1682,0	9,0	888,2	10,3	726,8	4,5
13	1710,8	17,3	952,4	68,5	773,2	10,1
14	1657,1	4,6	885,4	9,0	959,7	65,9
15	1728,8	24,4	878,8	6,4	787,6	12,6
16	1610,7	1,0	867,6	3,4	707,8	3,1
17	1779,0	50,0	934,7	50,0	914,4	50,0
min	1610,7	1,0	867,6	3,4	707,8	3,1
max	1947,4	99,0	1001,7	96,6	1120,9	96,9
coverage		98,0%		93,2%		93,8%

Multidimensional accommodation: 87,0% (PeopleSize software)
86% (BodyBuilder software)

Appendix 2

H-point locations

A2.1. H-point locations for RAMSIS Typology Manikin Family, Female

RAMSIS typology Manikin	Typology Length	Typology Corpulence	Typology Proportion	H-point x (mm)	z (mm)
1	Very short	Slim waist	Short torso	2961,2	515,4
2	Very short	Slim waist	Medium torso	2948,7	499,2
3	Very short	Slim waist	Long torso	2925,3	478,8
4	Very short	Medium waist	Short torso	2970,3	523,8
5	Very short	Medium waist	Medium torso	2947,4	496,8
6	Very short	Medium waist	Long torso	2923,3	471,5
7	Very short	Large waist	Short torso	2968,6	513,7
8	Very short	Large waist	Medium torso	2955,0	492,0
9	Very short	Large waist	Long torso	2924,2	475,5
10	Short	Slim waist	Short torso	2987,1	509,8
11	Short	Slim waist	Medium torso	2967,6	492,5
12	Short	Slim waist	Long torso	2948,3	466,0
13	Short	Medium waist	Short torso	2996,3	514,0
14	Short	Medium waist	Medium torso	2968,8	485,5
15	Short	Medium waist	Long torso	2938,9	457,8
16	Short	Large waist	Short torso	2988,7	503,0
17	Short	Large waist	Medium torso	2972,2	483,0
18	Short	Large waist	Long torso	2942,7	458,6
19	Medium	Slim waist	Short torso	3029,9	491,9
20	Medium	Slim waist	Medium torso	3005,5	476,2
21	Medium	Slim waist	Long torso	2983,5	461,8
22	Medium	Medium waist	Short torso	3036,0	503,3
23	Medium	Medium waist	Medium torso	3008,2	475,2
24	Medium	Medium waist	Long torso	2977,5	453,4
25	Medium	Large waist	Short torso	3031,4	490,5
26	Medium	Large waist	Medium torso	3011,0	473,3
27	Medium	Large waist	Long torso	2986,8	457,2
28	Tall	Slim waist	Short torso	3053,9	514,3
29	Tall	Slim waist	Medium torso	3040,5	492,2
30	Tall	Slim waist	Long torso	3023,5	475,0
31	Tall	Medium waist	Short torso	3064,8	511,0
32	Tall	Medium waist	Medium torso	3041,1	489,0
33	Tall	Medium waist	Long torso	3011,8	467,2
34	Tall	Large waist	Short torso	3056,9	500,6
35	Tall	Large waist	Medium torso	3042,8	492,4
36	Tall	Large waist	Long torso	3020,4	472,4
37	Very tall	Slim waist	Short torso	3077,2	517,6
38	Very tall	Slim waist	Medium torso	3051,0	499,3
39	Very tall	Slim waist	Long torso	3037,1	483,1
40	Very tall	Medium waist	Short torso	3089,2	522,3
41	Very tall	Medium waist	Medium torso	3058,7	502,7
42	Very tall	Medium waist	Long torso	3039,5	478,1
43	Very tall	Large waist	Short torso	3075,5	517,4
44	Very tall	Large waist	Medium torso	3058,6	496,6
45	Very tall	Large waist	Long torso	3036,6	481,1
			min	2923,3	453,4
			max	3089,2	523,8
			average	3004,1	489,6

A2.2. H-point locations for RAMSIS Typology Manikin Family, Male

RAMSIS typology Manikin	Typology Length	Typology Corpulence	Typology Proportion	H-point x (mm)	z (mm)
1	Very short	Slim waist	Short torso	3038,3	507,2
2	Very short	Slim waist	Medium torso	3007,5	500,5
3	Very short	Slim waist	Long torso	2980,2	482,8
4	Very short	Medium waist	Short torso	3048,0	499,8
5	Very short	Medium waist	Medium torso	3015,3	483,3
6	Very short	Medium waist	Long torso	2975,5	466,6
7	Very short	Large waist	Short torso	3036,2	482,0
8	Very short	Large waist	Medium torso	3015,0	471,8
9	Very short	Large waist	Long torso	2986,2	458,4
10	Short	Slim waist	Short torso	3058,6	512,5
11	Short	Slim waist	Medium torso	3033,8	502,9
12	Short	Slim waist	Long torso	3013,0	491,7
13	Short	Medium waist	Short torso	3065,9	504,1
14	Short	Medium waist	Medium torso	3037,6	488,0
15	Short	Medium waist	Long torso	3001,4	473,1
16	Short	Large waist	Short torso	3065,3	503,1
17	Short	Large waist	Medium torso	3041,9	487,3
18	Short	Large waist	Long torso	3016,4	468,2
19	Medium	Slim waist	Short torso	3090,9	507,7
20	Medium	Slim waist	Medium torso	3067,8	490,9
21	Medium	Slim waist	Long torso	3031,0	442,3
22	Medium	Medium waist	Short torso	3098,9	510,6
23	Medium	Medium waist	Medium torso	3066,8	483,2
24	Medium	Medium waist	Long torso	3032,1	462,9
25	Medium	Large waist	Short torso	3089,2	491,9
26	Medium	Large waist	Medium torso	3068,8	473,7
27	Medium	Large waist	Long torso	3041,8	463,5
28	Tall	Slim waist	Short torso	3100,3	487,0
29	Tall	Slim waist	Medium torso	3082,5	475,0
30	Tall	Slim waist	Long torso	3065,7	451,4
31	Tall	Medium waist	Short torso	3111,0	487,4
32	Tall	Medium waist	Medium torso	3086,3	465,8
33	Tall	Medium waist	Long torso	3052,5	443,4
34	Tall	Large waist	Short torso	3112,2	472,8
35	Tall	Large waist	Medium torso	3082,9	457,3
36	Tall	Large waist	Long torso	3062,2	440,0
37	Very tall	Slim waist	Short torso	3129,0	476,3
38	Very tall	Slim waist	Medium torso	3104,6	461,0
39	Very tall	Slim waist	Long torso	3078,3	442,7
40	Very tall	Medium waist	Short torso	3133,7	478,3
41	Very tall	Medium waist	Medium torso	3102,0	455,7
42	Very tall	Medium waist	Long torso	3070,1	429,0
43	Very tall	Large waist	Short torso	3126,5	470,1
44	Very tall	Large waist	Medium torso	3100,0	446,5
45	Very tall	Large waist	Long torso	3075,6	424,5
			min	2975,5	424,5
			max	3133,7	512,5
			average	3060,0	475,0

A2.3. H-point locations for A-CADRE Manikin Family, Female

A-CADRE Manikin	Stature %-ile Length	Waist circ. %-ile Corpulence	Sitting height %-ile Proportion	H-point x (mm)	 z (mm)
1	99,0	96,9	96,6	3076,1	482,3
2	91,0	95,5	89,7	3044,1	492,9
3	82,7	89,9	31,5	3066,2	510,7
4	95,4	34,1	91,0	3059,2	502,6
5	75,6	87,4	93,6	3007,6	463,5
6	52,0	13,2	85,0	2984,4	454,4
7	24,4	71,5	21,6	2987,0	490,1
8	38,3	83,8	83,2	2969,2	450,0
9	61,7	16,2	16,8	3046,9	504,7
10	75,6	28,5	78,4	3025,3	477,3
11	48,0	86,8	15,0	3031,7	500,0
12	9,0	4,5	10,3	2957,3	503,0
13	17,3	10,1	68,5	2940,9	459,7
14	4,6	65,9	9,0	2940,7	498,1
15	24,4	12,6	6,4	3000,9	510,9
16	1,0	3,1	3,4	2912,4	507,9
17	50,0	50,0	50,0	3009,1	476,5
			min	2912,4	450
			max	3076,1	510,9
			average	3003,5	487,3

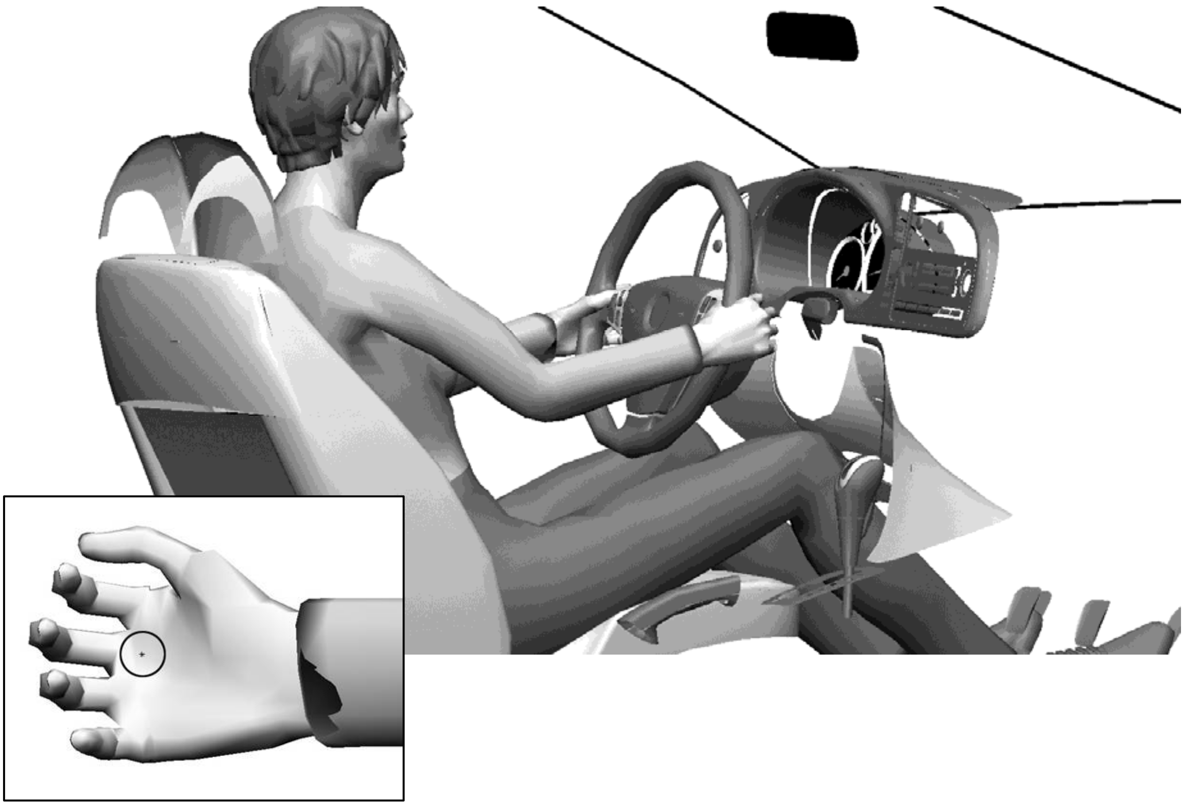
A2.4. H-point locations for A-CADRE Manikin Family, Male

A-CADRE Manikin	Stature %-ile Length	Waist circ. %-ile Corpulence	Sitting height %-ile Proportion	H-point x (mm)	 z (mm)
1	99,0	96,9	96,6	3131,1	428,8
2	91,0	95,5	89,7	3091,3	442,6
3	82,7	89,9	31,5	3129,6	489,2
4	95,4	34,1	91,0	3105,4	453,9
5	75,6	87,4	93,6	3048,8	439,0
6	52,0	13,2	85,0	3040,2	463,7
7	24,4	71,5	21,6	3054,5	494,5
8	38,3	83,8	83,2	3024,3	454,1
9	61,7	16,2	16,8	3109,2	517,6
10	75,6	28,5	78,4	3075,3	466,2
11	48,0	86,8	15,0	3094,4	506,4
12	9,0	4,5	10,3	3027,1	510,1
13	17,3	10,1	68,5	3001,4	477,5
14	4,6	65,9	9,0	3010,9	483,2
15	24,4	12,6	6,4	3077,1	521,5
16	1,0	3,1	3,4	2981,6	498,1
17	50,0	50,0	50,0	3067,8	484,5
			min	2981,6	428,8
			max	3131,1	521,5
			average	3062,9	478,3

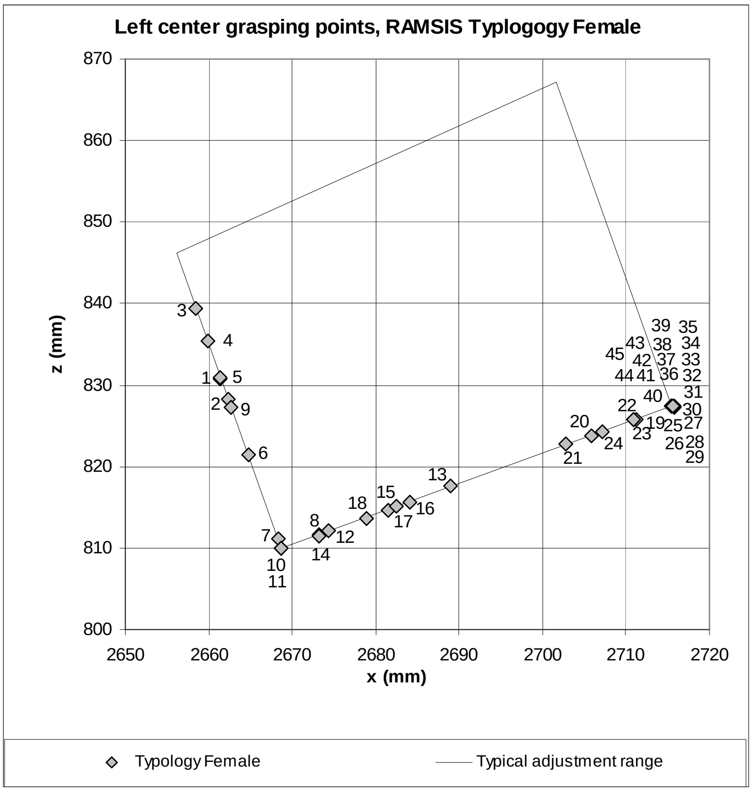
Appendix 3

Grasping point locations

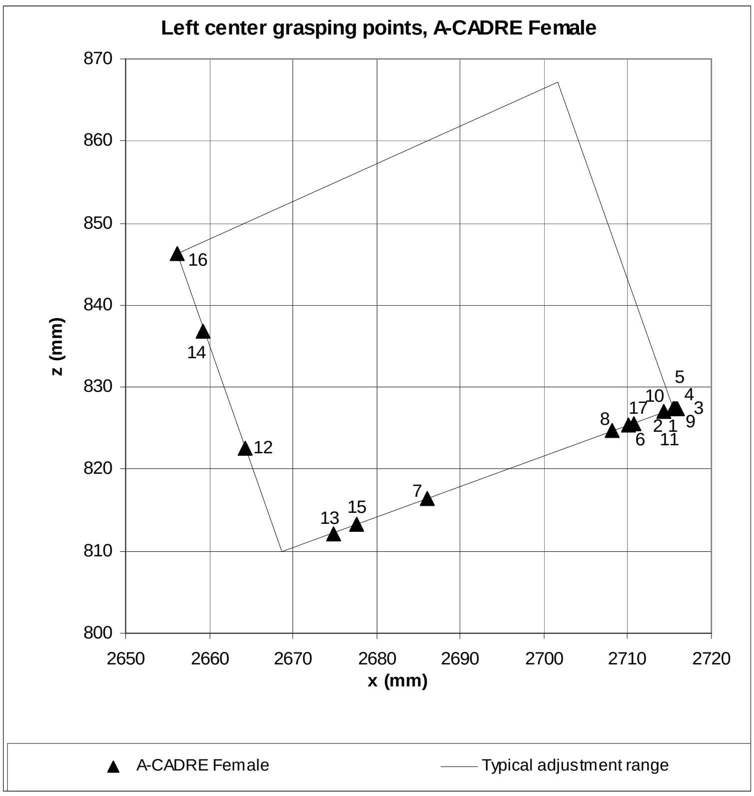
Comments: The following pages show grasping point locations as obtained by the study described in Section 5.2.2. The diagrams show the left hand grasping point plotted (the point's location in the hand is shown in the figure below). The location is very similar to the right hand grasping point in x and z direction but may differ slightly. The steering wheel adjustment area is positioned for quarter-to-three grasping as shown in the figure below. The constraint in the simulations was set to require the manikin to position its grasping points within a defined 'typical' steering wheel adjustment area. Results indicate that many manikins prefer to keep their hands low, and that many of the taller drivers select the most rearward position possible. In general, the RAMSIS Typology and A-CADRE manikin families show similar results.



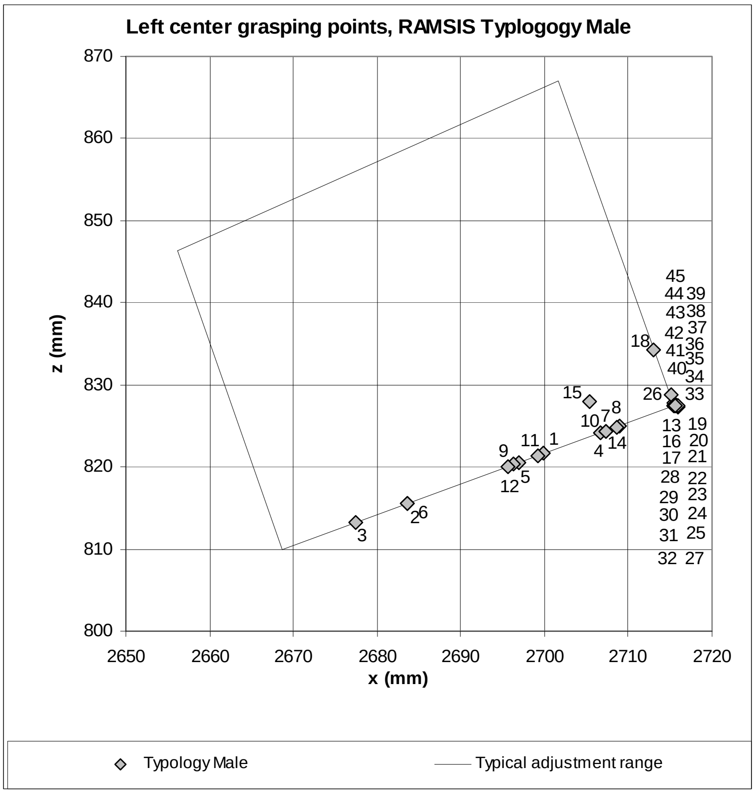
A3.1. Grasping point locations for RAMSIS Typology Manikin Family, Female



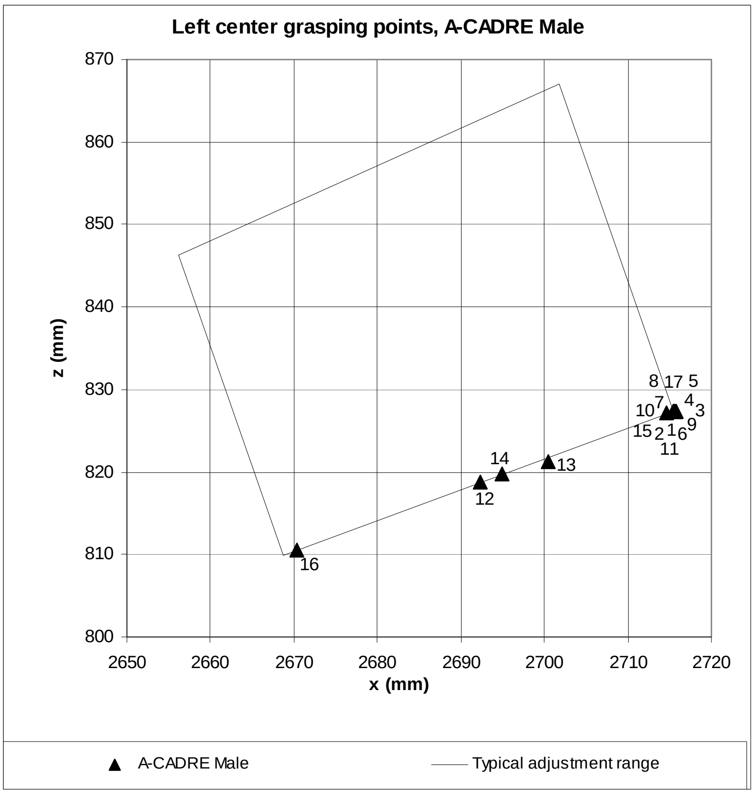
A3.2. Grasping point locations for A-CADRE Manikin Family, Female



A3.3. Grasping point locations for RAMSIS Typology Manikin Family, Male



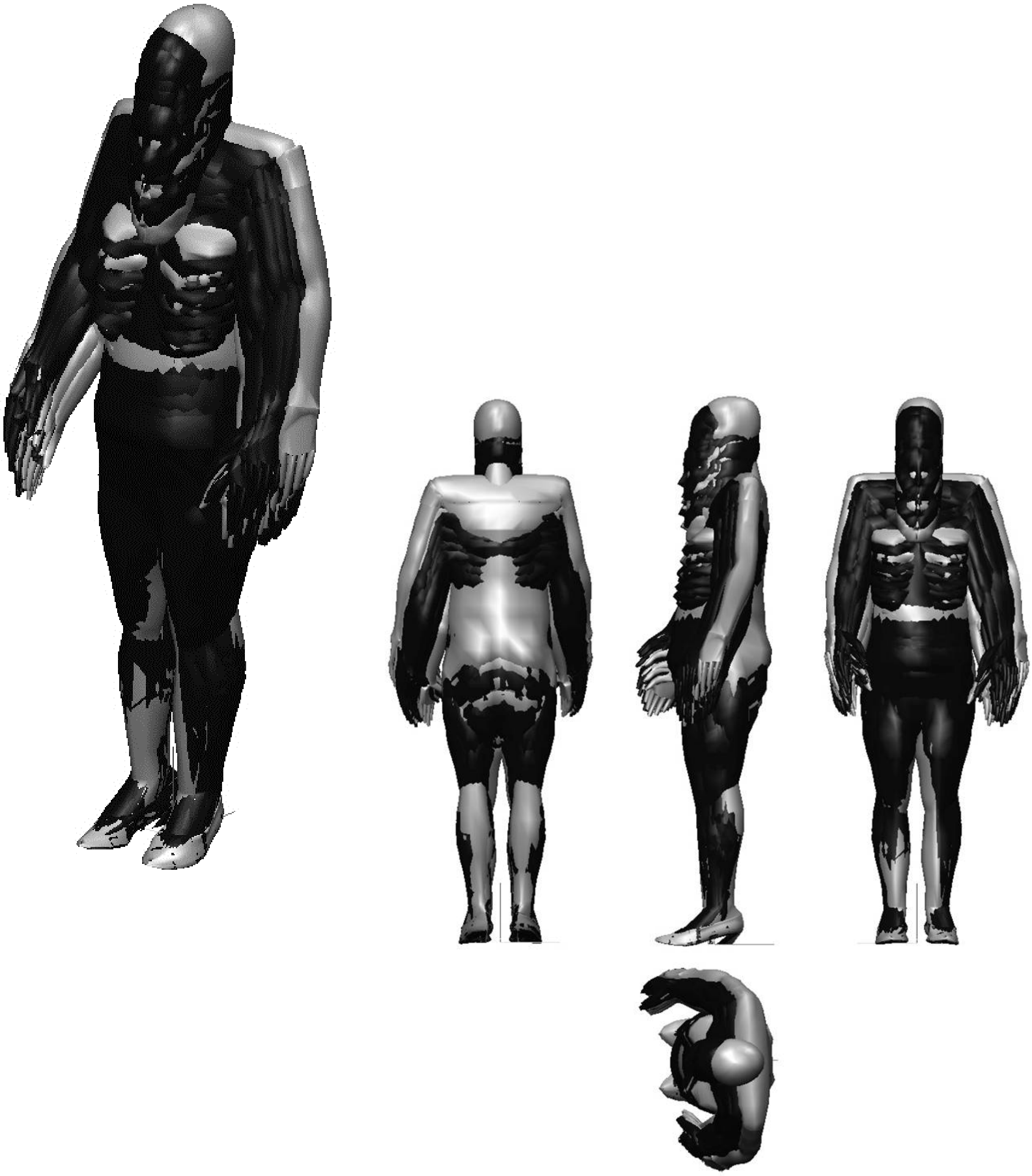
A3.4. Grasping point locations for A-CADRE Manikin Family, Male



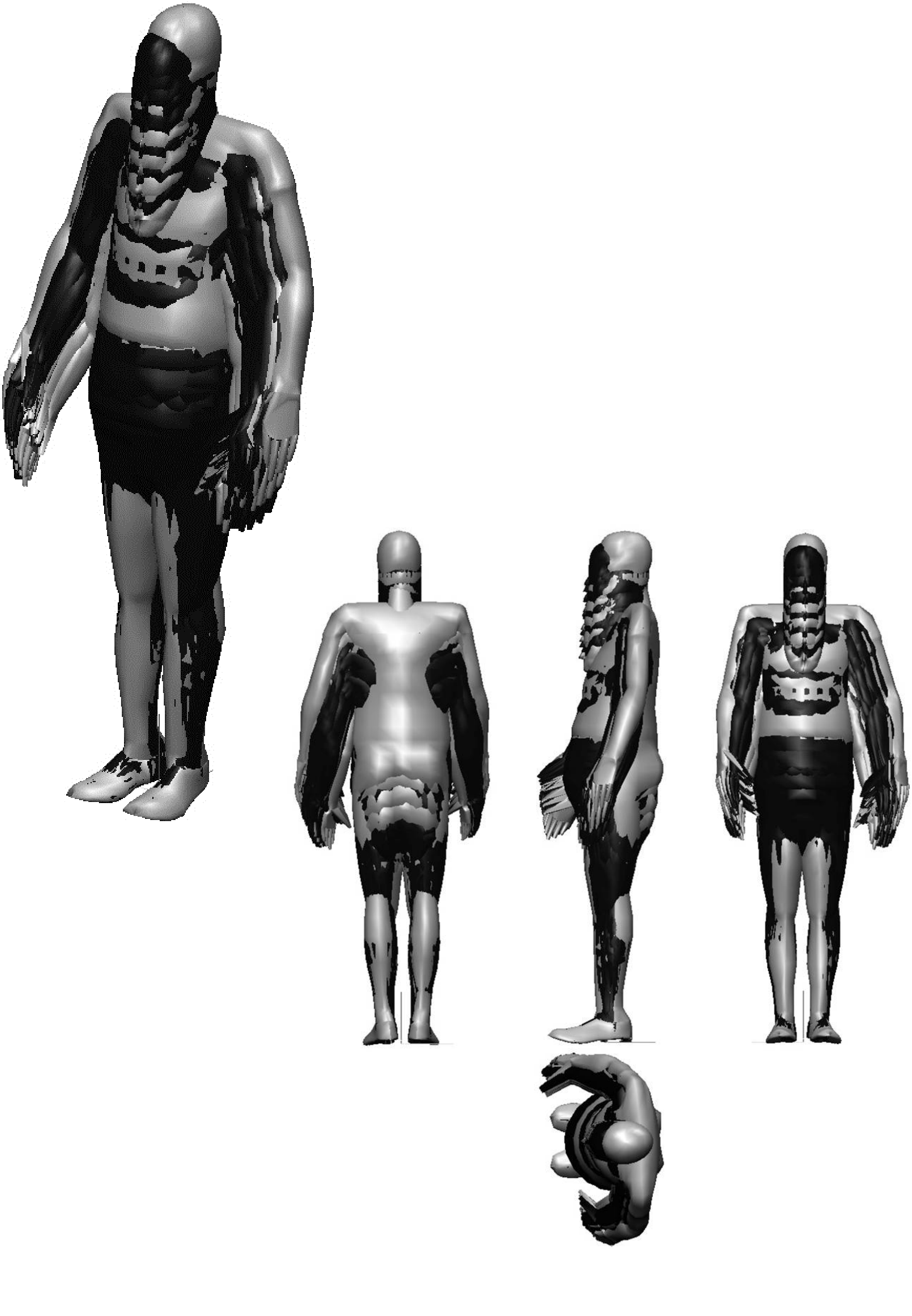
Appendix 4

Skin compositions

A4.1. RAMSIS Typology (black) and A-CADRE (grey), Standing, Female

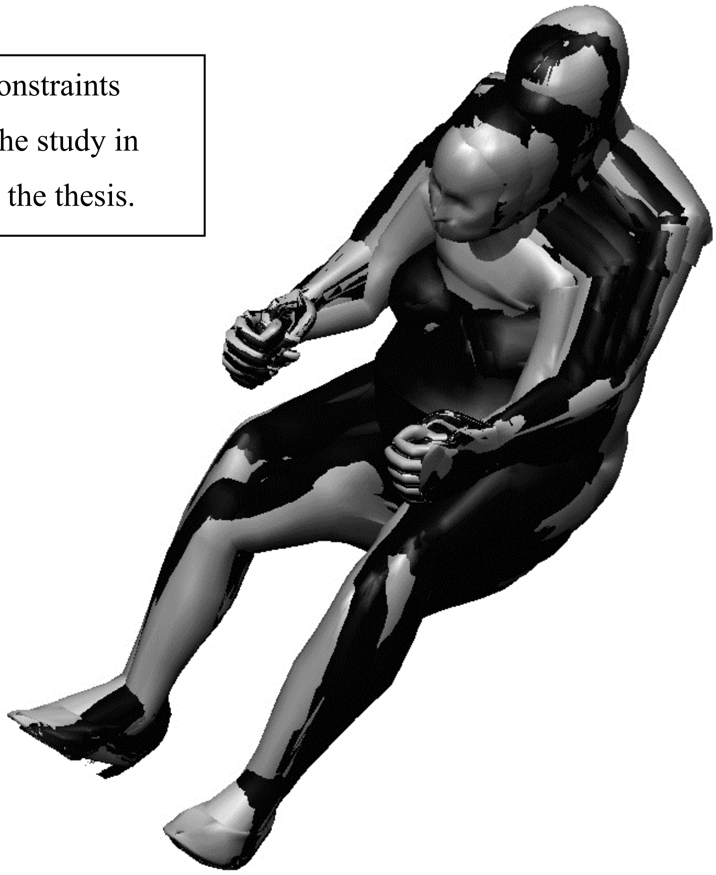


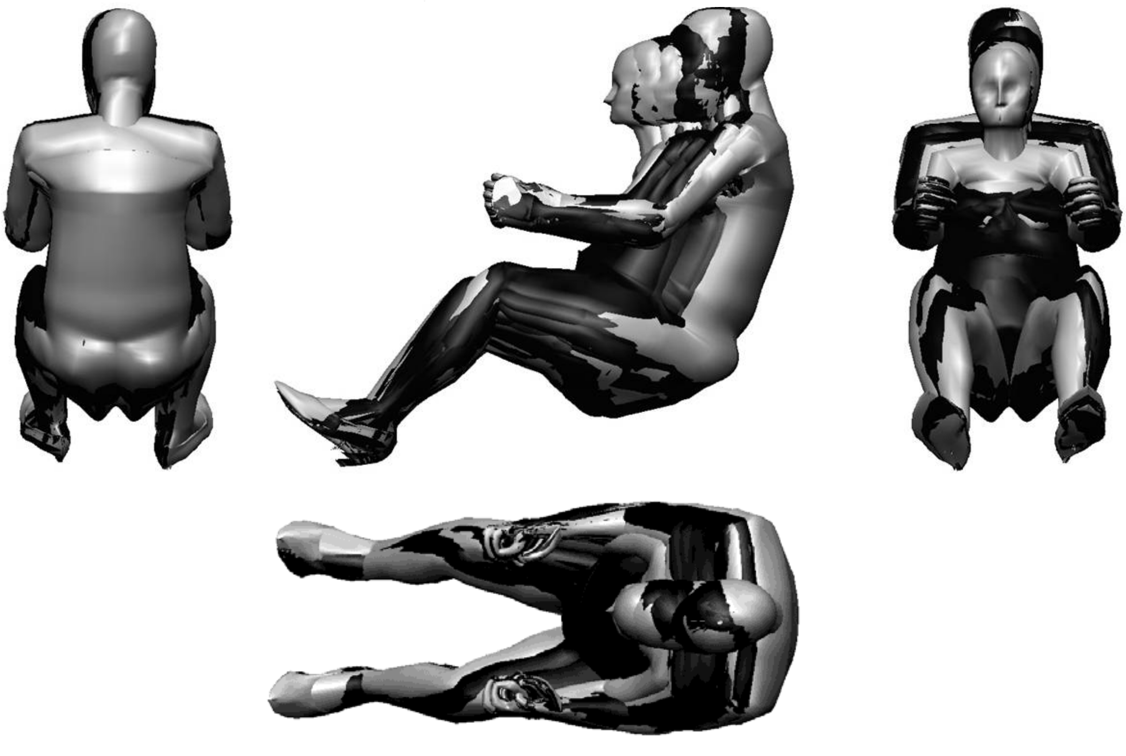
A4.2. RAMSIS Typology (black) and A-CADRE (grey), Standing, Male



A4.3. RAMSIS Typology (black) and A-CADRE (grey), Driving, Female

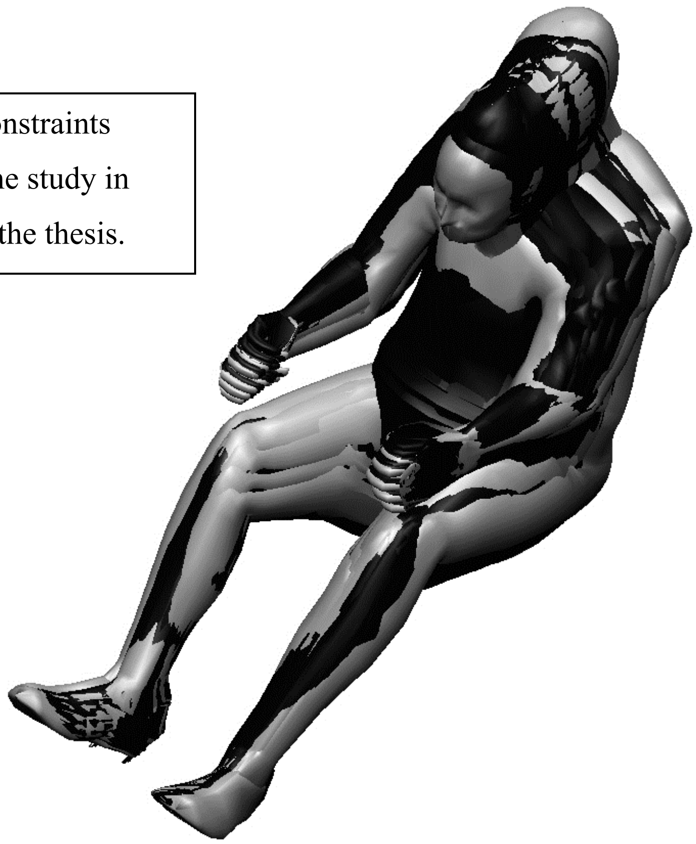
Comment: Constraints according to the study in Section 5.2 in the thesis.

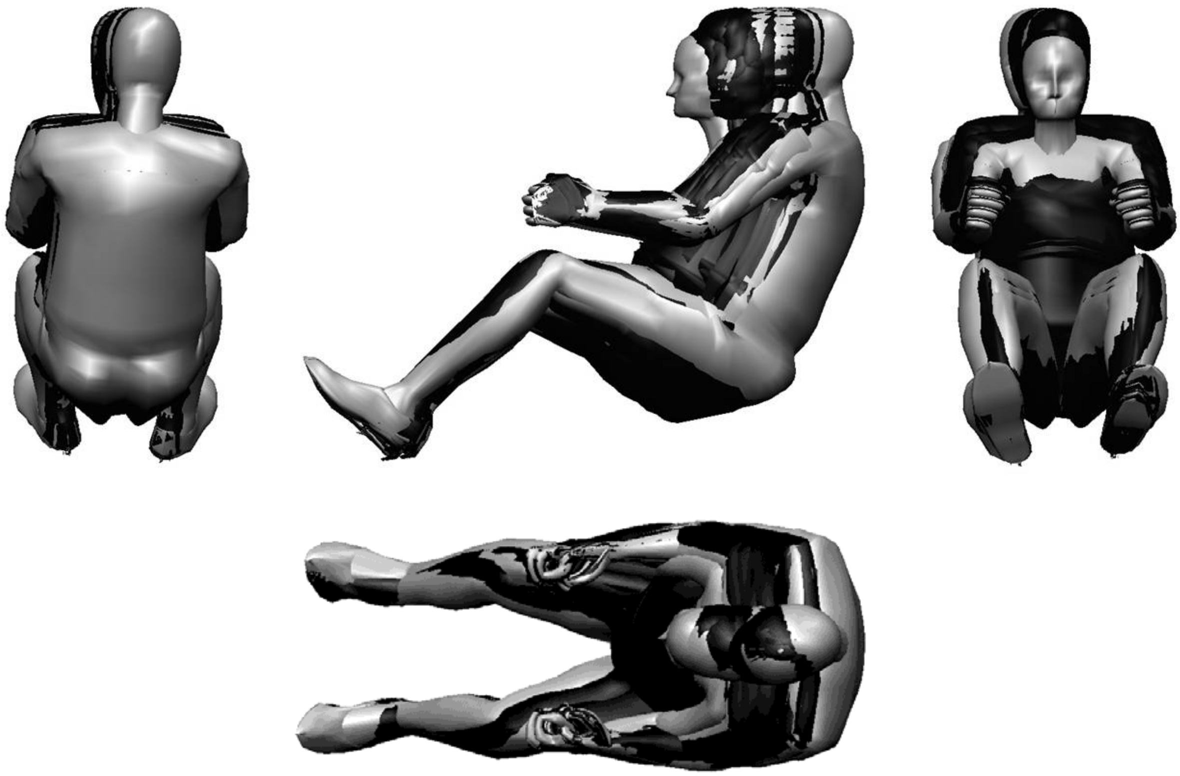




A4.4. RAMSIS Typology (black) and A-CADRE (grey), Driving, Male

Comment: Constraints according to the study in Section 5.2 in the thesis.

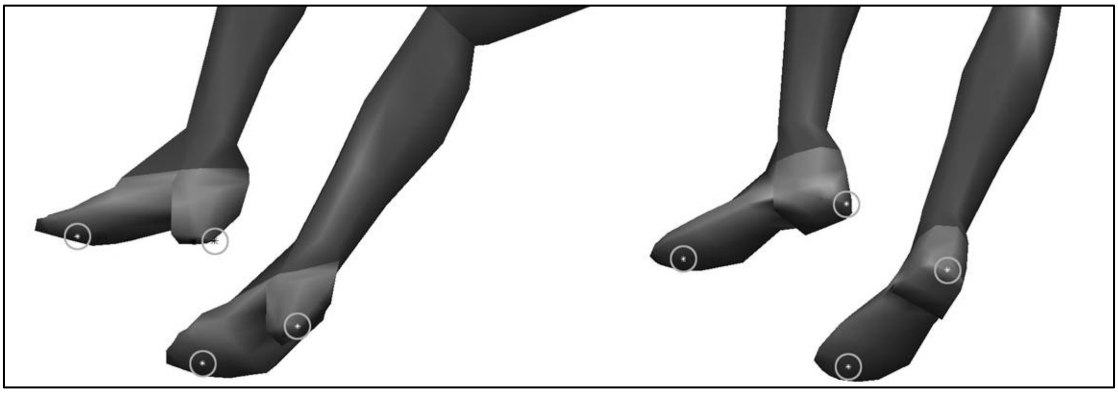




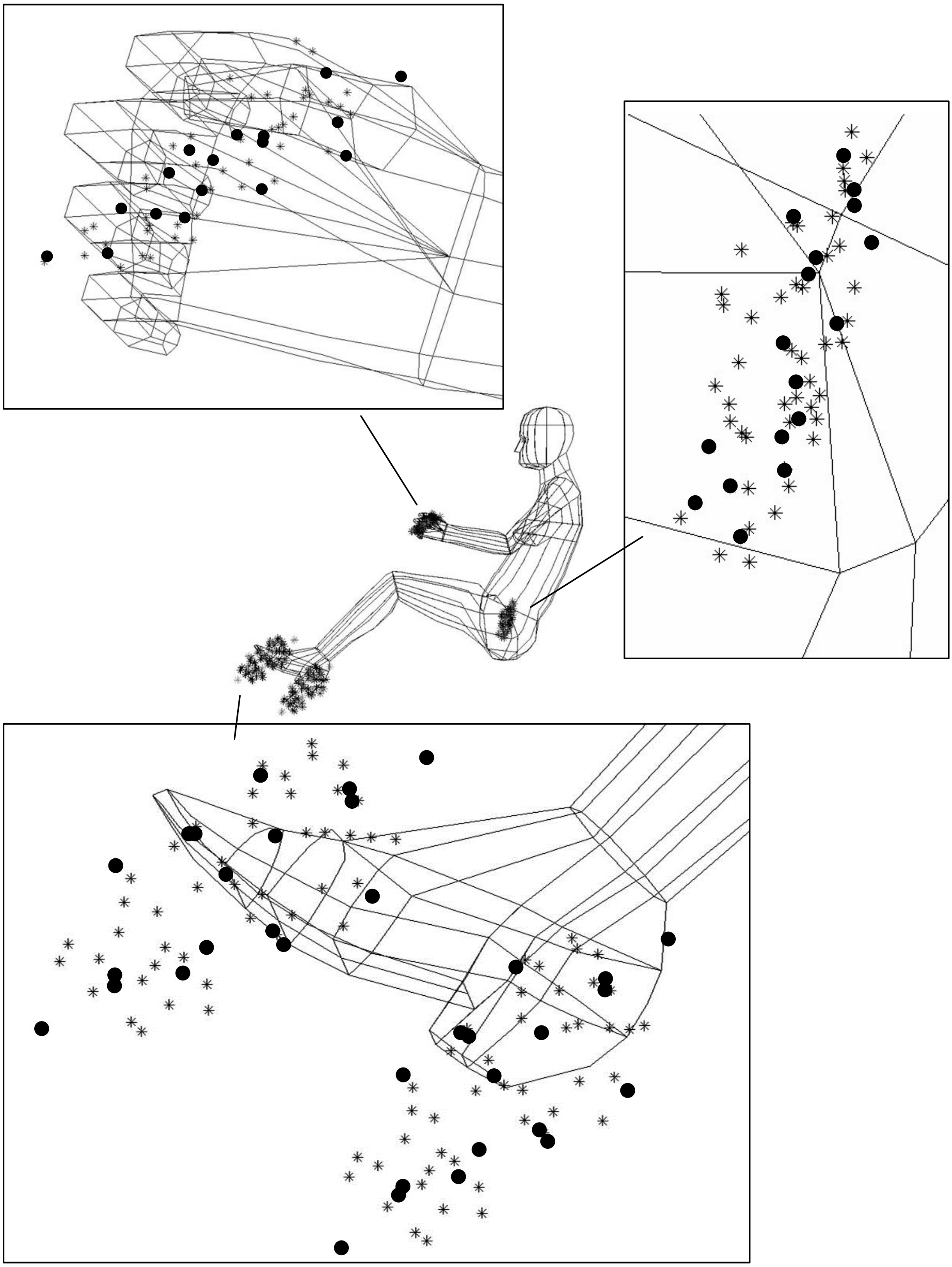
Appendix 5

Fixed mid eye point study

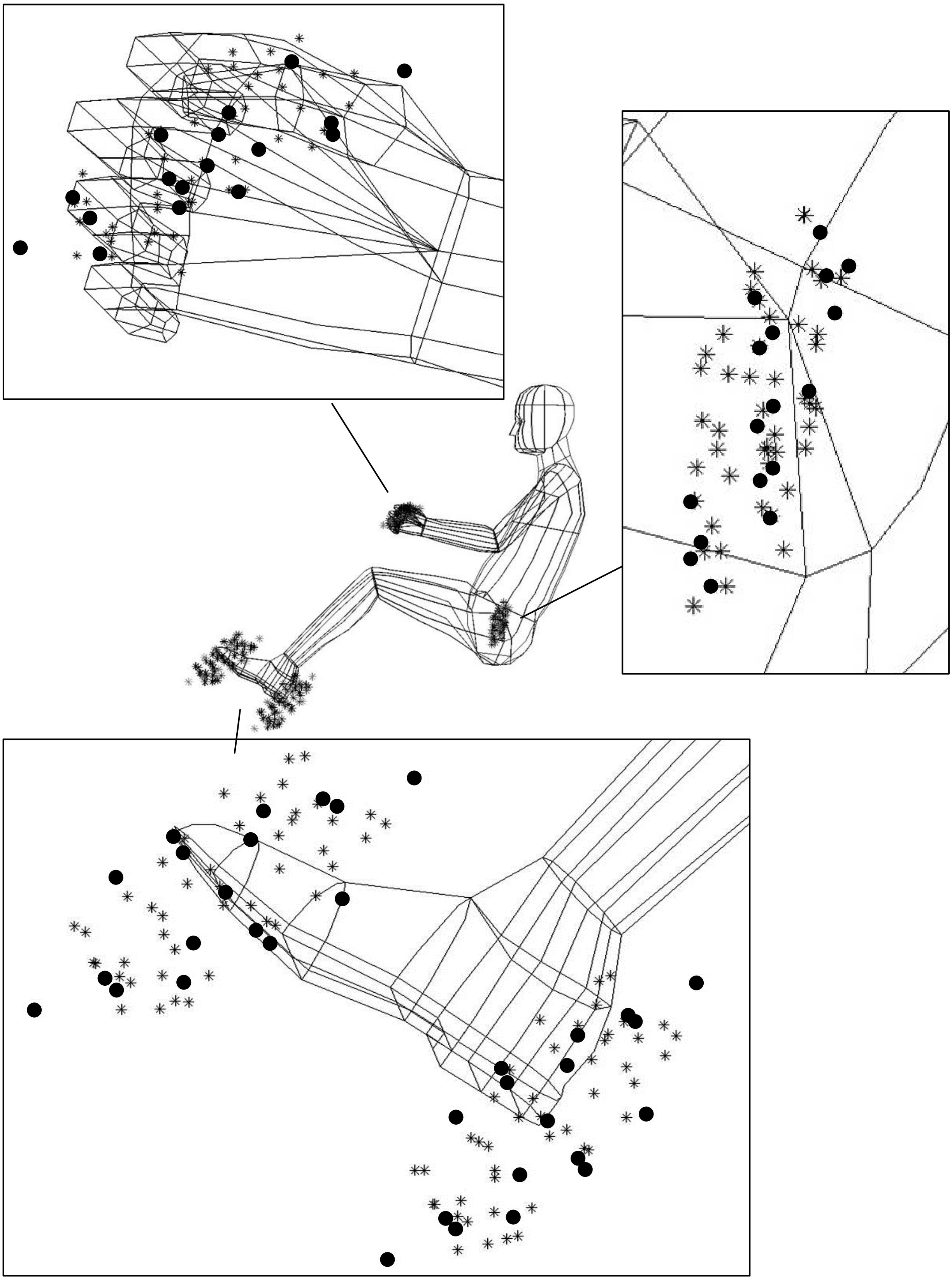
Comments: The following four pages show simulation results obtained from a fixed mid eye study. The constraints are set to keep all manikins' mid eye points (a point right between the eyes) in a fixed position and the line of sight 5 degrees down from the horizontal line. Besides these restrictions, the manikin selects the most comfortable position according to the posture prediction functionality in RAMSIS. The objective with the study is to illustrate similarities between results obtained from using the RAMSIS Typology family and the A-CADRE family. The first two pages show locations of the grasping points (location in hand shown in Appendix 3), the heel and pedal points (shown in the figure below) as well as the H-points (as described in Section 5.2). RAMSIS Typology manikin *Number 23* (medium in all three key dimensions) is shown as a reference. Page three and four show adjustment area dimensions generated when using each entire manikin family (both genders). The results are compared with a fixed eye point study by Vogt et al. (2005). Results show larger adjustments areas than the study by Vogt et al. This is however expected due to larger anthropometric coverage in the RAMSIS Typology and A-CADRE families. For example, the tallest person in the study by Vogt et al. is 1897 mm. The tallest person in RAMSIS Typology is 1909 mm and 1947 mm in A-CADRE. Overall, the results indicate that both manikin family approaches give quite similar results, where A-CADRE covers a larger range in height whereas RAMSIS Typology covers a larger range in corpulence.



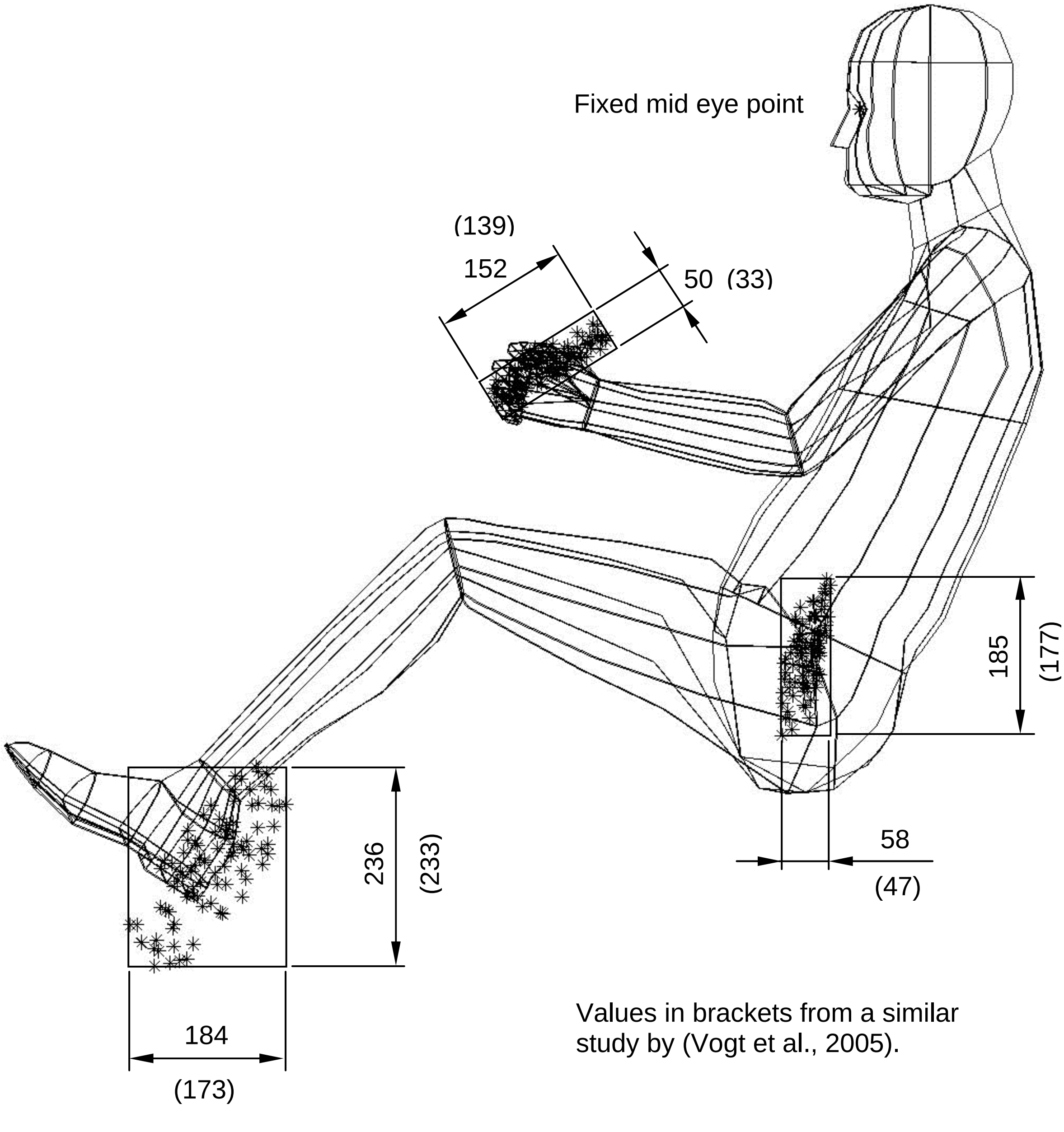
A5.1. Body point locations, RAMSIS Typology (Black stars) and A-CADRE (Black dots), Female



A5.2. Body point locations, RAMSIS Typology (Black stars) and A-CADRE (Black dots), Male

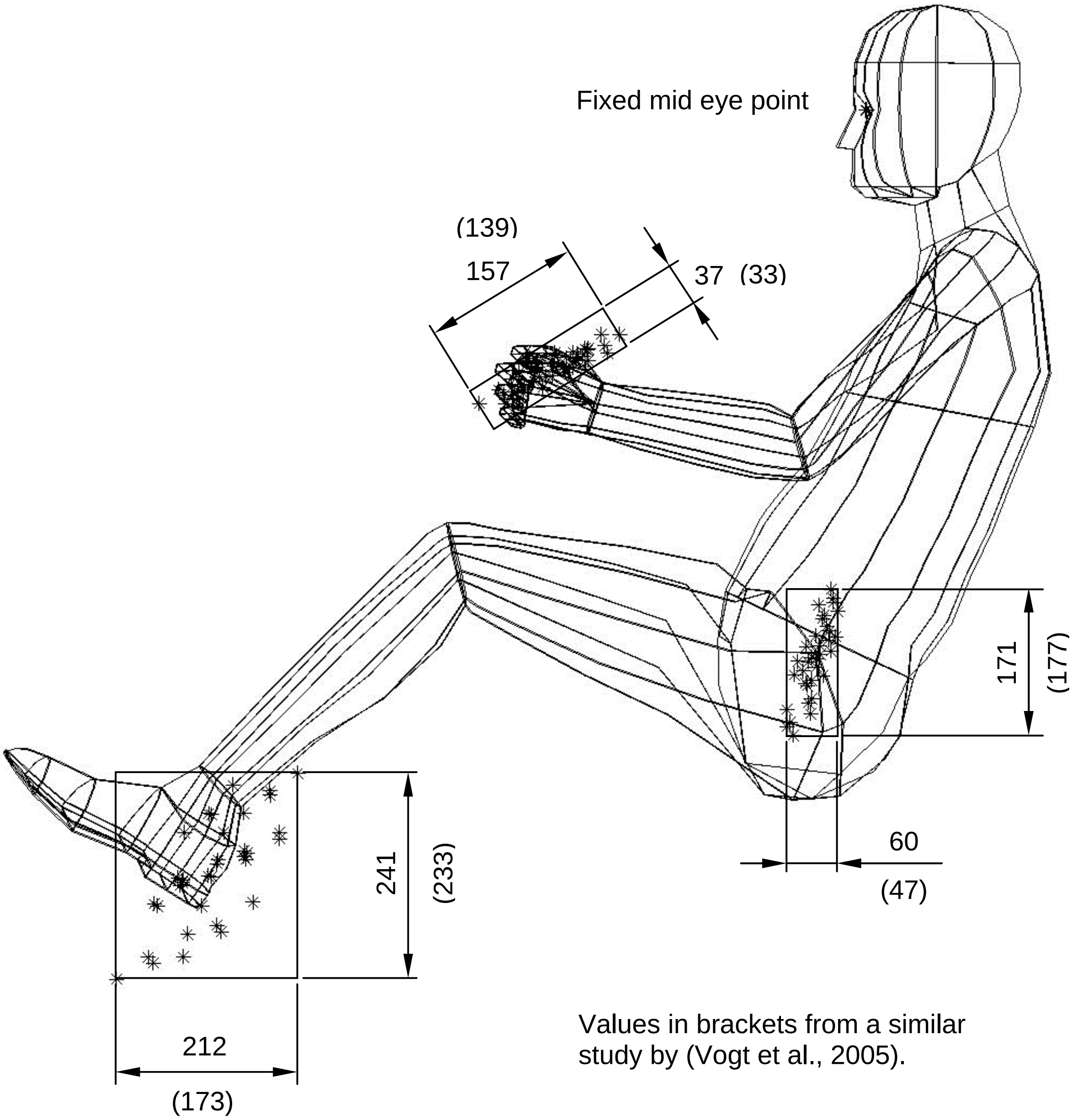


A5.3. Adjustment area dimensions, RAMSIS Typology, Female and Male



Values in brackets from a similar study by (Vogt et al., 2005).

A5.4. Adjustment area dimensions, A-CADRE, Female and Male



Appendix 6

List of publications relevant to the thesis

Initial issues related to the establishment of this research project, mainly associated to the subject of inclusive design (Section 2.4.6), is published in:

> Högberg, D. and Case, K. (2002). *Supporting 'design for all' in automotive ergonomics*. XVIth Annual International Occupational Ergonomics and Safety Conference, Toronto, Canada. CD-ROM.

The study of product developers' interaction with users (Section 2.5) was carried out in collaboration with Jenny Janhager at the Royal Institute of Technology as described in Section 1.4, 2.5.1 and 7.1. Results linked mainly to sub-question 1 and 2 in Section 2.5.1 are published in (Janhager and Högberg, 2004), a paper for which Janhager is the main contributor, and are incorporated in the thesis in abbreviated form.

> Janhager, J. and Högberg, D. (2004). *Product developers' relation to their users - an interview study*. NordDesign 2004, Tampere, Finland. 278-288.

Part of the results from the User Characters study (Section 3.2) is published in:

> Högberg, D. (2003). *Use of characters and scenarios in gear shift design*. Conference on Designing Pleasurable Products and Interfaces, Pittsburgh, USA. 140-141.

The results from the Overlapping Framework study (Section 3.3) is published in:

> Högberg, D., Case, K. and De Vin, L. J. (2002). *Overlapping ergonomic evaluation in the automotive design process*. 19th International Manufacturing Conference, Belfast, Ireland. 233-241.

The Simulation of human-vehicle interaction study (Section 4.2) was performed within the VERDI project, described in Section 1.4. All four authors contributed to the formulation of the objectives and methods, and were operationally involved in the collection of data as well as in writing the article. Hanson organised the writing process. The results from this study is published in:

> Blomé, M., Dukic, T., Hanson, L. and Högberg, D. (2003). *Simulation of human-vehicle interaction in vehicle design at Saab Automobile: present and future*. Warrendale, Society of Automotive Engineers**.** SAE Technical Paper 2003-01-2129.

The Web-based support system study (Section 4.3) was performed within the VERDI project, described in Section 1.4. All four authors were involved in the formulation of the objectives and methods of the study. Hanson and Blomé performed the operative work of creating and evaluating the web based protocol and organised the writing of the article, a process to which all authors contributed. The results from this study is published in:

> Hanson, L., Blomé, M., Dukic, T. and Högberg, D. (2004). Web-based human simulation system for improved process quality and documentation. *In: Human Vehicle Interaction: Drivers' Body and Visual Behaviour and Tools and Process for Analysis*, Hanson, L., Ergonomics and Aerosol Technology, Department of Design Sciences, Lund University, Sweden. Doctoral Thesis.

Initial results from the Computer manikin family study (Section 5.2) is published in:

> Högberg, D., Hanson, L. and Case, K. (2003). *Computer manikin family usage for human accommodation*. Nordic Ergonomics Society conference, Reykjavik, Iceland. 184-188.