Engineering Quality Feelings:
Applications for products, service environments and work systems

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Doctoral Thesis in Technology and Health
Stockholm, Sweden 2011
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Applications for products, service environments and work systems

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Doctoral Thesis
TRITA-STH Report 2011:5

Royal Institute of Technology
School of Technology and Health
Division of Ergonomics
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Abstract

Contemporary quality issues in product design are moving from materialistic to emotional user fulfillment; comprehensive research is needed to examine quality product feelings. This research is directed toward a deeper understanding of user and customer quality feelings for different product types, including services.

The quality feelings concept includes dimensions of product quality, especially functionality, ergonomics and aesthetics. The first objective of this thesis is to identify, prioritize and synthesize quality feelings into product attributes in product development applications. The second objective is to explore, test and propose methodological approaches for designing quality feelings into products.

Several methods from psychology, ergonomics, statistics and probabilistic methods and heuristics were applied to achieve the objectives. From a methodological viewpoint, Likert scales, free elicitation technique and Just About Right scales were applied for data collection. Multiple Regression, Factor Analysis, Correspondence Analysis, Genetic algorithms, Partial Least Squares (PLS) and Rough Sets (RS) were applied for data analyses. For ergonomic product evaluations, direct observations, 3D workload simulations, time and frequency analyses were conducted.

Five product applications are included in this thesis: operator driver cabin design of reach trucks, steering wheel design trigger switch design in right-angled nutrunners, bed-making systems-products and waiting room environments.

Heuristic methods were found effective when there is a high number of product attributes that interact to provide quality feelings. RS results are consistent with PLS attribute predictions. When the number of product attributes is large in comparison to the number of observations, PLS extracts informative results for quality feelings. The RS method is effective in identifying interactions among design attributes.

Quality feelings are associated with both tangible (tactile characteristics) and intangible (quick and easy to use) product characteristics. Words such as safety, functionality, ergonomics, comfort, reliability, supportiveness, usability, feedback, pleasantness, attractiveness, durability and distinctiveness describe quality feelings from tangible products and services. Based on product type, the quality dimensions represented by these words possess different interactions and dependencies. In work environments, products act as prostheses between workers for social interaction, which need to be considered as important quality feelings dimensions.

Keywords: new product development, ergonomics evaluation design for quality, Affective Engineering, servicescape design, product experience

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I express my deepest gratitude to my primary supervisor, Professor Jörgen Eklund, who provided me with an optimal infrastructure for my work. I would not have finished this study without his inspiring support, discussions and excellent suggestions.

Many thanks to Professor Mitsuo Nagamachi, the inspiration for me to start research on Kansei Engineering. His extensive experience guided me through my research and his initiation to start Kansei Engineering research is a milestone in my life.

To Professor Shigekazu Ishihara, my second supervisor, thank you for sharing your knowledge and experience on methodology during my research.

To Professor Tatsuo Nishino, thank you very much for your help explaining and guiding me through the Rough Sets method. I offer special thanks to Professors Nagamachi, Ishihara and Nishino for great hospitality in Japan.

I am grateful to my second supervisor, Professor Jens-Jörn Dahlgaard, and Doctor Mattias Elg for many interesting and motivating discussions. Thank you for supporting me during my doctoral research at the Quality Technology and Management division of Linköping University.

Special thanks to Professor Musa Senel, chairman of Industrial Engineering Department, Anadolu University, Turkey for supporting me to start a PhD in Sweden.

I am indebted to Doctor Simon Schütte for valuable support and providing a stimulating environment for Kansei Engineering, which helped me learn and grow.

This work in practice would not have been possible without support of companies and healthcare centers. I thank all participants for providing their insights.

Many thanks to my friendly colleagues from the Ergonomics division at KTH: Kjerstin, Linda, Mats, Persilla, Malin, Mikael, Carl, Simon, Annika and Teresia. I am grateful to my colleagues at Linköping University Beata, Bodil, Bozena, Lars, Mats, Susanne, Jostein and Vincent.

I thank my family, friends and Peter for continuous support in spite of not spending enough time with them during my research. Without your love and patience, I would not survive.

Stockholm, 2011-09-05
Ebura Ayas
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Paper I

Paper II

Paper III

Paper IV

Paper V

Paper VI

Paper VII
Author Contributions

Paper I
The author performed the study, analyzed the data and compiled the paper. Professor Eklund and Dr. Schütte supervised the author.

Paper II
The second author of this paper performed the study on design support system and compiled the related part in the paper.

Paper III
The author performed the study, analyzed the data and compiled the paper. Professor Eklund and Professor Ishihara supervised the author.

Paper IV
The author performed the study, analyzed the data and compiled the paper. Professor Eklund supervised the author.

Paper V
The author performed the study, analyzed the data and compiled the paper. Professor Eklund and Professor Ishihara supervised the author.

Paper VI
The author performed the study, analyzed the data and compiled the paper. Professor Nishino was involved in the data treatment. Professor Eklund, Professor Ishihara and Professor Nishino supervised the author.

Paper VII
The author performed the study, analyzed the data and compiled the paper. Professor Eklund supervised the author.
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1 Introduction

This chapter gives the reader an introduction to the research theme, product design for quality feelings. It is followed by objectives of the thesis and aims of the studies conducted, and the body of research questions to reach these aims.

1.1 Background to the research

Today’s users have high demands and needs for product quality; through in-the-field, voice-of-customer (VoC) work (Cooper, 2001), the quest for unique, superior products begins with a thorough understanding of the users’ unmet and often unarticulated needs. Verganti (2009), Norman (2010) and Krippendorf (1989) propose that through understanding meanings of products for customers, designing radical innovative products is achieved.

Meanings of products for users lie in understanding affective (feelings and emotion) needs and wants. Affective responses for products are generated by attributions, derived from product attribute satisfaction, which, in turn, influence global satisfaction judgments (Oliver, 1993). One reason to prioritize affective needs is that product design for quality has moved beyond functionality and usability (Childs et al., 2006; Norman, 2010). When all companies make products that perform functions well, products with appeal based on cognition and emotion become distinctive (Norman, 2010). This quality evolution of products follows a similar needs flow proposed by Jordan (1997), based on Tiger (1992).

Jordan (1997) classified three levels of user needs for products: functionality, usability and pleasure. If a product does not possess the correct functionality, it renders the user unsatisfied. The second level is that of usability. When users experience adequate functionality, they want a product that is easy to use. The third level is that of pleasure. After becoming used to a functional and usable product, users want a product that provides emotional benefits. The product quality
attributes extracted from identified emotional needs may cause a change in users’ preferences to evaluate the product positively, and prefer those products.

Parallel to shifts in customers’ needs from functional quality, customer research has moved toward a richer analysis of the central role affect plays in customers’ quality experiences, decisions, motives, and actions (Fishbein et al., 1975; Day et al., 1979; Damasio, 1994; Desmet and Helkert, 2007). To understand feelings toward product quality, communicating affective experiences and meanings of products appear important.

To answer product development for affective needs, Kansei (Affective) Engineering (KE) was proposed in 1970s under the name of Emotional Technology (Nagamachi et al., 1974). As a research base, KE translates human psychological processes - such as feelings and emotions - with ergonomics needs into appropriate product design attributes, such as size, shape, surface and other Engineering characteristics (Nagamachi, 2001) (see Chapter 2 and 3 for further information).

Current KE studies aim at finding effective ways to understand and relate affective needs to objective (technical aspects) design in different development processes of products, such as vehicle interior image (Tanoue et al., 1997), construction machinery (Nikaido et al., 1997), rocker switches (Schütte, 2005), vehicle interior (Jindo, 1997), train interior (Lanzotti and Tarantino, 2007), mobile phones (Yun et al., 2003; Barone et al., 2007; Lin et al., 2007; Seva et al., 2007), product form (Yang et al., 2011), moisture container and food wrapping (Childs et al., 2006), footwear (Alcantara et al., 2005; van Lottum et al., 2006), machine tools (Mondragon, 2005), product packaging (Barnes et al., 2003; Longstaff et al., 2005), product image (Lin et al., 2004), lowlifter platforms (Aueßsson et al., 2001), 3D shapes (Yamada et al., 1999), image retrieval systems (Hayashi et al., 1997; Tsai et al., 2006), and silk garments (Wang et al., 2011).

To understand feelings (affective needs) of product quality, this thesis is directed toward two major research issues. The first is how to approach the understanding of user affective needs (emotions and feelings) for quality feelings while considering objective and subjective ergonomic criteria. The second is how to explore methodologies that link product attributes to affective needs. The second issue is a developing research area within the statistics/heuristics/optimization research areas. Therefore, this PhD study answers the research needs presented above. The following sections provide a background to the research issues given above.
1.2 Experiencing products: Outgoing from affective quality perspective

Departing from Russell et al. (1999) definition on affective quality, Desmet and Hekkert (2007) describe product experience as a change in core affect that is attributed to human-product interaction. Affective quality is defined as the ability to cause a change in affect (Russell et al., 1999). Affect or “core affect” is the neurophysiologic state that is consciously accessible as a simple, non-reflective feeling that is an integral blend of hedonic (pleasure-displeasure) and arousal (sleepy-activated) dimensions (Russell, 2003). Desmet and Hekkert (2007) define product experience using three levels: first is aesthetic experience, which is the entire set of affects elicited by the interaction between a user and a product, including the degree to which all senses are gratified; second is the meanings we attach to the product (experience of meaning), and third is the feelings and emotions elicited (emotional experience).

To understand product quality experiences attributed to affective evaluations, we first need to realize basic and then higher level human needs. Maslow (1943; 1999) defined the order of deficiency needs of humans as: physiological needs, needs for safety and security, needs for love and belonging, needs for esteem, and needs to self-actualize. The individual feels nothing if these needs are met, but feels nervous if they are not. Maslow (1999) related these needs to human instincts. Dahlgaard Park and Dahlgaard (2003) suggested the trinity model, which involves spiritual needs (searching and creating meaning, trust, loyalty, spiritual love, sharing and respect) in human motivation models.

Subjective product experiences are elicited by interaction, including the degree to which senses are stimulated, the meanings and values attached to a product and the feelings and emotions elicited with a product (Schifferstein and Hekkert, 2007). The literature discusses the role of product experiences from multisensory integration of senses (visual-haptic), the level of interaction (in experience levels of seeing photographs, seeing the actual product, touching it and using it) (Vergara et al., 2011) and the role of sensory impairment on product perceptions (Schifferstein and Desmet, 2007). As an example, blocking audition results in communication problems and a feeling of being cut off, while blocking olfaction decreases the intenseness of the experience (Schifferstein and Desmet, 2007). User experience values were classified into five stages by Schmitt (2003) and Nagasawa (2006) (Table 1.1). These value classes represent how a person feels in relation to a product from different dimensions.
Any interaction with a product or service requires a cycle where the user perceives, thinks and acts; for the most part, perceiving requires sensory capability, thinking requires cognitive capability and acting requires motor capability (Clarkson et al., 2007). Interaction between a product or service and a user’s capabilities is influenced by the environment in which it is used (Clarkson et al., 2007). Several frameworks are proposed for product experiences. Interaction with products can be a result of instrumental and non-instrumental physical action, but also consist of passive perceptions or even remembering or thinking of a product (Desmet and Hekkert, 2007). Oppenheimer (2005) introduced a framework for developing the interaction between user and product, offering the metaphor of “conversation between people.” He called product interactions announce, explain, act, and notify to show possible ways a product and its qualities communicate with consumers (Table 1.2).

### Table 1.2 Framework for understanding user product interaction (Oppenheimer, 2005).

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<thead>
<tr>
<th>Evaluation steps of product</th>
<th>Example questions</th>
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<tr>
<td><strong>Announce:</strong> What are you?</td>
<td>What is it? What does the product serve for?</td>
</tr>
<tr>
<td><strong>Explain:</strong> What do you do?</td>
<td>What are all the things this product does? How do you control it? What would you do to perform the main function?</td>
</tr>
<tr>
<td><strong>Act:</strong> Do this for me.</td>
<td>What did the user intend to do? What does the user think he did?</td>
</tr>
<tr>
<td><strong>Notify:</strong> Here is what I did.</td>
<td>In the user’s mind, what should happen next? What does the user think actually happened next? Is that what the user expected?</td>
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Desmet (2007) linked three approaches to describe product emotions: a pleasure approach (Jordan, 2002), an appraisal approach (Desmet, 2002) and a process-level approach (Norman, 2004). Desmet (2007) discussed that Jordan (2002) used a psychological pleasure-framework to...
explain various product pleasure types, Desmet (2002) used cognitive appraisal theory to explain the process of product emotion, and Norman (2004) explained product emotion with a neurobiological emotion framework, which distinguishes several information-processing levels.

Jordan (2002) discussed that a product or service should engage with people at three abstraction levels. The first level is related to performance of a product for the task for which it was designed. The second relates to the emotions associated with the product or service in the context of the associated tasks. These emotions are part of the ‘user experience.’ The third level reflects the aspiration qualities associated with the product or service (i.e., personal or social factors). Desmet (2007) described four sources of pleasure from products: sensory quality of the product (physio-pleasure), the social context in which the product is used (socio-pleasure), task-related concerns of the user (psycho-pleasure) and user values (ideo-pleasure).

1.3 Proposed product quality classifications

Product quality is a product development performance measure (Krishnan and Ulrich, 2001). There are three experience categories for product qualities, two of which were defined by Nelson (1970) and the third Search qualities refer to attributes a consumer evaluates before purchase of the product (Alford and Sherrell, 1996). Experience qualities are attributes that can only be discerned during consumption or after purchase of the product (Alford and Sherrell, 1996). Search qualities make it more difficult to evaluate the product because there are fewer qualities for the consumer to use in an evaluation process (Alford and Sherrell, 1996). The third category Credence qualities refers to attributes that a consumer may not be able to evaluate even after purchase and consumption due to the level of knowledge required to understand what the product does (Alford and Sherrell, 1996).

Bandini Buti (2006) classified five product qualities based on perceptions: common, perceivable, non-perceivable, self-explanatory and induced. This classification is parallel to Maslow’s hierarchy of needs and Kano’s attractive quality theory (see Theory section on Kano model), excluding induced quality.

Common Qualities (Bandini Buti, 2006): qualities that must be considered common and generalizable to all potential users; they are linked closely to safety and security. Perceivable qualities (Bandini Buti, 2006): these may be perceived through normal senses (sight, touch, hearing, feeling a weight in one’s hand, smell, and taste). These change over time with the

explanation product or service (i.e., personal or social qualities, two of which were defined by socio-consumption or after purchase of the product (Alford and Sherrell, 1996). There are three experience categories for product qualities, one of which is related to induced quality.

Search qualities

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Bandini Buti (2006) classified five product qualities based on perceptions: common, perceivable, non-perceivable, self-explanatory and induced. This classification is parallel to Maslow’s hierarchy of needs and Kano’s attractive quality theory (see Theory section on Kano model), excluding induced quality.

Common Qualities (Bandini Buti, 2006): qualities that must be considered common and generalizable to all potential users; they are linked closely to safety and security. Perceivable qualities (Bandini Buti, 2006): these may be perceived through normal senses (sight, touch, hearing, feeling a weight in one’s hand, smell, and taste). These change over time with the
enriching of individual experience. Non-perceivable qualities (Bandini Buti, 2006): These may not be perceived by ordinary senses. They are either hidden, such as the quality of the structure of a panel covered by an outer finish. Such qualities need to be studied, analyzed and guaranteed by specialist bodies, laboratories or other experts. Self-explanatory qualities (Bandini Buti, 2006): These are present when the product informs the user of its qualities and use through appearance. Above all, they are present in products of a mechanical nature whose form is necessarily conditioned by their mechanical nature. Induced qualities (Bandini Buti, 2006): These are communicated by various means of advertising as possible or necessary for the user. For example, increasing ecological awareness led to respect for the environment on the part of producers in production, use and disposal of goods, becoming a required quality.

1.4 Role of affect in judging product quality

Perceptions of affect are represented by several synonyms (Russell, 2003) such as evaluation, automatic evaluation, affective judgment, appraisal, affective reaction, primitive emotion and affective responses. How to assess core affect, mood and evaluation depends on human "feelings." During product evaluation, core affect, mood and evaluation are integrated. Russell et al. (1999) explained this chain approach: Core affect is assessed by asking "how one is feeling right now." When extended over moderate lengths of time, core affect becomes a mood and is assessed by asking "how one generally felt during that period." Evaluation is assessed by asking "how one feels about X." When extended over time, evaluation becomes an attitude and is assessed by asking "how one generally feels about X." According to Zajonc (2000), core affect is mental but not cognitive or reflective. Attributed affect symbolizes the attribution of core affect to an object (the person, condition, thing or event); the mental state is directed (Russell et al., 1999). In its different forms, affect can be classified as integral, incidental (Bodenhausen, 1993) and task-related (Pham et al., 2001).

Integral affect refers to affective responses that are experienced genuinely and are linked directly to the object of judgment or decision (Bodenhausen, 1993). These affective responses are integral to the extent that they are elicited by features of the object, whether these features are real, perceived, or only imagined (e.g., the feeling of happiness while tasting or imagining eating chocolate) (Pham et al., 2001). Incidental affect refers to affective experiences whose source is unconnected clearly to the object evaluated (Pham et al., 2001). Pham et al., (2001) argue that in addition to current mood, incidental affect may also come from a person’s emotional dispositions (such as depression) and temperament (such as general optimism or...
pessimism), or from any contextual stimuli associated with integral affect (such as background
music, a pleasant scent, etc.). Task related affect refers to affective responses elicited by the task
or process of making judgments and decisions, as opposed to direct, integral responses to
features of the target objects or purely incidental feelings (Pham et al., 2001).

1.5 How are affective qualities for products measured?

Quantitative research between stimuli and responses has been under investigation from the
time Fechner (1889) introduced psychophysics to study quantitative relationships between
physical and psychological events (Guilford, 1971). It is the user who decides whether the
product has good or poor quality (Göransson, 1984; Parasuraman et al., 1985). Russell et al.
(1974) offered evidence that all stimuli, including large-scale environments, are perceived in
terms of affective qualities. Russell et al. (1981) later proposed two dimensions, (1)
pleasure/displeasure and (2) degree of arousal (amount of stimulation or excitement), to elicit
affective responses. (Figure 1.1). The scales are later analyzed by Factor Analysis.

Küller (1972) suggests Semantic Environment Description Method (SMB) (in Swedish:
Semantisk Miljö Beskrivning) for measuring affective qualities. SMB resulted in eight factors to
represent environmental description words: pleasantness, complexity, unity, enclosedness, social
status, potency, affection and originality to evaluate architecture and overall impression of an
environment. SMB has been applied to measuring impressions of vehicle interior design
(Karlsson et al., 2003). Emotion toward advertising is another starting research area for
studying affective qualities (Wiles and Cornwell, 1990; Batra and Holbrook, 1990; Edell and
Burke, 1987).

Developed by Mehrabian and Russell (1974), the PAD (pleasure-arousal-dominance) scale,
measuring environmental stimuli, is used widely in marketing research. Mehrabian and Russell
(1974) offered evidence that all stimuli, including large-scale environments, are perceived in
terms of affective qualities. Russell et al. (1981) later proposed two dimensions, (1)
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studying affective qualities (Wiles and Cornwell, 1990; Batra and Holbrook, 1990; Edell and
Burke, 1987).
From affective quality dimensions for environments, the horizontal dimension pleasant quality is described as how much an individual likes or dislikes the environment (Lovelock and Wirtz, 2004). The vertical dimension is arousal quality; this dimension of affective quality depends on environments’ “information load”, its degree of novelty (unexpected, surprising, new, and familiar) and complexity (number of elements and extent of motion or change) (Lovelock and Wirtz, 2004). If the environment is pleasant, increasing arousal leads to excitement and stronger positive consumer responses. If the environment is unpleasant, increasing arousal level moves consumers into the distressing region (Lovelock and Wirtz, 2004).

Ortony (1988) developed a comprehensive consumption emotion set that included non-emotion words (not sleepy), subjective evaluations such as feeling confident, behaviors and action tendencies such as crying and hesitancy, and cognitive states such as interested. Ortony (1988) supplemented this list with open-ended, self-reports of positive and negative feelings toward a variety of consumption experiences.

Schwarz and Clore (1988) proposed a heuristic process that assumes feelings as sources of information (Pham, 1998). This process is called “How do I feel about it?” (HDIF-heuristic). According to the HDIF heuristic, even if the target is not present in the direct physical environment, people still perform evaluations by examining their affective responses to a mental representation of the target (Pham, 1998). Sperling (2005) used user compass charts (UCC) for
evaluating surface materials in operator cabins to map product qualities. UCC is a game-board in the shape of a compass chart, with two crossing vectors and four sectors resulting. The chart points have labels with adjectives and their associations.

Regarding affective design of product quality, different concepts such as total ambience (functionality and styling) (Jindo and Hirosago, 1997), hedonic quality (Helander and Zhang, 2001), image/impression quality (Yun et al., 2003), product sensorial quality (Bandini Buti, 2001), and feeling quality (Lai et al., 2005) were investigated. Lai et al. (2005) use the term feeling quality to concretize the feeling effects evoked by a product. Hedonic quality (HQ) is another dimensional quality aspect addressing needs for novelty or change and social power (status) induced, for example, by visual design, sound design, novel interaction techniques and novel functionality (Hassenzahl, 2001).

The studies discussed above reflect dimensions of product qualities. Still, research is needed to understand quality feelings from products to product designs that appeal to people’s emotions, feelings and values; there is need to understand quality needs holistically.

### 1.6 Affective product development methods

In which stages of product development are affective needs involved? Van Kleef et al. (2005) discussed that consumer research methods are applied primarily in product development, testing and launch stages. Childs et al. (2006) defined six stages of new product development to integrate customers’ affective processes: target, ideate, develop, implement, scale-up, and deploy (Figure 1.2).

Figure 1.2 Six stage affective scheme (Childs et al., 2006).

Examine the marketing literature, consumer/user-based product development research is referred to as voice of the customer, user-focused product development, consumer decision-making and affective design and Engineering. As common research methods in this area, Kan’s model (Kano, 2001), QFD (Hauser and Clausing, 1988), conjoint methods (Green and Srinivasan, 1978), robust design (Taguchi, 1986) and Kansei (Affective) Engineering (Nagamachi, 1995).
approaches are identified from the literature. These approaches are described in the theory section.

1.7 Objectives and research questions

This study is directed toward a deeper understanding of users' and customers' quality feelings for different types of products, including services. The concept of quality feelings includes different dimensions of product quality (e.g., functionality, ergonomics and aesthetics). The first objective of this thesis is to identify, prioritize and synthesize quality feelings into product attributes in product development applications. The second objective is to explore, test and propose methodological approaches for designing quality feelings into products.

1.8 Outline of studies in this thesis

The outlines of the seven studies in this thesis are presented in Table 1.3 with aims and research contributions. The studies are concerned with improvement of existing products and new product designs. The products evaluated were operator cabin components of a new truck, the steering wheel of a reach truck, waiting environments in primary healthcare, powered tool trigger switches and bed-making products in healthcare.
<table>
<thead>
<tr>
<th>Papers</th>
<th>Product development category</th>
<th>Product types</th>
<th>Aims</th>
<th>Contributions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper I</td>
<td>Improvement of product design</td>
<td>Reach truck operator cabin</td>
<td>to explore design improvements for feelings of quality in a reach truck operator cabin and components</td>
<td>Identification of affective factors to design quality feelings</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Identification of operator cabin components that contribute total quality feelings</td>
<td></td>
</tr>
<tr>
<td>Paper II</td>
<td>New product design</td>
<td>Steering wheel</td>
<td>to develop and design an interactive decision support system to select product design attributes for design of a steering wheel that considers interactions between design attributes and feeling quality criteria</td>
<td>Development of decision support system for users</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Investigation of product attribute interactions for affective feeling preferences by genetic algorithms</td>
<td></td>
</tr>
<tr>
<td>Paper III</td>
<td>Improvement of service environment</td>
<td>Waiting room</td>
<td>to understand perceived and desired quality feelings that contribute to affective factors in a service environment related physical design attributes and interactions (as a study object, waiting areas are selected)</td>
<td>Identification of important quality feelings from waiting rooms</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Investigation of design attribute interactions to provide calm feeling by Rough Sets analysis</td>
<td>Preference mapping of waiting rooms on perceived affective qualities</td>
</tr>
<tr>
<td>Paper IV</td>
<td>New product design and improvement of existing products</td>
<td>Trigger mechanisms for powered tools</td>
<td>to identify the important subjective factors related to trigger switch feeling for electrical right-angled nutrunners</td>
<td>Identification of affective factors to design trigger feeling</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Comparison of users and product developers</td>
<td></td>
</tr>
<tr>
<td>Paper V</td>
<td>New product design and improvement of existing products</td>
<td>Linear and non-linear operating trigger mechanisms</td>
<td>to investigate affective preferences for trigger switch mechanisms and components related to attributes to improve design parameters by Rough Sets analysis to give quality, feedback, hardness and distinct perceptions</td>
<td>Identification of preferred mechanism types for quality feelings</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Investigation of design attribute interactions to provide calm feeling by Rough Sets analysis</td>
<td></td>
</tr>
<tr>
<td>Paper VI</td>
<td>New product design</td>
<td>Non-linear operating trigger mechanisms</td>
<td>to identify and investigate design characteristics of the trigger function associated with different feelings and preferences by assembly workers operating nutrunners</td>
<td>Investigation of interactions between design parameters by Rough Sets analysis to give quality, feedback, hardness and distinct perceptions</td>
</tr>
<tr>
<td>Paper VII</td>
<td>New product design and evaluation</td>
<td>Bed-making product</td>
<td>to understand nursing personnel’s perceptions towards the bed-making task with conventional and a new product from affective, productivity, physical load and discomfort perspectives</td>
<td>Identification of affective factors for bed-making systems</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Comparison of physical loads and time durations for job tasks</td>
<td></td>
</tr>
</tbody>
</table>
The research questions (RQs) explored in each study are given below:

**Paper I** examined two research questions. RQ1: Which design components in a driving environment communicate quality feelings? RQ2: How do design components contribute to the total (overall) quality feelings from the operator’s cabin?

**Paper II** examined one research question. RQ1: How can affective design decision support systems be developed for steering wheel design?

**Paper III** examined three research questions. RQ1: is there a difference regarding perceived affective factors between waiting areas? RQ2: what are the desired affective factors when experiencing waiting areas? RQ3: How do waiting area design attributes interact in creating affective factors?

**Paper IV** examined two research questions. RQ1: How do we define trigger feeling related to electrical right-angled nutrunners? RQ2: What are the differences between product developers and operators to define trigger feeling?

**Paper V** examined two research questions. RQ1: What are the differences regarding perceptions of different nutrunner trigger mechanisms? RQ2: How do trigger mechanism attributes relate to subjective needs?

**Paper VI** examined three research questions. RQ1: Is there a difference between subjective preferences and trigger switch force-travel mechanisms? RQ2: Which mechanism attribute levels interact to give a certain perception such as distinct trigger feedback? RQ3: What is the relationship between switch mechanisms and perceptions of quality?

**Paper VII** examined three research questions. RQ1: Are there any differences between subjective preferences of two bed-making systems? RQ2: Are there differences of time and task-related productivity aspects between two bed-making systems? RQ3: Are there differences between forward bending and elevation of hands over shoulder level time durations, frequencies and bending angles of participants for two bed-making systems?
1.9 Structure of the thesis

This thesis includes an extended summary and seven appended papers, which are referred to by roman numerals below. It begins with an introduction chapter and the background of the thesis and research objectives. The second chapter presents the theoretical framework of reference, a composition of product development, ergonomics and affective product development methods. The third chapter provides an overview of the methods, methodological procedures and validity criteria applied with methods. The fourth chapter provides a summary of the papers, where background and important results are presented. The fifth chapter discusses results and methods, and how the papers address the research questions within a framework generated from the results. The sixth chapter draws general conclusions and points out future research directions. The seven papers on which this thesis is based are appended in the last section.

Notes:

- Kansei is used as a word to describe affective (feeling, perceptions) for products in this thesis.
- “Affective quality needs”, “perceived quality” and “experienced quality” are used interchangeably with “quality feelings” throughout the thesis.
- Affective Engineering is used interchangeably with “Kansei Engineering” throughout the thesis.
- The term affective values are used to describe important quality feeling (affective) factors in study III.
- This thesis involves parts from author’s Licentiate thesis which was published in 2008 (Ayas, 2008).
2 Theoretical Frame of Reference

That all our knowledge begins with experience, there is indeed no doubt ... but although our knowledge originates with experience, it does not all arise out of experience. (Immanuel Kant)

This chapter covers quality concept starting from its effect on organizational performance, moving to the design process steps and integrating ergonomics (human factors) perspectives, and discusses the contributions of customer-focused product development methods. Essential definitions are given.

2.1 Product development

Product development is among the essential processes for success, survival and renewal of organizations, particularly for firms in either fast-paced or competitive markets (Brown and Eisenhardt 1995). Processes design for product development has been researched for many years (Cooper, 1990; Urban and Hauser, 1993; Ulrich and Eppinger, 2004). The process of product development is the sequence of phases or activities that must be performed to ideate design and introduce a product to the market (Whitney, 1990; Otto and Wood, 2001). In recent years, integrated product development (IPD) (Olsson, 1976 in Bergman and Klefsjö, 2010) is proposed to answer competitive market needs for product development. IPD process starts with acknowledging customer needs and competitor positions, and examining external design drivers (Magrab et al., 2009). Integrated design ensures that all required functional characteristics of the product are developed simultaneously during product design (Magrab et al., 2009). Concurrent Engineering (CE) is a systematic approach to integrated product development that emphasizes response to user expectations, and embodies team values of cooperation, trust and sharing in a way that decision-making proceeds with large intervals of parallel effort from all product lifecycle perspectives (Magrab et al., 2009).

Product effectiveness is determined by quality measures (e.g., sales, satisfaction/preferences, etc.) as indicators of product strategy (Sink et al., 1984). Quality measures show the efficiency of designing the desired user’s needs into products. Quality product design starts in the early processes of product development (Ulrich and Eppinger, 2004). Together, work design and
measurement effectiveness contribute to productivity, which then work with product innovation; quality of working life leads to organizational performance (Figure 2.1). Quality of design processes is also important to ensure product design quality dimensions. Leaving mass production strategies behind, producers in recent years have applied mass customization techniques to fulfill users’ preferences. Products in a mature market should be designed subjectively to appeal to customers over a long in-use life cycle phase; products in a rapidly changing market should similarly be designed to be valued, but in a way to encourage a short in-use phase (Childs et al., 2006). Tseng and Jiao (2001) defined mass customization as the technologies and systems to deliver goods that meet individual needs with near mass production efficiency. Mass customization can be implemented in several ways (Magrab et al., 2009): Self-customization, where the user alters or combines the product to suit his/her needs; Customization using a mix of standardized procedures, where either the first or last activities within the factory are customized while the others are kept standardized; Modular product architecture, where modular components are combined to produce a customized product; and Flexible customization, where a flexible manufacturing system produces customized products without higher costs.

![Figure 2.1 Total organization performance model (Sink et al., 1984).](image)

To answer user needs involvement in current product development methods, the traditional Stage-Gate new product development (NPD) model is proposed with multiple versions (Cooper, 1990; 2001). In the past, stage-gate models were criticized as slow, promoting high overhead, treating all projects and products the same and stifling innovation (O’Connor, 1994). Vergyzer and de Mozota (2005) proposed integrating user oriented design approaches to stage-gate models and showed entry points: the first version of Stage-Gate XPress is for projects such as improvements, modifications, and extensions; second is Stage-Gate Lite for small projects, such as simple user requests; and last Stage-Gate TD for technology development projects, where the deliverable is new knowledge, new science, or a technological capability.

![Figure 2.2 Total organization performance model (Sink et al., 1984).](image)

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An alternative product development process is a spiral type (Boehm, 1986). In a spiral process, the product development (PD) team cycles quickly through the stages from opportunity to testing (Hauzer et al., 2006). Hauzer et al. (2006) discussed the key difference between a funnel process like stage-gate and a spiral process; in the latter, there is a greater expectation of iterative feedback loops as successive journeys through the funnel lead to improvements. Childs et al. (2006) conducted a study with four companies to describe the processes product development teams are involved in concerning affective NPD. Participants agreed that in product development processes, one stage following another did not happen; iteration by doing was the way to involve user needs.

2.1.1 Open innovation stage-gate model to collect voice of customers

Radical product innovation does not result from user-centered innovation approaches (Verganti, 2009; Norman, 2010). Companies integrate design-based innovations by exploring lives of people, and how they attach meaning to objects in a broader context within the social environment they live. In the traditional or closed innovation model, input for user voice comes from internal and some external sources such as user input, marketing ideas, marketplace information and strategic planning (Cooper and Edgett, 2009). The act of involving the user in an aspect of the product creation process has been coined open innovation or co-design (Magrab et al., 2009). Cooper and Edgett (2009) proposed an open innovation stage-gate model (Figure 2.2) to integrate sources and collect customer voices during product development. In this paradigm, there are both out-bound innovation, where companies license or sell the technology or developed products to others, and in-bound innovation, where companies seek ideas, solutions, IP, development and marketing help from external sources for development projects under the general heading open innovation (Chesbrough, 2003; Cooper and Edgett, 2009).

Von Hippel (2001) proposed user toolkits to integrate user needs for innovation in products. Toolkits are designed first to enable users to carry out cycles of trial-and-error learning (von Hippel, 2001). Second, they offer users a solution space that encompasses the designs they want to create (von Hippel, 2001). Third, well-designed toolkits are user-friendly in the sense that users do not need to engage in much additional training to use them competently (von Hippel, 2001). Fourth, toolkits contain libraries of commonly used modules that the user can incorporate into his or her custom design (von Hippel, 2001). Fifth and finally, properly designed toolkits ensure that custom products and services are producible on manufacturer production equipment without requiring revisions by manufacturer-based engineers (von Hippel, 2001). Verganti (2009) argued that firms search for knowledge about meaning and error learning (von Hippel, 2001). Third, well-designed toolkits are user-friendly in the sense that users do not need to engage in much additional training to use them competently (von Hippel, 2001). Fourth, toolkits contain libraries of commonly used modules that the user can incorporate into his or her custom design (von Hippel, 2001). Fifth and finally, properly designed toolkits ensure that custom products and services are producible on manufacturer production equipment without requiring revisions by manufacturer-based engineers (von Hippel, 2001). Verganti (2009) argued that firms search for knowledge about meaning.
throughout their external environments. Companies are immersed in a collective research laboratory where they form relationships with several interpreters to pursue investigations, and are engaged with them in a continuous mutual dialogue Figure (2.3) (Verganti, 2009).

Figure 2.2 Open innovation stage-gate model (Cooper and Edgett, 2009).

Figure 2.3 Interpreter network to design innovative products (Verganti, 2009).
2.2 Product

Products include goods, services, experiences, events, persons, places, organizations, information and ideas (Kotler, 2000). All products begin with an idea whether from customers, competitors, suppliers or companies (e.g., iPad).

The origin of the word product comes from Middle English, from medieval Latin productum, from Latin, something produced, from neuter of productus, lengthened past participle of producere, to bring forward (Merriam-Webster’s online, retrieved 14.05.2011). The marketing concept definition of product is: a product is anything that can be offered to a market to satisfy a want or need (Kotler, 2008), a desired outcome of the development process (Cross, 2008; Ulrich and Eppinger, 2004). Monö (1997) examined product in a trinity model as a totality of technical aspects for products, ergonomics criteria and the communication of the product to the user.

Product is approached from three perspectives (Giudice et al. 2006): organizational, Engineering and marketing, Marketing perspective (Green and Srinivasan, 1990) regards products as a set of attributes, combined with the final price. The performance metrics are market adherence, user satisfaction and profit; from the Organizational perspective (Brown and Eisenhardt, 1995), the product is the result of the entire organizational process, and there are many measures involved starting from design phase to employee costs; the Engineering design perspective (Finger and Dixon, 1989) assumes a product with its physical dimensions, and examines it as a system of interacting components. Decision variables include function, configuration, shape and dimensions.

Ulrich and Eppinger (2004) break down products into three categories: user-driven products, technology-driven products and technology- and user-driven products. Typically, there is high interaction for the user with technology-driven products. The user-driven product is derived from the functionality of its interface and/or aesthetic appeal (Ulrich and Eppinger, 2004). A complementary definition to user-driven products is proposed with the meta-product concept by Linn (1990). Meta is a Greek word meaning beyond or after; it represents all the ideas and interpretations behind the physical product, such as prejudices, status, nostalgia, group affiliation and others (Monö, 1997).
2.2.1 Who are users of products?

In understanding quality feelings for products, defining user group(s) is essential. In this thesis, another word for user is customer. Bergman and Kjellström (2010) define customer as those people or groups for whom we want to create value (see Lean philosophy by Womack and Jones 1998).

The context of use determines selection of product attributes and design. Buur and Windum (1994) classified users according to development phases of a product: development, manufacture, use, sales and maintenance. Bandini Buti (2006) defined four user groups: users who work with the product, users who work on the product, users who handle the product (Eason, 1988) and users who eliminate, remove and destroy the product (Table 2.1). Janhager (2005) proposed co-user and side user concepts. Co-users are people who cooperate with a person who uses a product, and side users are people who have no certain purpose for interacting with a product.

Table 2.1 Classification of user types (Bandini Buti, 2006).

<table>
<thead>
<tr>
<th>Users who work with the product</th>
<th>Users who work on the product</th>
<th>Users who handle the product (Eason, 1988)</th>
<th>Users who eliminate, remove and destroy the product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unique user: when the product is destined for exclusive or private use. These are generic and professional &quot;maintenance&quot; people, who work with the product (wheel on a car, etc.).</td>
<td>These are retailers, workers, transport workers, installation workers, both those involved with distribution and those involved with the end-user.</td>
<td>These are ecological, recycling and disposal workers.</td>
<td></td>
</tr>
<tr>
<td>Multiple-definition, when the product is destined for definable group of people.</td>
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</table>

2.3 Product design

Design is any activity directed at changing existing realities that create the conditions one prefers (Simon, 2001). Krippendorf (1989) took the etymology definition of design: de+signare, which means making something, distinguishing it by a sign, giving it significance, and designating its relations to things, owners, users or goods. From this perspective, he defined design as making sense of things.
The word design is used to describe both the activity of product development as a technical concept and an implementation of product functions, and as the activity of conceiving ergonomic and aesthetically pleasing aspects of form and function in a product (Kamata, 2002).

The Industrial Design Society of America (IDSA) defined design as the professional service of creating and developing concepts and specifications that optimize the function, value, and appearance of products and systems for the mutual benefit of both user and manufacturer. In the International Council Societies of Industrial Design’s (ICSID) view, design is a creative activity whose aim is to establish the multi-faceted qualities of objects, processes, services and their systems in whole life-cycles. The IDSA definition gives industrial design a role to satisfy needs of the manufacturer and user, and uses function, value and appearance as quality dimensions; ICSID focuses on designing quality aspects into products and all related activities.

There are both product- and process-oriented design theories. Process-oriented design theories define design processes as a set of stages that needs to be followed. Designing a product requires a detailed understanding of the user and the context for which it is designed (Hassenzahl, 2008).

Jones (1992) defined design methods as divergent, transformational and convergent. Cross (2008) defined design methods as creative and rational. Giudice et al. (2006) proposed four types of design approaches: Creative design, including design studies constrained by specific requirements (functionality, performance, producibility) but with no specifications regarding the transformation of the idea into product or the realm of possible solutions; Innovative design (transformational design) (Jones, 1992), the overall design problem and its possible decomposition into simpler sub-problems. The possible alternatives for each constructional subunit are synthesized and can be reduced to a simple originate combination of preexisting components; Redesign is necessary when a product does not meet the prescribed requirements or when changes in the environment context happen; Routine design (convergent design, Jones, 1992), different characteristic design factors such that the form of the product, the method of design approach and the production system are known before the design process begins. Intervention is reduced to the choice of the best alternative with respect to each subunit of the product.

Semiotics and Semantics

Semiotics, the study of signs, goes back to Plato who discussed establishing relationships between the sign, its meaning and the thing it designates (Bürdek, 2005). Peirce (1867) emphasized that signs exist only if they relate to an object or interpreter (Bürdek, 2005).
Monö (1997) proposed four semantic functions to be designed in products; products need to be designed to describe its purpose and way of use; express its qualities, signal (communicate) users and identify its purpose and origin. Semantics is used to study semiotics to discover the meaning of signs individuals perceive from products. Wikström (2002) proposed Product Semantics Analysis (PSA) to formulate semantic needs and requirements verbally.

Morris (1938) in Bürdek, 2005 distinguished three semiotic dimensions related to product: the syntactic dimension, the formal relations of signs among each other and their relations to other signs; the semantic dimension, the relation of signs to the objects or their meanings; and the pragmatic dimension, the relation between the signs and the users of signs, the interpreters (Figure 2.4).

Figure 2.4 Semiotics-syntax-pragmatics (Morris, 1938).

2.4 Product quality

As a word, quality has its roots in the 13th Century from Old French "qualité", from Latin "qualitas" state, nature, from "quails" of what sort (The Collins English Dictionary, 2003). The word quality is derived from the Latin "qualitas" meaning “of what” (Bergman and Klefsjö, 2010). Cicero, the roman orator and politician (106-43 B.C.), is thought to be the one who first used the word (Bergman and Klefsjö, 2010). The official definition of quality is “the totality of features and characteristics of a product or service that bear upon its ability to satisfy stated or implied needs” (ISO 8402). However, the new quality concept today is to find latent or subconscious desires, and considers these desires as product features. The word quality means “having a high degree of excellence” (Pirsig, 1974), but like beauty, quality is subjective (Bergman and Klefsjö, 2010).

Monö (1997) proposed four semantic functions to be designed in products; products need to be designed to describe its purpose and way of use; express its qualities, signal (communicate) users and identify its purpose and origin. Semantics is used to study semiotics to discover the meaning of signs individuals perceive from products. Wikström (2002) proposed Product Semantics Analysis (PSA) to formulate semantic needs and requirements verbally.

Morris (1938) in Bürdek, 2005 distinguished three semiotic dimensions related to product: the syntactic dimension, the formal relations of signs among each other and their relations to other signs; the semantic dimension, the relation of signs to the objects or their meanings; and the pragmatic dimension, the relation between the signs and the users of signs, the interpreters (Figure 2.4).

Figure 2.4 Semiotics-syntax-pragmatics (Morris, 1938).

2.4 Product quality

As a word, quality has its roots in the 13th Century from Old French "qualité", from Latin "qualitas" state, nature, from "quails" of what sort (The Collins English Dictionary, 2003). The word quality is derived from the Latin "qualitas" meaning “of what” (Bergman and Klefsjö, 2010). Cicero, the roman orator and politician (106-43 B.C.), is thought to be the one who first used the word (Bergman and Klefsjö, 2010). The official definition of quality is “the totality of features and characteristics of a product or service that bear upon its ability to satisfy stated or implied needs” (ISO 8402). However, the new quality concept today is to find latent or subconscious desires, and considers these desires as product features. The word quality means “having a high degree of excellence” (Pirsig, 1974), but like beauty, quality is subjective (Bergman and Klefsjö, 2010).
The concept of quality changes over time. During the 1950s and 1960s, quality was defined as a product's fitness for use and value. In the 1970s and 1980s, the quality concept represented product conformance to requirements. Functionality, reliability and safety were prioritized in product design quality. Quality has been defined as conformance to specifications (Gilmore, 1974; Levitt, 1972), conformance to requirements (Crosby, 1979), fitness for use (Juran, 1988), aimed at the needs of customers, past present and future (Deming, 1982) and loss avoidance (Taguchi, 1986). The most pervasive definition of quality currently in use is the extent to which a product or service meets and/or exceeds a customer's expectations (Grönroos, 1984; Parasuraman et al., 1988). This definition grew out of the services marketing literature (Lovelock and Wirtz, 2004; Shostack, 1977; Zeithaml, 1981). Lean product development sets designing and developing value for customers as the focus, which is one of the proposed definitions by Feigenbaum (1951).

According to Deming (1982), one indication of product quality is the extent to which different user evaluations of the same product vary (in Lai et al., 2005). Degree of satisfaction from a product is proposed as an indicator of product quality (Gilmore, 1974). Ishihwan (1983) argued the extent to which the product satisfies the user's expectations is one implication of product quality (a similar approach to Gilmore, 1974). Quality by Design (QbD) (Taguchi, 1986; Juran, 1988) is another concept to define product quality; to design quality throughout a product's life cycle.

Shewhart (1980) proposed that product quality can be understood by comparing quality in different periods (1) to make it possible for one to see whether product quality for a given period differs from some other period taken as a basis of comparison, and (2) to make possible the comparison of product quality for two or more periods to determine whether the differences are greater than should be attributed to chance.

In summary, quality is to aim for excellence in product design and designing manufacturing processes. Producers want to anticipate, satisfy and exceed customer's needs and create value for their lives.

### 2.4.1 Product quality dimensions

Quality dimensions can be defined according to five major approaches to quality: transcendent, product-based, user-based, manufacturing-based and value-based (Hunt, 1992). Eight dimensions for product quality - performance, features, durability, conformance, reliability, serviceability, aesthetics and perceived quality - were provided by Garvin (1984) as a classification framework.
Based on: product-based, transcendent, user-based, value-based and manufacturing-based quality definitions (Table 2.2). Bergman and Klefsjö (2010) propose environmental impact as another quality dimension indicating a measure of how the product affects the environment.

Table 2.2 Product quality dimensions based on three approaches (Garvin, 1984).

<table>
<thead>
<tr>
<th>Product Quality</th>
<th>Dimension</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product-based approach</td>
<td>Performance</td>
<td>The primary operating characteristics of a product (car fuel efficiency)</td>
</tr>
<tr>
<td></td>
<td>Features</td>
<td>The secondary characteristics of a product that supplement its basic functioning (size, capability)</td>
</tr>
<tr>
<td></td>
<td>Durability</td>
<td>The product’s probability of failure-free performance over a specified period of time</td>
</tr>
<tr>
<td>Manufacturing-based approach</td>
<td>Conformance</td>
<td>The degree to which a product's physical and performance characteristics meet a number of design specifications</td>
</tr>
<tr>
<td></td>
<td>Reliability</td>
<td>A measure of useful product life (i.e., the amount of use a customer gets from a product before it deteriorates or must be replaced)</td>
</tr>
<tr>
<td></td>
<td>Servicability</td>
<td>The ease, speed, courtesy and competence of repair</td>
</tr>
<tr>
<td>User-based approach</td>
<td>Aesthetics</td>
<td>How the product looks, feels, sounds, tastes or smells; matters of personal preference</td>
</tr>
<tr>
<td></td>
<td>Perceived</td>
<td>Quality-based on image, brand name or advertising rather than product attributes; assessed subjectively</td>
</tr>
</tbody>
</table>

Sebastianelli and Tamimi (2002) examined the association between product quality dimensions and quality alternative definitions by applying factor and regression analysis. According to their study of a sample of quality managers in U.S. companies (N=188), the user-based definition was related to aesthetics and perceived quality, the manufacturing-based definition was related to conformance and the product-based definition was related to performance and features.

According to the Kano model and depending on their ability to create user satisfaction or dissatisfaction, quality is classified into six classes: must-be quality, attractive quality, one dimensional quality, indifferent quality, reverse quality, and skeptical quality (Kano, 2001). Must-be Quality (Figure 2.5): customers take must-be quality attributes of products for granted when fulfilled. However, if the product does not meet this basic need sufficiently, the user may become very dissatisfied. For example, when a user wants to buy a new car, no scratches may be such an attribute (Shen et al., 2000). (Kano also discusses that he is inspired by Herzberg’s Motivator-Hygiene Theory). One-dimensional quality attributes result in user satisfaction when fulfilled and dissatisfaction when unfulfilled. The better the attributes are, the better the user likes them (e.g., low fuel consumption). These attributes are also known as spoken qualities (Shen et al., 2008). In different quality cases, it is recognized as a neutral feeling for either the sufficient or
insufficient physical state, which means people are indifferent about the physical state (Kano, 2001). The absence of attractive attributes does not cause dissatisfaction because they are not expected by customers who are unaware of such product features. However, strong achievement in these attributes delights customers (e.g., power rearview mirror) (Shen et al., 2000). Reverse characteristics are those whose presence brings dissatisfaction. Combinations of insufficient and sufficient evaluations are regarded as skeptical because such combinations may be realistic or not.

Figure 2.5 Attractive quality model (Kano et al., 1984).

2.4.2 Service quality

Customers perceive services in terms of the quality of the service and how satisfied they are overall with their experiences (Zeithaml and Bitner, 2003). Satisfaction can be defined as the judgment that a product or a service feature, or the product or service itself, provides a pleasurable level of consumption-related fulfillment (Oliver, 1993). User satisfaction is influenced by service quality, product quality and price, and situational factors (Zeithaml and Bitner, 2003). With services, quality is whatever the user perceives it to be (Grönroos, 2000).

Service quality reflects the customer’s perception of interaction quality with the staff, physical environment quality and outcome (technical) quality (Brady and Cronin, 2001) (Figure 2.6).
Service quality dimensions are defined as what the user receives and how the user receives it; respectively, the technical result or outcome of the process (Outcome quality) and the functional dimension of the process (functional quality) by Grönroos (2000). The need for the physical environment of the service encounter is proposed as the third dimension (Grönroos, 2000). Grönroos (2000) argues that where of the service quality dimension needs to be added based on Rust and Oliver (1994) to what and how dimensions of service quality. This dimension is called servicescape quality (Grönroos, 2000). Some service quality dimensions proposed by Zeithaml et al. (1998) are given in Table 2.3.

The term servicescape was introduced to the services marketing literature by Bitner (1992) to describe various elements of the physical environment of the service encounter. It is important to take affective responses into account in service quality evaluations (Grönroos, 2000). Scales used in the literature, such as SERVQUAL (Parasuraman et al., 1988) and PANAS (Watson et al., 2000), cover limited exploration of moods related to service quality dimensions. Moods have positive or negative effects on customers’ evaluations. However, emotions that customers feel when consuming a service have not been included in perceived service quality models or in models measuring satisfaction of services (Grönroos, 2000). Method developments are needed in this area, for which an approach is presented in Paper III.
2.4.3 Method approaches to study physical environments

Examining the influence of the physical environment of waiting rooms, the literature identifies two approaches (Table 2.4). The first method is to isolate an environmental variable such as music (Routhieaux and Tansik, 1997), ambient odor of orange essential oil (Lehrner et al., 2000) or TV, (Pruyn and Smidts, 1998) and demonstrate that it affects aspects of patient outcomes negatively or positively. Mood-enhancing strategies using elements such as color, high and large windows with pleasant views or pictures on the waiting room wall yield positive effects in waiting rooms (Cameron et al., 2003). The second method is to examine multiple stimuli in waiting areas. With this approach, researchers compare users' experiences in renovated and un-renovated waiting areas cross-sectionally, in individual units longitudinally, and in pre- and post-renovation. According to a literature survey by Dijkstra et al. (2006), positive effects were found for patients' environmental appraisal, but with regard to patients' evaluations of physicians and nurses, results were less convincing. Table 2.3 shows the methods, outcome measures and results of these studies based on multiple stimuli. It appears that renovating or redesigning healthcare environments, in general, is appreciated by patients, but evidence of clinical effects is lacking. Moreover, the conflicting results for social behavior show that renovation may have negative consequences for specific types of patients and should be planned.
carefully. Arneill and Devlin (2003) argue that seniors were more concerned with the functional rather than structural nature or physical appearance of waiting rooms. These comments make sense from the perspective of people who may have movement or sensory challenges and are sensitive to environments that present problems in these areas. The majority of research on care environments (Rasmussen et al., 2006) employs experimental designs to test environmental variables (e.g., sound, color and architecture) in relation to patient outcomes such as recovery, pain and blood pressure. However, there is little research-based understanding of the meanings of being in these environments. Effective methods for reporting information on patient views are also needed to influence and improve healthcare processes and outcomes (Wensing and Elshyn, 2002). Both patients and personnel should contribute to the development of a preference framework, but they usually lack the expertise to generate a model on their own.

Figure 2.7 encapsulates the physical (i.e., manufactured, objective, or measurable), social, symbolic, and natural stimuli that may be contained in a servicescape and that may enhance or constrain employee and customer approach/avoidance decisions and social interaction behaviors (Rosenbaum and Massiah, 2011). These four dimensions are the physical (Bitner, 1992), the social (Berry et al., 2002, 2005), the symbolic (Rosenbaum and Massiah, 2004) and the natural (Rosenbaum, 2009a, b; Rosenbaum et al., 2009) dimensions.

Table 2.4 Multiple stimuli studies for waiting areas in healthcare.

<table>
<thead>
<tr>
<th>Author/date</th>
<th>Method</th>
<th>Outcome Measures</th>
<th>Results</th>
</tr>
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<tbody>
<tr>
<td>Ingham and Spencer (1997)</td>
<td>Controlled clinical trial</td>
<td>Evaluation of waiting room considerate/quality perception Mood: relaxation/security/comfort</td>
<td>Patients in the added comfort condition were more relaxed, secure and comfortable than those in the other two conditions.</td>
</tr>
<tr>
<td>Leather et al. (2003)</td>
<td>Controlled clinical trial</td>
<td>Self-reported stress</td>
<td>Subjects who were given the stress task reported higher stress levels than those who were not given the stress task.</td>
</tr>
<tr>
<td>Nilsson et al. (2004)</td>
<td>Requirement analysis</td>
<td>Evaluation of a waiting room Patient needs</td>
<td>It is important to feel safe in the environment, privacy, to be able to do things and find out information or be able to choose to wait in peace and quiet. The sustainability analysis showed that the environmental effects consisted primarily of the products and energy consumption.</td>
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</tr>
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<td>Controlled clinical trial</td>
<td>Data retrieved by observations and self-reported measures</td>
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2.5 Role of ergonomics in design for quality

Ergonomic qualities (EQ) are determined by verifying the positive or negative effects of the ergonomic characteristics under determined conditions of use, and evaluated by means of ergonomic parameters (Bandini Buti, 2001). Randini Butti (2001) proposed that to define ergonomic qualities, scales of quality and parameters relative to all the ergonomic characteristics of individual products must be allocated. These scales may be the object of objective measurements or of subjective evaluation.

Hassenzahl (2001) refers to the usability of the product, which addresses the underlying need for security and control with EQ. From these definitions, safety, security, control comfort, efficiency, usability, communication and ergonomic quality can be treated as dimensions for subjective needs from ergonomics design, and considered when designing working environments, products and human-machine systems.

Figure 2.7 Perceived servicescape dimensions (Rosenbaum and Massiah, 2011).
Clarkson et al. (2007) included subjective preferences in functional user capabilities (sensory, cognitive and motion), and integrates user physical attributes (such as height, reach) in requirements for ergonomics features (Figure 2.8).

**Figure 2.8** Ergonomic features to design user-product interaction (Clarkson et al., 2007).

### 2.5.1 Participatory ergonomics and participatory design

Both ergonomics and quality management disciplines believe in the integrity of the human operator as a person who desires quality and avoids errors (Eklund, 1995; Drury, 2006). Associating quality with normative aspects such as working conditions must be addressed as a further element of a comprehensive understanding of quality (Zink, 2006). Participatory ergonomics exists in the workers' active involvement in implementing ergonomic knowledge and procedures in their workplace, supported by supervisors and managers to improve working conditions (Nagamachi, 1995).

Quality and ergonomics use teams and active operator participation and quantification of measurement as a way of analyzing problems, implementing changes and fostering work simplification (Drury, 2006). Dempsey et al. (2006) discussed common ergonomics (human factors) definitions and research areas (Table 2.5 and Table 2.6). This classification shows that the ergonomics discipline covers a range of methods and approaches from design to optimization of a product. The final product or work system serves to create benefits to a single person or a group of people.

Clarkson et al. (2007) included subjective preferences in functional user capabilities (sensory, cognitive and motion), and integrates user physical attributes (such as height, reach) in requirements for ergonomics features (Figure 2.8).

**Figure 2.8** Ergonomic features to design user-product interaction (Clarkson et al., 2007).
Table 2.5 Proposed definitions for human factors/ergonomics (Dempsey et al., 2006)

<table>
<thead>
<tr>
<th>Authors</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brown, O. and Hendrick, H.W. (1986)</td>
<td>the relations between man and his occupation, equipment, and the environment in the widest sense, including work, play, leisure, home, and travel situations</td>
</tr>
<tr>
<td>Chaplin, A. (1995)</td>
<td>is a body of knowledge about human abilities, human limitations and other human characteristics that are relevant to design</td>
</tr>
<tr>
<td>Hancock, P.A. (1997)</td>
<td>is that branch of science which seeks to turn human-machine antagonism into human-machine synergy</td>
</tr>
<tr>
<td>Mark, L.S. and Warm, J.S. (1987)</td>
<td>attempts to optimize the fit between people and their environment</td>
</tr>
<tr>
<td>Howell, W. and Dipboye, B. (1986)</td>
<td>person-machine system design</td>
</tr>
<tr>
<td>Meister, D. (1989)</td>
<td>the application of behavioral principles to the design, development, testing and operation of equipment and systems</td>
</tr>
<tr>
<td>Corlett, E.N. (1984)</td>
<td>study of human abilities and characteristics which affect the design of equipment, systems, and jobs and its aims are to improve efficiency, safety, and well being</td>
</tr>
<tr>
<td>Sanders, M.S. and McCormick, E.G. (1993)</td>
<td>focuses on humans and their interaction with products, equipments, facilities, procedures and environments used in work and everyday living</td>
</tr>
<tr>
<td>Wickens, C.D. (1992)</td>
<td>is to apply knowledge in designing systems that work, accommodating the limits of human performance and exploiting the advantages of the human operator in the process</td>
</tr>
<tr>
<td>Dempsey et al. (2000)</td>
<td>is the design and engineering of human-machine systems for the purpose of enhancing human performance. Human performance includes health, safety and productivity</td>
</tr>
<tr>
<td>International Ergonomics Association, IEA(2000)</td>
<td>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 optimize human well being and overall system performance</td>
</tr>
</tbody>
</table>

Table 2.6 Research areas in ergonomics (Dempsey et al., 2006)

<table>
<thead>
<tr>
<th>Who</th>
<th>What</th>
<th>How</th>
<th>When/Where</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human System</td>
<td>Engineering</td>
<td>Environment</td>
<td>Safety</td>
<td></td>
</tr>
<tr>
<td>People Machine</td>
<td>Designing</td>
<td>Work</td>
<td>Comfort</td>
<td></td>
</tr>
<tr>
<td>Users Equipment</td>
<td>Applying</td>
<td>Life</td>
<td>Efficiency</td>
<td></td>
</tr>
<tr>
<td>Person Product</td>
<td>Studying</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technology</td>
<td>Optimizing</td>
<td>Quality</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2.5.2 Quality and ergonomics design in lean production

The first lean principle is to define the constructs for value of company processes and user needs. The starting point of lean production development is creating value by designing quality products to satisfy customer's subjective and physical needs (Haque and Moore, 2004). The value concept in lean production development flow (LPDF) is defined as delivering a robust product (design), satisfying stakeholders' (customer's) functional and contractual requirements and expectations, including all quality aspects and features.

The typical value proposition for product development is the subsequent ability to perform error-free and cost-effective production of the product, satisfying the needs of the user (Oppenheim, 2004). Principles of (LPDF) are described by Womack and Jones (1998):

1. Define value to the program stakeholders.
2. Plan the value-adding stream of work activities from raw materials until product delivery while eliminating waste.
3. Organize the value stream as an uninterrupted flow of work pulsed by the rhythm of tactical timing, and proceed without rework or backflow.
4. Organize the pull of the work-in-progress as needed and when needed by all receiving workstations.
5. Pursue 'perfection' (i.e., the process of never-ending improvements).

Ergonomics and design for quality (Womack and Jones, 1998) plays an important role in lean thinking philosophy. The possible relationships among quality, ergonomics and lean production development are defined in Figure 2.9 (Lee, 2005). In the product design phase, user needs can be captured by Kansei Engineering (see Introduction section and section 2.8.5), hierarchical user need disposition, identifying relationships and integrating attractive quality characteristics from the Kano model. Ergonomics and environmental standards also guide product development.

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2.6 Ergonomics methods

2.6.1 Analyzing postures and musculoskeletal loading

To assess whether a task or product design is feasible, a common method is to compare the forces on the spine or other body parts (e.g., shoulders) with recommended limits (Wilson and Corlett, 2005). Other complementary methods such as direct observation, discomfort charts and for repetitive jobs, physiological assessment methods need to be combined with biomechanical methods (Wilson and Corlett, 2005). Photographs or video record postures even though the data are retrieved from the recorded images (Wilson and Corlett, 2005). Besides recording postures, it is important to have data on task activities and the loads moved.

Methods for direct measurement of the effort involved in holding a posture include (Wilson and Corlett, 2005) estimation techniques (biomechanics and estimates from maximum voluntary contraction (MVC), measures of muscular activity (EMG signal measures), measures of resultant...
effects (e.g., spinal shrinkage (Eklund and Corlett, 1984)), subjective measures (e.g., discomfort surveys (Kuorinka et al., 1987; Borg, 1998) and a range of observation methods.

Key measurement components to evaluate posture and static work include (Wilson and Corlett, 2005) the angular relationship between body parts, distribution of body part masses, forces exerted on the environment during posture, the length of the time a posture is held, and effects on the person maintaining the posture.

2.6.2 Direct observation methods

In the 1970s, the methods developed for posture observation depended on manual recording. In the mid-1980s, computer programs were developed to tabulate trunk and shoulder postures (Keyserling, 1986). Common observational methods are summarized in Table 2.7. These methods are compared according to the type of task, body parts and angular information.

Among direct observation methods, posture targeting does not incorporate time recording. One limitation of these methods is that it is not clear how external force requirements interact with the frequency or duration of postural requirements identified by these methods, and to what extent the situation is hazardous (Chaffin et al., 2006).

Armstrong (1986) used videotaping and posture coding for upper extremity postures (e.g., wrist, hand, shoulder), and suggested surface electrode (EMG) for forceful hand exertions. Radwin and Lin (1993) suggested spectral analysis by goniometer; Yen and Radwin (2000) extended spectral analysis integrating frequencies.

Lumbar motion monitor (LMM) (Marras et al., 1992) allows a continuous reading of torso motions relative to the pelvis in flexion-extension, lateral bending and torso twisting. LMM offered highly repeatable measurements (Allread et al., 2000).

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Table 2.7 Observational body posture analysis methods.

<table>
<thead>
<tr>
<th>Observational methods</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posture targeting</td>
<td>A worker is observed at random times of the day, and job postures, angles and activity (hold, pull, push etc.) information about related body parts is noted. The analyst can identify the most frequent and potentially stressful job postures for a more detailed biomechanical analysis (Chaffin et al., 2006).</td>
</tr>
<tr>
<td>OWAS (Karhu et al., 1977)</td>
<td>OWAS (The Ovaco Working Posture Analysis System) is a method for identifying and evaluating unsuitable postures. This method consists of two parts: the first is an observation technique for the evaluation and recording of working postures with number coding. The second is used to record the percentage of time in a given posture.</td>
</tr>
<tr>
<td>RULA (Mc Atamney and Corlett, 1993)</td>
<td>This method is quite similar to OWAS and includes more detailed and rapid assessment of upper limb disorders (ULD). It also works with number coding of body parts and activities, and assessing angular positions of the body like in the OWAS procedure. Armstrong et al. (1982) later developed a procedure that also demonstrates frequently repeated or maintained adverse postures and forces to assess upper limb disorders.</td>
</tr>
<tr>
<td>Keyserling (1986)</td>
<td>A personal computer is used where trunk and shoulder postures are evaluated based on three recordings of a job. Frequencies of postural changes and the duration of time that a person is in a specific posture is also recorded. It distinguishes a variety of postures in a repeatable manner. There is a classification system for extreme postures.</td>
</tr>
<tr>
<td>Foreman et al. (1988)</td>
<td>The observer uses two letter mnemonics as postural inputs to the computer. The computer then outputs simple statistic descriptors about the job.</td>
</tr>
<tr>
<td>NIOSH lifting equation</td>
<td>The weight limits provided by the equation are dependent on factors such as the vertical location of the load, the distance the load is lifted, and the frequency at which the load is lifted. The equation is not robust to allow comprehensive exposure assessments of jobs. Spatial position of body segments and amplitude and direction of the action forces were described in detail. The NIOSH guide for manual lifting applies to lifting loads with both hands and other exertions; one-hand lifting cannot be analyzed (Chaffin et al., 2006).</td>
</tr>
<tr>
<td>Dortmund lumbar load study</td>
<td>Spatial position of the body segments and amplitude and direction of the action forces are coded to evaluate exertion on lumbar spine. Consecutive biomechanical model calculations for total shifts, time courses of various measures for the load on the lumbar spine, such as flexion or torsional moments of force and compression and shear forces at the lumbosacral disc were also conducted (Jäger et al., 2001).</td>
</tr>
</tbody>
</table>

Table 2.7 Observational body posture analysis methods.

<table>
<thead>
<tr>
<th>Observational methods</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posture targeting</td>
<td>A worker is observed at random times of the day, and job postures, angles and activity (hold, pull, push etc.) information about related body parts is noted. The analyst can identify the most frequent and potentially stressful job postures for a more detailed biomechanical analysis (Chaffin et al., 2006).</td>
</tr>
<tr>
<td>OWAS (Karhu et al., 1977)</td>
<td>OWAS (The Ovaco Working Posture Analysis System) is a method for identifying and evaluating unsuitable postures. This method consists of two parts: the first is an observation technique for the evaluation and recording of working postures with number coding. The second is used to record the percentage of time in a given posture.</td>
</tr>
<tr>
<td>RULA (Mc Atamney and Corlett, 1993)</td>
<td>This method is quite similar to OWAS and includes more detailed and rapid assessment of upper limb disorders (ULD). It also works with number coding of body parts and activities, and assessing angular positions of the body like in the OWAS procedure. Armstrong et al. (1982) later developed a procedure that also demonstrates frequently repeated or maintained adverse postures and forces to assess upper limb disorders.</td>
</tr>
<tr>
<td>Keyserling (1986)</td>
<td>A personal computer is used where trunk and shoulder postures are evaluated based on three recordings of a job. Frequencies of postural changes and the duration of time that a person is in a specific posture is also recorded. It distinguishes a variety of postures in a repeatable manner. There is a classification system for extreme postures.</td>
</tr>
<tr>
<td>Foreman et al. (1988)</td>
<td>The observer uses two letter mnemonics as postural inputs to the computer. The computer then outputs simple statistic descriptors about the job.</td>
</tr>
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</tbody>
</table>
2.6.3 3D Digital human modeling (DHM) tools

Digital Human modeling (DHM) tools are more frequently used in design, modification and analysis of workplace layouts. 3DSSPP (Chaffin et al., 2006), JACK (Badler, 1993), RAMSIS (Seidl, 1997), and Anybody modeling (Rasmussen and Christensen, 2005) are several common tools in research. Besides design for physical ergonomics, Höberg (2003) included users' emotional experiences and tested user characteristics (Buur and Nielsen, 1995) for development of gearshift systems in future automobiles. Design scenarios were created based on selected characteristics necessary to support designers and for exploration of user-product exploration.

Static strength prediction

To conduct postural analysis, related forces for the type of work required can be calculated in static posture in the sagittal plane if there is no twisting or lateral bending. 3D models can also be used where there is much lateral bending and twisting (Wilson and Corlett, 2005). In dynamic situations, accelerations cause extra forces so these forces also need consideration (Chaffin et al., 2006) for low frequency (fewer than 3 lifts per minute) static or slow exertions. 3DSSPP provides a means of considering population strengths, low back compression forces and one- and two-handed exertions simultaneously, performed by an anthropometrically diverse group of men and women (Chaffin et al., 2006). In biomechanical calculations, human variability due to body weight and stature can be representative of different muscle groups (e.g., the loads on the body are greatest for larger body weights and limb lengths) (Wilson and Corlett, 2005). 95th percentile body weights and statures are used to avoid errors and demonstrate safety suggestions (Wilson and Corlett, 2005).

2.6.4 Usability evaluation for user needs

Objectively and subjectively perceived quality of the interaction with a system is considered usability; it expresses the quality of a system from the viewpoint of the users' intentions and within the users' context (Han et al., 2000). Usability is defined as the measure of the quality of the user experience when interacting with something, whether a website, a traditional software application, or any other device the user operates (Nielsen, 1993). ISO 9241-11 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.

Hassenzahl et al. (2000) suggested a model that addresses usability and hedonic aspects as key factors for appealing and, thus, satisfying products. It consists of three layers: (a) objective
product quality (intended by the designers), (b) subjective quality perceptions and evaluations (cognitive appraisals by users), and (c) behavioral and emotional consequences (for the user).

Later Hassenzahl (2001) tested a framework to integrate hedonic quality (HQ) and ergonomic quality (EQ). Hassenzahl (2001) concluded that users perceive EQ and HQ aspects independently, and these qualities contribute equally to the overall judgment of a product’s appeal. Kahmann and Henze (2002) suggested the UseScan approach for the product development process as a whole. On the left side, materialization stages of the product are mentioned, while on the right side are the four basic phases: inspiration of a product from an idea, exploration of the idea and development into a product concept, developing and evaluation of prototypes and finally verification of product (Figure 2.10). See Nemeth (2004) for usability testing methods. Considering the ping-pong model, product needs arise at every stage of product development and during verification of each step.

![Figure 2.10 Ping-pong model (Kahmann and Henze, 2002).](image)

### 2.6.5 Cognitive systems engineering perspective

While designing for quality, an integrated systems approach needs to be considered for better communication between user and product (Figure 2.12). The human/product ensemble is examined as a joint cognitive system from cognitive systems engineering, and design and analysis starts at this level (Hollnagel and Woods, 2005). Joint cognitive systems (JCS) start with evaluating the product together with the user, and assess whether there are higher level aggregations where JCS becomes part of a super-ordinate system (a super system implemented by a set of interconnected systems, communicating with each other to fulfill the duties of the super system) (Hollnagel and Woods, 2005). Decomposition or disaggregation ends with the simplest JCS, which consists either of two cognitive systems, such as two people working
2.7 Understanding user perceptions

User product relationship is affected by usability, aesthetics, reliability, technical performance, emotions and associated values (Jordan, 1997). An individual’s underlying beliefs help form attitudes about specific products and services. Beliefs are deeply entrenched views often based on the core values of an individual’s country, subgroup and social class. Attitudes change more than beliefs, strongly influenced by family, social reference groups, lifestyle, age and income. Individuals also have objectives, priorities and aspirations that they strive to attain.

In product development processes, the entire team - technical, marketing, and operations - interviews and interfaces with real customers/users, and learns their problems, needs and challenges firsthand (Cooper, 2001). In user research, Hauser and Urban (1977) suggest the lens model, inspired from Brunswik’s (1952) structure model. The model explains that what really matters to customers is how they perceive the world (Hauser and Wisniewski, 1982) (Figure 2.11). Hauser and Wisniewski (1982) described that choice of products is affected by operational strategies (e.g., physical attributes) and/or psycho-social cues (e.g., advertising). Based on perceptions, users form preferences. These perceptions are, in turn, related to the particular product features in the design of the product (Urban and Hauser, 1993). The customer’s
perceptions are also influenced by advertising, packaging, statements from salespeople, recommendations from friends, and product reviews (Urban and Hauser, 1993).

Figure 2.12 Lens model of user perceptions (Hauser and Urban, 1977).

Existing information about customer needs is readily available from company sales records and demand for product redesign. Collecting new information requires different methods that assess user needs such as observational methods, focus groups and surveys (Magrab et al., 2009) (Table 2.7).

After customers/users increased use of Web 2.0, companies started using information pertaining to customers’ engagement with products from online resources. On the Web, customers interact to learn or share experiences with a product, including reading and writing a comments. Engagement is level of involvement such as website visits, keyword search page views, interaction, intimacy and influence that an individual has with a brand over time (Haven, 2007).

Table 2.8 Ways to obtain information about user needs (Magrab et al., 2009).

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<thead>
<tr>
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<td>Company sales records including repair and replacement parts;</td>
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<td>Observation using clinics and displays;</td>
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2.7.1 Introduction to affective needs: feeling-emotion-perception

In Engineering design, the goal is creation of an artifact, product or system that performs a function or functions to fulfill user needs (Hirtz et al., 2002). The next question is: how psychological and physiological needs can be integrated in product design to fit users’ mind and body? Before answering this question, concept definitions for feeling, emotion, affect and perception are explained. Feeling is one of the most important components of emotion according to Scherer (2003). One terminological confusion is the tendency to use the terms emotion and feeling as synonyms (for further discussion, see Scherer (2003) and Russell (2003)). Feelings are affective states that may grow out of a specific event or might be produced by a vague condition; those who experience the affect may be aware of what generated the feeling (Berkowitz, 2003).

Emotion is a complex set of interactions among subjective and objective factors, mediated by neural/hormonal systems, which (Kleinginna and Kleinginna, 1981) (a) give rise to affective experiences such as feelings of arousal, pleasure/displeasure; (b) generate cognitive processes such as emotionally relevant perceptual effects, appraisals and labeling processes; (c) activate widespread physiological adjustments to arousing conditions; and (d) lead to behavior that is often, but not always, expressive, goal-directed and adaptive. LeDoux (1998) describes emotions as biological functions of the nervous system.

Scherer (2003) classifies affective states as combinations of feelings and emotions; Emotions: angry, sad, joyful, fearful, ashamed, proud, elated, desperate; Moods: cheerful, gloomy, irritable, listless, depressed, buoyant; Interpersonal stances: distant, cold, warm, supportive, contemptuous; Preferences/Attitudes: liking, loving, hating, valuing, desiring; Affect dispositions: nervous, anxious, reckless, morose, hostile.

Perception is defined as the process of recognizing, selecting, organizing and interpreting stimuli to make sense of the world (Harrell, 1986). Perceptions of products and services depend in part on the stimuli to which users are exposed and in part on the way these stimuli are given meaning by users (Foxall and Goldsmith, 1994).

There are several human information processing models in literature. A model of human information processing by Wickens and Holland (1999) (Figure 2.13) shows that, for example, an operator uses long-term memory to store experiences and short-term memory for sensorial experiences; the model shows how an operator divides attention among tasks and operations.

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2.7.2 Cognition-emotion interaction in product perception

Humans have two information processing mechanisms that dominate decisions: the affective and cognitive systems. Over the years, a discussion ensued about whether affect and cognition are separate, which system follows the other or has a role in the genesis of the other, and if emotions precede cognitive processes or cognitive processes precede emotions (Arnold, 1960; Smith and Lazarus, 1993). Cognition is the mental process of including awareness, perception, reasoning and judgment (The American heritage dictionary, retrieved 14.05.2011).

Scherer (2003) argued that one of the most intriguing aspects of cognition-emotion interaction is the recursive chaining (Figure 2.14) that exists between these influence processes. The first source of recursive effects is the feedback from the pattern of emotional reactions in the response modalities of outgoing appraisal processes (arrow 1) (Scherer, 2003). The second source of recursive effects is shown with arrows 2 and 3, which show the impact of decisions or behaviors determined by specific emotional reactions both on the emotion itself - especially the component of subjective experience or feeling (arrow 2) - and the ongoing appraisal processes (arrow 3) (Scherer, 2003).
There are further attempts to treat cognition and emotion together including Schematic, Propositional, Analogical and Associative Representation Systems (SPAARS) (Beaty, 1995). This model evaluates four levels: analogical, associative, propositional and schematic. Stephane (2007) proposed a multi-agent framework using SPAARS that combines cognition/emotion interaction to approach user reaction. Starting idea products are designed to satisfy user needs at individual, cultural and social levels. Following Maslow’s need hierarchy, there is a complex layer of needs in the human mind.

How the user processes information about a product and its brand is described below (Foxall and Goldsmith, 1994). This description highlights emotional and cognitive processes a user goes through while evaluating a product.

- Receiving information from the environment,
- Interpreting this information regarding experiences, opinions, personal goods, values, personal characteristics and social position,
- Searching for additional information to clarify the want or need aroused,
- Evaluating the alternative competing brands available to satisfy this need or want,
- Developing beliefs, attitudes and intentions that determine whether a purchase takes place and if so, which brand is selected,
- Acting upon these intrapsychic forces to purchase and use the product and the brand,
- Reevaluating the attitudes and intentions in light of the satisfaction engendered by consuming the product,
- Storing the new attitudes and intentions in mind for future reference.
To identify user needs from products, Ulrich and Eppinger (2004) propose a five step process:
1. Gather raw data from customers,
2. Interpret the data in terms of user needs,
3. Organize the needs into hierarchy,
4. Establish the relative importance of needs, and
5. Reflect on the results and the process.
Several methods proposed to design user needs are shown in three phases: discovery, development and commercial development phases of products (Okamoto, 2010) (Table 2.9).

Table 2.9 Engineering tools used in product development phases (Okamoto, 2010).

<table>
<thead>
<tr>
<th>Discovery Phase</th>
<th>Development Phase</th>
<th>Commercialization Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Growth share model</td>
<td>Design automation tools</td>
<td>Advertisement</td>
</tr>
<tr>
<td>Benchmarking</td>
<td>Design of experiments (DOE)</td>
<td>User service</td>
</tr>
<tr>
<td>Business case/business plan</td>
<td>FMEA</td>
<td>ERP</td>
</tr>
<tr>
<td>Ethnography</td>
<td>KAIZEN activities</td>
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</tr>
<tr>
<td>Competitive intelligence</td>
<td>Kansei/Affective Engineering</td>
<td>Management</td>
</tr>
<tr>
<td>Conjoint analysis</td>
<td>Market testing</td>
<td>Market research</td>
</tr>
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<td>Outsourcing</td>
</tr>
<tr>
<td>Patent mapping and mining</td>
<td>Simulation</td>
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<tr>
<td>Pugh analysis</td>
<td>Technology road mapping</td>
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<td>QFD</td>
<td>Toyota production system</td>
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<td>TRIZ</td>
<td>Voice of the customer analysis</td>
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</tr>
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</table>

2.8 Methods to relate user needs with product attributes

2.8.1 Quality Function Deployment (QFD)

QFD and KE have the same point of departure: customer voice. The terms QFD and KE are similar: customer requirements (CRs), functional requirements (FRs), and Engineering characteristics (ECs). Customer requirements are phrases customers use to describe products and their characteristics (Hauser and Clausing, 1988). Functional requirements are those requirements that specify a mandatory action of a product or system (Magrab et al., 2009). Engineering characteristics are the relevant measurable characteristics that describe each of the product’s functional requirements (Magrab et al., 2009).
QFD also uses subjective ratings and prioritization ratings to prioritize user needs. Linking voice of the customer to required product technical characteristics follows different procedures in KE and QFD. Hoyle and Chen (2009) criticize that QFD involves unrealistic setting of target values and lacks a mathematical framework to incorporate uncertainty into decision-making. Product attribute function deployment was proposed based on a decision-based design approach (Hoyle and Chen, 2009) to be integrated in QFD. Product design specification (PDS) is a statement of what the product has to do, and is the fundamental control mechanism and basic reference source for the entire product development (Magrab et al., 2009).

2.8.2 Kano model

Kano et al. (1984) proposed the theory of Attractive Quality as a method to describe the relationship between objective and subjective quality aspects such as physical sufficiency and user satisfaction from a two-dimensional viewpoint, inspired by philosopher’s such as Aristotle and John Locke (Kano, 2001).

Kano’s model can be used to classify technical characteristics of a product and further research unknown needs. One advantage is that Kano’s model pertains to different user needs from user satisfaction to dissatisfaction, and product attributes are classified for these. This method assumes that fulfillment of a need and user satisfaction does not have a linear relation (Matzler and Hinterhuber, 1998).

There are several KE applications in the literature that integrated Kano’s model. Linares and Page (2011) integrated the, surveying to evaluate products (buildings) after spanning semantic space by factor analysis. Lanzotti and Tarantino (2007) applied the model to collect user needs in the first phase of Kansel Engineering. Chen and Chuang (2008) used it to collect user needs, identifying and weighing these criteria. Lanzotti et al. (2009) identified quality evaluation elements using the model for a user survey.

2.8.3 Conjoint methods

Conjoint analysis (CA) involves designing a series of stimuli and asking subjects to evaluate a single stimulus or sometimes multiple stimuli in a repeated-measures design (Hair et al., 2010). Data can be collected by Likert scales. Fractional factorial designs are used to design experiments in conjoint analysis. The major limitation of this approach is variations are ignored in less important factors, or factor levels are simplified (Green and Srinivasan, 1978), so experiment space is restricted to selected designs. A crucial consideration is the type of effects

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that are to be included because they increase the number of experiments necessary. Main effects, representing the direct impact of each attribute, can be augmented by interaction effects that represent the unique impact of various combinations of attributes.

Michalek et al. (2005) proposed Analytical Target Cascading (ATC) as an alternative to QFD where they used CA models to link users' current needs from marketing and Engineering design considerations. ATC works by viewing a complex system as a decomposable hierarchy of interrelated subsystems, each of which can be analyzed and optimized separately and then coordinated (Kim, 2001 in Michalek et. al., 2005).

2.8.4 Taguchi’s robust design approach to design quality feelings

In robust design approaches, two concepts - discrepancy and ambiguity - are reduced from quality evaluations of products. User expectations are concretized as a target feeling, and the feeling quality of the designed product is assessed by considering the so-called feeling discrepancy between the target and actual feeling (Lai et al., 2005). Feeling ambiguity is the degree of consistency of the output feelings for the same product (Lai et al., 2005).

Robust design employs an experimental approach to determine the optimal design parameter settings by analyzing the complex relationships among controllable factors (design parameters), uncontrollable factors (noise factors), and quality performance. Taguchi examines the combination of variables that produces the least average deviation from the target. In doing this, he neglects the interaction of the variables, one of the strongest arguments against the method (Box, Hunter and Hunter, 1978 (in Stamatis, 2003)). The noise factors to effect quality feelings evaluations come from the variation of product components and diversity in the external environment.

Noise factors are of five types (Stamatis, 2003): (1) Noise due to external causes from environment (e.g., temperature and humidity), (2) Noise due to internal causes occurring from variations in elements (e.g., wear, deterioration, fixture differences), (3) Noise due to part-to-part variation in incoming material, (4) use, and (5) Aging.

Lai et al. (2005) compared robust design approach to Kansei Engineering approaches. They argue that KE depend upon a large number of samples to ensure their accuracy, the robust design approach requires fewer experimental frequencies and a lesser number of experimental
2.9 Kansei Engineering: A multi-method approach to defining user needs

2.9.1 What is Kansei?

Describing the meaning of Kansei, first character Kan means sensation, sense or feeling, and the second character sei means personality or concept (Nagamachi, personal communication, February 2010). In Korean and Chinese languages, Kansei is not the same word and does not carry the same meaning. In Chinese, just the Kan character exists, which means sensation. Nagamachi refers to and uses the Kansei with Japanese meaning as the base for his starting thoughts (Nagamachi, personal communication, February 2010).

Nagamachi (2001) describes Kansei as a Japanese word for an individual’s subjective impression from a certain artifact, environment, or situation using all the senses of sight, hearing, feeling, smell, taste as well as recognition. If used in Engineering and business, Kansei should be considered a series of information-processing processes of sensation, perception, cognition, sentiment and expression (Nagasawa, 2004).

The Japanese Society of Kansei Engineering (www.jske.org, retrieved 15.06.2011) makes the definition of Kansei an integrated function of the mind; various functions exist while receiving and sending information.

In 1997, the University of Tsukuba in Japan initiated a study to define Kansei (Lee, 2000). Statements were analyzed and key words were clustered into five main aspects:

1. Kansei is a subjective effect, which cannot be described by words alone.
2. Kansei is a cognitive concept, influenced by a person’s knowledge, experience and character.
3. Kansei is a mutual interaction between intuition and intellectual activity.
4. Kansei entails sensitivity to aspects such as beauty or pleasure.
5. Kansei is an effect for creating the images often accompanied in the human mind.

Kansei is the mental process of experiencing the product, and described as "psychological feelings and image regarding a product" (Nagamachi, 2002). There are several definitions given...
in this thesis concerning Kansei. For a detailed discussion of Kansei, an article by Nagasawa (2004) is suggested. In this thesis, Kansei is used with the same meaning as affect.

In 2007, Ministry of Economy, Trade and Industry (METI) in Japan initiated a manufacturing movement on Kansei product design, which moves from materialistic to emotional fulfillment (www.meti.go.jp, information retrieved 18.08.2011) and proposed Kansei as a new dimension of value in manufacturing. METI (2011) discussed that Kansei involves the idea of skillfully incorporating a new economic value into manufacturing - a value that becomes perceivable when a product appeals to consumers' sensibilities in a way that impresses them, or encourages them to empathize with it. This is expected to be an additional strength of Japanese products, which have traditionally been recognized for features such as advanced functionality, reliability, and reasonable pricing.

METI (2011) further defined Kansei value (Figure 2.15). Kansei value manifests from the psychological interaction between people and products. Kansei research is proposed as a new vision for manufacturing that transcends conventional product value dependent on performance and cost, and is a new value axis for Japan's competitiveness. METI (2011) argues that products evoke Kansei by recalling experiences and memories; they initiate a psychological call-and-response between the product and the user, which leads to feelings of empathy and attachment. The new relationship generates new values for both creators and users of a product.

Figure 2.15 New value axis for product development (www.meti.go.jp, information retrieved 18.08.2011).
METI further envisioned the following three realms where resonance between people and products manifests through Kansei understanding:

1. **New Reality:** Products in this realm stimulate physical being, consciousness, identity or lifestyle.
2. **New Communication:** Products in this realm offer new ways for people, products and services to relate to or associate with each other.
3. **New Relation:** Products in this realm cultivate new ways for users to relate to or associate with the world around them, their community, history, tradition, nature and environment.

### 2.9.2 What is Kansei (Affective) Engineering?

Current Kansei Engineering (KE) (Affective Engineering-AE) is defined as the trans-disciplinary Engineering that spans humanities, social and natural science (www.iide.org, retrieved 15.06.2011). According to Nagamachi (2001), Kansei feelings can be captured in several ways: KE uses people’s behaviors and actions, words (spoken), facial and body expressions and physiological responses (e.g., heart rate, body temperature).

Kansei Engineering was proposed by Nagamachi in the 1970s first as Emotional Technology (Nagamachi et al., 1974) to understand and quantify human needs (psychological and physiological) for product design (Nagamachi, 1995, 2010). KE is used widely in Asia; there is no corresponding Engineering area in Western countries. Later, Affective Engineering was proposed to represent KE in Europe. Affective Engineering is a Western interpretation of KE; it is about measuring people’s subjective responses to products, identifying the properties of the product eliciting those responses, and using the information to improve design (Affective Engineering website, Leeds university, retrieved 18.08.2011).

Ken’ichi Yamamoto, former president of Mazda Motor Company, used Kansei (1986) in the United States while giving lectures on the design success of Japanese cars. In recent years, KE has been applied increasingly in product development that focuses on researching affective needs and preferences of customers/users in product design. KE is applied to products such as car interiors (Jindo and Hirasago, 1997; Nakada, 1997; Tanoue et al., 1997), office chairs (Jindo et al., 1995), floor mats (Nishino and Nagamachi, 2009), packaging (Henson et al., 2006), and mobile phones (Barone et al., 2007).

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Nagamachi (1989) proposed KE as a framework for gathering all current and future methods to design customers’ Kansei (affective responses) into tangible and intangible products. In the literature, researchers from different countries provide several definitions of the Kansei concept related to their own research. In Japan, the translation of Kansei draws back to Amane Nishi (1829-1897), the first person who used Kansei as a philosophical term for sensibility (Nagasawa, 2004). In 1921, Teiyu Amano used the German term Sinnlichkeit (sensitivity) in Critique of Pure Reason to translate Kansei (Kant, 2003).

KE emphasizes understanding the whole product experience from ergonomic and emotional perspectives, and synthesizes the two perspectives to get the whole picture of the total product experience. The interaction between physical design attributes and emotional needs is another research area receiving attention from KE researchers. Nagamachi (1995) emphasizes capturing and understanding customers’ and users’ affective needs, products values and the importance of human factors by using ergonomics to complement product design.

According to Nagamachi (2001), there are three focal points of KE: (1) how to understand Kansei accurately, (2) how to reflect and translate Kansei into product design, and (3) how to create a system and organization for Kansei-orientated design.

KE has three main research areas: evaluation that measures human emotion and sensibility by various subjective and psycho-physiological measurement methods, simulation in which reaction of emotion and sensitivity is obtained in advance in a simulated environment and application, which applies research results into manufacturing of specific products (Table 2.10).

Compared to product design research, Kansei machine-vision technology is also a developing area. Some examples include inspection of cosmetics and jewelry (Nagata et al., 1992) applied by simulating human vision, individual authentication in security systems (Samal, 1992) applied for monitoring human beings, face Engineering (Koshimizu et al., 1999) and surgical simulation (Toriwaki, 1996) as applications of human-machine interfaces.

2.9.3 Overview of method approaches in Kansei Engineering

KE (Nagamachi, 1995, 2002) applies to both subjective (e.g., semantic differential) (Osgood et al., 1957), Likert scales (Likert, 1932) and objective measurements to collect users’ physical and psychological responses to product features (Table 2.10).
In KE, qualitative and/or quantitative methods can be applied. Quantitative methods range from statistical methods to knowledge information engineering methods (heuristics), and physiological measurement methods (e.g., EMG, EEG). Individual and group multi-criteria, decision-making methodologies like Analytic Hierarchy Process (AHP) technique have also been used. By this technique, the most important and least important factors were found (Kanda, 2005).

Data collection

Qualitative methods are used to generate ideas and verbal expressions about products. For collection of subjective responses, Likert and Semantic differential scales are used commonly. The Likert scale is one of the category methods used for perceptions evaluations. The Likert scale (Likert, 1932) includes a statement to which a respondent indicates degree of agreement. Traditionally, a five-point scale is used; however, many psychometricians (like in SD scales) advocate seven- or nine-point scales. The category method involves corresponding category to stimulus, or difference of stimuli, from a category set.

Data analysis

Treating Likert scales as Ordinal data: Responses to a single Likert item are treated normally as ordinal data, because especially when using only five levels - one cannot assume that respondents perceive the difference between adjacent levels as equidistant. When treated as ordinal data, Likert responses can be analyzed using non-parametric tests such as the Mann-Whitney test, the Wilcoxon signed-rank test, and the Kruskal-Wallis test. Treating Likert scales like Interval data: When responses to several Likert items are summed, they may be treated as interval data measuring a latent variable. If the summed responses are distributed normally, parametric statistical tests such as the analysis of variance (ANOVA) can be applied.

Statistical Methods used often consist of data reduction and multivariate statistics. Data reduction methods such as PCA (Principal Component Analysis) and Cluster Analysis are used to collate words that describe feelings and cluster them. Cluster Analysis is also used to cluster individuals based on preferences (Ishihara, 2010).

Statistical product evaluation methods and heuristic approaches were applied in the literature to link product properties and feeling statements. Multivariate methods predict linear relationships between independent (product attributes) and dependent variables (feeling
Heuristics such as Artificial Neural Networks (ANN) (Nishio, 1994) and Genetic Algorithms (see Appendix A) evaluate preferences for product attributes. From linear statistical approaches, Multivariate regression, Partial least squares regression are described in this thesis (see Appendix A). For application of logistic regressions, see Barone et al. (2007).

Table 2.10 Methods used in Kansei Engineering (Nagamachi, 2010).

2.9.4 Quantification Theory

Quantification theory type I (QT1) (Hayashi, 1952) is an expansion of multiple regression that has been applied in previous KE studies. Design elements such as color, type, selection and the presence or absence of functions or illustrations can be expressed by quantity or order using this method. It deals with nominally scaled, explanatory variables and an interval or proportionally scaled objective variable. It has a weak point in that combination effects of design

Subjective measurement | Subjective data reduction and mapping | Modeling soft computing | Psycho-physiological measurement (Emotion recognition from bio-signals)
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Self Reports | | | | Likert Scales

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elements or non-linear relationships cannot be considered. Ishihara (2010) discusses that in a multiple regression model, simultaneous equations could not have solved when the number of variables exceed the number of samples, and many cases have the larger number of design variables (Ishihara, 2010). Then, the analyst has to divide design variables to do analysis (Ishihara, 2010). Other quantification theory methods are: Quantification theory type II (QT2) is qualitative discriminant analysis. Quantification theory type III (QT3) is qualitative correspondence analysis. Quantification theory type IV (QT4) is qualitative multi-dimensional scaling.

### 2.9.5 Partial Least Squares Regression

Partial Least Squares (PLS) (Wold et al., 1984) and non-linear PLS (Wold, 1992) was developed for modeling information-scarce situations in the Social Sciences and chemometrics. When the number of predictors is large compared to the number of observations, \( X \) is likely to be singular and the regression approach is not feasible (i.e., because of multi-collinearity) (Abdi, 2003; Alvarez and Alvarez, 2007). As multi-collinearity increases, it complicates interpretation of the variate because it is more difficult to ascertain the effect of any single variable, owing to an interrelationship (Hair et al., 2010).

PLS is becoming more popular in evaluating customer preferences to overcome problems stated above: food preferences (Endritzi et al., 2010; Zhao et al., 2007), cosmetics (Vinzi et al., 2007) and customer satisfaction (O’Loughlin and Coenders, 2004). In cases of analyzing large numbers of explanatory variables, Ishihara (2010) suggested general multivariate analyses; PLS can be better because larger numbers can be included in the model.

Cassel et al. (1999) used the Swedish Customer Satisfaction Index (SCSI) to generate simulated data, and studied the PLS algorithm in the presence of three inadequacies: skewed instead of symmetric distributions for manifest variables, multi-collinearity within blocks of manifest and between latent variables, and misspecification of the structural model (omission of regressors). The simulation showed that the PLS method is quite robust against these inadequacies. The bias caused by inconsistency of PLS estimates increases substantially only for extremely skewed distributions and for the erroneous omission of a highly relevant latent regressor variable.

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2.9.6 Non-linear models

Non-linear models such as rough set theory and genetic algorithms (GA) are more effective in KE applications because KE deals with vague concepts or parameters such as Kansei words or psychophysical elements. These methods handle non-linearity in data to find interactive relationships between multiple variables of feeling evaluations and product attributes, such as when what affects a driver’s preferences is an interaction with several physical design attributes rather than one. GA uses binary coding of product attributes in a chromosome structure, while RS is based on categorical classification of data and probability assumptions.

GA is based on the process of Darwin’s theory of evolution. Starting with a set of potential solutions and changing them over generations, GAs converge on the best-fit (optimum or near optimum) solution (Holland, 1992). The natural selection process of GA extracts useful design items from a multitude of design attributes in Kansei studies (Tsuchiya et al., 1996) such as eyeglass frames (Yanagisawa and Fukuda, 2003), canned coffee (Tsuchiya et al., 1999), evaluation of food advertisements (Tsuchiya et al., 2001), fashion designs (Kim and Cho, 2000) and human-oriented image retrieval systems (Cho and Lee, 2002). The method is capable of solving the difficulty in treating numerous independent variables concurrently in a short computation (Tsuchiya et al., 1996).

2.9.7 Rough Sets Analysis

Nagamachi et al. (2006) proposed Rough set (RS) theory (Pawlak, 1991) as a systematic knowledge discovery tool with analytical power in dealing with rough, uncertain and ambiguous data (see Appendix A and Paper VI for more discussions).

RS is a new method in user research and offers promising results for KE problems (Nishino et al., 2001, 2006; Greco et al., 2005; Inuguichi et al., 2009). RS is used to deal with subjective evaluations that contain considerable rough and ambiguous information with uncertainty and non-linear relationships to product characteristics (Nishino et al., 2006).

RS is embedded in set theory. Data are presented as a decision table, columns of which are labeled by attributes and rows by objects, where entries of the tables are attribute values. Attributes are distinguished into two classes called condition and decision attributes.
approach assumes that decision classes of human evaluation occur with different prior probabilities. One is the probability $P(Y|E_i)$ of decisions dependent on the attributes of product $E_i$, and the other is the prior probability $P(Y)$ of decision class $Y$.

Considering the methods discussed above, Kansei (Affective) Engineering (KE) can be viewed as a future generation of marketing and customer voice research. KE integrates methods such as QFD, Kano’s model and conjoint methods. This methodology follows a hierarchical basis to investigate a domain design concept from related affective descriptors. Given the literature background, this thesis is based on investigating quality feelings and KE hierarchical bases as a starting point.
3 Research process and methods

The whole of science is nothing more than a refinement of everyday thinking/Albert Einstein

In this section, the research process and materials for each study are explained.

3.1 Introduction

This thesis is inspired by epistemological methods such as meaning of language and deductive/inductive reasoning, and methods of practical thinking such as heuristic methods and statistics. Approaches used in this thesis are a set of methods from psychology, ergonomics, heuristics and statistics (Figure 3.1).

Methods varied due to study objectives and accessibility to subjects in terms of time and environmental conditions. Both qualitative and quantitative methods were used. Deductive (inference from the general to particular) and inductive (inference from particular to general) reasoning were carried out depending on the study’s purpose (Bürdek, 2005).

In Table 3.1, an overview of the applied research is presented according to the types of studies, the participants, data collection methods and analysis software.

Next, methodological procedures to collect and analyze data in relation to each study are presented in Figures I, II, III, IV, V, VI, and VII. Theoretical backgrounds of the applied methods are given in Appendix A.
Figure 3.1 Applied research methods in the studies.

- Multiple regression
- Partial Least Squares regression
- Factor Analysis
- Correspondence analysis
- Nonparametric methods (Mann-whitney, Kruskall-Wallis)
- Tukey post-hoc
- Rough set analysis (Probabilistic method approach)
- Genetic algorithms
- Likert scales
- Just about right (JAR) scales
- Free elicitation/association technique
- Exploratory (qualitative) research
- Subjective measurements
- Digital human modelling (simulation) (DHM) (Biomechanical prediction)
- Biomechanics
- Discomfort evaluation
- Job task evaluation
- Participatory ergonomics
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- Discomfort evaluation
- Job task evaluation
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Table 3.1 Overview of the research material.

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3.2 Applied research methodology

Table 3.2 shows the papers’ contributions to quality feelings modeling in relation to Kansei/KE methodology phases. Phases of data evaluation approaches are also provided.

The general methodological model of Kansei/KE is described below in connection to the research applied in this thesis (Nagamachi, 1995; Schütte, 2005; Okamoto, 2010).

1. **Selection of the product or service domain and definition of the strategy**: includes the selection of the product or service (existing or totally new one), definition of the market and current competition with its solutions, potential market segments, senses to be used in the study (sight, taste, smell, touch, and hearing) and their combinations and the general definition of the strategy and project plan. This phase includes potential concepts and solutions not yet developed to cover a larger scope of the domain.

2. **Definition of the semantic space and its structure**: includes the collection of adjectives that describe the product or service domain and potential Kansei needs (i.e., profound needs of the market) called Kansei words (e.g., elegant, masculine, sober, attractive, urban-like, sexy, heavy), their categorization, definition of the hierarchical structure, and data collection. The Kansei words are collected from various sources such as a team of experts, designers, experienced users, advertisements, magazines, ideas, direct observation and interviews. The list may include 50 to more than 500 Kansei words, and is categorized commonly (i.e., in groups) in a manual or statistical database. In the manual form, a group of experts organizes the Kansei words hierarchically, depending on how specific or general the adjective is. The statistical approaches include factor, principal component, cluster, and other analyses. The main objective is to determine the most representative Kansei (affective) needs.

3. **Definition (spanning) of physical space**: The objective is to determine potential properties or design elements (i.e., technical and design requirements) of future products or services, which include collection of existing products, creation of new concepts, identification of potential customers and company images and priorities, and the definition of properties, elements (i.e., attributes or characteristics) and design categories.
4. **Data collection**: This phase is where the semantic space or Kansei needs are related to the potential product or service properties through evaluations made by user surveys, direct observations, or physiological measurements. Kansei need is treated as a response variable, and the potential properties or design elements are the independent variables in the model.

5. **Data analysis**: Data are processed and analyzed through manual (e.g., category classification method), statistical (e.g., regression analysis), or non-statistical methods (e.g., Rough Sets theory; Nishino et al., 2001) to obtain the best approximation of the relationship between profound Kansei needs and design elements.
### Table 3.2 Applied methods to analyze quality feelings.

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</tr>
<tr>
<td>Mapping Konsel</td>
<td>Data collection</td>
<td>Contingency Coefficients</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Methodological Steps**

- Exploratory research
- Product Semantic Structure Identification
- Product Relationship Identification
- Mapping Konsel

**Applied methods to analyze quality feelings**

- Qualitative data collection
- Open-ended questionnaires
- Likert scales
- Free association
- Semantic analysis
- Factor analysis
- Replication
- Partial Least Squares
- Correspondence Analysis
- Contingency Coefficients
3.2.1 Paper I: Designing quality feelings in reach trucks: A Kansei Engineering approach

Study design and questionnaire

Paper I deals with two research questions. RQ1: Which design components in a driving environment communicate quality feelings? RQ2: How do design components contribute to the total (overall) quality feelings from the operator's cabin?

First, affective descriptors (spanning the semantic space) were searched that evoke quality feelings for operator cabin components. Two-hundred sixty-five descriptors were collected from various resources: magazines related to vehicles (e.g., Industrial Vehicle Technology), from the literature and from interviews with operators that reflect, describe and evoke the quality feelings about operator cabin components (Appendix B). Twenty descriptors were selected to represent quality feelings by applying affinity analysis described in the analysis section.

Computerized data collection was used for the qualitative questionnaire (Figure 3.2); the qualitative questionnaire for manual data collection is given in Table 3.3 (the entire questionnaire is given in Appendix B). Forty-seven students studying an Ergonomics and design course rated cabin components with 20 descriptive words on 7-degree Likert scales. Subjects made overall quality ratings of eight operator cabin components and total quality feelings evaluation of the cabin itself. Subjects were asked to comment on several design aspects regarding operator cabin components including design, size, shape, color, look, style, material/texture, layout, and information that affected their quality feelings.

Analysis

To reduce the number of words, the Affinity Analysis technique was used. The team developing the Affinity Diagram in this study consisted of three people. The descriptive words collected earlier were written on sticky notes and arranged on a white board. This way, all notes were accessible and could be moved from one side to the other easily. The group sorted the descriptive words into homogeneous clusters and assigned corresponding headings for each cluster. Sorting was done without discussion among group members. Sorting lasted until the word groups were formed and each group member was content with the coherence of groupings. Twenty-three affinity clusters were formed from descriptors (Appendix B).
Factor analysis was conducted on the data. According to the Kaiser rule, the components with eigenvalues above 1.0 are selected. Varimax with Kaiser Normalization was used as the rotation method. Varimax rotation is an orthogonal rotation, which helps to obtain independent factors. Then, factor loadings were calculated. Also called component loadings in Principal Component Analysis Factor, loadings are the correlation coefficients between variables (rows) and factors (columns). Factor loadings are the basis for attributing a label to the different factors. Loadings above 0.7 are considered high and those below 0.6 are low. Verification of the data for the analysis was done by checking the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy value and Bartlett’s Test of Sphericity. To answer the second research question, Multiple Regression Analysis was used to predict the contribution of product components on the criterion variable from a set of predictors. Then correlation effects of cabin components were examined by analyzing the data with all possible regressions.

Table 3.3 Semantic space defined for quality evaluation of reach truck operator cabin components.

<table>
<thead>
<tr>
<th>Attractive</th>
<th>Pleasing</th>
<th>Distinctive</th>
<th>Productive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ergonomic</td>
<td>Reliable</td>
<td>Heavy</td>
<td>Safe</td>
</tr>
<tr>
<td>High tech</td>
<td>Supportive</td>
<td>Comfortable</td>
<td>Precision</td>
</tr>
<tr>
<td>Durable</td>
<td>Professional</td>
<td>Functional</td>
<td>Robust</td>
</tr>
<tr>
<td>High-quality</td>
<td>Spacious</td>
<td>Nice to touch</td>
<td>User friendly</td>
</tr>
</tbody>
</table>

Figure 3.2 An example of an evaluation page for interior cabin components with Kansei words.
Figure 3.3 Methodological procedure for study 1.

Stage I
Quality feelings evaluation of product components using Kansei words

Step 1
Feeling of Quality

Step 2
Stage I
Quality feelings evaluation of product components using Kansei words

Step 3
Span the semantic space

Step 4
Affinity analysis

Step 5
Choose Kansei words

Step 6
Construct semantic differentials scales

Stage II
Overall quality feelings evaluation of product components and the product

Step 7
Identify product components

Step 8
Construct rating scales for product components and the product

Step 9
Data Collection

Step 10
Factor Analysis (PCA)

Step 11
Extract “affective factors” that represent quality feelings for product

Step 12
Multiple Linear Regression

Step 13
Determine “important product components” that effect the overall quality feelings for the product

Step 14
Provide design suggestions for the product
3.2.2 Paper II: Interactive design support system design by genetic algorithms

Study design and questionnaire

The research question for the second study examined an affective design decision support system for steering wheel design. A typical steering wheel is comprised of a metal insert, a steel hub and a layer of material (molding) to cover part of the insert. In the designed system, subjective evaluations of design samples are regarded as a fitting function, and the system calculates suitable design parameters using the Genetic Algorithm. Twenty design attributes were selected from these three layers. The applied GA parameters were: Population Size=20, Crossover Rate=65%, Mutation Rate=5%, Tournament Size=2, Maximum Iteration=100 and Random Seed Number=1. In the evaluation phase, a customer rates each generated design sample based on his or her degree of satisfaction.

The product attribute space was constructed beforehand. First, the user rated the importance of the descriptors that resulted from Paper I: attractive-nice to touch, ergonomic, functional, high-tech, reliable, robust, and spacious as importance criteria. Then the user evaluated the product samples on a 100-degree scale using the same scales. The system was written in C# programming language. Importance and preference ratings were used to calculate the fitness values for the steering wheel sample.

GA application steps are: (1) Proposed design samples consist of calculated parameters by GA; (2) GA begins with a population of “chromosomes” (e.g., candidate solutions to a problem) and moves them to a new population together with the genetic operators, crossover and mutation. Design parameters are coded to a bit array called a gene array. Each chromosome consists of “genes,” each representing an instance of a particular “allele” (e.g., 0 or 1); (3) Enter emotional criteria for the product. The system enables use of Kansei words from the semantic space extracted for a product as criteria weights; (4) The design support system generates N rule-sets randomly, and encodes the rule-sets as chromosomes. Set iteration counter to 1 (i.e., t=1), and initialize the upper bound of generation; (5) The user evaluates design samples in the computer environment. The fitness value is calculated based on the evaluation; (6) Apply genetic operators (selection, crossover, mutation) to the population and generate a new population. Set t=t+1 and go to Step 2. The selection operator chooses the fittest chromosomes from the population to participate in reproduction. The crossover operator exchanges subparts of two chromosomes to exploit the search space. Mutation operator chooses the fittest chromosomes from the population to participate in reproduction. The crossover operator exchanges subparts of two chromosomes to exploit the search space. Mutation operator chooses the fittest chromosomes from the population to participate in reproduction. The crossover operator exchanges subparts of two chromosomes to exploit the search space.
randomly changes the values of some genes to include new genetic material to the population. GA continues to perform the selection, crossover, and mutation operators until the termination criterion is reached (Kapanoglu and Alikalfa, 2004); (7) The system repeats until the user receives a satisfactory sample.

Figure 3.4 User evaluation page for a steering wheel sample.

Figure 3.5 Methodological procedure for GA application in study II.
3.2.3 Paper III: Affective design of waiting areas in primary healthcare

Study design and questionnaire

In this study, the first research question was: RQ1: is there a difference regarding perceived "affective factors" between waiting areas? RQ2: what are the desired "affective factors" when experiencing waiting areas? RQ3: How do waiting area design attributes interact in creating "affective factors"? The methodological procedure is given in Figure 3.7.

For the present study, primary healthcare centers were selected based on two criteria of qualitative research: pragmatism and representativeness (Hackley, 2003). There were 35 health centers in Sweden’s Östergötland County. Two focus group meetings were carried out with contact persons from the County Council in Östergötland to choose representative health centers. Seven health centers were chosen in the first meeting. The person responsible for waiting rooms introduced the study to the health centers and asked if they would participate. All but one of the health centers accepted. For that reason, the study was undertaken at the six health centers chosen to represent socially and regionally distinct areas in the county. Two centrally located health centers were chosen from two cities, one central health center was chosen from a town in an industrial area, one health centre was located outside of the city (a residential area), and the two were located in places where people from different cultures lived.

Pre-visits and several contacts were made to the health centers. During the pre-visits, the study was introduced to the health center managers, who informed staff about the study before the interviews were conducted. The study was also introduced again to the staff at the conduction of interviews, and participants were asked to express their ideas on waiting rooms/areas freely. In-depth interviews were conducted with ten patients and five staff members working in different positions at each of these centers. The patients were interviewed while they waited to see physicians or before laboratory tests. Drop-out rates were judged to be below 15 percent for patients and 20 percent for staff members. One of the reasons for drop-outs was lack of time.

Analysis

Free elicitation/association technique was used for data collection. Free association is one of the psychoanalytic techniques (Kernberg, 2004) used in qualitative research primarily for conducting psychoanalysis (Parker, 2004), called free elicitation in activity theory and free recall in cognitive psychology (Olson and Muderrisoglu, 1979 in Steenkamp and Van Trip, 1997).

3.2.3 Paper III: Affective design of waiting areas in primary healthcare

Study design and questionnaire

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By applying free association technique patients were asked to think about and realize their needs toward a product or an environment; they express feelings that are important for them and relate those feelings to design attributes (Figure 3.6). Interviews were conducted by the author and a psychology graduate student. The responses collected were classified under three main quality feel dimensions: Affective qualities (Russell et al., 1981), technical quality and interaction quality between staff and patients (Brady and Cronin, 2001).

A Microsoft Excel database (named as a Kansei database) was constructed to store the feelings and design attribute responses. Responses were classified under quality dimensions. First, Correspondence analysis (CA) was applied to position the waiting areas according to perceived qualities. To find desired “affective factors”, needs statements were grouped and χ2 analysis was applied to test whether there were significant differences in the participants’ statements. The hypotheses were: H0: All categories of feelings are equally important; H1: Some categories of feelings are more important. The interactions between design attributes for the commonly desired feelings were analyzed with ROSE software and the Rough Set method (Pawlak, 1991). The minimal covering rule (LEM2 algorithm) was applied to obtain associations between design attributes. The decision rules were then examined according to their relative strengths to explain the data, and with syntax to identify important design attributes.
Figure 3.7 Methodological procedure for study III.

Step 1: Identify participants

Data collection: Free association method

Stage I: Perceived feelings for different products

Stage II: Desired important feelings and related design attributes

Step 4: Record semantic space

Step 5: Record design attributes

Step 6: Verify Kansei words and their relationships to design attributes with each participant

Step 7: Build Kansei database from responses

Step 8: Classification of perceived feelings under affective quality dimensions

Choose significant feelings to represent Kansei

Step 9: Mapping waiting rooms according to perceived affective quality dimensions

Analyze data using data mining

Extract decision rules for Kansei values based on design attributes

Step 10: Test of significance for verification of perceived qualities

Identify interactions of design attributes

Step 11: Identify interactions of design attributes
3.2.4 Paper IV: Identifying trigger feeling factors

Study design and questionnaire

In this study (Figure 3.9), the first research question was: RQ1: How do we define trigger feeling related to electrical right-angled nutrunners? RQ2: What are the differences between product developers and operators to define trigger feeling?

A pre-study was conducted to span descriptive terms that could underlie trigger feelings. In total, 124 Kansei (affective descriptors) were collected from literature databases (Science Direct, Scopus, Ergonomics Abstracts, IEEE) and from interviews with technicians and product designers (Figure 3.8).

These words were reduced to 52 affective descriptors at a workshop with an ergonomist, a product design engineer and a technician applying Affinity analysis. Words were grouped according to whether they represent technical or affective characteristics such as release, feedback and soft start.

In the main study, 52 words (see Paper IV) were rated on 5-degree Likert scales according to their importance to define trigger feelings by 15 operators and 11 people as a product developer group. The Open-ended items were also provided for subjects to identify new words.
Analysis
No new words appeared from open-ended questions. First, possible differences between users and product development group evaluations were analyzed with the Mann-Whitney test. Next, ratings for 23 affective descriptors (questionnaire items) from the product development groups and ratings for 29 affective descriptors from the operator group’s responses were submitted to factor analysis based on principal components. For selecting those items, item-total correlations were computed based on summarized responses of the judges (correlations greater than .60 were selected as significant). This analysis reduced the feeling descriptors to a smaller number before conducting principal component analysis.

Principal components analysis was performed on the responses gathered from the two groups to investigate correlations among subsets of responses to Kansei words. An initial number of possible factors (based on components with eigenvalues greater than 1) were derived. These factors identified the underlying structures for operators’ preferences and operator groups’ preferences to define trigger feelings.
Figure 3.9 Methodological procedure for study IV.

Step 1

Step 2

Step 3

Step 4

Step 5

Step 6

Step 7

Step 8

Step 9

Step 10

Step 11

Semantic identification of trigger feeling

Span the semantic space.

Affinity grouping of semantic space

Choosing representative words

Construct semantic differentials scales.

Data Collection

Data Analysis

Extract "design factors" that represent trigger feeling

Comparison of responses for operator and product development group

Factor Analysis (PCA)

Mann-Whitney analysis

Comparison of responses for operator and product development group

Mann-Whitney analysis
3.2.5 Paper V: Kansei Engineering applied to triggers in powered hand tools

Study design and questionnaire

Paper V (Figure 3.10) dealt with two research questions: RQ1: What are the differences regarding perceptions of different nutrunner trigger mechanisms?; RQ2: How do trigger mechanism attributes relate to subjective needs? To compare preferences for linear and non-linear operation, four trigger switches were selected. Two non-linear operating mechanisms - one with short travel distance and another with a long travel distance - were selected. The third trigger mechanism displayed a relatively non-linear mechanism and had a low trigger actuation force level and low travel. The last trigger mechanism had a built-in linear mechanism that allows linear force increase and release. The last mechanism was the current mechanism that the operators used in their jobs.

The study followed three evaluation phases to answer the research questions. First, twenty-three operators rated four trigger switches according to quality, usability, feedback, controllability, safety, feels good, repeatability, distinct, and felt difference between push-release forces. These words were entered into the PLS regression. Cross validation was used to validate the number of factors required.

As a second step, operators made comparisons of the switches according to best feeling on the same scale. In the third phase, operators evaluated three trigger attributes using JAR scales (just about right), maximum force (e.g., too low, just about right, and too high), travel distance and hardness/acceleration. These scales were used to get complementary information about switch attributes for PLS analysis.

Analysis

The Kruskal-Wallis test was applied to compare preferences for triggers. This test evaluated whether sum of ranks for triggers are disparate, not likely to have come from samples drawn from the same population (Siegel, 1956). Multiple comparison tests using Tukey's post-hoc test were conducted to find which triggers differ from one other. Preferences about trigger attributes and preferred mechanisms were extracted using PLS. Average preference values for the 10 feeling words were entered into the PLS regression. Cross validation was used to validate the number of factors required.
Figure 3.10 Methodological procedure for study V.

Comparison of non-linear and linear operating trigger mechanisms

Choosing evaluative words

Construct Likert scales

Data Collection

Data Analysis

Comparison of trigger mechanisms

Comparison of trigger attributes on behalf of maximum force, travel distance and firmness (hardness)

Kruskall-Wallis test

PLS regression

Identify design dimensions for trigger feeling

Step 11

Identify trigger parameters

Construct rating scales (JAR) for trigger parameters

Frequency histograms

Spearman correlations

Step 12
3.2.6 Paper VI: Affective Engineering evaluation of non-linear trigger switch mechanisms

Study design and questionnaire

The last study on trigger mechanism design (Figure 3.12) examined three research questions: RQ1: Is there a difference between subjective preferences and trigger switch force-travel mechanisms?; RQ2: Which mechanism attribute levels interact to give a certain perception such as distinct trigger feedback?; RQ3: What is the relationship between switch mechanisms and perceptions of quality?

Twenty-six operators evaluated five trigger switches. To evaluate perceptions of trigger forces (peak-drop-bottom), two low-force levels, two medium-force levels, and one high-force level, installations were selected. The attribute set for the switch mechanism consisted of fifteen elements: Forces, distances and gradients (the slope between forces during force increase and decrease) between forces were chosen as independent variables from the trigger operation process explained above. Based on previous studies (Ayas and Eklund, 2010; Ayas et al., 2010), four words were chosen as dependent variables to evaluate trigger mechanisms: quality, feedback, firmness and distinctness. Five-degree Likert scales with anchors (not at all, very much) were used in the questionnaire.

The experiment took part in a separate room located at the engine assembly unit of an automotive manufacturer in Sweden. After an introduction, task one was to push down until the medium-force calibrated mechanism was achieved. Following the task, the subjects received a questionnaire to make subjective ratings of their experience with the mechanism. Task two was to experience four mechanisms and to make similar ratings. Switch mechanisms were rated randomly. Each subject performed 20 evaluations and there were 2 to 3 minutes of calibration time for each mechanism; thus, subjects could rest between trials.

Analysis

To answer RQ1, equality of mean ratings for switch mechanisms were tested using one-way ANOVA and Kruskal-Wallis sum of ranks (p<0.05). Post-hoc comparisons were also calculated (Siegel and Castellan, 1988) including Spearman correlations to identify relationships of perceptions from operator evaluations. Statistica (Statsoft, v8, 1999) was used for all analyses and Rough sets were applied in a program made in Excel.

3.2.6 Paper VI: Affective Engineering evaluation of non-linear trigger switch mechanisms

Study design and questionnaire

The last study on trigger mechanism design (Figure 3.12) examined three research questions: RQ1: Is there a difference between subjective preferences and trigger switch force-travel mechanisms?; RQ2: Which mechanism attribute levels interact to give a certain perception such as distinct trigger feedback?; RQ3: What is the relationship between switch mechanisms and perceptions of quality?

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PLS prediction models were used to evaluate which attributes are important for selected perceptions to answer RQ2. Cross-validation was used to choose predictive models with the smallest corresponding root mean square error (RMSE) ($p<0.001$). To test the accuracy of the model, VIP (variable importance) values were computed; variables with small influence (<0.8) (Wold et al., 2001) were excluded from the model stepwise.

Rough Set Analysis (RS) (Pawlak, 1991; Nishino et al., 2006) was applied to obtain information on how product characteristics interact to provide quality, feedback, firmness and distinctness perceptions. RS requires a four-step decision on evaluative words and ratings, constructing a decision table by calculating probabilities of ratings, approximation of data by setting threshold values and extraction of decision rules based on product development prioritizations (Figure 3.11).

In this study, there were 26 evaluators for 5 mechanisms denoted by $U=\{x_1, \ldots, x_{26}\}$. An evaluation event of the $j$th evaluator to the $i$th mechanism is denoted as $x_{ij}$. Object set $U$ is the set of switch mechanism evaluations. $U/A = \{E_1, \ldots, E_m\}$ for $m$ mechanisms, and $D = \{D_1, \ldots, D_r\}$ are decision classes where $D_j = \{x|d(x)=j\}$.

Figure 3.11. Application process of Rough Sets. (Nishino, 2010).

To conduct RS, the evaluation scores on the Likert scales were classified into (0 and 1) probabilistic decision classes; (1 and 2) as not distinct (0) and (3, 4, and 5) as distinct (1). Responses for firmness were classified $\{1, 2, 4, 5\}$ as negative (0) and $\{3\}$ as positive (1). For quality feelings analysis, operator responses were classified $\{1, 2\}$ as negative (0), $\{3\}$ as same and $\{4, 5\}$ as positive (1). To select the most effective decision rules, the rules were sorted based on the product of certainty, coverage values and values of strength.
Figure 3.12 Methodological procedure for study VI.

Step 1
Trigger feeling

Step 2
Identification of preferences for non-linear operating trigger mechanisms

Step 3
Choose evaluative words
Choose trigger installation designs for experiment

Step 4
Construct Likert scales
Construct rating scales (JAR) for trigger parameters

Step 5

Step 6
Data Collection
Data Analysis

Step 7
Comparison of trigger installation designs
Analysis of design attributes and interactions for subjective preferences

Step 9
Kruskall Wallis
One-way ANOVA

Step 11
PLS
Rough Sets analysis

Step 2

Step 3

Step 4

Step 5

Step 6

Step 7

Step 8

Step 9

Step 10

Step 11
3.2.7 Paper VII: An Affective Engineering assessment of a hospital bedding system innovation

Study design and questionnaire

Paper VII dealt with three research questions: RQ1: Are there any differences between subjective preferences of two bed-making systems?; RQ2: Are there differences of time and task-related productivity aspects between two bed-making systems?; RQ3: Are there differences between forward bending and elevation of hands over shoulder level time durations, frequencies and bending angles of participants for two bed-making systems?

In this study, subjective evaluations and objective measurements were collected for conventional and new bed-making products (Figure 3.13). Both qualitative and quantitative questionnaires were used. Fourteen nurses participated in the study voluntarily. First, the new product was introduced to the nursing personnel in a one-day seminar; after three weeks, a qualitative questionnaire was applied to identify problems with bedding systems, and identify personal suggestions about how the bed-making systems can be improved.

The quantitative study was carried out after nurses had three months of experience with the new bedding system. Basic category classification procedures for KE were applied to develop a questionnaire evaluating subjective perceptions (Nagamachi 1995, 2010). Category classification is a tree structure from main event to subsequent sub-events. The zero concept was considered a quality perception. This top concept was applied to sub-concepts, representing perceptions of physical attributes and bed-making tasks. The questionnaire measured perceptions of physical characteristics, activities, overall experiences and overall quality of the bed-making product. In a quantitative questionnaire, bedding products were rated on 7-degree Likert scale according to steady, light, nice to touch, soft, quick, comfort, easy to work with, usable, simple and quality concepts.

Analysis

Univariate statistics were used to examine the means and standard deviations of the responses, and check for possible outliers or entry errors. Two-tailed significance at the $p<0.001$ level was used to make statistical interpretations. A paired samples t-test was performed to examine participants' subjective responses and overall experiences with the new and conventional systems. The null hypothesis was defined as the two populations for the two bed-making types having the same mean...
ratings. Spearman’s rank correlation coefficient rho values (Siegel and Castellan, 1988) were computed to see how closely the variables (descriptive words) were associated.

Partial Least Squares (PLS) prediction models were used to evaluate which descriptors were important in defining quality of tactile feel. To show model dimensionality, cross-validation was used to choose predictive models, and corresponding root mean square errors (RMSE) were calculated ($p<0.001$). To test the accuracy of the model, VIP (variable importance) values were computed; variables with small influences (<0.8) (Wold et al., 2001) were excluded from the model stepwise.

Working postures were recorded on videotape for the total duration of the bed-making tasks. These activities were analyzed from the video recordings. The following activities were divided into critical steps. Direct observations and 3D static modeling were used to evaluate the physical loads of subjects from the bed-making tasks. Productivity-related measurements were made and analyzed including measures of work cycle times, duration of postures and related frequencies.

DIN EN 1005-1 (2000) defines postures as static, lasting longer than 4 seconds at a constant or slightly changing force. All trunk movements outside the neutral range were examined to establish whether they lasted longer than 4 seconds. The frequency was then calculated. DIN EN 1005-4 (2005) defines a body movement as frequent if it is performed twice or more per minute for an extended period. To compare compression forces on the L5/S1 joint and evaluate forward-bending and compression forces on L4/L5 joints, exertions from lifting above shoulders were evaluated (Bean et al., 1988). The back compression design limit (BCDL=3400N) and back compression upper limit (BCUL=6365N) were used for comparison. Short duty cycles (fewer than 20 seconds of work and 40 seconds of rest) with low hand loads (less than 0.4 kg) and with arms below shoulder level are acceptable provided this work activity is not maintained for long periods (Chaffin et al., 2006).
Figure 3.13 Methodological procedures for study VII.

Spanning the semantic space to identify evaluation dimensions

Choosing evaluative words

Construct Likert scales.

Choosing evaluative words

Construct Likert scales.

Prediction of physical loads by 3DSSPP

Qualitative analysis

Analysis of physical loads

Time analysis

Comparisons of the two bedding systems

Analysis of design attributes for quality feelings preferences

Quality perceptions

Discomfort

Time

Physical load on shoulders and lower back

Paired t-tests

Analysis of physical loads

Time analysis

Comparisons of the two bedding systems

Analysis of design attributes for quality feelings preferences

Quality perceptions

Discomfort

Time

Physical load on shoulders and lower back

Paired t-tests

Figure 3.13 Methodological procedures for study VII.
4 Summary of the studies

This chapter provides the reader summaries of the papers included in this thesis. Study aims, applied methods, results and study contributions are presented.

4.1 Introduction

The research on quality feelings presented here (Table 4.1) is based on a range of product applications from operator cabins to tactile perceptions. To start research on quality feelings, the reach truck named BT Reflex gave inspiration for the first study presented in Paper I. Quality design improvement solutions for future operators’ cabins of a reach truck model were the aim. Cooperation took place with BT Industries AB, Sweden. The perceived feelings of qualities for operator’s cabin components were identified and prioritized in this study. The second study presented is based on the first. An interactive design and decision support system is developed for affective evaluations of steering wheels. By identifying interactions between design attributes, the best design alternative can be selected.

Quality feelings needed from a service environment and needs for physical design attributes in relation to those were identified in Paper III. Waiting areas in primary health care were studied where tangible and intangible qualities interact. This study follows a different data extraction and method than other studies. Feelings of quality are important in tactile design of control switches for powered tools. Papers IV, V and VI are tied in this common base. The studies were made in collaboration with Atlas Copco and Scania AB. Paper IV identifies feelings from trigger switch mechanisms for right-angled nutrunners, and compares if product developers and users have the same views for product design needs. Paper V presents comparisons of four trigger mechanisms for the same hand tool. Paper VI investigates which operational stages are preferred for a new non-linear operating trigger mechanism and identifies design quality needs. Finally, paper VII describes the evaluation of quality feelings through physical load of work, productivity and aesthetic
Qualitative and quantitative analysis were conducted for investigation.

Table 4.1 Summary of aims and results of the studies.

<table>
<thead>
<tr>
<th>Papers</th>
<th>Aims</th>
<th>Main results</th>
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<tbody>
<tr>
<td>Paper I</td>
<td>to explore design improvements for feelings of quality in a reach truck operator cabin.</td>
<td>Interior cabin surfaces, actuating wheel and the dashboard have a significant effect to provide overall quality feelings in operator cabin. Quality, usability, functionality, aesthetics and ergonomics are the main affective quality needs from the reach truck cabin.</td>
</tr>
<tr>
<td>Paper II</td>
<td>to develop and design an interactive decision support system which take into account interactions between design attributes and feeling quality criteria.</td>
<td>The result of the study is design decision support system aims to find best steering wheel design alternative for the individual user. The decision support system &quot;learns&quot; the preferred design attributes and creates new design samples based on the findings from the previous evaluations. The program considers users' ratings for importance of affective needs.</td>
</tr>
<tr>
<td>Paper III</td>
<td>to understand perceived and desired quality feelings that contribute to &quot;affective factors&quot; in service environment (waiting rooms), related physical design attributes and interactions.</td>
<td>Patients want to feel calm, welcome and safety-security in a waiting room. To create calm feeling, privacy, colors, plants and location of play areas for children are interacting as design attributes. Good design of lighting, seating arrangements and minimal noise are also needed.</td>
</tr>
<tr>
<td>Paper IV</td>
<td>to identify the important affective factors related to trigger switch feeling for electrical right angled nutrunners.</td>
<td>Soft start together with end feedback is associated with well-built, convenient and safe trigger switch for operators. Six factors define trigger switch feeling, professional performance, safety and tactile feeling, usability, smooth operation, communication and durability, convenient and comfortable. Non-linear operating mechanisms with drop force were preferred to give more quality and feedback. The non-linear trigger mechanism contribute positively to quality feelings, while the linear trigger mechanism contributed negatively. When the switch mechanism was designed to give more distinctness and feedback, higher quality is perceived during loading and unloading phases of trigger operation. The trigger switch mechanism with a combination of high peak-drop-bottom forces was perceived with better quality, feedback, and distinctness.</td>
</tr>
<tr>
<td>Paper V</td>
<td>to investigate affective preferences for quality and related mechanism attributes for trigger switch mechanisms of nutrunners.</td>
<td>Aims to understand perceived and desired quality feelings that contribute to &quot;affective factors&quot; in service environment (waiting rooms), related physical design attributes and interactions.</td>
</tr>
<tr>
<td>Paper VI</td>
<td>to identify and investigate design characteristics of the trigger function associated with different feelings and preferences by assembly workers operating nut runners in their daily work.</td>
<td></td>
</tr>
</tbody>
</table>
4.2 Paper I: Designing quality feelings in reach trucks: a Kansei Engineering approach

Background
To strengthen the emotional bond between vehicles and drivers, it is important to design quality feelings. When we refer to embodiment relation, the artifact or vehicle part becomes transparent to the user so that it is not experienced as an object, but instead becomes a part of how the vehicle driving is experienced. The objective in study I was to identify and analyze aspects of quality feelings in a reach truck operator cabin. To achieve this objective, the first sub-aim was defining and understanding the quality feelings concept from a KE perspective; the second aim was extracting semantic factors for quality feelings (making a Kansei database) for steering wheel, hydraulic controls, seat, pedals, control console, dashboard, overhead guard and interior cabin surfaces of operator cabin, and determining the important cabin components that contribute to quality feelings.

Users’ recognition and evaluation of a product and the combination of their feelings and emotions represent Kansei. In this study, verbal expressions represented human Kansei for cabin components. Two-hundred sixty-five descriptors were collected from various resources that reflect, describe and evoke the quality feelings about operator cabin components (Appendix B). These were reduced to 20 using Affinity analysis by a focus group. Forty-seven mechanical Engineering students evaluated cabin components on 7-degree Likert scales, using 20 Kansei words that represent the quality feelings. For analysis, Reliability, Factor and Multivariate Regression Analyses were applied to the data.

Primary results and contributions of results
Reliability analysis gave high alpha values for internal consistency (>0.7). Factor Analysis with PCA extraction of cabin component ratings with affective descriptors resulted in four to seven factor dimensions (Table 4.2). A Multiple Linear Regression model with curve estimation analysis resulted in a quadratic model with the smallest $C_p=1.9, R_{adj}^2=75\%$. Steering wheel, hydraulic controls, dashboard, overhead guard, and interior cabin surfaces, $X_1, X_2, X_3, X_4$, and $X_5$ as independent variables are given in eq.1 correspondingly.

\[ Y = 0.23 + 0.4X_1^2 + 0.02X_2^2 + 0.003X_3^2 - 0.18X_4^2 + 0.52X_5^2 + 1.39 \]  \hspace{1cm} (Eq. 1)

Interior cabin surfaces were found the most effective component to raise total quality feelings in the truck operator cabin. The underlying quality factors to design interior cabin surfaces were robust.

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Interior cabin surfaces were found the most effective component to raise total quality feelings in the truck operator cabin. The underlying quality factors to design interior cabin surfaces were robust,
ergonomic, nice to touch, high-tech and spacious. Additionally, the steering wheel and the dashboard were second in importance to enhance the total quality feelings of the cabin. In general, results indicate that operator cabin components give rise to different dimensions for quality feelings. These dimensions include quality, usability, functionality, aesthetics and ergonomics. In conclusion, the methodological approach presented in this study assists determining user preferences and helps product developers and designers reflect quality feelings and other concepts. Another contribution is that semantic factors assist designers and product design engineers with user need considerations, and can be used to evaluate cabin components in future and existing designs.

Table 4.2: Extracted factors to represent quality feelings for operator cabin components.

<table>
<thead>
<tr>
<th>Steering Wheel</th>
<th>Operator's Seat</th>
<th>Pedals</th>
<th>Dashboard</th>
<th>Cabin</th>
<th>Interior</th>
<th>Control</th>
<th>Hydraulic Controls</th>
<th>Overhead Guard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attractive</td>
<td>Attractive</td>
<td>Nice to Touch</td>
<td>Attractive</td>
<td>Ergonomic</td>
<td>Attractive</td>
<td>High-tech</td>
<td>Attractive</td>
<td>Ergonomic</td>
</tr>
<tr>
<td>Nice to Touch</td>
<td>High-quality</td>
<td>Comfort</td>
<td>Ergonomic</td>
<td>Functional</td>
<td>Reliability</td>
<td>Heavy</td>
<td>Heavy-robust</td>
<td></td>
</tr>
<tr>
<td>Touch</td>
<td></td>
<td>High-tech</td>
<td>Ergonomic</td>
<td>Nice to touch</td>
<td>Heavy</td>
<td>Heavy-robust</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ergonomic</td>
<td>Comfort</td>
<td>Nice to Touch</td>
<td>Ergonomic</td>
<td>Functional</td>
<td>Reliability</td>
<td>Robust</td>
<td>Precision</td>
<td></td>
</tr>
<tr>
<td>Ergonomic</td>
<td>Nice to Touch</td>
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<td>Heavy-robust</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Functional</td>
<td>High-quality</td>
<td>Productive</td>
<td>Ergonomic</td>
<td>Robust</td>
<td>Heavy</td>
<td>Robust</td>
<td>Precision</td>
<td></td>
</tr>
<tr>
<td>High-tech</td>
<td>Heavy</td>
<td>User-friendly</td>
<td>Functional</td>
<td>Robust</td>
<td>Heavy</td>
<td>Robust</td>
<td>Spacious-supportive</td>
<td></td>
</tr>
<tr>
<td>Heavy</td>
<td>Spacious</td>
<td>Robust</td>
<td>Spacious-supportive</td>
<td>Robust</td>
<td>Spacious</td>
<td>Robust</td>
<td>Spacious</td>
<td></td>
</tr>
<tr>
<td>Robust</td>
<td>Spacious</td>
<td>Supportive</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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4.3 Paper II: Interactive design support system design by Genetic algorithms

**Background**
The study in Paper I resulted in quality feelings improvement directions for several components of operator cabins. Paper II, therefore, accomplished designing a decision support system to evaluate steering wheel designs. It also incorporates customer intuition and affect, where a customer can participate personally in the design process. The second aim addresses that it is rarely possible to analyze non-linear interactions of product attributes with statistical models.

Time, efficiency and costs are important restrictions in method applications. A person does not usually relate a sporty steering wheel in his mind to just one design attribute such as material, but also shape and other attributes. Therefore, the efficiency of heuristics was tested to approach non-linear parameter interactions in Paper II.

For this system, the product attribute space has to be constructed first; then subjects rated the importance of the affective descriptors resulting from Paper I: attractive-nice to touch, ergonomic, functional, high-tech, reliable, robust, and spacious. The customer then evaluates the product samples on a 100-degree scale. The system was based on Genetic operations and written in the C# programming language. Importance and preference ratings are used to calculate the fitness values for the steering wheel samples.

**Main results and contributions of results**
The program is designed to find the best steering wheel design based on affective preferences. From the new design population, the genetic system "learns" the preferred design attributes and shows new design samples based on findings from the previous evaluations.

The system has several advantages for further applications. First, it enables searching through a large number of parameters (color, shape etc.) according to product design applications. Product manufacturers and researchers can use these in early product design applications. A group of people or individuals can make evaluations and/or a joint design can be determined.
4.4 Paper III: Affective design of waiting areas in primary healthcare

Background
It is proposed that waiting experiences can be created that connect service providers with patients on a deeper level. Transforming the environment into spaces of greater significance by distinguishing important feelings from intangible and tangible quality characteristics was tested in this study. A new data collection and analysis method was applied. The first aim was to investigate perceived and desired quality feelings; the second was to find related physical design attributes and interactions among design attributes that contribute to “affective factors” in waiting areas of six healthcare centers. If these feeling interactions could be investigated, this would contribute to a better understanding of the design of waiting rooms for patient well-being. The purpose was to apply and test a technique where data were collected from free associations of affective descriptors and design attributes. Specifically, three main research questions were investigated: RQ1: is there a difference regarding perceived “affective factors” between waiting areas?; RQ2: what are the desired “affective factors” when experiencing waiting areas?; RQ3: How do waiting area design attributes interact in creating “affective factors”? Sixty patients and 28 staff working in different positions - managers, doctors, and receptionists - were interviewed. The study was undertaken at six primary health centers chosen to represent socially and regionally distinct areas in Sweden's Östergötland County.

Main results and contributions of results
The desired affective qualities from waiting areas were relaxing, pleasant and arousing. Considering pleasant qualities, pleasantness, comfort and warm feelings were found important. As a common result for patients and staff, calm, welcome and safety/security feelings appeared significant.

RS analysis provided design decision rules for calm feelings such as privacy, colors, plants and location of play areas for children (Table 4.3). Good design of lighting, seating arrangements and minimal noise are also necessary. Core attributes for calm feelings resulted in the subset of design attributes privacy, children’s play area, color and plants. Further, strong decision rules (covering index>0.30) were selected to express the feeling of calmness. Covering index values show the ratio of primary attribute category compositions for calmness. If the covering index is 1, it represents that the power of the rule is sufficient to design calm feelings.


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Calm was found especially important to offering relaxing quality. A fresh feeling with bracing appeared important to provide an Arousing Quality; security-safety, functionality and privacy feelings appeared as the primary design needs for technical qualities. CA results showed that waiting area E is perceived with distressing quality. Waiting area C was perceived with positive qualities such as relaxing and exciting. Waiting areas A, B and E were located with unpleasant and gloomy (sleepy) qualities, representing negative affective qualities; the rest of waiting areas C, D and F were associated with positive qualities.

This study identified important affective needs for waiting rooms in primary health centers. Quality dimensions perceived as important affective needs were identified in various waiting rooms. This study allows healthcare providers to understand patients’ affective needs from waiting rooms. Health service providers must give attention not only to the objective reality of waiting times, but also to how wait is experienced.

Managing the psychological experience of a customer’s waiting experience by reducing the perceived waiting time can be as effective as reducing the wait time itself (Katz et al., 1991). Six waiting areas were mapped according to perceived affective qualities. This assists the service provider concerning the design quality of waiting rooms. Another important contribution of this study was that design attribute interactions can be identified to design different patient groups such as family and elderly citizens’ wants in waiting rooms.

### Table 4.3 Selected decision rules for calm.

<table>
<thead>
<tr>
<th>Waiting Room</th>
<th>Decision Rules</th>
<th>Design attribute Interactions</th>
<th>Covering Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>a1a8</td>
<td>privacy, sitting places</td>
<td>0.48</td>
</tr>
<tr>
<td></td>
<td>a2a8a10a12</td>
<td>lightning, sitting places, art, plants</td>
<td>0.48</td>
</tr>
<tr>
<td>B</td>
<td>a7a8</td>
<td>interaction quality, sitting places</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>a2a12a13</td>
<td>lightning, plants, entertainment</td>
<td>0.33</td>
</tr>
<tr>
<td>C</td>
<td>a3a8a9a12a15</td>
<td>sound level, sitting places, colour, plants, reading material</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>a1a12a13</td>
<td>privacy, plants, entertainment</td>
<td>0.33</td>
</tr>
<tr>
<td>D</td>
<td>a2a8a10</td>
<td>lightning, sitting places, art</td>
<td>0.44</td>
</tr>
<tr>
<td>E</td>
<td>a1a2a3a7a8a12a15</td>
<td>privacy, lightning, sound level, interaction quality, sitting places, plants, reading material</td>
<td>1</td>
</tr>
<tr>
<td>F</td>
<td>a2a3a10</td>
<td>lightning, sound level, art</td>
<td>1</td>
</tr>
</tbody>
</table>

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4.5 Paper IV: Identifying trigger feeling factors

Background

Papers IV, V and VI focus on trigger feel design of switches in hand tools; the three studies are related. The first aim of Paper IV was to investigate affective descriptors and related affective design dimensions to define trigger tactile feeling for electrical right-angled nutrunners. The second aim was to see if users (operators that work at an automotive assembly plant of the tools) and product developers’ share the same views. One-hundred twenty-four Kansei words (descriptors) were collected and reduced to 52 through affinity analysis. These affective descriptors were rated according to their importance by 15 operators and 11 people as product developer group on 7-degree Likert scales. The questionnaire is shown in Paper IV.

Main results and contributions of results

The Mann-Whitney test on rank sums showed that effective, ergonomic, creative, modern, resistance, exact, optimal, quick start, stable and safe were more important to the operator group than the product developers. Descriptors such as comfort, control and soft start were more important to the product developers.

From the operator group’s responses, six factors explaining 87% of the variation were extracted to define trigger feeling as professional performance, safety and tactile feeling, usability, smooth operation, communication and durability, convenient and comfortable. For the product development group, five factors explaining 89% of the variation were extracted including robust and appealing, ergonomics and operator performance, controllability and predictability, creativity and modern and powerful. Results showed that the start phase and especially the quick start of the trigger mechanism were more important to operators, while end feedback was more important to product developers.

According to product developers, soft start of the trigger was correlated with ergonomics, optimal, clear operation and performance. Soft start together with end feedback was associated with well-built, convenient and safe for operators. Ergonomic was rated as the most important descriptor for trigger feeling in addition to user-friendly, easy to use, long life time and comfortable for both groups. The identified feeling needs of operators and differences between operators and product developers.
views can be used to include user needs while designing new trigger switches and improving existing hand tool switches.

4.6 Paper V: Kansei Engineering applied to triggers in powered hand tools

Background
Trigger switch mechanisms are important for operators to perceive feedback while tightening bolt joints, but previous studies did not focus on trigger feeling. The purpose of Paper IV was to compare preferences for linear and non-linear trigger switch operations, and investigate trigger attributes that influence trigger feeling. Two non-linear operating mechanisms, Trigger A with short travel distance and Trigger B with a long travel distance (Table 5), were selected. The next trigger mechanism C displayed a relatively non-linear mechanism and had a low trigger actuation force level and low travel. The last trigger mechanism D has a built-in linear mechanism that allowed linear force increase and release.

The study consisted of three phases. First, twenty-three operators rated four trigger switches according to quality, usability, feedback, controllability, safety, feel good, repeatability, distinct, felt difference between push-release forces criteria on 5-degree Likert scales from not at all to very much. As a second step, operators made comparisons of the switches according to the best feeling on the same scale. In the third phase, operators evaluated three trigger attributes with JAR scales (just about right): maximum force (e.g., too low/just about right/too high), travel distance and hardness/acceleration. These scales were used to obtain complementary information about switch attributes for PLS analysis.

Primary results and contributions of results
Kruskall-Wallis test results show that operator preferences for trigger mechanisms differ (p<.05). The non-linear trigger mechanisms A, B, and C contributed positively to quality feelings, while the linear trigger mechanism D contributed negatively. An increase of travel distance and of initial, peak, and final reaction force decreased the perception of quality feelings. Trigger D with linear operating mechanism and high peak and final reaction force was rated lower in comparison to other triggers. For quality feelings, the triggers A (mean=3.74), B (mean=3.78) and C (mean=3.91) received similar high evaluation scores. The highest evaluation difference was between triggers B (mean=3.87) and D (mean=1.83) in comparison to the "best" trigger. Results showed that triggers B and C gave more feedback compared to other trigger switches. Examining the effects of parameters

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to affective preferences resulting in drop reaction force having an important effect on increased feedback feel. Results also showed that force decrease installed between push and release forces influenced distinct feeling positively.

Positive attribute drivers of trigger feelings evaluated in this study were drop reaction force, difference between push-release forces and drop displacement; negative drivers were initial reaction force, peak reaction force, final reaction force and travel distance. The just about right scale application resulted in hardness and travel distance perceptions being positive and highly related to peak force (maximum force) perceptions for non-linear operating mechanisms. For linear operating mechanisms, hardness was correlated strongly with maximum force.

Results of this study provide information to the product manufacturer about how trigger mechanism attributes contribute to design of mechanism. In the meetings with the product manufacturer, it was observed that they do not make structured evaluations for subjective experiences. Therefore, this study also provides knowledge about how operators associate affective needs to various mechanisms for product development stages. Paper V focused on distinguishing preferences between linear and non-linear mechanisms. If switch installations are made with distinguishing characteristics, these aid operators by giving them feedback on tool activation, tightening and ending operation with the powered tools.

4.7 Paper VI: Affective Engineering evaluation of non-linear trigger switch mechanisms

**Background**

Paper VI sets a further step approach to trigger feeling design compare to Paper IV and V. The general aim for the study in Paper VI was to test a new non-linear operating trigger switch mechanism and to find installation preferences for that. The study investigated how affective perceptions are related to attributes such as peak force, release force, and distance travelled by the mechanism. Previous studies in literature focus on associations between discomfort evaluations and powered tool operation. First research question was to find if there is a difference for subjective preferences in evaluations of trigger switch force-travel mechanisms. Second research question was to investigate which mechanism attribute levels interact to give perceptions of quality, feedback, firmness, and distinctness. Third research question was to find the relationship between perceptions of quality and switch mechanisms.
Twenty-six operators evaluated five trigger switches. To evaluate perceptions of trigger forces (peak-drop-bottom), two low-force levels (1 and 2), two medium-force levels (3 and 4), and one high-force level (5) mechanisms were selected. The attribute set for the switch mechanism consisted of fifteen elements. Forces, distances, and gradients (the slope between forces during force increase and decrease) between forces were chosen as independent variables from the trigger operation process explained above.

**Main results and contributions of results**

One-way ANOVA and Kruskal-Wallis tests identified no significant differences between mechanisms for quality and feedback perceptions. For distinctness and firmness perceptions perceptual differences between trigger mechanisms were significant. According to post-hoc comparisons, for perceptions of distinctness, mechanism five had significantly higher preference ratings compared to mechanisms one and two. For feeling of firmness, mechanisms medium high peak force installed mechanism gave significantly higher preference ratings compared to lower force-installed mechanisms one and two.

Spearman correlations between perceptions showed that, distinctness and feedback were significantly correlated with perceptions of quality ($r=0.22$, $p$ two-tailed $<0.05$; $r=0.26$, $p$ two-tailed $<0.01$). Firmness and feedback were significantly correlated with distinctness perceptions ($r=0.39$, $p$ two-tailed $<0.01$; $r=0.71$, $p$ two-tailed $<0.01$). Feedback was significantly correlated with distinctness perceptions ($r=0.41$, $p$ two-tailed $<0.01$).

Partial Least Squares (PLS) prediction models were used to evaluate which attributes are important for trigger perceptions. According to RS if peak force is calibrated high, gradient between release and final forces is calibrated low, drop displacement and distance to bottom force is calibrated long then the trigger switch mechanism satisfies needs for operator quality, feedback, distinctness, and firmness perceptions together. Results also revealed that loading and unloading phases of trigger operation are significant predictors for perceptions of quality. The trigger switch mechanism with a combination of high peak-drop-bottom forces was perceived with better quality, feedback, and distinctness in comparison to the other mechanisms. RS results were found consistent with PLS attribute predictions. The study revealed that when the switch mechanism was designed to give more distinctness and feedback, higher quality is perceived.

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4.8 Paper VII: An Affective Engineering assessment of a hospital bedding system innovation

Background
Developing bed-making products for healthcare requires consideration of human-product interactions such as usability and quality aspects besides ergonomics and productivity. Paper VII describes an investigation of affective preferences for a product and the system of working with it. Extant studies focused on associations between discomfort evaluations and physiological measurements in conventional bed-making. The purpose of this study was to assess a new bed-making system (Figure 4.1) by investigating nursing personnel’s affective and discomfort perceptions, physical loads and time use. A questionnaire measured perceptions of physical characteristics, activities, overall experiences and overall quality of the bed-making product. Products were rated with steady, light, nice to touch, soft, quick, comfortable, easy to work with, usable, simple, and quality concepts on 7-degree Likert scales. Working postures were recorded on videotape for the total duration of the bed-making tasks.

Nearly all measures for the new bed-making system showed an improvement on nursing tasks. However, independent t-tests resulted in higher than average compression forces on L5/S1 discs while bending forward (p<0.001) for the new bed-making system (2585, ± SD=365 N) and for the conventional bed-making system (2274, ± SD=164 N). For both bed-making systems, the calculated compression force values were below the safety limits considering the lower back within the NIOSH model (3400 N). Independent t-tests showed significant differences for required compression forces

Main results and contributions of results

Paired t-test comparisons of ratings showed that the new bed-making system received high ratings, and nurses’ quality and overall experiences were positive. Spearman correlations showed that quality perceptions were associated with tactile qualities such as soft, nice to touch and quick applicability of the product. PLS analysis showed that for both products, softness of material and easy to work were common quality evaluation characteristics.

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on L4/L5 joint for hand elevation \((p<0.001)\). On average, applying conventional bed-making \((1348, \pm SD=328 \text{ N})\) produced higher compression forces in comparison to the neutral position \((512, \pm SD=64 \text{ N})\).

As a general result, there were significant improvements regarding work load with the new bed-making system. Furthermore, one person was able to work with the new bed-making using fewer actions. Time analysis also yielded significant improvements (i.e., less time to make a bed with the new bed-making system). Considering physical loads, the average time and frequency of forward bending were lower for the new bed-making. Soft, nice to touch and quick with were common quality characteristics for both products.
4.9 Summary of quality feelings identified from studies

The important quality descriptors selected from the studies are presented below (Table 4.4).

<table>
<thead>
<tr>
<th>Products</th>
<th>Quality feeling descriptors</th>
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<tbody>
<tr>
<td>Operator cabin</td>
<td>Attractive, Nice to Touch, Ergonomic, Functional, High Tech, Reliable, Robust, Spacious, Supportive</td>
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</tr>
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<td>Waiting room</td>
<td>Calm, Pleasant, Fresh, Secure, Safe, Functional, Privacy, Welcome</td>
<td></td>
</tr>
<tr>
<td>Trigger switch</td>
<td>Professional, Performance, Safety, Tactile feeling, Usability, Smooth, Operation, Communication, Durability, Convenient, Comfortable</td>
<td>Soft start together with end feedback is associated with well-built, convenient and safe</td>
</tr>
<tr>
<td>Feedback</td>
<td>Effective, Creativity and Modern, Resistance, Exact, Optimal, Powerful, Quick Start, Stable</td>
<td>The more distinctness and feedback, the more higher quality perception</td>
</tr>
<tr>
<td>Firmness Feedback</td>
<td>Effective, Creativity and Modern, Resistance, Exact, Optimal, Powerful, Quick Start, Stable</td>
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</tr>
<tr>
<td>Distinctness</td>
<td>Firmness Feedback, Distinctness</td>
<td></td>
</tr>
<tr>
<td>Feedback</td>
<td>Good To Push, Safe</td>
<td></td>
</tr>
<tr>
<td>Bedmaking products</td>
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<td>Quality perceptions were associated with tactile qualities such as soft and nice to touch and quickness applicability</td>
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5 Discussion

This chapter discusses the findings from the studies with focus on research questions.

5.1 Methodological contributions and considerations

Product manufacturing companies react critically to product development methods such as QFD and KE as cumbersome and time-consuming. However, to design user needs, companies need to apply structured methods, but these take considerable time. Therefore, researchers need to develop and test methods that effectively and efficiently identify user needs in product design. This thesis contributes to that in terms of tested data evaluations and analysis methods in multiple product design contexts to evaluate quality feelings of products.

First, this study approached design improvements for a driver environment by evaluating cabin components, followed by an overall quality evaluation of the cabin. This way of data collection provided quality contributions of each cabin component toward the overall evaluation.

Second, this study proposed to give new design solutions for steering wheels. Therefore, the methodological approach involved users rating the importance of affective descriptors, then making prototype design evaluations based on those criteria.

To evaluate service environments, the third study integrated qualitative and quantitative methods. Common environmental attributes were investigated from individual needs.

As a methodology for assessing new product design and evaluations, the trigger mechanism studies (Papers IV, V and VI) followed four main evaluation stages to discover needs and expectations:
discovery of semantic space and categorization, selection of important descriptors for these needs, positioning of a new mechanism compared to existing products and testing alternative designs of new products by identifying design attribute preferences and interrelations among attributes for the new product. The study in Paper IV also involved comparison of users' and product developers' views of affective needs from a product. Overall, data collection in which both designers and users participate is a supportive approach to improving validity for product development.

Paper VII identified affective preferences for new bed-making and conventional products. User product needs were approached first with an exploratory analysis. After giving users three months experience with the new product, affective evaluations in addition to physical load (ergonomics measures) and productivity analyses were conducted to make product comparisons from an overall perspective.

5.2 Data collection

The studies presented in this thesis test and investigate quality feelings for products through rating quality directly, and with several dimensions. Asking about quality feelings directly does not, in some cases, provide information about the user's needs such as trigger mechanism feeling. Therefore, such needs for quality feelings are represented by trigger feeling in Papers IV, V and VI by asking important needs in Paper III and through categorization of several dimensions.

As an outcome of this thesis, interviewer supervision and providing meaning of the words helped to evaluate products with descriptive words. This helped subjects make clearer associations and product evaluations. As a conclusion from that researchers need to set the product evaluation and judgment setting by providing support, planning atmospheric effects and talking about the quality concept with subjects to extract their thoughts on products.

Data collection methods were limited to product types. To study tactile feeling of trigger mechanism design, the operator's experience with using their tool is important. Thus, selecting subjects with varying experience levels in groups from less experienced to experienced operators (even their judgments can be weighted) is helpful to obtain an overall picture of product needs. Another important aspect regarding tactile evaluations is that even if producers design advanced control systems for improving operations with hand tools, acceptability is limited by the cognitive abilities

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of the operators to feel the operational stages. This can be designed through sensitive installation, an evaluation that is an important contribution to Paper VI.

Studies investigating quality feelings must be designed carefully according to products’ natures and its users’ perceptions. For example, in trigger button evaluations, not one but several pilot studies are necessary for choosing evaluative words. For linear operating trigger switches, not much feedback is felt; for non-linear operating switches, operators may feel feedback in several phases of operation. These attributes need to be defined to understand which stages of the operation are more important to the operator.

Rating scales are used to obtain a measure on quality feelings. The researcher first develops a number of dimensional attitude statements, product or service attributes, image dimensions, etc. Subjects position how they feel about each statement using a defined rating scale. Instead of using 5D scales, the Likert scales used in the studies are labeled with "not at all" and "very much" on the anchors. One Likert scale (Likert, 1932) is a statement; the subject indicates degree of agreement with the statement. A reason not to use opposite word meanings at the anchors is that sometimes there is no opposite adjective (ambiguous labels), which may create confusion. Subjects also find it more suitable to label positions with verbal qualifiers instead of numbers, or not label for ease of expressing opinion, ease of completion, comprehensiveness and overall preference (Heise, 1970; Garland, 1990).

Five-point and seven-point scales are used in general and found effective for studies with 15-30 subjects. However, many psychometricians (like in SD scales) advocate using a seven- or nine-point scale (Guilford, 1971). Ospood et al. (1957) found that a large number of subjects’ responses gave equal frequencies on seven-degree scales. A disadvantage could be a five-degree scale is more easily understood by the subject, but is sometimes experienced as too narrow because the first and the last steps were considered as positive or negative infinity by the subject, and the remaining three steps do not provide sufficient differentiation.

A number of biases affect the rating scales results used in this thesis (see Spector, 1992). One of these is the halo effect, where the respondent has already decided that one of the products is the best. Another is leniency, where respondents are unwilling to be critical and adjust ratings to demonstrate that clearly (Wilson and Corlett, 2005).
In Paper V, product attributes were rated with JAR scales. These scales are used as diagnostic tools to provide directional information for optimizing products (Xiong and Meullenet, 2006). One endpoint of this scale is labeled “too little” of the characteristic and the other endpoint is labeled “too much;” the mid-point is labeled “just right” or “just about right.” The reason to use this type of scale was to get supportive information concerning tactile preferences of users on attribute parameters. This is used as a triangulation method with other methods to approach operators’ feeling needs from the trigger mechanism.

One observation from Paper III (waiting room design study) is that when the product/service has many attributes, it is difficult for a user to prioritize. Free association (elicitation) technique is used in Paper III to understand how people think and make associations in their minds about a certain object/environment. It permits subjects to reveal what they think in their own words (Bague et al., 2004). Free elicitation (FE), hierarchical dichotomization (HD), and Kelly’s repertory grid (BG) were compared on type of information generated, convergent validity, efficiency in data collection, and consumers’ reaction to the elicitation task (Steenkamp and Trijp, 1997) FE yielded more attributes, a higher proportion of abstract attributes, and a higher level of articulation and was more time efficient.

Product evaluation environments may have positive or negative psychological effects on the results of the studies. The study on evaluating operator cabins was performed in a laboratory environment. One advantage of using a laboratory environment is that participants can focus on the study. This type of evaluation environment may be different from real-world conditions. The second study considers evaluating products in a computer environment, and usability aspects that need to be investigated. User experiences are limited to visual evaluations. This type of product evaluation allowed searching among many design solutions.

5.2.1 Data analysis and validation

Responses to a single Likert item are treated normally as an ordinal datum, especially when using five point scales; it cannot be assumed that subjects perceive the difference between adjacent levels as equidistant. When treated as ordinal data, Likert responses can be analyzed using non-parametric tests such as the Mann-Whitney test, the Wilcoxon signed-rank test and the Kruskal-Wallis test. Skewed and flat distributions were observed in the data during the studies, which were transformed then to appropriate distributions such as lognormal. Likert data transformations provide the principal means of correcting non-normality and heteroscedasticity (Hair et. al., 2010).
PLS was used to predict contributing product attributes in Papers V, VI and VII. For validation of PLS models, interpretation of the latent variables is helped by examining graphs akin to PCA graphs (Abdi, 2003). It is suggested that standardizing or centering independent variables avoids computational errors by lowering the correlation between the product indicators and their individual components (Smith and Sasaki, 1979). In cross-validation, the data set is divided into a number of groups (Stone, 1974 and Geisser, 1974 in Wold et al., 1984). PRESS statistic is used as a measure of the predictive power of the model with the complexity for the data set (Wold et al., 1984). The maximum recommended value of the PRESS statistic is 1.0 (Hoerl and Kennard, 1970 in Wold et al., 1984). Another examined statistic in this thesis is Variable importance plot (VIP) for projection. This is a weighted sum of squares of the PLS weights, with the weights calculated from the amount of Y variance of each PLS component (Wold et. al., 2001).

During the studies, it was observed that non-linear models such as Rough Set Theory (Paper III-VI), and Genetic Algorithm (GA) (Paper II) are effective for finding interactions between multiple variables of Kansei evaluations and product elements (Nishino, 2010).

5.3 Thesis and study contributions

How users prioritize the quality dimensions is essential knowledge for product manufacturers. Product development teams need to apply systematic procedures to consider affective needs for quality in product design.

Given the needs above and throughout this thesis, the first study contributes by identifying perceived quality needs in operator driving cabins. Second, it provides guidance on the components necessary for product quality improvements. Paper I identified interior surfaces, steering wheel and dashboard design as important for quality improvements in reach truck driver environments.

The second study provided design solutions for design of attribute selections for steering wheels. The contribution of this study is a decision support tool that integrates the importance of affective preferences for the user and preference valuations. Another important contribution concerns applying Genetic algorithms as a method to search interactions between design attributes so that the best design alternative is selected.
Contributions from Paper III were that affective quality needs and related physical design attributes were identified for service environments. Second, this study contributes to the literature by integrating qualitative data extraction with the Rough Sets method.

Studies focusing on trigger feeling and affective quality needs for trigger mechanisms were not found in the literature. The three studies contribute to supply knowledge on operator needs for trigger mechanism design. Papers V and VI on new trigger mechanism design contributed information on design attributes related to quality needs for control system engineering. As new methods, Rough Sets and JAR scales contribute to tactile feeling product analyses.

Paper IV identified affective needs from trigger switch mechanisms for right-angled nutrunners, and found that product developers and users have differing viewpoints concerning product design needs. Paper IV extracted six factors to define trigger feeling, professional performance, safety and tactile feeling, usability, smooth operation, communication and durability, convenience and comfort. One important contribution is that tactile quality needs are associated with distinctness and feedback for trigger switches. Paper V took Paper IV a step further and offers that new non-linear operating switches are preferred by operators, and resulted in preferred design attributes and parameters for affective descriptors. Paper VI identified preferences and installation design of a new mechanism. The studies described in Paper V and VI offered confirming results that drop displacement (the distance between peak and drop force), drop force (difference between peak and drop forces) and push and release forces impact quality feelings. As a general result, Papers V and VI showed that quality feelings can be related to trigger mechanism parameter installation designs.

Paper VII contributed with knowledge on bed-making product evaluations, examining perceptions and improvements of bed-making. This study also contributed to healthcare and work evaluation research. There are no studies in literature on nurses' affective evaluations of bed-making tasks.

Complex products such as operator cabins and waiting rooms are comprised of different components where functionality and comfort (aesthetic and technical) quality dimensions arise, such as in the design of interior cabin surfaces and waiting room furniture. The design of interior surfaces, steering wheels and dashboards are important for quality feelings improvements in reach trucks. Controllability in steering is also important to give quality feelings; relaxing and pleasant feelings combined with privacy, security, safety and functionality are some of the dimensions contributing to waiting rooms quality feelings. Different user groups had different preferences, but

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so did product developers and users. For trigger design, the words effective, ergonomic, creative, modern, resistance, exact, optimal, quick start, stable and safe perceptions were found more important to the operator group in comparison to the product development group.

Several factors contribute to research on quality feelings for products:

- If the study is going to be conducted in a company, managers and their influence on workers to participate in the study is important. If communication between management and workers is not established well, this contributes to study effectiveness directly.
- A good communication base with the company
- Careful planning of the settings, participants (expert users and inexperienced users), data collection strategies etc.
- A research group with expertise with the product development area
- A knowledge base to understand how to treat the product design problem

The studies presented in this thesis address the pleasure needs proposed by Desmet (2007). Users in this thesis related quality to underlying product affect needs, a part of sensory quality of the product (physio-pleasure) (all studies), the social context in which the product is used (socio-pleasure) (Paper VII), task-related concerns of the user (psycho-pleasures) (Papers IV, V, VI and VII) and user values (ideo-pleasures) (Papers III and VII).

5.3.1 A proposed needs chain for quality feelings

Figure 5.1 presents a needs chain in a person’s mind that consists of affective product needs. The highest degree of quality feelings can be explained as overall quality. It is the representation of grouping important quality needs and their interactions. Starting with a simple need like an ergonomic product, the customer realizes his/her needs and various levels of interactions arise so that a person who wants an ergonomic product as his/her first affective need experiences a pleasing feeling. These two types of feelings interact (second-level quality need) in the person’s mind according to several personal selection criteria such as physical attributes and emotional experiences. Then, the next highest level is the interaction of customer needs in their minds.

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5.3.2 Optimization of design for quality feelings

To solve the problem of optimizing quality feelings presented above requires considering several factors (Figure 5.2). The first point to be considered is related to the design question of feelings for whom. What is the purpose of the design? Design for all or design for one or design for a group? Inclusive designs versus exclusive designs?

The second consideration is how can we approach and investigate "affective factors". Data collection and analysis methods need to be chosen carefully in this step. The third consideration is allocation and availability of resources. If there are limited resources in a design project, optimization of controlled resources are necessary.

Considering design attribute optimization, a preferred design attribute for a quality need may interact negatively with other design attributes (Figure 5.3). This optimization problem then leads to another decision-making problem. Appropriate solutions require both justifying the levels to optimize negative interactions and the need to apply a creative problem-solving process to design a new physical attribute. Probabilistic methods such as Rough sets, Robust design, heuristic methods can be applied at this step.
Figure 5.2 Optimization dimensions for quality feelings.

Figure 5.3 Representation of possible interactions between design attributes.
5.3.3. Overall discussion of product and service quality dimensions

Research findings in this thesis show that perception of support from the product functioning, communication of product with user is important quality aspects and need to be validated through perceptual evaluations. Feedback perception can be thought as a dimension of communication. To design a competitive characteristic distinctiveness feeling need to be designed into products. Ergonomics and comfort are also important quality aspects which need to be used as perceptual evaluation dimensions for products.

Table 5.1 An overview of product quality dimensions with research findings.

<table>
<thead>
<tr>
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<th>Products (Garwin, 1984)</th>
<th>Findings from the research presented in this thesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability</td>
<td>Reliability</td>
<td>Reliability</td>
</tr>
<tr>
<td>Maintainability</td>
<td>Serviceability</td>
<td>Supportiveness</td>
</tr>
<tr>
<td>Performance</td>
<td>Performance</td>
<td>Functionality</td>
</tr>
<tr>
<td>Conformance</td>
<td>Conformance</td>
<td>Precision</td>
</tr>
<tr>
<td>Durability</td>
<td>Durability</td>
<td>Tactile feel</td>
</tr>
<tr>
<td>Appearance</td>
<td>Aesthetics</td>
<td>Attractiveness</td>
</tr>
<tr>
<td>Flawlessness</td>
<td>Perceived</td>
<td>Pleasantness</td>
</tr>
<tr>
<td>Safety</td>
<td>Safety</td>
<td>Environmental impact</td>
</tr>
<tr>
<td>•Environmental impact</td>
<td>•Ergonomics</td>
<td>•Comfort</td>
</tr>
<tr>
<td>•Empathy</td>
<td>•Communicative</td>
<td>•Empathy</td>
</tr>
<tr>
<td>•Credibility</td>
<td>•Feedback</td>
<td>•Credibility</td>
</tr>
<tr>
<td></td>
<td>•Distinctiveness</td>
<td></td>
</tr>
</tbody>
</table>

Note: Italic words are the dimensions that stand individually from each grouping of quality dimensions.
Together with interaction and environmental design features, satisfying user or customer’s feeling needs are important. As an outcome of this thesis, these quality feelings can be communicated with user or customer through affective design of environment, through interactions providing the service and after the service.

Table 5.2 shows how this thesis approached servicescape quality dimensions and which dimensions appeared as most important from those.

### Table 5.2 An overview of service and servicescape dimensions with research findings.

<table>
<thead>
<tr>
<th>Services (Zeithaml, 1990)</th>
<th>Servicescape dimensions (Rosenbaum and Massiah, 2011 see theory section)</th>
<th>Findings from the research presented in this thesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socially symbolic dimension</td>
<td>Ethnic signs/symbols/Ethnic objects/artifacts</td>
<td>Affective qualities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Relating quality (calm, relax)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pleasant quality (pleasant, comfortable, warm, home feeling, cosy, enjoying)</td>
</tr>
<tr>
<td>Natural dimension</td>
<td>Being away/Fascination/Compatibility</td>
<td>Arousing quality (fresh, bracing)</td>
</tr>
<tr>
<td>Tangibles</td>
<td>Temperature/Air quality/Noise/Music/Older/Space/Function/Layout/Equipment/Furnishings/Signs, symbols and artifacts</td>
<td>Technical qualities (Service environment)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Privacy</td>
</tr>
<tr>
<td>Reliability/Courtesy</td>
<td>Employees/Customers/Social density/Displayed emotions of others</td>
<td>Interaction qualities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Welcome</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Caring staff</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Staff give attention</td>
</tr>
<tr>
<td>Communication</td>
<td></td>
<td>Service oriented</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Confidence inspiring</td>
</tr>
</tbody>
</table>

**Note:** Italic words are the dimensions that stand individually from each grouping of quality dimensions.
6 Conclusions and further research

This chapter consists of closing comments. Finally future research issues are identified.

6.1 Conclusions

Quality is a multifaceted phenomenon. Users and customers require that quality is designed into products. Producers emphasize quality and quality feelings in product design. In parallel, researchers work continuously to test and develop methods to measure and quantify quality feelings from products to provide product design knowledge that assists producers.

Users differentiate between different quality dimensions, and show preferences for products and product variants. Interactions identified among quality feeling dimensions affect users’ evaluations of product design. Quality feelings signify different meanings for different product types. Quality feelings are not only aesthetics; they include, for example, tactile experiences, material design and ease of use.

Safety, functionality, ergonomics, comfort, reliability, supportiveness, usability, communicative, feedback, pleasantness, attractiveness, durability and distinctiveness contributed to describe quality feelings from tangible products and services. These dimensions interact with and depend on each other based on product type.

Quality feelings are associated with both tangible (e.g. tactile characteristics) and intangible (e.g. quick and easy to use) product characteristics. In work environments, products act as prostheses between workers for social interaction, which needs to be considered as an important quality feeling dimension.
In service environment design, emotional, functional and physical interactions with service providers contribute to quality feelings. Interaction quality with the service provider accommodates important design aspects. The study on waiting environments confirmed that environment design influences a patient’s perceptions of service quality, for example, negatively when seeing stressed personnel hurrying through corridors. For all types of products, substantial improvements of quality feelings are possible to obtain.

Regarding conclusions on methodology, heuristic methods were found effective when there was a high number of product attributes that interact to provide quality feelings. Applying genetic algorithms, the best design alternatives were selected from many product design alternatives. Rough Sets results were consistent with PLS attribute predictions. When the number of product attributes was large in comparison to the number of observations, PLS extracted informative results for quality feelings. The Rough Sets method was effective in identifying interactions among design attributes.

6.2 Future research

There are many important studies that need to be performed in this field. First, future research needs more effective methods for understanding user needs. The following future research studies were identified in relation to this thesis:

- In evaluation of quality feelings for comparison of existing and new products, users bring experiences, beliefs and attitudes that contribute to product evaluations. As a supportive measure, user experiences can be added as a factor in future studies. Positive and negative experiences may change the direction of evaluations. During evaluation of quality feelings for new products, trials with products over time (longitudinal studies) should be conducted, since first impressions change over time.

- For some products, e.g. fashion products, studies need to be performed repeatedly and quickly, since peoples preferences sometimes change rapidly.

- Users may be classified into smaller clusters so that individuals that present similar needs on quality feelings can be examined separately.

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- Users may be classified into smaller clusters so that individuals that present similar needs on quality feelings can be examined separately.
6.3 Recommendations to the industry

New product development

- Prototype product evaluations are important in new product development. Users need to be involved actively to provide impressions in product development project groups. Companies may involve experienced and inexperienced users from the target customer groups.

Understanding user needs regarding quality feelings:

- Product development groups need to consider the importance they attribute to evaluations of research and development products.
- Time efficiency in the chosen product evaluation and analysis methods are important to respond to, especially for short product life cycles when designing quality feelings into products.
- Different evaluation scales (e.g., JAR and Likert) need to be combined to verify quality feelings from related tangible (e.g., force level) and intangible product attributes (e.g., feedback).
- Qualitative and quantitative studies need to investigate quality feelings from products; it was observed in this thesis that they are complements.

For the service sector:

- User needs in complex service environments may be defined by applying a methodology that combines qualitative (free elicitation) and quantitative techniques (Rough Sets); concrete, effective and time efficient results may be obtained.

A research framework is needed that shows and integrates the contributions of cognitive abilities, moods and perceptions that evolve from quality feelings.
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Comparison between using spectral analysis of...


APPENDICES

Appendix A: Methods

Appendix B: Affinity diagram for quality feelings in reach truck operator cabin.

Appendix C: Suggestions for further improvements of the reach truck

Appendix D: Quality feeling questionnaire (Paper A- Part 2)

Appendix E: Quality feeling-questionnaire (Paper C)
Appendix A: Methods

Multiple Regression Analysis

Multiple linear regression (MLR) is a method of analysis for assessing the strength of the relationship between each of a set of explanatory variables (known as independent variables), and a single response (or dependent) variable (Hair et. al., 2010). The regression procedure provides five methods to select predictor variables: forward selection, backward elimination, stepwise selection, forced entry, and forced removal (Montgomery and Runger, 2003). MLR is used when exploring linear relationships between the predictor and criterion variables – that is, when the relationship follows a straight line. To examine non-linear relationships, special techniques need to be used. The criterion variable to predict should be measured on a continuous scale (such as interval or ratio scale).

MLR requires a large number of observations. The number of cases (participants) must substantially exceed the number of predictor variables you are using in your regression. The absolute minimum is that you have five times as many participants as predictor variables. A more acceptable ratio is 10:1, but some people argue that this should be as high as 40:1 for some statistical selection methods (Brace et al., 2006).

Applying MLR, to a set of data provides regression coefficients. These coefficients give the estimated change in the response variable associated with a unit change in the corresponding explanatory variable, conditional on the other explanatory variables remaining constant.

The multiple regression equation takes the form (eq 1)

\[ y = b_1x_1 + b_2x_2 + \ldots + b_nx_n + c. \]  

(eq 1)

The b's are the regression coefficients, representing the amount the dependent variable y changes when the independent changes 1 unit. They are estimated by least squares method. The c is the constant, where the regression line intercepts the y axis, representing the amount the dependent y will be when all the independent variables are 0. The standardized versions of the b coefficients are the beta weights, and the ratio of the beta coefficients is the ratio of the relative predictive power of
the independent variables. There are other regression methods called logistic, ordinal and 
the independent variables. There are other regression methods called logistic, ordinal and 
regression that can be used for dichotomous dependent variables (not covered in this thesis).

Analysis of variance (ANOVA) (Table 1) is used to uncover the main and interaction effects of 
categorical independent variables (called "factors") on interval dependent variable. The ANOVA 
test the overall significance of the regression equation model. The key statistic is the F-test of 
difference of group means; testing if the means of the groups formed by values of the independent 
variables are different enough not to have occurred by chance. If the group means do not differ significantly then it is inferred that the independent variable(s) did not have an effect on the dependent variable. If the significance of F value is below 0.05 the models for 
each step are significant (Garson, 2004). 

Table 1 ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>Degrees of Freedom</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>SS_R</td>
<td>k</td>
<td>SS_R / k</td>
<td>F_R</td>
</tr>
<tr>
<td>Error</td>
<td>SS_e</td>
<td>n - p</td>
<td>SS_e / n - p</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>SS_t</td>
<td>n - 1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total Corrected Sum of Squares (SST): Squared deviations of observations from overall averages. 
Error Sum of Squares (SSR) Squared deviations of observations from treatment averages. Treatment 
Sum of Squares (SSR) Squared deviations of treatment averages from overall average (times n)

Coefficient of Multiple Determination

$R^2$, multiple correlations, represent the percent of variance in the dependent variable explained 
collectively by all of the independent variables (Garson, 2004). The numerator gives the error sums 
of squares and the denominator gives the total variation. If $R^2$ is close to 1 then it means that the 
fitting by the regression model is good and the error is small.

$R^2 = \frac{SS_R}{SS_t}$

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fitting by the regression model is good and the error is small.

$R^2 = \frac{SS_R}{SS_t}$
Durbin-Watson test tests the assumption that the residuals in the regression analysis are independent. Residual indicates the difference between expected and obtained scores of the dependent variable for each case. The value of d, ranges from 0 to 4. Values close to 0 indicate extreme positive autocorrelation; close to 4 indicates extreme negative autocorrelation; and close to 2 indicates no serial autocorrelation.

Selection of Variables and Model Building

An important problem in application of regression analysis is selecting the set of regressor variables to be used in the model. Sometimes previous experience or underlying theoretical considerations can help the analyst specify the set or regressor variables to use in a particular situation. Usually, however, the problem consists of selecting an appropriate set of regressors from a set that quite likely includes all the important variables, but we are sure that not all these candidate regressors are necessary to adequately model the response.

All Possible Regressions

This approach requires that the analyst fit all the regression equations involving one candidate variable, all regression equations involving two candidate variables, and so on. Then these equations are evaluated according to some suitable criteria to select the "best" regression model. Hence, the number of equations to be examined increases rapidly as the number of candidate variables increases. Several criteria may be used for evaluating and comparing the different regression models obtained.

Selection upon Coefficient of Multiple Determination

A commonly used criterion is based on the value of $R^2$ or the value of the adjusted $R^2$, $R_{adj}^2$. We tried to find that the $R_{adj}^2$ will stabilize and actually begin to decrease as the number of variables in the model increases. The model that maximizes the $R_{adj}^2$ value also minimizes the mean square error, so this is a very attractive criterion (Montgomery and Runger, 2003).

$$R_{adj}^2 = 1 - \frac{\text{SSE}}{\text{SST}} \left( 1 - \frac{n}{n-k-1} \right)$$

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$$R_{adj}^2 = 1 - \frac{\text{SSE}}{\text{SST}} \left( 1 - \frac{n}{n-k-1} \right)$$
Evaluating regression models according to Cp statistic

Another criterion used to evaluate regression models is the Cp statistic, which is a measure of the total mean square error for the regression model. We choose as the "best" regression equation either a model with minimum Cp or a model with a slightly larger Cp, that does not contain as much bias (Montgomery and Runger, 2003).

\[ C_p = \frac{SSE}{SSE_0} + 2\frac{p(p+1)}{n} \]

\[ C_p \geq \text{min} \left\{ C_p \mid p=1,2,\ldots,k \right\} \]

Using PRESS statistic

PRESS is an acronym for Prediction Error Sum of Squares, and it is defined as the sum of the squares of the differences between each observation \( y_i \) and the corresponding predicted value based on a model fit to the remaining \( n-1 \) points. PRESS provides a measure of how well the model is likely to perform when predicting new data or data that was not used to fit the regression model (Montgomery and Runger, 2003). Thus PRESS is easy to calculate from the standard least squares regression results. Models that have small values of PRESS are preferred.

\[ \text{PRESS}_p = \frac{SS_{E_p}}{n-k-1} \]

\[ \text{PRESS}_p \leq \text{min} \left\{ \text{PRESS}_p \mid p=1,2,\ldots,k \right\} \]

The final model obtained from any model-building procedure should be subjected to the usual adequacy checks, such as residual analysis, lack-of-fit testing, and examination of the effects of influential points. The analyst may also consider augmenting the original set of candidate variables with cross-products, polynomial terms, or other transformations of the original variables that might improve the model.

In multiple linear regression problems, certain tests of hypotheses about the model parameters are useful in measuring model adequacy. In this section, we describe several important hypothesis testing procedures. As in the simple linear regression case, hypothesis testing requires that the error terms in the regression model are normally and independently distributed with mean zero and variance value.
Test for Significance of Regression

The test for significance of regression is a test to determine whether a linear relationship exists between the response variable $y$ and a subset of the regressor variables $x_1, x_2, \ldots, x_k$.

$H_0: \beta_1 = \beta_2 = \cdots = \beta_k = 0 \rightarrow$ Model

$H_1: \beta_j \neq 0$ for at least one $j$

Test Statistic:

$$F = \frac{MSR}{MSE}$$

$F_k; n-k-1$

Significance level $\alpha = 0.05$

$H_0$ hypothesis is rejected if the computed value of $F$ statistic $> F_{\alpha, k, n-k-1}$ Rejection of implies that at least one of the regressor variables $x_1, x_2, \ldots, x_k$ contributes significantly to the model.

Tests on Individual Regression Coefficients and Subsets of Coefficients

We tested hypotheses on the individual regression coefficients to determine the potential value of each of the regressor variables in the regression model. For example, the model might be more effective with the inclusion of additional variables or perhaps with the deletion of one or more of the regressors presently in the model (Montgomery and Runger, 2003). Adding a variable to a regression model always causes the sum of squares for regression to increase and the error sum of squares to decrease (this is why $R^2$ always increases when a variable is added) (Montgomery and Runger, 2003). We must decide whether the increase in the regression sum of squares is large enough to justify using the additional variable in the model (Montgomery and Runger, 2003). Furthermore, adding an unimportant variable to the model can actually increase the error mean square, indicating that adding such a variable has actually made the model a poorer fit to the data (this is why $R^2_{adj}$ is a better measure of global model fit than the ordinary $R^2$) (Montgomery and Runger, 2003). The hypotheses for testing the significance of any individual regression coefficient, $H_0: \beta_j = 0$

$H_1: \beta_j \neq 0$ for at least one $j$

Test Statistic:

$$F = \frac{MSR}{MSE}$$

$F_j; n-k-1$

Significance level $\alpha = 0.05$

$H_0$ hypothesis is rejected if the computed value of $F$ statistic $> F_{\alpha, j, n-k-1}$ Rejection of implies that at least one of the regressor variables $x_1, x_2, \ldots, x_k$ contributes significantly to the model.
The null hypothesis $H_0: \beta_j = 0$ is rejected if $t_j \leq t_{\alpha/2,k-n-1}$ or $t_j \geq t_{1-\alpha/2,k-n-1}$. This is called a partial or marginal test because the regression coefficient depends on all the other regressor variables that are in the model (Montgomery and Runger, 2003).

**Multicollinearity**

In multiple regression problems, we expect to find dependencies between the response variable $Y$ and the regressors $x_j$. In most regression problems, however, we find that there are also dependencies among the regressor variables $x_j$. In situations where these dependencies are strong, we say that multicollinearity exists. Multicollinearity can have serious effects on the estimates of the regression coefficients and on the general applicability of the estimated model. These factors are an important measure of the extent to which multicollinearity is present (Montgomery and Runger, 2003).

\[ \text{VIF}(\beta_j) = \frac{1}{1-R_j^2} \quad j=1,2,...,k \]

**Partial Least Square Regression**

Unlike MLR which is based on the assumption of independence of the $X$-variables, PLS assumes just a linear relation between $X$ and $Y$ (Abdi, 2003). Moreover, PLS assumes that $X$ and $Y$ are manifestations of the same set of underlying, latent variables (LVs), that is, the $X$ and $Y$ variables are related to each other via these LVs (Wold et al., 1984). Partial least squares (PLS) works by extracting one factor at a time. Below PLS regression steps were given based on algorithm in JMP software (SAS Institute Inc. 2009):

Let $X = X_0$ be the centered and scaled matrix of predictors and $Y = Y_0$ the centered and scaled matrix of response values.

The PLS method starts with a linear combination $t = Xw$ of the predictors, where $t$ is called a score vector and $w$ is its associated weight vector. The PLS method predicts both $X_0$ and $Y_0$ by regression on $t$.

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The evaluation scores on 5 degree scales were classified on a = Y

The vectors p' and c' are called the X- and Y-loadings, respectively.

For validation of PLS regression models the interpretation of the latent variables is often helped by examining graphs akin to pca graphs (e.g., by plotting observations in a t1 × t2 space) (Abdi, 2003). Comparison of PLS with ridge regression and principal components regression see in (Wold et al., 1984).

Theoretical Structure of Rough Set Theory

Data are presented as a decision table, columns of which are labeled by attributes and rows by objects, whereas entries of the tables are attributes values. Attributes are distinguished into two classes, called condition and decision attributes. This approach assumes that decision classes of human evaluation are assumed to occur with different prior probabilities. One is the probability P(Y|Ei) of decisions dependent on the attributes of product Ei and the other is the prior probability P(Y) of decision class Y.

In trigger design study trigger attribute set is defined as [F1, F2,..,Ft] and rows by objects, whereas entries of the tables are attributes values. Attributes are distinguished into two classes, called condition and decision attributes. This approach assumes that decision classes of human evaluation are assumed to occur with different prior probabilities. One is the probability P(Y|Ei) of decisions dependent on the attributes of product Ei and the other is the prior probability P(Y) of decision class Y.

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into two decision classes \(D = \{0, 1\}\) which is not distinct and distinct. Evaluation scores \(3, 4, 5\) were classified as e.g. ‘distinct’ \(1\) and \(1,2\) as ‘not distinct’ \(0\).

Nishino et al., (2007) describes information gain of \(Ei\) with \(P\{Y|Ei\}\) \(P\{Y\}\) denoted as

\[
g_{\text{info}}(Y) = \frac{H(Ei) - H(Ei|Y)}{H(Ei|Y)},
\]

\(0 < \beta < 0.5\) means that the larger the conditional probability relative to prior probability is, the larger

the information gain is.

The positive region by using the information gain with the attribute \(\beta\) (error tolerance level) \(0 < \beta < 0.5\) is defined as

\[
\text{POS}(Y) = \{x \in Ei : \text{gain}(Ei, \beta) > \beta\}
\]

which means the region that \(Ei\) belongs possibly to \(Y\) with \(\beta\). We call \(\text{POS}(Y)\) as \(\beta\)-lower (upper-lower) positive approximation of \(Y\).

\[
\text{NEG}(Y) = \{x \in Ei : \text{gain}(Ei, \beta) < \beta\}
\]

which means the region that \(Ei\) does not belong possibly to \(Y\) with \(\beta\). \(\text{NEG}(Y)\) and \(\text{BND}(Y)\) are \(\beta\)-lower (upper-lower) positive approximation of \(Y\).

In addition, we can define:

\[
\text{UPP}(Y) = \{x \in Ei : \text{gain}(Ei, \beta) > \beta\}
\]

which means the positive region by using the information gain with the attribute \(\beta\) \(0 < \beta < 0.5\) is defined as

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\[
\text{BND}(Y) = \{x \in Ei : \text{gain}(Ei, \beta) < \beta\}
\]

which means the region that \(Ei\) does not belong possibly to \(Y\) with \(\beta\). \(\text{BND}(Y)\) and \(\text{POS}(Y)\) are \(\beta\)-lower (upper-lower) positive approximation of \(Y\).

In order to compute decision rules of these approximated decision classes, we will use a discernibility matrix which means m \(m\) matrix, rows of which are product set \(Ei\) \(i=1,\ldots,m\) belonging to approximated decision class (for example \(\text{POS}\) class), and columns are product set \(Ej\) \(j=1,\ldots,n\) belonging to the other approximated class (for example, \(\text{NEG}\) and \(\text{BND}\) classes). In this case, the decision rules of \(\text{POS}\) class will be extracted.

Evaluation Measures of Decision Rules

Discernible entry elements in the matrix are as follows: The entry is the set of all attribute-attribute value pairs that discern product set \(Ei\) and \(Ej\). Thus, the discernibility matrix image with respect to \(\text{POS}\) class is shown in Table 2.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|}
\hline
\text{POS} & \text{NEG} \\
\hline
\text{UPP} & \text{POS} \\
\hline
\text{BND} & \text{NEG} \\
\hline
\end{tabular}
\caption{An example of discernibility matrix}
\label{tab:example}
\end{table}
Table 2. An example of discernibility matrix

<table>
<thead>
<tr>
<th>A_1</th>
<th>A_2</th>
<th>A_3</th>
</tr>
</thead>
<tbody>
<tr>
<td>E_4</td>
<td>E_5</td>
<td>E_6</td>
</tr>
</tbody>
</table>

We can derive decision rules by decision functions from approximation regions as follows:

\[ f^{-1}(A) = \forall \exists \cdot \bigvee (E, E) \]

where \( \forall \exists \cdot \bigvee (E, E) \) and \( \land \) denote Boolean "or" and "and" respectively. Extracted decision rule is denoted as IF \( \rightarrow \) THEN \( \rightarrow \). Then, we define the following measures for decision rule where \( || \cdot || \) is cardinality. This measure indicates the number of events satisfied with decision rules.

\[ \text{Supp}(\Phi, \Psi) = || \Phi \cdot \Psi || \]

Three important measures for validity; Strength(Str), Certainty(Cer), and Coverage(Cov) of RS were explained below. Strength of each decision rule explains that stronger rule will cover more objects. Certainty (Cer) (correctness) indicates the extent to which if its conditions are satisfied, decision can be derived. Inversely, Coverage(generality) indicates the extent to which if its decision is satisfied, condition can be derived.

\[ \text{Supp}(\Phi, \Psi) \]

\[ \text{Str} = \frac{|| \Phi \cdot \Psi ||}{|| \Phi ||} \]

\[ \text{Cer} = \frac{|| \Phi \cdot \Psi ||}{|| \Psi ||} \]

\[ \text{Cov} = \frac{|| \Phi \cdot \Psi ||}{|| \Phi \cdot \Psi ||} \]
Appendix B: Affinity diagram for quality feelings in reach truck operator cabin.

<table>
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<tr>
<th>INTELLIGENCE</th>
<th>COSTS</th>
<th>LIGHT</th>
<th>DESIGN</th>
<th>TRENDY</th>
<th>ENERGY</th>
<th>IMPRESSION</th>
<th>DEVELOPED</th>
<th>MOVEMENT</th>
</tr>
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<tbody>
<tr>
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Appendix C: Questionnaire (Paper I- Part 2)

1. How do you rate your quality feeling of these components in the reach truck cabin?

- **Steering Wheel**: None
- **Electronic Hyd. Controls**: None
- **Driver's seat**: None
- **Truck's pedals**: None
- **Control Console**: None
- **Dashboard**: None
- **Overhead guard**: None
- **Interior Cabin Surfaces**: None

2. Please rate your total quality feeling about the interior cabin?

- a) None
- b) Please explain which aspects about the components affected your quality feeling:
  - Design:
  - Size:
  - Shape:
  - Color:
  - Look:
  - Style:
  - Material/Texture:
  - Layout:
  - Information:

3. How can the quality feeling be improved in the interior cabin of the fork-lift truck?
Appendix D: Suggestions for further improvements of the reach truck

According to qualitative responses, the design attributes and improvements for design of the reach truck, in general, and specific improvements and the quality perceptions of cabin components were discussed below. The pictures of the study object and the interior cabin components are shown in Figure A.1.

The cabin’s interior design looks traditional. Reducing the industrial feel and designing it like a car’s interior offers the feeling of fun to drive. Angular and round designs are used in the cabin, which are preferred by most of the participants; softly rounded forms are desired. Component designs need to be proportional to give a more substantial feeling. The pedals and driver’s seat can be designed more suitable for the human form. Spacious design is necessary, in general. The steering wheel should be more stable and robust; some parts can be changed to metal to offer a more robust feeling. For left-handed people, an armrest while using the steering wheel is needed. The electronic hydraulic controls could have better form and design; they have the same design for each direction, and to give a more robust feeling, they can be replaced with a joystick. The driver’s seat was difficult to adjust; it should be adjustable electronically. The material used in the seat was nice to touch; however, it makes the person feel like it absorbs dust. The pedals are not the same shape and size, which are perceived as low quality. Besides less plastic, sounds are expected from the pedals. They should be designed to give more feedback when used. The control console was hard to adjust; its material is too plastic and light, which gives it a feeling like of toy. Adjustment of the control console should be changed according to clock directions to remove when getting out of the truck. The dashboard layout seems too simple and is lower quality. Improving dashboard layout and controls offers a feeling of being more powerful. It was difficult to reach the dashboard through the control console. The display on the dashboard was difficult to see through the control console; its position should be changed to another part of the dashboard to make it easier to see. Nicer material should be used for the dashboard. The buttons look old and give a loose feeling; they should be designed with lights showing that they are activated. The designs of the buttons are varied; a consistent design should offer a quality feeling. Fewer “plastic” sounds from the controls and buttons are preferred; they should be designed with more symbols to give information about the buttons’ functions. The design is too plastic for the buttons. Color changes to some buttons would make them easier to recognize. Fewer buttons are preferred; some multifunction buttons should be designed; they

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should be designed bigger to offer a more reliable feeling. The emergency button was perceived as distant and not easily accessible for emergency situations; it should be placed on the control console. For improvement of the interior cabin, unexpected and attractive quality features should be added to delight the driver. For example, some controls should be placed on the steering wheel.

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**Figure A.1** Study object reach truck and its components in Paper A.
Appendix E: Questionnaire (Paper III)

1. What would you like to do while you are waiting?

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2. Which things are important for you while waiting?

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3. What would you like to have while you wait?

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4. What would you dislike while you wait in the waiting area?

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5. How do you feel in the waiting area?

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6. What important feelings would you like to get from a waiting area?

7. Try to think how do you relate your important feelings to design features in a waiting area?

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<th>Design Parameter 3</th>
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Feeling: [ ]
Design Parameter 1: [ ]
Design Parameter 2: [ ]
Design Parameter 3: [ ]
8. Can you describe how does your dream waiting room look like?
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Comments.............................................................................................................................
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Demographic Information
Gender: ♂ M
♀ K
How old are you? ......