Design Parameter Shift Evaluation

Development and Evaluation of a Method to Improve Design Predictability in the Automotive Context
Design Parameter Shift Evaluation

Development and Evaluation of a Method to Improve Design Predictability in the Automotive Context

PROEFSCHRIFT

ter verkrijging van de graad van doctor aan de Technische Universiteit Eindhoven, op gezag van de Rector Magnificus, prof.dr.ir. C.J. van Duijn, voor een commissie aangewezen door het College voor Promoties in het openbaar te verdedigen op donderdag 18 september 2008 om 16.00 uur

door

Julian Eichhorn

geboren te Stade, Duitsland
Dit proefschrift is goedgekeurd door de promotoren:

prof.dr.ir. L.M.G. Feijs
en
prof.dr. C.J. Overbeeke

Copromotor:
dr.ir. S.A.G. Wensveen
Clichés tell that research is conducted in ivory towers by wacky scientists surrounded by bizarre equipment. My personal experience in the past 3 years tells different. Research requires distinctive teamwork and unfolds, next to research results, congenial acquaintance and close friendship. I would like to devote the following lines to express my sincere gratitude to people who contributed to this thesis in manifold ways.

First and foremost, I would like to express my sincere gratitude towards the members of the Industrial Design Department of the Eindhoven Technical University for their professional supervision and cordial support. Stephan Wensveen, it is luck to have someone as you as the daily supervisor. Thank you for the collegiate time with candid expertly support, your persuasiveness, patience and friendship. Next to the department, I would like to thank Dik Hermes for your friendly and enduring help at all times in psycho-acoustics. You provided fascinating information about it in musical context and shared a lot of your time. Philip Ross, thank you for your friendly lessons in Max/MSP and showing your bright and highly creative design approaches and designs to me. I really enjoyed the two PDC field tests and our conversations. I am much obliged that you agreed to be my paranimf. This research was conducted within and also for the BMW Group Design. Cordial thanks to Christopher Bangle for your advice and direct feedbacks, brilliant impulses and the food for thought. I appreciate the value of the time and knowledge you shared.

Sabine Zemelka, I am much obliged you committed this subject for my dissertation. Thank you also for our controversial and helpful discussions. I enjoyed your efficient, earnest and similarly pleasant communication.

I would like to thank Bernhard Krebs for your enduring support and for assigning challenging projects to me and leaving enough space to do the necessary research. Wolfgang Vollath, you contributed to my understanding of business with your helpful counsels. Thank you for your knowledge, your straight honesty and directness during and after the time at your department.

Jeffrey Hands, you helped moving doors which are quite heavy (and some that are difficult to see). I really enjoyed the time at your department before backsliding into this research excursion. I am grateful for the profound and supporting knowledge you shared at all times. Thank you for the great music, the coffee mugs and for lending your ear.

Cordial thanks to Gerhard Roth at the Hanse Institute for Advanced Study for your time and highly prized knowledge you shared within our dialogues. I would like to thank Peter König at the Osnabrück University – Institute of Cognitive Sciences for your time, knowledge and friendly help with statistical analyses.

This thesis would not have been possible without the enduring contribution from my partner Annika, my immediate family and friends throughout the years. I am grateful for all minor and major support in form and content discussion as well as personal motivation and aid. The latter often consisted in your company and partnership, your altruistic patience and love. Andreas, thank you for imprinting your free thinking and for being my sturdy paranimf.

I express my sincere gratitude to my parents to whom this thesis is dedicated: You provided the fundamental equipment that afforded the way to this thesis (you know what this includes).
Preamble

It has long been a goal of design management to reduce the unknowns in the creative process as far as possible, to go straight to the heart of the matter regarding the objectives of Commercial Industrial Design; that is, to motivate real people in a real world to spend their resources on said designs and use and enjoy them as the designers intended. There are many who believe that this causal clarity can never be extrapolated from experimental data in parallel (but not identical) contexts, but I think that the potential of linking the tools of production to the grounded research of objective-subjective relationships is too important to ignore. It takes a bold researcher to immerse himself in the creative breeding ground of a design studio, full of intuitive driven designers, and apply statistical expertise to refined subjective decision making, but that is what good Dogma-Free design management should promote. As in all that challenges our established methodologies, there is much to be learned and improved upon.

This body of research reveals that limitations do indeed exist in the quest to link a physical design to a subjective response (or the other way round) in a calculated, predictable fashion. Nevertheless, it provides a strong basis in its approach to analyze and explain the dependencies seen between the designed object and the invoked reaction and begins to answer some of the why, where and how questions in understanding design perception.

Christopher E. Bangle
Munich, September 2007
Even Clerk Maxwell, who wanted nothing more than to know the relation between thoughts and the molecular motions of the brain, cut short his query with the memorable phrase, “but does not the way to it lie through the very den of the metaphysician, strewn with the bones of former explorers and abhorred by every man of science?”

Let us peacefully answer the first half of his question “Yes”, the second half “No” and then proceed serenely. Our adventure is actually a great heresy. We are about to conceive the knower as a computing machine.

From Warren McCulloch’s paper
“What’s in the Brain That Ink May Character” (McCulloch, 1965)
1. Introduction
1.1 Overview of this Thesis

This doctoral thesis documents the result of an approximately 3 year research program carried out at BMW Group Design in Munich, Germany and the Department of Industrial Design (Designing Quality in Interaction) at the Technische Universiteit Eindhoven, The Netherlands.

My research designation and motivation is to provide the consumer product industry, especially the automotive industry with a holistic method to evaluate and consolidate subjectively perceived product attributes and qualities – such as the perceived design effect, the product character, gesture, aesthetic appearance or stance – among all involved departments and process partners when planning and developing a product.

My research result is the innovative Design Parameter Shift Evaluation (DPSE): By parameterization and interpolation of design aspects and the mapping of subjectively perceived attributes, the design and its effect can be planned and done more intentionally, efficiently and reliably.

Since opinions and other subjective issues are difficult to measure (they are always correlated, never absolutely linkable to physical stimuli), this thesis also explores the task immanent limitations of the attempt of forecasting the future product design impact into the market by giving insight into the background of product perception. Both the design process and the design perception are non-mechanistic but rather emergent processes, so the design effect of a product is predictable only with probabilistic and not with deterministic methods. The DPSE approach evidentially provides effective operation. Nevertheless, the complexity and fragility of the analysis increase with the targeted analysis “granularity” and the complexity of the object or product, which makes it difficult to apply to daily design business to full extent, (i.e. finest analysis granularity applied on the whole automobile).

However, incorporating and respecting the principles of product perception and the DPSE method both described in this thesis into the product development processes supports addressing the targeted customer on the appropriate subjective level. Therefore it helps reducing the risk of a product missing the challenging demands of the present-day market.

The thesis is subdivided into seven main chapters.

- The first chapter provides the introduction.
- The second – more theoretical – chapter points out those circumstances within product development and design perception that have a major influence upon the target-oriented method structure.
- The third chapter provides an overview of existing methods having similar targets.
- Within the fourth chapter, the innovative and novel Design Parameter Shift Evaluation method (DPSE) is developed starting from the conclusions of the previous chapters.
- Subsequently, the fifth and sixth experimental chapters demonstrate and discuss the functioning by means of two exemplary elements from automotive exterior and interior. The first example concerns the product character induced by the headlamp’s facial expression and the second example concerns the acoustic man-machine-interface of the PDC (Parking Distance Control).
- Finally, the conclusions of this research are drawn in chapter seven.
1.2 Definition of Terms

Since this dissertation deals with content that has its roots in several branches of science or that is usual within automotive design department, central terms should be defined in this early place to ensure a common understanding while reading. Although all terms deserve more detailed discussion, they are treated only briefly to limit the scope of this chapter.

Automotive Body Language

Since products, especially automobiles, often are personated, they display a body language similar to persons or animals. This body language includes stance, gesture or facial expression and consists out of metaphorical or semiotic design aspects that communicate an inner attitude or (impending) action. It reflects or emphasizes the product’s real capabilities. The stance of an automobile describes how it stands on its wheels from front or rear view. The gesture describes whether the automobile is, for example, crouching tensely upon the street or wafting over it, mostly from side view. The exterior proportions, the surface language or the graphic details of an automobile design can, for example, visualize a product’s inner physical or mental tension, and reflect or emphasize its real capabilities (Jeffrey Hands, personal communication, September 2007). According to Feijs & Meinel (2005), a designer has to be capable of designing these messages and forms to express semiotic signs within the design.

Character

The term character originates from Greek (характер) and denoted an embossed pattern (e.g. on coins). In the figurative sense, character denotes the distinctive and recognizable recognition features of persons and artifacts, exacting (Meyers Lexikonverlag: Charakter, 1979):

1) The recognition features of complex artifacts (e.g. music genre, landscape, architecture etc). This definition stands in direct context with this thesis.
2) In psychology, character is the structural arrangement of inherited disposition and acquired attitudes and ambitions which appears outwards as relatively constant behavior patterns. Character determines the individual peculiarity of people. This definition stands in indirect context with this thesis under the aspect that products are personated.

Design

The International Council of Societies of Industrial Design (ICSID, 2007) defines that “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. Therefore, design is the central factor of innovative humanization of technologies and the crucial factor of cultural and economic exchange. Design seeks to discover and assess structural, organizational, functional, expressive and economic relationships, with the task of:

- Enhancing global sustainability and environmental protection (global ethics)
- Giving benefits and freedom to the entire human community, individual and collective final users, producers and market protagonists (social ethics)
- Supporting cultural diversity despite the globalization of the world (cultural ethics)
- Giving products, services and systems, those forms that are expressive of (semiology) and coherent with (aesthetics) their proper complexity.
Design concerns products, services and systems conceived with tools, organizations and logic introduced by industrialization - not just when produced by serial processes. The adjective “industrial” put to design must be related to the term industry or in its meaning of sector of production or in its ancient meaning of “industrious activity”. Thus, design is an activity involving a wide spectrum of professions in which products, services, graphics, interiors and architecture all take part. Together, these activities should further enhance - in a choral way with other related professions - the value of life. Therefore, the term designer refers to an individual who practices an intellectual profession, and not simply a trade or a service for enterprises.”

According to the online encyclopedia Wikipedia (Wikipedia: Design, 2007) “Design – usually considered in the context of the applied arts, engineering, architecture, and other such creative endeavors – is used both as a noun and a verb. As a verb, “to design” refers to the process of originating and developing a plan for a product, structure, or component. As a noun, ”a design” is used for either the final (solution) plan (e.g. proposal, drawing, model, description) or the result of implementing that plan (e.g. object produced, result of the process). More recently, processes (in general) have also been treated as products of design, giving new meaning to the term “process design”. Designing normally requires a designer considering aesthetic, functional, socio-cultural and other aspects of an object or process, which usually requires considerable research, thought, modeling, interactive adjustment, and re-design.”

Architect, designer and design manager Marzano (1993) states that “Design is a political act. Every time we design a product we are making a statement about the direction the world will move in.”

**Design Effect**

The term design effect describes the holistic influence that a designed object, mostly a product, has upon the perception of an individual viewer or upon the society that is confronted with the product. The influence ranges from varied positive or negative emotions towards the product or the ascription of character attributes to the product. Ultimately, this is influencing the individual purchasing decision itself, creating phenomena like a “hype” resulting in product success – or failure.

**Determinism**

Determinism is the doctrine that all occurrences are clearly determined through causes and every prospective event is determined by previous events. Within the field of physics, determinism originates from natural philosophy associated with classical mechanic. In the interpretation of quantum mechanics, determinism is put into question by Bohr, Heisenberg and von Weizsäcker. Deterministic models in the fields of anthropology, ethics, political and history philosophy exclude free will (Meyers Lexikon: Determinismus, 2007).

**Mechanism**

Next to the technological Mechanism, e.g. in a gearbox, Mechanism is also a doctrine of natural philosophy which describes that the setup of the universe and all natural events are subjected to mechanic laws and regularities. In its extreme forms, mechanism does not only concern inorganic and physical occurrences but also includes phenomena of life (mechanistic world view). Against mythic thinking and its explanatory models, early Greek Philosophy (Empedocles, Democritus) tried to explain the origination and movement of cosmic processes by means of
mechanism. In modern times, Descartes evolved his mechanistic world view, where all material processes are caused by forces and impacts and are subjected to mathematical laws. Hobbes broadened the focus of mechanism to mental phenomena like thinking and cognition (Meyers Lexikonverlag: Mechanismus, 2007).

Thus, apart from philosophical and ethical issues, the designer’s creative process is not dealt with as a mechanism since it is extremely complex and we do not have enough insight into designer’s internal working.

**Objectivity**

A characteristic of events, assertions or attitudes which particularly expresses independence from individual circumstances, historical coincidence or involved persons. Objectivity is often determined as an agreement of a thing under exclusion of all subjective influences. The “objective judgment” in the sense of a factual and value-free is the paradigm of a scientific assertion (Meyers Lexikonverlag: Objektivität, 1979).

**Perception**

Perception is a psycho-physical process, in which an organism develops an ostensive representation of its own body and environment according to internal and external stimuli. The field of philosophy deals with perception as one of the fundamental principles of human cognizance. Perception psychology investigates the underlying information processing and neurophysiology investigates the underlying organic principles of perception (Meyers Lexikonverlag: Wahrnehmung, 2007).

Gibson’s (1979) ecological approach to perception diverges from the conventional approach of perception. Gibson accentuates the environmental information available in extended spatial and temporal pattern in optic arrays (the “scene” we see), for controlling the behaviors of animals (and human beings).

Arnheim (1954) states: “What a person perceives is not only an arrangement of objects, colors, shapes, movements and sizes, but, perhaps first of all, interplay of directed tensions. The latter are inherent in any percept. Because they have magnitude and direction they are called psychological forces.”

**Probabilism**

Within epistemology and science philosophy, probabilism is the conception wherein no absolutely true, but only likely or probable propositions exist. Concerning quantum physics, probabilism means that certain occurrences are only predictable with probability (Meyers Lexikonverlag: Probabilismus, 2007).

**Subjectivity**

Subjectivity originates from Latin and is 1) an attribute of assertions, judgments, attitudes and value or action orientations. This attribute is dependant from the recognizing, asserting and judging subject and 2) the resulting subject’s validity including its non-verifiability (Meyers Lexikonverlag: Subjektivität, 1979).

According to the online encyclopedia Wikipedia (Wikipedia: Subjectivity, 2007), “subjectivity refers to the property of perceptions, arguments, and language as being based on a person’s point of view, and hence influenced
in accordance with a particular bias. Its opposite property is objectivity, which refers to observations based in a separate, distant, and unbiased point of view, such that concepts discussed are treated as objects. In philosophy, subjectivity refers to the specific discerning interpretations of any aspect of experiences. They are unique to the person experiencing them, the qualia that are only available to that person's consciousness. Though certain parts of experience are objective and available to everyone, (such as the wavelength of a specific beam of light), others are only available to the person experiencing them (the quality of the color itself).”
2. Chapter: Motivation, Background & Research Approach
2.1 Motivation

The motivation to conduct this research mainly roots in the field of business economics, product marketing and design management. Amongst others, their targets are to optimize the product development and production costs and to maximize profit by placing the right product into the right market. But also from design view it is desirable to detect the interdependencies between the physical design parameters and their effect upon the viewer or user in order to design the parameters intentionally. Obviously, this research is interdisciplinary and should illuminate important touch points and overlapping with various fields of research. Therefore, this chapter is not treated within the introduction since it is not just a starting point but provides detailed information about circumstances within study relevant fields.

However, design is the core field of this research and therefore this research is called a designer's approach, in the sense that the research is done through an Industrial Designer within a design department where broad design and design management expertise was considered with the development and experimental application of the method. This research also considers and respects the requirements of design processes with all its creative, resourceful and inventive aspects.

2.1.1 Action Research

Traditional Sciences, Engineering Sciences and the Design Process can be attached to different categories of research. According to Archer (1995), several distinctive categories of research are recognized; they are distinguished by their intentionality. Archer describes the following accepted categories, quoted in the following:

(i) Fundamental Research: Systematic enquiry directed towards the acquisition of new knowledge, without any particular useful application in view.

(ii) Strategic Research: Systematic enquiry calculated to fill gaps in Fundamental Research and/or to narrow the gap between Fundamental Research and possible useful application.

(iii) Applied Research: Systematic enquiry directed towards the acquisition, conversion or extension of knowledge for use in particular applications.

(iv) Action Research: Systematic investigation through practical Action calculated to devise or test new information, ideas, forms or procedures and to produce communicable knowledge.

(v) Option Research: Systematic enquiry directed towards the acquisition of information calculated to provide grounds for decision or Action.

In the following, the fields of traditional science, engineering and design will be compared according to Bartneck & Rauterberg (2007). The scientist's ambition is to analyze conditions in order to explain them by means of models. These models have either to be logically or experimentally approved or falsified. The knowledge generated thereby is explicit.

However, the engineer's ambition is different. Here, the impellent ambition is to change conditions. This is achieved through condition analysis to obtain models that allow specific Actions in order to change these conditions (iteratively). These models do not necessarily need to be completely scientifically approved or falsified as long as they support the targeted change. Like in science, engineering mainly deals with explicit knowledge.
Finally, also the designer's ambition is to change conditions through targeted Actions; the difference is concerning the kind of knowledge, which is often implicit. This is summarized in Table 2.1.

Table 2.1: Comparison of Science, Engineering and Design.

<table>
<thead>
<tr>
<th>Field</th>
<th>Science</th>
<th>Engineering</th>
<th>Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambition</td>
<td>explain the world</td>
<td>change the world</td>
<td>change the world</td>
</tr>
<tr>
<td>Knowledge</td>
<td>explicit</td>
<td>explicit</td>
<td>implicit</td>
</tr>
<tr>
<td>Procedure</td>
<td>analysis</td>
<td>model</td>
<td>influence (Action)</td>
</tr>
<tr>
<td></td>
<td>model</td>
<td>influence (Action)</td>
<td>change</td>
</tr>
</tbody>
</table>

The work described in this thesis resides in the intersection of engineering and design. Referring to Archer’s categories, the work is best classified as Action Research, since it is calculated to provide a method applicable to solve conflicts that are inherent to industrial product development. Action Research is becoming an accepted approach in the design community (Swann, 2002). Swann discusses Action Research in design in a historical context, distinguishing three eras:

1. Pioneering era (of e.g. Bauhaus, Peter Behrens, Raymond Loewy)
2. Design as a distinguished profession
3. Design as a discipline

Swann explains how there has been a belief that research in design should be founded in scientific objectivity and a positivist approach, but as Swann puts it: “Design is for human consumption and not bounded by the quantifiable ‘certainties’ of the physical world. Of course, material technology plays an important part in building and mass production. However, it is the end usage of a designed product that belongs in the social science world. Design deals in human interactions with artefacts and situations that contain a great deal of uncertainty.”

Swann defines Action Research as arising from a problem, dilemma or ambiguity in the situation in which practitioners find themselves. In this thesis, the practitioners are BMW employees in an industrial setting involved in product development. Action Research is done at two levels:

- **Process Level:** In this thesis a change is proposed to the design process itself. The process is analyzed and (partially) modeled and a specific modification is suggested. In an industrial setting it is out of the question to completely restructure the development process, since this is too complex and risky. Instead, the existing process (see section 2.2.2 to 2.2.4) is kept in place, but if necessary, a new parallel DPSE process track is added and connected to the product development process (see Figure 2.1).
Product Level: At the abovementioned connections, specific changes to a specific product configuration are proposed. In Chapter 5 the Action Research is about the headlamps’ facial expression. In Chapter 6 the Action Research is about the acoustic interface of the Park Distance Control. Here, analysis and modeling take place, not with the goal of getting complete knowledge and “eternal truth” about design parameters but to provide a transparent decision basis for change. Unavoidably, this involves inductive steps but in Chapters 5 and 6 it is tried to make at least the underlying assumptions explicit.

2.1.2 Product Purchasing Triggers
Desmet (2002) states that all products affect the consumer by evoking emotional responses interconnected with personal needs, concerns and dreams. According to Aaker (1999) several marketing studies have shown that consumers prefer self-congruent brands and products. Therefore, by predefining a brand personality and product personality, which is similar to the consumer’s personality, a designer is able to stimulate a product relation between the target group and the product or brand.

With today’s products that technically become increasingly homogeneous, it is known that this intended emotional product relation is a major purchasing trigger. This trigger mostly is marked by subjectively and unconsciously perceived criteria. Neuro-scientist Roth (2007) mentions that about 90% of human perception and information processing, therefore purchasing decisions as well, happens unconsciously (Gerhard Roth, personal communication, July 05, 2007).

Buck & Vogt (1996) also share the opinion that these subjective and immeasurable design factors have authoritative influence on the perceived product qualities – not only in the sense of product “workmanship” but in the sense of product “attributes”. Therefore these subjective factors have increasing influence on consumer behavior.

Buck & Vogt (1996) define: Product quality always means quality from customer view. These contexts make clear that image and design oriented aspects have to be considered to determine product quality. This means that quality is not only defined through objective parameters but arises through subjective evaluation.

This subjective evaluation is only possible on a level of perceivable and communicable design. It is a design management task to analyze these contexts and to manage them in practice.

2.1.3 Automotive Context
Many products, especially automobiles, directly exude a character more or less similar to a living being or indirectly by allowing associations to established socio-cultural aspects. Automobiles reflect status, lifestyle, social and intellectual affiliation. They are able not only to fulfill people’s needs but also their wants and wishes.

Desmet, Hekkert & Hillen (2004) state that these psychological and socio-cultural features directly contribute to our perception, preferences and our general well-being. Saatweber (1997) writes that, nowadays, 70% of all products flop when launched into the market. Successful companies cannot take such high risks.
Keeping in mind that the development costs of a luxury premium automobile lies in dimensions up to a billion Euros and that the automotive industry is one of the key industries in Germany and other countries, potential deficits in this field have to be ruled out already within the product development process. From this view, an automobile is a relevant object for this doctoral research.

2.2 Background

2.2.1 Business Economical Approach

From the view of business economics, there is a significant demand for transparency and standardization in all partitions of the complex product development process, thus as well in the design process. In a highly competitive and global market one apparent reason is the need to substantiate and to assure the right design decisions taken on every hierarchical level by design experts as well as non-experts throughout the product development process. Countless design decisions have to be taken when translating the customer requirements into the design sketches and models, from there into the production tools and from there again into the product launched into the market. In order to save product development costs, it is desirable to consolidate as many design issues as possible in earlier stages of product development.

A simple chart (Aitken et al., 2003) points out the obvious economical benefits of a method like DPSE (see Figure 2.2).

![Figure 2.2: Economical benefits of a quality up-front development effort within product development (Aitken et al., 2003).](image)

Another reason is described within the fields of business economics by Jensen & Meckling (1976): According to the principle-agent-theory as one of the main theories in new institutional economics, interest divergence and information asymmetry between a principal and an agent tend to generate additional process costs.

It is assumable that these two problems appear within the automotive product development process as well: Concerning the information asymmetry, the principle – i.e. a company’s CEO or members of the executive board – has less detailed information about the efficiency of single product development process partitions than the specialized agent – i.e. the engineers or the designers – who are generating the concrete hardware solutions. The theory assumes human opportunism on both parties as well, which tends to lead to interest divergences.

Now it is self-evident that a method capable of making design issues more transparent and objective is desirable from a business economist’s view: Turning implicit knowledge into explicit knowledge saves process costs.
It is strongly emphasized that not necessarily the designers themselves have this demand because they are highly educated specialists turning the product idea from the first sketches into reference models.

Furthermore, every methodology or academic approach tends to “bureaucratize” the design process which is the demise of a healthy and successful design process; the approach has to preserve the creative space as the basic supposition for the design process. It is indispensable to communicate this supposition to all process partners and specialists including engineers, economists and designers when establishing such a method. On the one hand the targeted method has to be seen as a guidelal which keeps the designer within a preconcerted interpretation corridor and on the other hand as a justifiable argumentation chain for the designer when fighting for the one necessary design solution in order to achieve the preconcerted effect, even if it is a cost intensive design solution. These points form the main advantages for the designer.

### 2.2.2 Information Flow within Product Development

Product development involves the processing of rich and complex information over a duration of several years between specialists from several fields, such as marketing, design, engineering etc. The majority of information is represented through objective information. However, a smaller – but at least tantamount – portion of information remains subjective. This research is focused upon the ascertainment of the latter kind. Figure 2.3 demonstrates this in a simplified way. Next to the main ideal communication paths with objective and subjective content visualized with light and dark blue paths, the cross communication between the departments is visualized as grey lines.

![Figure 2.3: Simplified visualization of objective and subjective information flow and cross communication within product development process.](image)

A pilot-map over the departments of design, marketing and engineering and the kind of information they process is developed by Sanabria, Levy & Lee (2003). The y-axis shows a scale from objective aspects to subjective aspects; the x-axis shows a scale from user related aspects to product related aspects. It is in evidence that marketing and design tend to deal with rather intangible aspects (see Figure 2.4).
2.2.3 Objective Product Development Targets

At the very beginning of the product development process, physical product specifications and requirements – for example body dimensions, fuel consumption, top speed, acceleration etc. – are laid down in documents. Of course, also the future purchase price of the product is stipulated. During the five years of automotive product development process they serve as targets that have to be reached within the time span until serial production. This kind of objective specifications has the great advantage to be measurable, adjustable, comparable to competitors and reproducible with low tolerances on a successor product. It should be clarified in what sense “objective specifications” are used: The objective specifications cited in this paragraph (e.g. acceleration, top speed, interior volume) are quantifiable. In business practice they are used to define product development targets and, for example, conduct competitor benchmarks. Of course, they also strongly contribute to subjective qualities (e.g. perceived acceleration, perceived speed, perceived interior space), which are depending on many other obvious or hidden parameters as well (e.g. transmission concept and exhaust system, driver position, colors and surface language).

2.2.4 Subjective Product Development Targets

But also the character and many other subjectively perceived qualities that the product should exude through its design are being elaborated between marketing and design departments and laid down in agreements and documents. These agreements deliver soft targets, yet immeasurable and mostly difficult to aim at from distance. Additionally to verbal information, the design departments create mood boards (see Figure 2.5) to gather information that helps describing the product character. A mood board is a collection of reference samples and pictures from fashion, architecture, persons, material, graphics, color, feel, lifestyle, pace and emotions and is an essential tool to inspire designers, marketers or anyone involved with the product design. Mood boards and sample boards are a common and efficient tool to communicate, for example, material feel and are used by marketing as well as by design departments.
2.2.5 Semantic Gap

The differences between the available information within a data or language structure – may it be verbal or technical – and the real physical world are known from information technology as the “semantic gap”. Dorai & Venkatesh (2003) define that the semantic gap describes the semantic difference between two explanations of an object that occurs due to usage of different representation manners, e.g. different languages. On an abstract level, the semantic gap is a major obstacle within this research. Verbal specifications (e.g. the term *Elegance*) contain less information about the product target than, for example, a design sketch or a clay model. In this case, the interpretation tolerance of a word is much higher than in a physical object. This discrepancy between the informatory levels is the semantic gap. An analogy can be seen in the field of lossy digital image or acoustic data compression techniques such as JPG or MP3 (see Figure 2.6). There, the compression is achieved by allowing irrecoverable loss of information (unlike e.g. ZIP compression).

Due to strong compression, the picture on the right side requires less information but also delivers a fuzzy image. Even the left picture – though better in quality – purely provides visual two-dimensional information. It is still far from providing information about the holistic product experience. This might only be accessible if the information includes the resonating engine sound and the familiar odor of oil, rubber and leather and most probably it also requires adequate scenic context. Hence, in order to describe soft targets unambiguously and precise, the necessary information amount asymptotically tends to infinity. According to Luhmann (1984), only complexity is able to reduce complexity. The following chart (Figure 2.7) visualizes this fact.
2.2.6 Semantic Gap within Product Development

In order to convey a coherent character throughout the holistic product, a wide variety of experts from highly specific fields, such as marketing managers, designers, psychologists, economists and an innumerable amount of specialized engineers are engaged within the upfront research and the actual product development. Each group speaks its own scientific lingo and has its own rationality and mindset which is involved when interpreting subjective information.

Two problems are encountered that are linked to the semantic gap:

1. Describing complex actuality with verbal language allows a high degree of interpretation tolerance. This tolerance can also be visualized as an interpretation corridor. The corridor actually is required to be wide for a healthy and creative design process in order not to constrict the best design solution but it should be defined narrowly enough to exclude design solutions that would miss the targets. These requirements are rather contrary and may exclude each other (which might be a quintessence of this thesis).

2. Due to the fact that the interpretation corridor will not and cannot be zeroed, other occupational groupings with different mindsets and mental concepts may interpret the specifications in an unwanted manner.

The following visualization abstractly shows an example on an unpretentious level to clarify the term interpretation corridor (see Figure 2.8). Of course, the true difficulties begin just beyond the “horizon”.

2.2.7 Adding Meaning to the Physical World

Concerning the context of Gestalt psychology, science historian Breidbach (2001) constitutes: “What is Gestalt? Neuro-sciences tell us how we see. They describe the mechanisms that display something within our inner brain that is actually outside our brain. Thereby it is evidenced that objects that are perceived are not just imprinted into the perceiving organ, the brain, but rather are imaged according to the inner organization of the brain tissues. We are ‘thinking’ the world from inside to the outside and not from the outside to the inside. The subject and its ‘experienced world’ is the corrective that ensures the reality to us. Here, art and sciences and sciences and art are indented.” If objects that we regard as real are imaged inside our brain according to our specific brain tissues, those brain tissues are a major “modulator” within the catena of “client requirements – marketing – design – engineering – serial production – client”. Commonly, this phenomenon is termed “subjectivity”.

Figure 2.8: Information narrows the interpretation corridor.
2.2.8 Subjectivity Foils the Attempt to Manage Information

Subjectivity and profession specific discrepancies in the idea, the lingo and mindset between involved specialists can turn out to be a significant drawback within a tightly synchronized product development process. All physical and technical product requirements made on an automobile, such as acceleration, maximum speed, fuel consumption or total weight are concrete values and physical characteristics, which can objectively be anchored into the product requirement catalogue at the beginning of the whole process and can objectively be affirmed at the later stages of product development; some requirements even already induce their technical solutions. The reader could object by asking whether physical characteristics are not derived from a desired product character. Indeed, the premium automotive manufacturers put a lot of effort to create a brand- and concept-specific engine character and driving performance. However, soft targets are grasped in measurable characteristics as far as possible to ensure comparability and reproducibility. For example, \textit{powerfulness} can be specified, amongst others, through torque characteristics and acoustical characteristics and \textit{smoothness} through acoustical roughness and vibration measurement.

Design attributes, such as the product character, effect, gesture, appearance or personality are generally softer, but the only way to translate their subjective and implicit idea into reality and serial production is via concrete engineering under a limited budget. These soft attributes can be inserted into the product requirement catalogue as well, but their proper interpretation and implementation through the process partners is not completely ensured during the product development process. As a result, essential but still implicit information within the product development process runs the risk of being misinterpreted, not officially agreed upon or simply dropped out. The revisions of potentially resulting lapses require increasing temporal and financial effort the further the product development process already has proceeded. Alternatively, the lapse can cause long-term brand damage after product launch; this can even befall a technically perfect product.

However, the design process, the convergence process of design and technology and the process of object perception – especially subtle aspects – are complex and cannot be emulated accurately with any model or method. One might object that methods, such as for example the ViP (Hekkert & Van Dijk, 2000) can be used to design context, subject and object as one system and the qualitative values are the starting points in the design process. Here, the emphasis is led on the term “accurately”: In practice, the concerted collaboration of a many thousand people over 60 months situated within the car companies or at suppliers around the world cannot be grasped or emulated in full complexity within theoretical models. Therefore, the resulting product characteristics can not accurately be predicted.

Consequently, many evaluations concerning product design, effect and character will stay subjective to a high degree and cannot be dealt with by mathematical accuracy. This leads to the conclusion that design effect and character of a product are not predictable to full extent before launched into the market. Even months after the launch, the design impact remains a rather dynamic process which can for example be grasped with repeated evaluation. This idea is applied in the Repeated Evaluation Technique (RET) developed by Carbon & Leder (2005). This technique considers dynamic effects within the evaluation of innovativeness and attractiveness.
2.2.9 Probabilism vs. Determinism

Breidbach (2006) phrases that “product design obviously implies too many entangled degrees of freedom to predefine the appropriate solution deterministically” (Olaf Breidbach, personal communication, January 16, 2006). However, a suggested approach to predefine the subjectively perceived design effect as good as possible is to seize the effect upon the individual viewer and to expose and understand those concrete design factors or objective attributes that induce a certain subjective impression within the viewer. Because a product is developed for more than one person in the majority of cases, it is reasonable to conduct a data ascertainment with more than one person and generate a statistical average. With this average, probabilistic statements can be provided.

2.2.10 Probabilistic Statements through Statistical Average

It is contended whether design should be based upon statistical average or if it should be based exclusively upon individual expertise. Design is supposed to generate a creative advance throughout the years; the statistically averaged opinion might protract this advancing. However, it might also provide new insight into design perception.

Pirsig (1974) provides a very important approach towards the ascertainability of values and qualities: A noteworthy criterion of “quality” is its dynamic. This is oppositional to our perception of the objects in the world, which seem to be fairly static. In this regard, Pirsig defines quality as an event. As such an event, quality never is ascertainable. Therefore, quality cannot be observed as a marked-off object of investigation in the sense of natural sciences. Pirsig uses the Sanskrit doctrine “Tat tvam asi” (You Are That). This doctrine asserts that “everything you think you are (subjective) and everything you think you perceive (objective) is undivided.”

The central idea in the citation of Pirsig is that object qualities are strongly depending upon the object, the subject and the surrounding context. Pirsig denies the separation of subject from object (in this thesis: the user from the car).

Neuro-scientist Roth (2007) and science historian Breidbach (2001) also state that the subject’s brain (structurally organized through both genetic disposition and life-long experience) is a strong modulator with the evaluation of objects. So it is out of the question to try measuring product quality by focusing on the object alone. The subjects and the context have to be considered.

Within the research of this thesis in a business context, these insights support two important decisions: a) The consideration of test persons (experts and non-experts) and statistical analysis and b) providing an adequate context for objects or object parts (it is emphasized that in the industrial context and during product development, the product is often seen as many separate, technical components instead of the holistic client-relevant product experience). With respect to subjects, a statistical approach is chosen and context is used in the experiments (e.g. in Chapter 6: The subjects perform a parking maneuver whilst evaluation).

According to the principle of the statistical average, Grötker (2005) mentions that the averaged opinion statistically can be more precise than an expert’s opinion: Let a group of people estimate any amount, weight or number and calculate the average estimation. The result will at least be as precise as the single estimation, but mostly even more precise than the single estimation, even if the test group only consists of two persons.
Surowiecki (2004) also suggests that large groups of people are smarter than an elite few, no matter how brilliant they are. They are better at solving problems, fostering innovation, coming to wise decisions, even predicting the future. Of course, one has to be cautious with this approach because it delivers the average opinion of the group but not an opinion that every one in the (target) group can agree on. This means that one cannot find collective wisdom via compromise.

Surowiecki (2004) says within this context: “I think the most important lesson is not to rely on the wisdom of one or two experts or leaders when making difficult decisions. That does not mean that expertise is irrelevant, or that we don’t need smart people. It just means that all of us together know more than any one of us does.”

Of course, having a good grasp of math, performing on a piano with virtuosity or – again – designing a successful and desirable product are not “averaged performances” but individual professions. Transferring this statement upon the requirements of the targeted method, the average opinion could be seen as a helpful auxiliary input when experts have to take difficult design decisions. The designers’ individual expertise therefore remains essential but can be referenced with averaged perception.

It appears understandable that statistical input and individual expertise complement one another.

Basically, this is an established method already used in so-called product clinics, which is an external, anonymous evaluation of a prototype through potential buyers concerning desirability, customer acceptance, brand assignment and product performance. Customer preferences are collected and – if possible – considered in the further product development. It would be interesting to extract more detailed information from these product clinics: Not only the quantitative information of how much the persons like the object, but especially qualitative information, why they like it, why they sense a certain emotional quality and what induces this emotional quality.

What are the factors and parameters that cause a technical product to exude qualities like “smartness, functioniness, sexiness or driviness” (Christopher E. Bangle, personal communication, February 19, 2006)?

2.3 Second Chapter Conclusion

The following conclusions can be drawn with respect of the previous text:

On a highly competitive market, the designing industry has an urgent demand to grasp the interdependencies between subjective character terms and a design. This helps to align and to control the design effect from the standpoint of business economics to ensure product success.

Compared to strictly mechanical processes, the product development process contains too many dynamic internal and external variables that cannot fully be considered within any theoretical model. According to individual factors, such as the genetic disposition and different experiences during life, perception is a strongly individual process, so the prediction of the effect that the object design has upon the viewer’s perception has to involve the viewer (including specialists and laymen). This means that a representative survey has to be conducted to grasp the averaged perception about the interdependencies between a design and the perceived effect.
This is the exclusive basis for the further method development. The subjective impression within a contemplator cannot be grasped deterministically but probabilistically.

Through statistical analysis, something that can be illustrated as an “orientation dent” is generated within the interpretation corridor (see Figure 2.9). This dent provides orientation since it displays the mutual understanding over certain subjective, verbal specifications. It functions as an orientation guide and is a premise for a more trustable alignment and controlling of the targeted design effect.

The advantages of an approach should be:

1. For the designers and the design research: Emphasis of the context between concrete, objective design parameters and their expressed character and induced emotion. The designer keeps the design competence because he is the specialist providing the necessary input variables (a design framework) and interpreting and optimizing the analysis results.

2. For the designer: Creation of a justifiable argumentation chain when arguing for a more suitable but strenuous or costly design solutions in the phase of serial development.

3. For the product development process and the company: Picking out priorities to spend limited budget. Creation of a guiderail which keeps the designer within a preconcerted interpretation corridor.

In the following chapter, other methods that manage subjectively perceived product qualities have to be explored. Subsequently, a suitable survey and analysis method has to be developed that is capable to discover the interdependencies between tangible design factors and descriptions of the subjective sentience that they cause.
3. Existing Methods to Manage Product Qualities
3.1 Third Chapter Target

Because members of the design research and industrial design communities have detected the immanent lack of objectivity in product development and assume an optimization potential, several approaches to evaluate and manage product qualities have been developed. In this chapter, several methods are presented to a certain detailing. It is obvious that full detailing would extend the scope of this dissertation too far. Since methods with a similar or equal target, e.g. Attribute Engineering, provide potentially relevant input for the development of this specific methodical approach, they should be available in the chronological reading sequence of the thesis.

3.2 Inapplicable Methods

In the following, less suitable methods are listed first. Although they are helpful and common in the product development and quality management, they are considered inapplicable for the specific concern to find interdependencies between design parameters and emotional customer response:

**Six Sigma**

Six Sigma was officially deployed in the mid 1980s at Motorola. It is a quality management method (or set of methods) and a business execution strategy that is engaged to extinct demerits in products, services or processes, whereas demerits are defined as deviances from a specified target. With Six Sigma, statistically only 3.4 demerits do occur out of one million possible demerits. Six Sigma also helps lowering costs and reducing complexity (Motorola, 2007). It is not applicable to manage subjective product qualities.

**Benchmarking**

One of the common and suitable methods to gather and analyze the design and engineering data is benchmarking. The benchmarking database contains objective information about technical specifications or information about perceivable product parts, e.g. part fit, gaps and materials etc. The benchmarking is also carried out on competitor products where they are rated intuitively on a scale on criteria as volume, proportion and execution.

Also benchmarking does not lay focus on the perceived product experience or character yet but rather compares objective criteria.

**Evaluating Craftsmanship**

A reckoner chart based evaluation method exists. It was developed and patented by the original equipment manufacturer Johnson Controls Technology Company under the title “System and Method for Evaluating Craftsmanship”. This tool calculates evaluation indices for car interiors and their single elements based on a useful element structure and intuitive evaluation of these elements. This method to evaluate the craftsmanship of a manufactured object may include a list of components to be evaluated, a list of attributes by which the components are to be evaluated, and a report providing a quantitative score of each component according to each attribute. The attributes include visual attributes, tactile attributes, functional attributes, and psychological attributes (Aitken et al., 2003).

The method does not provide insight into interdependencies between design and subjective evaluation.
**PrEmo**

*PrEmo* is a tool developed by Pieter Desmet (2000) that is able to gather information about seven pleasant emotions (desire, pleasant surprise, inspiration, amusement, admiration, satisfaction, fascination) and seven unpleasant emotions (indignation, contempt, disgust, unpleasant surprise, dissatisfaction, disappointment, boredom) elicited by products. The main advantage is simple use and cross-cultural reliability since an animated cartoon-like character is used for evaluation instead of verbal terms (see Figure 3.1). The main disadvantage is that 14 prefixed emotions are used to evaluate different products.

If other subjective qualities are to be polled, *PrEmo* is inappropriate.

**Exploiting Customer Feedback & Press Evaluations**

Useful information sources often are customer feedback and press evaluations. It might provide direct hints why people like a design, why they ascribe subjective qualities to a product. However, since this information is mostly based upon individual opinions, it is unhelpful to be relied on statistically. Furthermore, this information is rather qualitative than quantitative, it has to be clustered in order to generate statistically reliable output. Finally, this source only works with products already on the market (or unveiled concept cars) and therefore has limited predictive power.

**3.2.1 Assessment of the Inapplicable Methods**

The abovementioned tools provide the possibility to poll and manage objective and subjective product qualities or product evaluations but they still lack the capability to emphasize interdependencies between objective design parameters and the impression that they cause.

**3.3 Applicable Methods**

However, there are already different methods for measuring users’ impressions of products, architectural surroundings and services. Those methods have in common that they measure the viewers’ impressions regarding existing products, models or visualizations. Some of the methods are able to emphasize the interdependencies between design parameters and subjective impressions that the products cause.

The results are, for example, used by designers and serve as a feedback in the design process. By measuring impressions customer-focused product development is facilitated (Frisk & Järleskog, 2003).
These methods are considered to be more successful attempts to bridge the emotional-lingual and practical conversion gaps within the chain of “client requirements – marketing – design – engineering – serial production – client” and to achieve more transparency to ensure the target-oriented design decisions.

In the following, those methods that provide a good basis are listed and assessed afterwards.

**Semantic Environment Description**

According to Schütte (2002), the Swedish car manufacturer Volvo deploys a benchmarking method named “Semantic Environment Description” (or SMB, for Swedish: *Semantisk Miljö Beskrivning*) to measure experienced qualities of an automobile and to describe an automobile using semantic descriptive terms with a scaling system. Originally, it was a method used for evaluating the impression of architectural environments and later was also applied to car interiors. The SMB-method measures the impression with eight factors: pleasantness, complexity, unity, potency, social status, enclosedness, affection and originality.

The SMB-method is a useful tool for measuring the impression of a vehicle interior (Karlsson, Aronsson & Svensson, 2003). The execution is structured as follows: By presenting images, models or films to participants their emotional impressions of the environment can be measured and evaluated by using statistics. The results are used to plan environments like room furnishing or renewal of a city center (Schütte, 2002).

**Measuring Sensorial Quality in Car Interiors**

Another approach to this subject concerning automobile interiors is attempted by Jayshree Kerai (2005), who currently is a researcher at the Loughborough University, UK in collaboration with the original equipment manufacturer Lear Corporation in Sweden. The research title is: “Development of a method to measure and evaluate sensorial quality in car interiors”. The aim of Kerai’s research is to develop a methodology for evaluating and measuring the sensorial quality of car interiors throughout the development process. The first part of her paper provides background into the literature reviewed and gives examples of methods and tools currently used to determine product quality. The second part of the paper outlines industrial interviews carried out at four major car manufacturers and the key findings establishing the need and direction for future work. Initial findings show the needs and requirements for this methodology.

**Psychometric Scaling**

Peter Engeldrum’s book “Psychometric Scaling: A Toolkit for Imaging Systems Development” (Engeldrum, 2000) provides a statistical method to emphasize and optimize those physical image parameters that cause certain customer preferred perceptual attributes.

**SEQUAM**

Bonapace (2002) mentions the Sensorial Quality Assessment Method (SEQUAM) which was developed on request by Fiat Auto in 1992 with order to increase perceived pleasure of Fiat Auto’s product image and use. The method was intended for interior components that have high impact on the car “feel” such as the steering wheel or the door handles etc. Next to those components the method was also applied to automatic and manual gear shifts, internal and external door handles, column mounted
lever systems, push buttons and turn knobs for heaters and air conditioning systems, internal door panels and car information systems. Bonapace (2002) uses Maslow’s hierarchy of needs to create a hierarchal model for product design with safety and well-being, at ground level, moving up to functionality and then usability, leading up to the apex of pleasure. This study proposes to take a broad perspective by looking at the user experience as a whole and applying a case study approach to a number of on-line collections. The study will ask questions such as “What is the philosophy behind the design of the interface? What does it encourage the user to do? Where does it take the user intellectually and emotionally? Does it provide for meaningful and significant experiences?”

Conjoint Analysis

Conjoint Analysis (from “considered jointly analysis”) is a method that allows evaluations about how different product attributes affect the respondent’s product choice. As an example, an attribute could be color, taste, shape or price of an automobile. The choice is most likely based on several attributes. There are two basic methods of Conjoint Analysis according to Green & Srinivasan (1990): The trade-off procedure and the multiple-factor procedure. The trade-off procedure is simple because attributes are considered in pairs. The multiple-factor procedure on the other hand utilizes whole concepts that the respondents evaluate.

The Conjoint Analysis is applicable upon design aspects of a new product as well as upon pricing, market segmentation, advertising, competitive analysis and distribution. The method is costly and therefore more suitable for major concerns. According to Gustafsson (1993), there are three elements included in a Conjoint Analysis that need to be defined to enable a survey:

1. Concept construction,
2. Means of data collection and the
3. Type of scale and criteria used to evaluate the concepts.

The first step in the construction of concepts is to determine what kind of data collection procedure to use. The simplicity of the trade-off procedure makes it suitable for verbal data and the more complex multiple factor procedure is more suited if aesthetics are being evaluated. When constructing a concept, the following aspects must be considered: a) What attributes to include, b) Levels for the attributes and c) Design of the concepts.

Gustafsson (1993) states that different methods of collecting data from respondents can be used, such as personal interviews, questionnaires or computer-interactive methods. Personal interviews are time consuming but deliver detailed data, whereas questionnaires or computer-interactive methods are efficient but risking misinterpretation of the context. The response scales that are used most frequently in conjoint surveys are rating scale and rank order. Green & Srinivasan (1990) state the rank order as the most reliable method, considering the fact that it is easier for the respondent to say which object he prefers more instead of expressing the magnitude of his preference.

Quality Function Deployment

According to Saatweber (1997) one auspicious method called “Quality Function Deployment” (QFD) emphasizes and organizes client quality-related requirements and puts them into context with their solutions (see Figure 3.2). It was developed by Yoji Akao and applied 1966 at Bridgestone Kurume Factory. Matsushita developed QFD concepts in 1969. In 1972 it
had its breakthrough when applied by Mitsubishi Heavy Industries shipyard. It was engaged and developed further by Toyota in 1974 where 61% launch cost savings were achieved and a changing rate decreased by 50%. Lexus, a luxury derivative brand from Toyota is a later QFD development.

One central idea behind QFD is that not only the company’s solutions are considered to be the best but that the solution accepted by the client counts. Basically, QFD arranges the question of “What do we want to achieve for our customers?” together in a matrix with “How do we achieve it?”

Furthermore, it structures the product development process. QFD transforms customer requirements into business specific skills.

Although the following methods are not descendants of the QFD, they all have in common that they gather subjectively perceived criteria and objective design attributes and emphasize probable correlations between them, often by means of opinion polls.

Concerning the adaptability of QFD, Akao phrased: “Copy the spirit, not the form”, which means that the method should not be copied matrix by matrix but stay flexible and adopt case specific functionalities. Bob King, one of Akao’s students, enhanced QFD by integrating concept planning.

![Figure 3.2: QFD “House of Quality” (Wikipedia: A1 House of Quality, 2007).](image-url)
Kansei Engineering

Kansei Engineering (KE) is a method used in product development where focus is put on the user's feelings and emotional impressions. Basically, it enables the designer to translate a user's feelings into objective design parameters. It originates from Japan and was developed by Professor Mitsou Nagamachi in the early 1970s and the translation of the Japanese expression Kansei is approximately “total emotions”. Sanabria, Levy & Lee (2003) explain the etymology of Kansei as seen in Figure 3.3:

![Figure 3.3: The etymology of Kansei (Sanabria, Levy & Lee, 2003).](image)

The Kansei method had been applied in the development of several products worldwide. The most known example is probably the Mazda Miata, where many details of the car were developed with the support of Kansei Engineering (Schütte, 2002). KE can be applied within all areas where the customer has a relation and connection to the product. In the following, the procedure of KE is described shortly:

1. Selection of Kansei words regarding the products; the majority of the words are adjectives but certain nouns can also be used.
2. Evaluation; the product is presented as a picture, 3D model or an actual product and is evaluated by test persons using Kansei words. The words are graded on five- or seven point semantic differential scales. The poles on the scale could for example be “extremely comfortable” and “extremely uncomfortable”.
3. Statistic analysis of gathered data; different kinds of analysis methods are used to analyze the product, the Kansei of the product, the relationship between words and the physical product characteristics.
4. Construction of a Kansei Engineering System (KES); with the results from the analysis above a KES can be generated. The KES is a program that gives recommendations of how a product should be designed to correspond with the consumer’s Kansei.

According to Schütte (2002), six different types of Kansei Engineering do exist. They enable a wide range of applications and can either be used separately or combined:

- **Kansei Engineering Type I – Category Classification**
  This is the simplest way of making a Kansei analysis. The tool used is a tree structure that breaks down a design concept into several sub concepts. Evaluations of sub concepts are done until the parameters can be determined.

- **Kansei Engineering Type II – Kansei Engineering System KES**
  This type of Kansei Engineering connects the user’s Kansei to the products properties by using a computer program. The program contains four databases: Kansei words, images of the examined products, knowledge about how the different data are related to each other and (combined) design and color.

- **Kansei Engineering Type III – Hybrid Kansei Engineering System**
  The databases used in this type of Kansei Engineering are the same as in the previous but the program is especially developed for the product designer. A database from related products is set up and used in reverse.
order. This is called backward Kansei Engineering system and enables a vague prediction of the Kansei the user will have from a drawing or a concept. Accordingly the Kansei Engineering Type II is a forward KES. Because forward and backward KES use the same databases, they are combined often. This combination creates the hybrid KES.

*Kansei Engineering Type IV – Kansei Engineering Modeling*

Instead of the databases used in KE type II and III, a mathematical model called fuzzy logic is used. For example, the system is used to determine the feeling about a brand name.

*Kansei Engineering Type V – Virtual Kansei Engineering*

This type additionally places the user into a virtual 3D environment and is suitable for the evaluation of virtual rooms or spaces, e.g. example flats or kitchens.

*Kansei Engineering Type VI – Collaborative Kansei Engineering Designing*

This is an internet supported KES that allows to bring together viewpoints of designers and customers. The system offers many benefits, such as fast and efficient product development, effective consumer-producer dialogue and co-operative work of participants.

**Attribute Engineering**

*Attribute Engineering* (AE) is an approach similar to Kansei Engineering. It describes a discipline to intentionally achieve emotional product, assembly or part qualities or attributes through product engineering. AE is for example applied to achieve a targeted, characteristic engine sound (Ulrich Wagner, personal communication, August 2005) or to engineer the desirable pleasant and functional tactility of a pushbutton or a clutch (Nikolaj Klingemann, personal communication, August 2006). The Danish high-fidelity electronics manufacturer Bang & Olufsen – well-known for its Scandinavian state of the art design – deploys a highly trained expert group to employ a statistical tool capable of identifying and objectifying the cardinal visual and acoustical attributes that contribute to the customer-perceived quality (Søren Bech, personal communication, March 28, 2006).

The principle behind AE is explained shortly by means of color:

1. Generation of reasonable subjective attributes and metrics (the exemplary subjective attribute is “color”, the subjective metrics are the different perceived colors “blood red”, “grass green”, “sky blue” etc.). Appropriate attributes are found by means of statistical surveys or are defined by the marketing department.

2. Generation of reasonable objective descriptors and metrics (the exemplary objective attribute is “wavelength” and the objective metric is 680 nm, 560 nm, 460 nm etc.)

3. Compilation of objects with altering objective metrics (objects that emit/reflect light with a wavelength between 680-460 nm)

4. Within an opinion poll, people ascribe the subjective metrics to the altering variants (e.g. a red dot is mostly like ascribed with the subjective metric “red”).

5. Correlation analysis of this subjective and objective metrics to find interdependencies (e.g. that most people ascribe the subjective metric “red” to the objective metric 680 nm and “blue” to 460 nm).

6. With further causality verification tests, quasi-correlations can be excluded and real correlations can be attested.
3.3.1 Assessment of the Applicable Methods

The listed methods have in common that they all need test persons (in fact more than one expert) to gather information about subjective percepts while some methods use numeric scales and some use semantic scales (like simple vs. complex or enticing vs. repulsive). This fact – together with the conclusions from the previous chapter – indicates that subjective percepts exclusively can be measured by involving test persons concerning a concrete object. In principle, the test persons might be experts as well as laymen. If both groups are available, the comparison between the group results is worthwhile in order to draw conclusions in how far the averaged expert’s opinion differs from the layman’s opinion.

The methods are able to provide statistical models that allow conclusions about the interdependencies between objective parameters and the subjective impression that they cause. This again – under certain conditions – allows anticipative conclusions for the development of upcoming products.

The idea of AE is considered to provide a good disposition for further research after slight adaptation for product design.

3.4 Third Chapter Conclusion

As a conclusion of the previous tool descriptions, especially the AE approach, the target-oriented combination of the following components seems promising for application:

1. A parameter input specifically generated for the object or part of the object (product) under perception psychological aspects.
2. Objects with varying parameter values.
3. A suitable data collection method that delivers subjective evaluation results concerning the different parameter values.
4. The actual analysis consists out of a correlation analysis between the objective design parameter values and the subjective evaluation. The results have to be interpreted by experts.
4. DPSE Method Development
4.1 Fourth Chapter Target

Based upon the information of the previous chapters, this fourth chapter synthesizes and presents the novel Design Parameter Shift Evaluation (DPSE) method. The DPSE method is applicable to analyze the correlative mapping between objective design parameters and subjectively perceived product attributes. Therefore it contributes a solution to minimize the semantic gap problem – and the connected operational risks – in product development.

4.2 Abstract Method Definition and Naming

Physiologist and neuro-scientist Singer (2003) provides a crucial premise for the method development: Between the describing systems of humanities and the ones of natural sciences no direct bridges can be built. No consistent transition is constructible between them. Here we content ourselves with correlations. Basically, the DPSE method should be aligned to provide correlative interdependencies between objective design parameters and the subjective character impressions that are caused by the object design.

A designed object can be understood as a very large combined set of fixed variables (or parameters) concerning surface geometry, material composition, sound, function, interaction possibilities etc. Accordingly, the design process itself can be defined as the determining of all (product-internal) variables. This set of determined variables induces a subjective impression within the viewer. The sum of all determined objective parameter variables is related to the total perceived subjective impression (see Figure 4.1).

Concerning the designing of a product character, Low (2006) developed a similar approach (see Figure 4.2). The designer encodes the product character by means of physical specifications within the designed product. This product again functions as a medium which provides stimuli to the user. The user decodes the product character by means of the stimuli.

To identify the influence that a specific parameter has upon the product perception, this design parameter can be altered while a possible shifting of the subjective impression should be observed. A mapping between objective parameters and subjective impression is done.

A metaphor might be a marionette with its strings tangled up: To find out which string controls which extremity of the marionette you carefully pluck one string and watch which extremity moves on the marionette. In the experiment, the “string plucking” happens with a set of design variants, whereas altering objective design parameters are understood as the strings and the parameter shifting is understood as the plucking. The marionette “movement” is evaluated by test persons. Therein lays the justification for the naming Design Parameter Shift Evaluation.
4.2.1 Novel and Unique Aspects of DPSE

Basically, DPSE is the designerly adaptation of the Attribute Engineering idea to product design. The main novelty concerns the third step of Attribute Engineering: Within DPSE, the design parameters are treated as continuous, interpolatable parameters in order to embody them as design variants of one original design framework. These design variants with the shifted design parameters replace the compilation of objects. Accordingly, the third step would be:

3. Generation of a set of variants with deliberately, continuously altering objective metrics (objects that emit light with a wavelength of inter alia 680 nm, 560 nm, 460 nm etc.)

This matter of fact is visualized in Figure 4.3. Two designs, a circle and a square, are given. The two variants in between are interpolated designs and visualize the continuous design parameter. The subjective, continuous scale stands below with its poles roundness and angularness.

![Figure 4.3: Treating a design parameter as a continuous parameter.](image)

Product Design is an extremely interdisciplinary field. Therefore, another novelty is that experts from different fields – in case of the DPSE method: Design skilled persons and, e.g. perception psychologists – have to be consulted to generate the adequate parameter input data sets from point one to six (otherwise, significant correlations may not be found).

The data collection itself should involve experts as well as laymen. The experts’ opinion is necessary to evaluate advanced and new design issues in order to maintain design progression, but laymen ensure a representative opinion since automobiles are not only purchased by experts. Involving both groups allows conceiving a validated opinion and discovering in how far opinions between both groups diverge or correspond.

With this setup, it is obvious that design competence (design synthesis) and design evaluation (design analysis) still stay within the design department, which is another fundamental premise for a successful design process. By means of DPSE, methodical and scientific design evaluation (design analysis) is done additionally and provides auxiliary input.

Every perceivable subjective attribute, like a product gesture or character or a conglomerate of several attributes could theoretically be analyzed with such a method if the possible objective descriptors and subjective evaluation scales are selected accurately. As a result, the context between certain objective design parameters and the thereby caused subjective effects on the recipient can be indicated as statistical correlations. Within an interview, König considered this approach promising as a prospective study (Peter König, personal communication, December 19, 2005). The correlating results might be found through an independent component analysis or a multivariate regression analysis under consideration of moderator effects (Marcus Hattula, personal communication, August 8, 2006).
4.3 DPSE Input

Generally, the DPSE method needs three input values which are processed within the analysis:

1. Subjective character attributes that an object or product should express have to be defined. When planning a product, this definition of subjective attributes usually happens in early stages in collaboration of the marketing and design departments by investigating the future product’s target group. A suitable product character is elaborated and verbally laid down in terms like: *Precise Elegance* or *Inviting Modernity*. During product design and development, every perceivable part has to be designed and engineered to contribute to these verbal targets in order to achieve a harmonic, holistic Gestalt. These verbal targets provide the subjective scales with their semantic poles for DPSE. It is emphasized that it is not the aim of this method to determine whether the character terms are appropriate for the target group.

2. The method needs an object (or parts of an object) that has to be evaluated and analyzed. Normally, those parts are of interest for DPSE analysis, that differ between the suggested design solution and the (economically and technically) feasible construction solution.

3. The designer extracts objective design parameters that comply with the following requirements:

   a) The objective parameter diverges between the design model and construction data. The parameter range spans the design model parameters and construction solution parameters.

   b) The objective parameter allegedly has strong influence on the aspired product character attribute. At best, this influence will statistically be validated later. If the influence cannot be validated, the parameter most probably was not chosen accurately or interactions with other parameters conceal other possible correlations.

In most instances, the DPSE method is able to provide information of how certain objective design parameters elicit certain favored (or unfavored) subjective impressions within a viewer if especially the second and third input is selected accurately. When defining the objective design parameters input from other scientific fields, such as facial research, Gestalt psychology or psychoacoustics etc. might be helpful, as shown in the dark grey box “Analogous Science Field” (see Figure 4.7). The kind of object that has to be analyzed determines which scientific field is of interest.

This, for example is done within Klooster’s Design Movement approach (Klooster et al., 2004) to integrate principles of dancing choreography (i.e. Labanotation) into product and interaction design. A similar approach is chosen by Ross (Ross et al., 2007), who also considered Labanotation when defining objective aspects of interaction.

Concerning the design of (virtual) interaction within electronic products, also Wensveen (2004) incorporates important analogies: the real physical world. He states that unifying action and information on the six aspects time, location, direction, dynamics, modality and expression makes interaction intuitive.

Looking at - for example - Apple’s Multitouch User Interfaces, this seems plausible.
4.4 Segmentation of Objects to be Analyzed

The final product can be seen as a coherent Gestalt. However, within industrial practice, there are parallel tracks where the whole product architecture is conceived on the one hand but on the other hand separate parts and assemblies are developed. Engineers at the manufacturer or supplier begin developing concepts or adapting parts before they know the whole Gestalt (see Figure 4.4).

Figure 4.4: Manufacturer View and User View.

In early stages of product development, engineers need detailed information which is not fully available. As soon as character disharmonies emerge while the product ripens, the DPSE method can be engaged to analyze and solve these disharmonies. Especially with complex products that are composed out of countless components, the objects that are going to be analyzed with the DPSE method might not be the complete, final product but might rather be its components or subsystems. It has to be considered, that the segmentation into components and sub-components has to be done carefully since it might corrupt the analysis results due to a phenomenon named emergence.

4.4.1 Emergence Phenomenon

Considering the Emergence Phenomenon as important for the adequate segmentation of assemblies in order to analyze them, it should be provided here in this reading sequence. Emergence describes the phenomenon within philosophy and psychology that certain attributes and capabilities of a system or ensemble cannot be explained by means of the component attributes alone. Aristotle phrased this with his expression: “The whole is more than the sum of its parts”. Within this context Metzger (1987) states that Gestalt Quality is the over-summative characteristic of the holistic ensemble. Gestalt is existent if the characteristics persist, even though parts of the holistic ensemble are altered. Emergence often is characterized by unpredictability or imprecise predictability: When a new subsystem is embedded into an existing system and the system elements are being interconnected through their effect relations, the whole system can develop emergent attributes that were not predictable. The reasons are:

1. The system is so complex that it is not examinable or simulatable without reduction (irreducibility).
2. Between the system elements, new interconnections and effect relations emerge that were not planned.
3. Existing interconnections between system elements are being modified with the integration of a new system element.

Mayr (2000) defines the phenomenon as the emerging of attributes within a system on higher organizational levels that were not predictable by means of its known components on lower organizational levels. A palpable example is that the ant-hill is unforeseeable by looking at the single ant or two. Not until a critical mass of ants is reached, a new capability, the construction of the anthill, emerges out of the whole interacting system.
Another example might be the single body cell (which already is complex enough): A Thomas Mann novel is unforeseeable by understanding how a single cell works. The novel emerges out of the complex interactions between hundreds of specialized cell types and Mann’s individual experiences during life. The emergence phenomenon can be transferred upon design perception when the following elements are defined as system elements as seen in the following Figure 4.5: The object (including its sub-aspects), the subject (including its sub-aspects) and their context (including its sub-aspects) as well. Not before all systems, sub-systems, sub-sub-systems etc. are being defined and adjoined, an idea, something over-summative, emerges out of it: The design effect upon the user.

In order to analyze detached elements or subsystems of a complex product like an automobile contextually and coherently, it might be insufficient to describe the perceivable criteria of all its single elements separately, but ideally to put them into a suitable context as far as possible. This context does not have to be the geometrically surrounding context – which would be the first three dimensions – but should consider the holistic design effect of product experience (see Figure 4.5).

It is known that Gestalt theory mentions that objects are perceived holistically as a Gestalt. However, it is common in automotive design practice that designs usually ripen firstly in their proportions, secondly in surface-refinement and thirdly in their details. Therefore, it is understandable that car design analysis can be clustered, when approaching it, firstly into the proportion, secondly the surface and thirdly the details; this is illustrated as a simplified model on the right side of Figure 4.4 and applies to both exterior and interior. In the automotive context, these steps can be described as perceptive layers. The notion of perceptive layers is to some extent supported by the Laws of Gestalt Theory. Most of what we see can be categorized as objects (figure) or background (Arnheim, 1954). This is why a car is seen as a whole car, for example with its proportions. Familiarity plays a role in what we perceive as a figure as well as boundaries of a figure. They determine the car proportions. The same laws apply at other levels; one can see the headlamp assembly as object against the rest of the car being background. The notion of perceptive layering lies at the root of the phased development of the car (proportion, surface detail). Of course, it is a simplifying assumption that also object evaluation follows this layering, since object identification is a complex topic by itself; e.g. Treisman & Gelade (1980) describe two parallel processes in visual perception, one serial and the other one top-down.
4.4.2 Perceptive Layers

In consumer products such as automobiles, there are aspects, such as relations or material and semantic interdependencies affecting more than one perception layer. Some affect all layers from posture to surface to detail each with a different impact per layer. In the following chart, this structural condition is visualized as a plotted impact curve running through the three perception layers with a peak impact value within one or more layers and lower impact values at other positions (see Figure 4.6). The total impact is varying as well; some large parts barely contribute to the total character and some other – they still might be very little in size – have major influence on the perceived character.

![Perceptive Layers Diagram](image)

**Figure 4.6: Door handle and gear shift as example elements with different impacts on the perceptive layers. The red plotted curve visualizes the varying impact per layer.**

With the claim of accuracy, the complete information perceived on each of the three layers would be necessary to conceive the object character within an analysis. Although the involvement of all layers and all senses is required, de facto practical basic conditions, such as available time or budget, often generate constraints when conducting an analysis, what might reduce the robustness and reliability of the analysis assertions. The main result will be that the tested object cannot claim to be embedded into its whole context or that it will not be fully authentic regarding size, materials, functions etc. But in many cases the object quality might be sufficient as a 2D visualization or context isolated samples like switches or turn knobs. It is necessary to choose the most suitable layer context for each analysis. For example, a headlamp concerning its size and shape should be evaluated rather from posture layer, its graphical array from surface layer, whereas the evaluation of material and color should most likely be evaluated from detail layer. Especially on the detail layer, not only the visual sense is affected. When analyzing an object, it is necessary to take all human sensory channels into consideration because, according to Schifferstein & Spence (2008), multisensory perception of a product effect is exclusively measured with a holistic method. In the following, the sensory contingents for human perception are listed by their relevance: Visual Perception, Haptic Perception, Auditory Perception and Olfactory Perception.

4.5 Ascribing Character to Products

Attributes are needed to describe the qualities of parts, assemblies or the whole product. Oftentimes, these attributes are equal to the ones used to describe persons or details of persons due to the following assumptions: Products, especially automobiles form more than the sum of their parts; they are nearly personated, thence the perception, evaluation and description of it or its parts are quite analogous to the perception, evaluation and circumscription of a human person. Indications for these assumptions are the following:
1. The manner how we treat a computer or a car if it does not do what we expect it to do. We begin talking and blustering; even if the product lacks an acoustical interface. Nass & Reeves (1996) state within their media equation that people treat computers or media as social actors. It is assumable that this applies upon different products, such as automobiles as well.

2. The vocabulary used to describe a product. The main source for this vocabulary might be special interest magazines or customer feedback. Cars are termed to be friendly, serious, aggressive, slim, bulky, brawny or spiritless (since these sources, although not scientific, provide a representative overview of how cars are characterized, they are considered as reliable source for character terms).

3. Desmet, Hekkert & Hillen (2004) state that products induce emotions within their viewers and users: fascination, satisfaction, inspiration, admiration, amusement, pleasant surprise, desire, boredom, disappointment, dissatisfaction, unpleasant surprise, contempt, indignation, disgust. Most of them are related to or equal to the emotions that are induced by persons as well.

4. Govers (2004) states that products have a personality. The assumption that products, especially automobiles often are personated and describable with human character terms herewith seems agreeable. In combination with the fact that it is indeed customary to use also person-based terminology in automobile design departments, this approach will be a justified element of DPSE.

To measure a product’s character an appropriate scale is required. This scale is described in the following.

4.5.1 Semantic Differential

The Semantic Differential is a type of a rating scale designed to measure the connotative meaning of objects, events, and concepts. Osgood’s (1957) Semantic Differential was designed to measure the connotative meaning of concepts and to understand their underlying fundamental dimensions (i.e. evaluation, potency and activity). The respondent is asked to choose where his or her position lies on a scale between two bipolar words or a range of words or numbers ranging across a bipolar position, e.g.: excellent / good / adequate / poor / inadequate or from 5 (powerful) down to 1 (weak). In order to obtain rather qualitative instead of quantitative information the Semantic Differential can be slightly adapted since the character terms used by design and marketing departments of the consumer product industry are often composed of an adjective and a noun, e.g. Precise Elegance or Inviting Modernity. In the DPSE method, the noun (e.g. Modernity) usually is related to the brand’s core values and therefore remains as a constant noun. However, it is being specified or modulated through the adjectives (e.g. Inviting) that are adaptable to different car projects. Consequently, it is advisable to offer two different (e.g. contrary) qualities of that noun by spanning the semantic space with the adjective pair that stands in the context with the noun. Hence, the differentials would be constituted like Precise Elegance / Imprecise Elegance or Inviting Modernity / Repelling Modernity. The automotive brand Lexus, for example, uses the character terms Conscious Simplicity, Fascinating Elegance and Perfect Construction as guideline for their product development (or at least afterwards for marketing communication). During product development, these semantic differentials can provide a common understanding about the product character targets. It is obvious that some differentials would be more suitable than others. It is advisable to inquire support from linguists to discover all denotations and connotations of suitable character terms and differentials. The disadvantage of Semantic Differentials is that the terms might not be freely associated within the respondent by the stimulus but
might instead be “provoked” because the respondent can only choose between a few predetermined terms. A concrete example would be that a test person had to evaluate a “red” object on a spectral scale that ranges from “green” to “blue” (and this would probably not lead to high statistical significances).

4.6 Fourth Chapter Conclusion

The basic idea is that targeted product character terms are analyzed concerning their correlation with objective and measurable design parameters in order to identify if and what kind of influence the parameters have upon the product character. This correlation analysis should be done between objective scales and subjective scales. The units of the objective scale are physical units and its values are systematically altered (shifted), whereas the subjective scales show two semantic poles that are related to the targeted product character. If significant influences of design parameters upon the subjective impression are found, these interdependencies can be used to argue for certain necessary design parameters or they can help with the general understanding of product perception. A further verification test might be conducted to consolidate the results. The design parameters might also be interpolated or even extrapolated in order to amplify the targeted product character experimentally. In this thesis, the term extrapolation is used to mean such steps of an inductive nature including interpolation and extrapolation. However, since extrapolation of analysis data is only reliable within a limited range and interaction effects between design parameters are expectable, the extrapolated design should be re-tested by means of a verification test. It is emphasized that intrinsic limitations should be expected: Firstly, it cannot be ensured that all optimal parameters are observed, secondly interaction effects between the suggested parameters might impede clear analysis results and therefore, thirdly, many subjective impressions only emerge in a certain parameter constellation.

In the following (Figure 4.7), the DPSE method principle is depicted. The light grey boxes are product development process-related aspects and the dark grey boxes show the DPSE process.

![Figure 4.7: Design Parameter Shift Evaluation process chart.](image-url)
5.1 Fifth Chapter Target

The experimental chapters five and six are supposed to investigate the DPSE method’s practical application by means of two experiments. The first experiment concerns the automotive exterior and the second experiment concerns an acoustical man-machine-interface.

In the fifth chapter, design parameters within the headlamps are analyzed concerning their influence upon the product character.

To facilitate acceptance in the intended professional environment, the steps and justifications elaborated in the previous chapters are embedded into fictive but believable scenarios that might occur in a business setting.

Besides the validation that the DPSE method works well, also its limitations are pointed out.

5.1.1 Annotation

It is emphasized that the aim of the following experiment is not to find the best headlamp design per se but to test a method that is capable to find those designs that are optimized to contribute to an agreed product character. The concrete product character terms developed for the experiments are suitable for BMW but fictive.

5.2 Experiment No. 1: Headlamp Facial Expression

When an automobile is personated, it can be assumed that the headlamps of an automobile are metaphorically seen as the automobiles eyes. According to Ekman & Friesen (1978) inter alia the human eye area is strongly involved with the facial expression of emotions.

Due to confidentiality reasons within this dissertation, the object that has to be analyzed is the headlamp of a recent black BMW 5 series touring (E61) with an optional aerodynamic package. The object is displayed from the front view with neutral background. Disturbing details like screws, sensors etc. had been removed (see Figure 5.1).

Figure 5.1: The analyzed object is a recent BMW 5 series touring (E61).
The headlamp scenario was chosen because it actually is not too inappropriate: Similar situations have occurred more than once in the automotive product development. The aspired product character attributes concerning the automobile exterior front view were agreed as usual about 60 months before start of serial production. In this case they are:

- Incisive Mindset
- Natural Aplomb
- Attentive Expression

These fictive attributes were elaborated with the BMW Group Design Strategy Department and considered by Hands to suit the context of this dissertation (Jeffrey Hands, personal communication, February 16, 2006).

About 40 months before start of serial production of the car it turns out that the headlamp construction department is not able to realize the exact visual design specifications due to package, heat dissipation and production cost reasons. As a result, the automobile character and facial expression strongly run the risk of diverging from the character originally agreed through marketing and design.

This should be the point where the design department might engage the DPSE method to justify a technology or construction revision. With help of DPSE, a well-balanced design decision can be substantiated and made more transparent to the decision maker, who also has to bear in mind development and production budget (oftentimes, the decision maker is not a designer). It is emphasized again that an early revision is usually much less cost intensive than taking late decisions.

### 5.2.1 Case Analysis

#### 5.2.1.1 Object, Conflict, Parameters and Metrics

The automobile's headlamps are assumedly equivalent to the eyes and therefore contribute significantly to the product character. Parts of the headlamp are often named after their biological correspondent, such as the eyebrow etc. On a certain point of product development, two different variants of the front lights exist: One variant is the agreed design solution that – when put into its surrounding context – assumedly contributes to the agreed product character. This can be seen as the target. The other variant – yet available as a virtual 3D model or as a rapid prototyping part – is the construction solution generated through engineering departments according to the design specimens and item descriptions in a part list. This variant typifies the scheduled solution. The following Figure 5.2 shows the two fictive diverging variants as analysis basis:

![Figure 5.2: Design solution (left) and diverging construction solution (right).](image)

According to the two existing variants seen above, the following Figure 5.3 defines the main five objective design parameters that are diverging between these two solutions. According to the designer’s expertise, these design parameters have strong influence upon the agreed product character attributes and are therefore interesting for an analysis.

95

96
The design parameters are the Ellipsoid Lens Diameter (ELD), Light Ring Diameter (LRD), Eyebrow Angle (EBA), Average Upper/Lower Eyelid Coverage (AEC) and the Side Indicator Color (SIC). The parameter divergences between the two solutions can be measured. The values of the five important diverging design parameters are displayed in the following Table 5.1 (1:1 ELD and LRD mm values are in brackets):

<table>
<thead>
<tr>
<th>Table 5.1: Values of the Design and Construction Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solution</td>
</tr>
<tr>
<td>---------------</td>
</tr>
<tr>
<td>Design</td>
</tr>
<tr>
<td>Constr.</td>
</tr>
</tbody>
</table>

The design department objects that the construction solution would not contribute to the agreed product character as well as the original design solution. In the following Table 5.2, the reasons for discrepancies between the two variants within the five design parameters are described and reasoned verbally:

<table>
<thead>
<tr>
<th>Table 5.2: Reasons for Differences between Original and Construction Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Light Ring Diameter</strong>: This value is smaller in the construction solution due to a carry-over-part strategy. This means that this part is carried over from other models or model derivatives for cost reasons.</td>
</tr>
<tr>
<td><strong>Ellipsoid Lens Diameter</strong>: This value is smaller in the construction solution due to a carry-over-part strategy. This means that this part is carried over from other models or model derivatives for cost reasons.</td>
</tr>
<tr>
<td><strong>Eyebrow Angle</strong>: This value is smaller in the construction solution due to the package density caused by side indicator light bulbs (this package problem could be solved through more expensive but smaller LEDs + fiber-optics suggested by the design department).</td>
</tr>
<tr>
<td><strong>Average Eyelid Coverage</strong>: In the construction solution, the light rings are covered in the lower segment due to the package density within and around the lamp cluster housing and a carry-over-part strategy (this package problem could be solved through more expensive but space saving LEDs suggested by the design department).</td>
</tr>
<tr>
<td><strong>Side Indicator Color</strong>: The construction solution has orange side indicator glasses and low cost white light bulbs behind due to cost reasons. The design model has white side indicator glass and costly transparent LEDs which only emit orange light when switched on.</td>
</tr>
</tbody>
</table>
5.2.1.2 Analogous Fields of Research: FACS

At this point the DPSE method prescribes to import a body of knowledge from an analogous field of research. This field of research should be about the expressivity of a form. Since product character is given by properties usually associated with either semiotic aspects or humans (e.g. *Attentive Expression* – *Naïve Expression*), it is reasonable to consider the ways humans express themselves. Two main approaches suggest themselves readily:

- The analogy between the car and the human body,
- The analogy between the car and the human face.

It turns out that both approaches are used in automotive design. The first approach is mostly used when addressing the proportions, surfaces and graphics, considering the car from side view. The second approach is mostly used when addressing the front proportions, surfaces and graphics of the car. The precise mapping between car elements and facial elements of course depends on the design but for recent BMW cars under consideration, it is customary to say that, for example, the lower air intake is analogous to a human mouth. The mapping is never one-by-one, i.e. the BMW headlamp assemblies have double-round lamps, whereas the human eye has one pupil. The car design does not imitate mouth or eyes but the equivalent design elements show analogous expression.

For this case study, the analogy between car front and human face is chosen. So what are the theories at this disposition that describe the expression of human faces? Since the goal is to design an automotive character, the first idea is to use theories that relate human faces to human character. An alternative is to use theories that relate human faces to human emotions. Here, the second idea is pursued since it is attractive for several reasons. Firstly, this theory gets a lot of attention by researchers in social robotics and affective computing (Picard, 1997; Bartneck, 2002 and Brooks, 2002). Secondly, the theory allows dynamic effect, i.e. changing emotions, which will become an advantage in the upcoming decades when car elements might become dynamic, too (see Figure 7.16). In that sense, the choice for emotion theory is future-proof. Since character is a relatively static notion and emotion a dynamic notion there are still some challenges ahead to bridge these notions but the approach will be pushed forward as far as possible. For the time being character and emotion are equated, it is proposed to see “emotion” as a frozen emotion.

How would the application of an analogy work in the ideal theoretical way? The theoretical pure examples of such analogy usage are for example found in mathematics: Addition is easier to do than multiplication. So moving from a multiplicative world (algebra) to an additive world means taking logarithm. To multiply 100 and 1000, note that the logarithms are 2 and 3 respectively. In the additive world it is known that $2 + 3 = 5$. Going back, indeed $100 \times 1000 = 10^5$ (see Figure 5.4).

![Figure 5.4: Homomorphic mapping in mathematics.](image)

The challenge ahead is moving from the car world to a facial world and back via a kind of homomorphic mapping (see Figure 5.5). The facial expression theory proposed is the Facial Action Coding System FACS (see Table 5.3) developed by Ekman & Friesen (1978).
Ekman has two relevant pieces of knowledge to offer. His work tells that the set of facially expressed emotions contains six basic emotions (i.e., anger, disgust, fear, surprise, sadness and happiness). Ekman also documented the relations between these emotions and the states of involved facial muscles. FACS defines 64 facial Action Units (AU) together with their involved muscles. Transferred upon facial expression, the following equivalent to headlamp parameters can be assumed:

<table>
<thead>
<tr>
<th>Design Parameter</th>
<th>Facial Expression Equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Ring Diameter</td>
<td>Ratio: Eye Size / Pupil Size</td>
</tr>
<tr>
<td>Ellipsoid Lens Diameter</td>
<td>Pupil Size</td>
</tr>
<tr>
<td>Eyebrow Angle</td>
<td>Eyebrow Angle</td>
</tr>
<tr>
<td>Eyelid Coverage</td>
<td>Lid Position / Pupil Position</td>
</tr>
<tr>
<td>Side Indicator Color</td>
<td>No anatomic equivalent in FACS</td>
</tr>
<tr>
<td></td>
<td>(anyhow, test persons mentioned analogies to heavy eye make-up, which still might be interesting)</td>
</tr>
</tbody>
</table>

According to FACS, the action unit equivalents of the defined design parameters mentioned above have definitive influence upon the encoding of facial expression. These equivalent action units are listed in the following Table 5.3.

### Table 5.3: Experiment relevant extraction of FACS (Ekman & Friesen, 1978)

<table>
<thead>
<tr>
<th>AU</th>
<th>Description</th>
<th>Facial Muscle</th>
<th>Example Image</th>
<th>Headlamp Analogy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Inner Brow</td>
<td>Frontalis, pars medialis</td>
<td></td>
<td>Direct: negative EBA, indirect: AEC, relative LRD</td>
</tr>
<tr>
<td>2</td>
<td>Outer Brow</td>
<td>Frontalis, pars lateralis</td>
<td></td>
<td>Direct: positive EBA, indirect: AEC, relative LRD</td>
</tr>
<tr>
<td>3</td>
<td>Brow Lowerer</td>
<td>Corrugator supercilii, Depressor supercilii</td>
<td></td>
<td>Direct: positive EBA, indirect: AEC, relative LRD</td>
</tr>
<tr>
<td>4</td>
<td>Upper Lid</td>
<td>Levator palpebrae superioris</td>
<td></td>
<td>Direct: EBA, AEC, indirect: relative LRD</td>
</tr>
<tr>
<td>5</td>
<td>Lid Raiser</td>
<td>Orbicularis oculi, pars orbitalis</td>
<td></td>
<td>Direct: AEC, indirect: relative LRD</td>
</tr>
<tr>
<td>6</td>
<td>Lid Tightener</td>
<td>Orbicularis oculi, pars palpebralis</td>
<td></td>
<td>Direct: AEC, indirect: relative LRD</td>
</tr>
<tr>
<td>41</td>
<td>Lid droop</td>
<td>Relaxation of Levator palpebrae superioris</td>
<td></td>
<td>Direct: AEC, indirect: -</td>
</tr>
<tr>
<td>42</td>
<td>Slit</td>
<td>Orbicularis oculi</td>
<td></td>
<td>Direct: AEC, indirect: -</td>
</tr>
<tr>
<td>43</td>
<td>Eyes Closed</td>
<td>Relaxation of Levator palpebrae superioris</td>
<td></td>
<td>Direct: positive AEC, indirect: -</td>
</tr>
<tr>
<td>63</td>
<td>Eyes up</td>
<td></td>
<td></td>
<td>Direct: negative AEC, indirect: -</td>
</tr>
<tr>
<td>64</td>
<td>Eyes down</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The pictures in Table 5.3 only show the eye area cut out from complete faces; Ekman & Friesen used complete faces, of course.
5.2.1.3 Variant Generation

The target is to validate and optimize those objective parameters that contribute to the agreed product character. In order to find the statistical correlations between the product character attributes and the objective parameters, a reasonable amount of variants with altering objective parameters has to be generated. These variants are going to be evaluated by test persons.

Although a context as authentic as possible would be worthwhile, in this case an amount of 20 2D-variants is a reasonable compromise regarding available experimental time and budget. König considered this variants with respect to quantity and quality sufficient (Peter König, personal communication, December 19, 2005).

There are two underlying assumptions: The first assumption is that seeing 2D pictures of the variants has a negligible effect compared to seeing the variants in 3D. This assumption appears reasonable and moreover it is efficient, but it is an assumption.

The 20 variants had been visualized by means of digital photo retouching whereas each variant basically shows the identical car. Purely the lamp clusters are slightly altering within the five predefined criteria. The systematical alterations had been made mono-factorial (Variant 1, 2, 5, 6, 12, 13, 19 and 20) and multi-factorial (Variant 3, 4, 7, 8, 9, 10, 11, 14, 15, 16, 17 and 18) and were positive and negative deviances relatively to the original.

The following Table 5.4 provides an overview about the alterations measured in the 20 visualizations. All values were extracted from the visualizations with a stencil according to Figure 5.3. The 1:1 ELD and LRD mm values are in brackets. In order to avoid an exhaustive amount of variants and due to limited time and budget, the alterations where not made fully factorial, which would mean that every possible parameter combination had to be tested. Identical parameter values are light grey.

There is a second implicit assumption which ought to be made explicit here: The five parameters are independent (except of course that ELD must be less than LRD). The parameters are real numbers, which thus can be varied in a continuous manner. So in principle they span a sub-space of \( \mathbb{R}^5 \) and in theory the optimal solution could be any point in this space. For example, variants with the parameters \((0.36, 0.69, 6, 12.9, 0)\) and \((0.40, 0.70, 7, 13, 0)\) are points appearing fairly close in this space. But in theory one could imagine that both solutions are evaluated in their Mindset as 100% incisive, whereas \((0.38, 0.695, 6.5, 12.95, 0)\) could be evaluated as naïve although it is an interpolated variant.

Yet we sample this space with 20 based on the assumption that the dependant variables such as Mindset, Aplomb and Expression vary in a continuous and smooth way as a function of the five parameters.
Table 5.4: Objective Parameter Alterations of the 20 Headlamp Variants

<table>
<thead>
<tr>
<th>Variant</th>
<th>ELD (≈ 69 mm)</th>
<th>LRD (≈ 132 mm)</th>
<th>EBA</th>
<th>AEC</th>
<th>SIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>0.36 (≈ 69 mm)</td>
<td>0.69 (≈ 132 mm)</td>
<td>+6°</td>
<td>+12.9 %</td>
<td>0 (white)</td>
</tr>
<tr>
<td>01</td>
<td>0.36 (≈ 69 mm)</td>
<td>0.69 (≈ 132 mm)</td>
<td>+6°</td>
<td>+30.0 %</td>
<td>0 (white)</td>
</tr>
<tr>
<td>02</td>
<td>0.36 (≈ 69 mm)</td>
<td>0.69 (≈ 132 mm)</td>
<td>+6°</td>
<td>-20.0 %</td>
<td>0 (white)</td>
</tr>
<tr>
<td>03</td>
<td>0.36 (≈ 69 mm)</td>
<td>0.69 (≈ 132 mm)</td>
<td>-1°</td>
<td>+16.1 %</td>
<td>0 (white)</td>
</tr>
<tr>
<td>04</td>
<td>0.36 (≈ 69 mm)</td>
<td>0.69 (≈ 132 mm)</td>
<td>-7°</td>
<td>+16.7 %</td>
<td>0 (white)</td>
</tr>
<tr>
<td>05</td>
<td>0.36 (≈ 69 mm)</td>
<td>0.69 (≈ 132 mm)</td>
<td>+13°</td>
<td>+12.9 %</td>
<td>0 (white)</td>
</tr>
<tr>
<td>06</td>
<td>0.36 (≈ 69 mm)</td>
<td>0.69 (≈ 132 mm)</td>
<td>+6°</td>
<td>+12.9 %</td>
<td>1 (orange)</td>
</tr>
<tr>
<td>07</td>
<td>0.47 (≈ 90 mm)</td>
<td>0.86 (≈ 165 mm)</td>
<td>+6°</td>
<td>+18.9 %</td>
<td>0 (white)</td>
</tr>
<tr>
<td>08</td>
<td>0.26 (≈ 50 mm)</td>
<td>0.49 (≈ 94 mm)</td>
<td>+6°</td>
<td>0.0 %</td>
<td>0 (white)</td>
</tr>
<tr>
<td>09</td>
<td>0.26 (≈ 50 mm)</td>
<td>0.49 (≈ 94 mm)</td>
<td>+1°</td>
<td>0.0 %</td>
<td>1 (orange)</td>
</tr>
<tr>
<td>10</td>
<td>0.26 (≈ 50 mm)</td>
<td>0.49 (≈ 94 mm)</td>
<td>+1°</td>
<td>-9.1 %</td>
<td>1 (orange)</td>
</tr>
<tr>
<td>11</td>
<td>0.47 (≈ 90 mm)</td>
<td>0.86 (≈ 165 mm)</td>
<td>+13°</td>
<td>+24.3 %</td>
<td>0 (white)</td>
</tr>
<tr>
<td>12</td>
<td>0.56 (≈ 107 mm)</td>
<td>0.69 (≈ 132 mm)</td>
<td>+6°</td>
<td>+12.9 %</td>
<td>0 (white)</td>
</tr>
<tr>
<td>13</td>
<td>0.22 (≈ 42 mm)</td>
<td>0.69 (≈ 132 mm)</td>
<td>+6°</td>
<td>+12.9 %</td>
<td>0 (white)</td>
</tr>
<tr>
<td>14</td>
<td>0.52 (≈ 99 mm)</td>
<td>0.93 (≈ 178 mm)</td>
<td>+6°</td>
<td>+32.5 %</td>
<td>0 (white)</td>
</tr>
<tr>
<td>15</td>
<td>0.42 (≈ 80 mm)</td>
<td>0.84 (≈ 161 mm)</td>
<td>+21°</td>
<td>+20.0 %</td>
<td>0 (white)</td>
</tr>
<tr>
<td>16</td>
<td>0.45 (≈ 86 mm)</td>
<td>0.84 (≈ 161 mm)</td>
<td>+6°</td>
<td>-25.7 %</td>
<td>0 (white)</td>
</tr>
<tr>
<td>17</td>
<td>0.36 (≈ 69 mm)</td>
<td>0.69 (≈ 132 mm)</td>
<td>-12°</td>
<td>+23.3 %</td>
<td>0 (white)</td>
</tr>
<tr>
<td>18</td>
<td>0.36 (≈ 69 mm)</td>
<td>0.69 (≈ 132 mm)</td>
<td>-12°</td>
<td>+23.3 %</td>
<td>1 (orange)</td>
</tr>
<tr>
<td>19</td>
<td>0.36 (≈ 69 mm)</td>
<td>0.69 (≈ 132 mm)</td>
<td>+6°</td>
<td>+36.7 %</td>
<td>0 (white)</td>
</tr>
<tr>
<td>20</td>
<td>0.36 (≈ 69 mm)</td>
<td>0.69 (≈ 132 mm)</td>
<td>+6°</td>
<td>+50.0 %</td>
<td>0 (white)</td>
</tr>
</tbody>
</table>

On the following pages, the 20 lamp cluster visualizations are displayed enlarged in Figure 5.6. Some aspects concerning the following visualizations have to be emphasized:

1. It has to be underlined that these variants must not be understood as design proposals but as visualization media of the five altering design parameters. Also by this reason, certain variants appear far fetched.

2. The variants on the following pages show the trimmed and enlarged Element of Interest, the right headlamp. This is done in order to show the significant parameter changes within the Element of Interest without padding out this book. However, the stimuli showed to the test persons contained the whole car front as displayed in Figure 5.10. This is done in order to provide the product context as far as possible.
Figure 5.6: Lamp cluster variants; the variant pictures are trimmed to fit the page.

Design and construction solution are displayed in Figure 5.2.
5.2.1.4 Subjective Metrics

In order to provide an evaluation scale to the test persons, subjective metrics had to be generated according to the product character attributes. For this purpose, semantic differentials are applicable. The poles that span the semantic space also were elaborated and agreed under analysis of all related denotations and connotations with the BMW Group Design Strategy in order to achieve maximum authenticity within this fictive scenario. The subjective metrics that allow the qualitative evaluation of the character components Mindset, Aplomb and Expression are the following:

**Mindset**
- incisive
- naive

**Aplomb**
- staged
- natural

**Expression**
- attentive
- relaxed

Alternatively, instead of a qualitative evaluation, a quantitative evaluation would be possible with a more/less- or stronger/weaker-scale. Additionally, the test persons’ affection towards each variant B was tested with the question whether they like or dislike it.

5.2.2 Data Collection

5.2.2.1 Questionnaire Design

The questionnaire was designed in dialogue with a BMW psychologist (Sarah Rehmann, personal communication, June 2006) and optimized by means of three pretests with BMW employees. It contained an introduction into the study, the assignment, an evaluation example, 20 blank evaluation scales for the evaluation of three character components per variant and person-related questions (see Figures 5.7, 5.8 and 5.9). A German questionnaire translation was also available for the test persons.
5.2.2.2 Relative Evaluation

When evaluating objects, it is easier for test persons to evaluate relatively to a reference or to generate a ranking order with at least two positions than evaluating on an absolute scale. As it can be seen in the questionnaire assignment, the test persons were asked to evaluate the vehicle on the right side (variant B) compared to the reference vehicle on the left side (variant A). On the evaluation scale, variant A was used as a reference in the middle, so the test persons had to decide if – for example – variant B expressed a rather Incisive Mindset or a rather Naïve Mindset compared to variant A. In this way, the test persons are calibrated by the reference with each evaluation and unwanted statistical variability is reduced. According to Kahnemann & Tversky’s prospect theory (1979), evaluation usually happens related to referencing points.

5.2.2.3 Test Group

To achieve statistical reliability, a neutral group consisting out of 50 test persons was asked to evaluate the 20 variants concerning the three character components Mindset, Aplomb and Expression. BMW employees were excluded to ensure that the result is influenced through expertise knowledge as less as possible. Due to limited time and budget, a convenience sample group was preferred instead of a representative BMW client group – the average BMW buyer in Germany, Great Britain, France, Italy and Spain is male and aged 48 (Josef Köster, personal communication August 27, 2007). The underlying assumption here is that the result from this convenience sample predicts the results that would have been obtained from a sample of average BMW buyers. The convenience sample comprised 50 students addressed at the library of the Ludwig-Maximilian-Universität München in August 2006; according to Hattula (Marcus Hattula, personal communication, October 22, 2007) n=50 is the statistical basis of the law of large numbers and is considered to be sufficient. The test group was constituted as follows:
Gender: 48% of the test persons were male
52% of the test persons were female

Age: 6% of the test persons were between 18-20 years old
86% of the test persons were between 20-30 years old
8% of the test persons were between 30-40 years old

Culture: 90% North-Western European
8% Southern European
2% Asian

5.2.2.4 Stimulus Presentation

The variants were displayed on a 15” glare widescreen notebook as it can be seen below in Figure 5.10. The picture on the left side (variant A) was static during the complete interrogation, only the picture on the right side (variant B) displayed the 20 variants one after another. To avoid order effects, the stimuli order was completely randomized for each test person.

One might wonder whether it is appropriate to show and test other parameter alterations within the whole front of the car. It could be argued that the facial expression involves all Facial Action Units, so why not involve restyling (i.e. parameter shifting) of the bumper or the grille? The reason behind this lies in the heart of the DPSE process (see Figure 4.7). In an industrial context, such as an automotive design management department, it is no option to consider simultaneous shifting of all parameters. As a matter of managing complexity, once the Design Framework (i.e. the design model) has been developed, most parameters are fixed. After that, the DPSE analysis work focuses on a limited amount of Elements of Interest. Of course, all elements are potentially interesting for analysis, but the formal definition of Element of Interest says that there is either a major disagreement between the suggested design solution and the economically and technically feasible construction solution or a general innovation demand.

A second methodological question is whether the headlamps should be shown to the test persons either in isolation or in left-right pairs or within the context of the whole car. To avoid confusion, a few things are clarified first. The pictures in Table 5.3 (FACS) only show the case study relevant eye area cut out from complete faces; Ekman & Friesen used complete faces, of course. Similarly, the pictures of Figure 5.6 exclusively show the Element of Interest; in the experiment reported in this chapter, the complete car front including the Element of Interest (left and right headlamp) has been used as stimuli as seen in Figure 5.10. The reason to show full faces and full front views is that most probably a face, or car front, is perceived as a Gestalt. Although specific elements are optimized, the perception of the whole is not just the set of perceptions of its parts.
In this case study, neither the bumper nor the grille are Elements of Interest. In other words, except for the headlamp assembly, the other elements are technically and economically unproblematic and therefore fixed in the design.

5.2.2.5 Data Results

The 50 test persons reported their subjective impression and affection towards the 20 variants concerning each character component. All scales of subjective reports are encoded as followed: Subjective reports on the left part of the scale obtain negative values (down to -10) and subjective reports on the right part of the scales obtain positive values (up to +10). Thus, neutral reports are encoded with zero (0).

5.2.3 Data Analysis

The linear regression analysis was conducted with friendly help from Prof. Peter König, Hans-Peter Frey and Selim Onat at the Universität Osnabrück Institute for Cognitive Sciences. The software used for this purpose was Matlab (MatWorks).

5.2.3.1 Distribution of Independent Variables

The design of the study is not factorial: It is centered on a default set of features (Ellipsoid Lens Diameter ELD = 0.36 ± 69 mm, Light Ring Diameter LRD = 0.69 ± 132 mm, Eyebrow Angle EBA = 6.0, Average Eyelid Coverage AEC = 12.9 and Side Indicator Color SIC = 0 ± white) instead of presenting an exhaustive list of all possible feature combinations. For example, the Side Indicator Color with the value of 1 (orange) was tested in combination of a restricted centered subset of values of Average Eyelid Coverage only. Hence, the interaction of more extreme values of Average Eyelid Coverage with Side Indicator Color remains unknown. Similar statements can be made for other combinations.

5.2.3.2 Variability of Subjective Reports

As a first step, the variability of subjective report in the four different questions (Mindset, Aplomb, Expression and Like/Dislike) was surveyed. The subjective assessment differs considerably across variants. This is an important aspect for further evaluation. However, the variability across subjects is large which might be reasoned in the high level of the product character judgments. Hence, care has to be taken, that the results do not depend on individual outliers. For that purpose a qualitative overview of the combined dependence of the subjective report on variant and subject identity was obtained.

Table 5.5: Mean and Standard Deviation of Subjective Reports

<table>
<thead>
<tr>
<th>Subjective Reports (n=50)</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mindset</td>
<td>-0.244</td>
<td>5.272</td>
</tr>
<tr>
<td>Aplomb</td>
<td>-2.296</td>
<td>4.777</td>
</tr>
<tr>
<td>Expression</td>
<td>-1.187</td>
<td>5.442</td>
</tr>
<tr>
<td>Affection</td>
<td>0.334</td>
<td>0.472</td>
</tr>
</tbody>
</table>

5.2.3.3 Influence of Individual Features on Subjective Report

In the following 20 tables and plots, the influence of the individual features (Ellipsoid Lens Diameter, Light Ring Diameter, Eyebrow Angle, Average Eyelid Coverage and Side Indicator Color) on the subjective reports (Mindset, Aplomb, Expression and Affection) is displayed.
Mindset vs. Ellipsoid Lens Diameter

**Table 5.6: ANOVA of Ellipsoid Lens Diameter – Dependent Variable: Mindset**

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ellipsoid Lens D.</td>
<td>2.08</td>
<td>1</td>
<td>2.08</td>
<td>0.35</td>
<td>0.5601</td>
</tr>
<tr>
<td>Error</td>
<td>112.35</td>
<td>19</td>
<td>5.91</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>114.43</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 5.11: Bivariate fit of “Mindset” by “Ellipsoid Lens Diameter”**.

**Interpretation**

These two variables are not significantly correlated.

---

Mindset vs. Light Ring Diameter

**Table 5.7: ANOVA of Light Ring Diameter – Dependent Variable: Mindset**

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Ring D.</td>
<td>4.56</td>
<td>1</td>
<td>4.56</td>
<td>0.7892</td>
<td>0.3854</td>
</tr>
<tr>
<td>Error</td>
<td>109.87</td>
<td>19</td>
<td>5.78</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>114.43</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 5.12: Bivariate fit of “Mindset” by “Light Ring Diameter”**.

**Interpretation**

These two variables are not significantly correlated.
Mindset vs. Eyebrow Angle

Table 5.8: ANOVA of Eyebrow Angle – Dependent Variable: Mindset

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eyebrow Angle</td>
<td>27.09</td>
<td>1</td>
<td>27.09</td>
<td>5.89</td>
<td>0.0253</td>
</tr>
<tr>
<td>Error</td>
<td>87.34</td>
<td>19</td>
<td>4.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>114.43</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5.13: Bivariate fit of “Mindset” by “Eyebrow Angle”.

Interpretation
These two variables are significantly negatively correlated.

Mindset vs. Average Eyelid Coverage

Table 5.9: ANOVA of Eyelid Coverage – Dependent Variable: Mindset

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eyelid Coverage</td>
<td>54.17</td>
<td>1</td>
<td>54.17</td>
<td>17.08</td>
<td>0.0006</td>
</tr>
<tr>
<td>Error</td>
<td>60.26</td>
<td>19</td>
<td>3.17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>114.43</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5.14: Bivariate fit of “Mindset” by “Average Eyelid Coverage”.

Interpretation
These two variables are significantly negatively correlated. It is noteworthy that the high Mindset values are supported by other variants than in the Mindset Eyebrow Angle relation.
Mindset vs. Side Indicator Color

Table 5.10: ANOVA of Side Indicator Color – Dependent Variable: Mindset

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side Ind. Color</td>
<td>13.76</td>
<td>1</td>
<td>13.76</td>
<td>2.60</td>
<td>0.1235</td>
</tr>
<tr>
<td>Error</td>
<td>100.67</td>
<td>19</td>
<td>5.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>114.43</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5.15: Bivariate fit of “Mindset” by “Indicator Color”.

Interpretation
These two variables are not significantly correlated.

Mindset Summary
Mindset is mainly influenced by Eyebrow Angle and Average Eyelid Coverage. The interaction of these two variables might be synergistic, but this would need additional experimental data.

Aplomb vs. Ellipsoid Lens Diameter

Table 5.11: ANOVA of Ellipsoid Lens D. – Dependent Variable: Aplomb

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ellipsoid Lens D.</td>
<td>24.26</td>
<td>1</td>
<td>24.26</td>
<td>6.13</td>
<td>0.0228</td>
</tr>
<tr>
<td>Error</td>
<td>75.14</td>
<td>19</td>
<td>3.95</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>99.40</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5.16: Bivariate fit of “Aplomb” by “Ellipsoid Lens Diameter”.

Interpretation
These two variables are positively and significantly correlated. However, this correlation is to a large part due to two single variants (11 and 12). Furthermore, maximal and minimal Aplomb values are observed at the “default” value of 0.36 of Ellipsoid Lens Diameter. Finally, the Aplomb assessment at minimal Ellipsoid Lens Diameter is slightly larger than at the second largest Ellipsoid Lens Diameter.
Aplomb vs. Light Ring Diameter

Table 5.12: ANOVA of Light Ring Diameter – Dependent Variable: Aplomb

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Ring D.</td>
<td>21.60</td>
<td>1</td>
<td>21.60</td>
<td>5.27</td>
<td>0.0332</td>
</tr>
<tr>
<td>Error</td>
<td>77.80</td>
<td>19</td>
<td>4.09</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>99.40</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5.17: Bivariate fit of “Aplomb” by “Light Ring Diameter”.

Interpretation
The interaction of these two variables is quite identical to the previous. It is positive and significant. Partially, this is a direct effect of the correlation of independent variables in the experimental design. Variants 8, 9 and 10 combine low values of Ellipsoid Lens Diameter and Light Ring Diameter. Ignoring variants 12 and 13, the correlation of these two independent variables is nearly perfect. Viewing variant 13 as an outlier in previous interaction, the correlation of Aplomb with Light Ring Diameter seems to be slightly more robust as a qualitative assessment.

Aplomb vs. Eyebrow Angle

Table 5.13: ANOVA of Eyebrow Angle – Dependent Variable: Aplomb

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eyebrow Angle</td>
<td>0.18</td>
<td>1</td>
<td>0.18</td>
<td>0.03</td>
<td>0.8561</td>
</tr>
<tr>
<td>Error</td>
<td>99.22</td>
<td>19</td>
<td>5.22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>99.40</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5.18: Bivariate fit of “Aplomb” by “Eyebrow Angle”.

Interpretation
The interaction of these two variables is weak and not statistically significant.
Aplomb vs. Average Eyelid Coverage (Linear Fit)

Table 5.14: ANOVA of Eyelid Coverage – Dependent Variable: Aplomb

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eyelid Coverage</td>
<td>1.03</td>
<td>1</td>
<td>1.03</td>
<td>0.20</td>
<td>0.6599</td>
</tr>
<tr>
<td>Error</td>
<td>98.36</td>
<td>19</td>
<td>5.18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>99.39</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5.19: Bivariate fit of “Aplomb” by “Average Eyelid Coverage”.

Interpretation
The linear correlation of these two variables is weak and not statistically significant. However, a stronger quadratic fit is observed as displayed on the following page.

Aplomb vs. Average Eyelid Coverage (Quadratic Fit)

Table 5.15: ANOVA of Eyelid Coverage – Dependent Variable: Aplomb

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eyelid Coverage</td>
<td>22.00</td>
<td>2</td>
<td>11.00</td>
<td>2.56</td>
<td>0.1053</td>
</tr>
<tr>
<td>Error</td>
<td>77.40</td>
<td>18</td>
<td>4.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>99.40</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5.20: Quadratic fit of “Aplomb” by “Average Eyelid Coverage”.

Interpretation
As seen before, the linear correlation of these two variables is weak and not significant. However, a somewhat stronger, but still weak quadratic fit is observable, indicating that extreme values of Average Eyelid Coverage lead to low values of Aplomb.
Aplomb vs. Side Indicator Color

Table 5.16: ANOVA of Side Indicator Color – Dependent Variable: Aplomb

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side Ind. Color</td>
<td>25.86</td>
<td>1</td>
<td>25.86</td>
<td>6.68</td>
<td>0.0182</td>
</tr>
<tr>
<td>Error</td>
<td>73.54</td>
<td>19</td>
<td>3.87</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>99.40</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5.21: Bivariate fit of “Aplomb” by “Indicator Color”.

Interpretation
Here a significant negative correlation is observed.

Aplomb Summary
Light Ring Diameter, Ellipsoid Lens Diameter and Side Indicator Color contribute significantly to Aplomb. The first two contribute positively, the latter negatively. At extreme values of Average Eyelid Coverage Aplomb is reduced. Eyebrow Angle does not significantly affect Aplomb.

Expression vs. Ellipsoid Lens Diameter

Table 5.17: ANOVA of Ellipsoid Lens D. – Dependent Variable: Expression

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ellipsoid Lens D.</td>
<td>0.06</td>
<td>1</td>
<td>0.06</td>
<td>0.01</td>
<td>0.9150</td>
</tr>
<tr>
<td>Error</td>
<td>104.07</td>
<td>19</td>
<td>5.48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>104.13</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5.22: Bivariate fit of “Expression” by “Ellipsoid Lens Diameter”.

Interpretation
This interaction is weak and not significant. No higher order correlation is obvious.
Expression vs. Light Ring Diameter

Table 5.18: ANOVA of Light Ring Diameter – Dependent Variable: Expression

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ellipsoid Lens D.</td>
<td>0.95</td>
<td>1</td>
<td>0.95</td>
<td>0.18</td>
<td>0.6804</td>
</tr>
<tr>
<td>Error</td>
<td>103.19</td>
<td>19</td>
<td>5.43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>104.14</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5.23: Bivariate fit of “Expression” by “Light Ring Diameter”.

Interpretation

This interaction is weak and not significant. No higher order correlation is obvious.

Expression vs. Eyebrow Angle

Table 5.19: ANOVA of Eyebrow Angle – Dependent Variable: Expression

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eyebrow Angle</td>
<td>39.25</td>
<td>1</td>
<td>39.25</td>
<td>11.49</td>
<td>0.0031</td>
</tr>
<tr>
<td>Error</td>
<td>64.89</td>
<td>19</td>
<td>3.42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>104.14</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5.24: Bivariate fit of “Expression” by “Eyebrow Angle”.

Interpretation

This interaction is strong, negative and highly significant.
Expression vs. Average Eyelid Coverage

Table 5.20: ANOVA of Eyelid Coverage – Dependent Variable: Expression

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eyelid Coverage</td>
<td>31.50</td>
<td>1</td>
<td>31.50</td>
<td>8.24</td>
<td>0.0098</td>
</tr>
<tr>
<td>Error</td>
<td>72.64</td>
<td>19</td>
<td>3.82</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>104.14</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 5.25: Bivariate fit of “Expression” by “Average Eyelid Coverage”**.

**Interpretation**

This interaction is strong, negative and highly significant. In view of the effect on Aplomb, it is worth mentioning that low values of Expression are already reached at intermediate values of Average Eyelid Coverage (variants 1, 11, 14 and 19).

Expression vs. Side Indicator Color

Table 5.21: ANOVA of Side Indicator Color – Dependent Variable: Expression

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side Ind. Color</td>
<td>3.80</td>
<td>1</td>
<td>3.80</td>
<td>0.72</td>
<td>0.4067</td>
</tr>
<tr>
<td>Error</td>
<td>100.34</td>
<td>19</td>
<td>5.28</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>104.14</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 5.26: Bivariate fit of “Expression” by “Indicator Color”**.

**Interpretation**

This interaction is weak and not significant.

**Expression Summary**

Expression is mainly influenced by Eyebrow Angle and Average Eyelid Coverage. Both correlate strongly and negatively with the subjective Expression rating.
**Affection vs. Ellipsoid Lens Diameter**

**Table 5.22: ANOVA of Ellipsoid Lens D. – Dependent Variable: Affection**

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ellipsoid Lens D.</td>
<td>0.31</td>
<td>1</td>
<td>0.31</td>
<td>6.90</td>
<td>0.0166</td>
</tr>
<tr>
<td>Error</td>
<td>0.85</td>
<td>19</td>
<td>0.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1.16</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Figure 5.27: Bivariate fit of “Affection” by “Ellipsoid Lens Diameter”](image)

**Interpretation**

These two variables are positively and significantly correlated.

---

**Affection vs. Light Ring Diameter**

**Table 5.23: ANOVA of Light Ring Diameter – Dependent Variable: Affection**

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Ring D.</td>
<td>0.26</td>
<td>1</td>
<td>0.26</td>
<td>5.40</td>
<td>0.0314</td>
</tr>
<tr>
<td>Error</td>
<td>0.90</td>
<td>19</td>
<td>0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1.16</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Figure 5.28: Bivariate fit of “Affection” by “Light Ring Diameter”](image)

**Interpretation**

These two variables are positively and significantly correlated. It is noteworthy that high ratings are already obtained at combinations of intermediate values and even neutral values. This indicates that a saturation, which is not captured by a linear model, of Like/Dislike as a function of these two variables occurs.
**Affection vs. Eyebrow Angle**

**Table 5.24: ANOVA of Eyebrow Angle – Dependent Variable: Affection**

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eyebrow Angle</td>
<td>0.08</td>
<td>1</td>
<td>0.08</td>
<td>1.35</td>
<td>0.2590</td>
</tr>
<tr>
<td>Error</td>
<td>1.08</td>
<td>19</td>
<td>0.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1.16</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Figure 5.29: Bivariate fit of “Affection” by “Eyebrow Angle”.*

**Interpretation**

These two variables are weakly and not significantly correlated.

---

**Affection vs. Average Eyelid Coverage (Linear Fit)**

**Table 5.25: ANOVA of Eyelid Coverage – Dependent Variable: Affection**

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eyelid Coverage</td>
<td>0.18</td>
<td>1</td>
<td>0.18</td>
<td>3.58</td>
<td>0.0740</td>
</tr>
<tr>
<td>Error</td>
<td>0.97</td>
<td>19</td>
<td>0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1.15</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Figure 5.30: Bivariate fit of “Affection” by “Average Eyelid Coverage”.*

**Interpretation**

These two variables are weakly and just not significantly linearly correlated. However, a nonlinear fit with a quadratic function is observable and displayed on the following page.
Affection vs. Average Eyelid Coverage (Quadratic Fit)

**Table 5.26: ANOVA of Eyelid Coverage – Dependent Variable: Affection**

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eyelid Coverage</td>
<td>0.35</td>
<td>2</td>
<td>0.17</td>
<td>3.82</td>
<td>0.0414</td>
</tr>
<tr>
<td>Error</td>
<td>0.81</td>
<td>18</td>
<td>0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1.16</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Figure 5.31: Bivariate fit of “Affection” by “Average Eyelid Coverage”.*

**Interpretation**

As mentioned before, these two variables are weakly and just not significantly linearly correlated. However, a nonlinear fit with a quadratic function indicates a negative Like/Dislike rating with extreme values of Average Eyelid Coverage.

Affection vs. Side Indicator Color

**Table 5.27: ANOVA of Side Indicator Color – Dependent Variable: Affection**

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side Ind. Color</td>
<td>0.34</td>
<td>1</td>
<td>0.34</td>
<td>7.74</td>
<td>0.0119</td>
</tr>
<tr>
<td>Error</td>
<td>0.82</td>
<td>19</td>
<td>0.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1.16</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Figure 5.32: Bivariate fit of “Affection” by “Indicator Color”.*

**Interpretation**

These two variables are significantly and negatively correlated.

**Affection Summary**

Affection is mainly influenced by Ellipsoid Lens Diameter and Light Ring Diameter. Extreme positive or negative values of Average Eyelid Coverage lead to a negative Like/Dislike Rating.
5.2.3.4 **Overall Summary**

It is noteworthy that Aplomb is influenced by Ellipsoid Lens Diameter and Light Ring Diameter, but not (linearly) by Eyebrow Angle and Average Eyelid Coverage. For Expression, a complementary dependence is observed. These dependencies are again found in the multivariate analysis.

5.2.3.5 **Multivariate Analysis of Dependent Variables**

The multivariate analysis demonstrates a close positive relation of the subjective reports of Aplomb and Affection \( r = .85; \ p < .05 \) and of Mindset and Expression \( r = .89 \ p < .05 \). These two groups are only weakly negatively correlated. The grouping into two pairs is further supported by the analysis of partial correlations between Aplomb and Affection \( r = .89 \ p < .05 \) and Mindset and Expression \( r = .81 \ p < .05 \). Expression and Aplomb are weakly positively correlated \( r = .32 \ p < .05 \), Affection is weakly negatively correlated with Mindset \( r = -.46 \ p < .05 \).

5.2.3.6 **Generative Model**

Modeling the subjective report with five hidden nodes leads to a reasonable prediction based on the given parameter set in form of the 20 variants (predictability: Aplomb 98 %, Expression 98 %, Affection 99 % and Mindset 98 %). Five nodes seem suitable considering the amount of degrees of freedom (modeling with less than five nodes lead to bad fits, six and seven nodes do not yet reach the point of overfitting). Given the limitations of the experimental design, for feature combinations outside the parameter space tested, additional experimental data should be obtained to validate these predictions.

5.2.4 **Data Interpretation**

Based on the previous detailed data analysis, the following conclusions can be drawn for each character component and for the test persons' affection.

To provide the agreed product character tending to Incisive Mindset, Natural Aplomb and Attentive Expression to the product, the design parameters should tend as described in the following:

Figure 5.33 indicates that stronger positive Eyelid Coverage and stronger positive Eyebrow Angle contribute to the perception of a rather Incisive Mindset.

![Figure 5.33: Mindset vs. Eyelid Coverage and Eyebrow Angle.](image)

Figure 5.34 indicates that larger Light Ring Diameter and larger Ellipsoid Lens Diameter, as well as the white Side Indicator Color contribute to the perception of a rather Natural Aplomb. A moderate Eyelid Coverage weakly contributes to Natural Aplomb.
Figure 5.34: Aplomb vs. Light Ring Diameter, Ellipsoid Lens Diameter, Side Indicator Color and Eyelid Coverage.

Figure 5.35 indicates that stronger Eyelid Coverage and stronger Eyebrow Angle contribute to the perception of a rather Attentive Expression.

Figure 5.35: Expression vs. Eyelid Coverage and Eyebrow Angle.

Figure 5.36 indicates that larger Light Ring Diameter and Ellipsoid Lens Diameter, as well as the white Side Indicator Color and a moderate Eyelid Coverage contribute to the test persons’ positive Affection, which means that they like it better.

Figure 5.36: Affection vs. Light Ring Diameter, Ellipsoid Lens Diameter, Side Indicator Color and Eyelid Coverage.

5.2.5 Conclusion and Parameter Extrapolation

The targeted product character is achieved best with large Light Ring and Ellipsoid Lens Diameters, a white Side Indicator and lowered Eyebrows.

One compromise has to be made concerning the Average Eyelid Coverage: While Natural Aplomb and Positive Affection require moderate positive Average Eyelid Coverage values the Incisive Mindset and Attentive Expression require higher values. The result would be a positive, but not too extreme Average Eyelid Coverage value (Figure 5.37).

Figure 5.37: Cumulated design parameters and expressed character.
The resulting design deduced from the previous conclusion is shown in the following (see Figure 5.38). This extrapolation was not only performed mathematically, but harmonically again with a designer’s eye in order to incorporate parameter interaction effects. It is an extrapolated design that statistically should express increased Incisive Mindset, Natural Aplomb and Attentive Expression and furthermore should statistically be liked by most test persons. For reasons of comparison, the fictive construction solution (see Figure 5.39) and the original headlamp design (see Figure 5.40) are presented again on the right page.

As already mentioned at the beginning of this chapter, it is emphasized again that the aim of the experiment is not to find the best headlamp design per se but to test a method that is capable to find and optimize those design parameters that contribute to an agreed product character.
The five design parameters values of the original headlamp design, the construction solution and the extrapolated design and are presented below in Table 5.28.

Table 5.28: Values of the Original, Construction and Extrapolated Solution

<table>
<thead>
<tr>
<th>Solution</th>
<th>ELD  (≈ 60 mm)</th>
<th>LRD  (≈ 132 mm)</th>
<th>EBA</th>
<th>AEC %</th>
<th>SIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>0.36</td>
<td>0.69</td>
<td>+6°</td>
<td>12.9%</td>
<td>0</td>
</tr>
<tr>
<td>Constr.</td>
<td>0.34</td>
<td>0.65</td>
<td>+3°</td>
<td>-8.0%</td>
<td>1</td>
</tr>
<tr>
<td>Extrapol.</td>
<td>0.47</td>
<td>0.86</td>
<td>+11°</td>
<td>19.0%</td>
<td>0</td>
</tr>
</tbody>
</table>

5.2.6 Verification Test

A verification test with 20 further test persons was conducted to examine whether the extrapolated analysis results are valid and whether there were divergences between expert and layman. 50% of the test persons were Dutch students and employees (both not from the educational field of design) of the Technical University of Eindhoven and the other 50% were BMW, MINI and Rolls-Royce designers. To reduce the task complexity, the test persons were asked to attribute two out of three variants with the targeted character term and the character term to be avoided. Therefore, the third variant that was not attributed by the test persons lies between the poles automatically.

The verification test questionnaire can be seen in Figures 5.41 and 5.42 and the stimuli are presented in Figure 5.43. Variant A shows the fictive construction solution, variant B the extrapolated headlamp design and variant C the original BMW E61 headlamp design. Of course, this was not told to the test persons.

Figure 5.41: Verification test questionnaire.
5.2.6.1 Verification Test Results

The verification results are displayed numerically in Table 5.29 and graphically in Figures 5.44 and 5.45.

Table 5.29: Numerical verification test results

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>C</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>A</td>
<td>A</td>
<td>C</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>A</td>
<td>A</td>
<td>C</td>
</tr>
<tr>
<td>4</td>
<td>C</td>
<td>A</td>
<td>A</td>
<td>C</td>
</tr>
<tr>
<td>5</td>
<td>C</td>
<td>B</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>6</td>
<td>C</td>
<td>B</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>7</td>
<td>B</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>8</td>
<td>B</td>
<td>C</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>9</td>
<td>C</td>
<td>A</td>
<td>A</td>
<td>C</td>
</tr>
<tr>
<td>10</td>
<td>C</td>
<td>A</td>
<td>C</td>
<td>A</td>
</tr>
<tr>
<td>11</td>
<td>B</td>
<td>A</td>
<td>A</td>
<td>C</td>
</tr>
<tr>
<td>12</td>
<td>C</td>
<td>A</td>
<td>C</td>
<td>B</td>
</tr>
<tr>
<td>13</td>
<td>C</td>
<td>A</td>
<td>C</td>
<td>B</td>
</tr>
<tr>
<td>14</td>
<td>B</td>
<td>A</td>
<td>C</td>
<td>B</td>
</tr>
<tr>
<td>15</td>
<td>B</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>16</td>
<td>C</td>
<td>A</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>17</td>
<td>B</td>
<td>A</td>
<td>C</td>
<td>B</td>
</tr>
<tr>
<td>18</td>
<td>C</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>19</td>
<td>C</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>20</td>
<td>B</td>
<td>A</td>
<td>A</td>
<td>B</td>
</tr>
</tbody>
</table>

Previous Table 5.29 displays that the fictive construction solution A was only preferred by one non-designer.

The verification test showed the extrapolated headlamp design variant B was clearly preferred by most test persons as can be seen in Figure 5.44.
Figure 5.44: Test person preferences.

Figure 5.45 shows the distribution to which percentage a given character term was ascribed by the test persons to variant A (fictive construction solution), variant B (extrapolated design) and variant C (design solution).

The verification test clearly demonstrates that the extrapolated headlamp design variant B de facto statistically expresses more Incisive Mindset, Natural Aplomb and Attentive Expression than the construction solution variant A. This means that the DPSE method in this case worked well. Moreover, it would be desirable that the extrapolated headlamp design variant B would beat the original headlamp design variant C as well, which is indeed given with Natural Aplomb and Attentive Expression. Only variant C is assessed by most test persons to express a stronger Incisive Mindset than variant B. This might be the case because the extrapolation of the data does not consider interaction effects. Further analysis would be necessary to give reasons for this actuality.

It is conspicuous that some character components are much easier to evaluate than others. The test persons’ responses for Naïve Mindset, Attentive Expression or Relaxed Expression showed less variability than for example for Staged Aplomb. This might be founded in the fact that some of the used character terms are more popular than others. It also stands out that variant B and C are concurring in their perceived character components while variant A is definitely shifted away. This is explainable since the variant B and C design parameters are quite close while the variant A design parameters are diverging considerably from B and C.

The verification test also emphasized that in this experiment a difference between layman and expert evaluation is observable. The evaluations of the non-designers showed certain diffusion into “unpredicted” directions while the designers’ evaluations seemed more unisonant and – above all – they evaluated as “expected”: Overall, the laymen had 8 reports that were contrary to what was expectable and 39 reports as expected. The experts only had 4 contrary reports and 44 reports as expected.
Assumedly, experts seem to have more congruent mental concepts about product related character terms which should be understandable since it is their business to implement a product character into an object by defining the duly proportions, modeling ingenious surfaces and choosing adequate materials. Furthermore, they work in one design studio and have a professional activity in common. This should be taken as an important quintessence of this experiment.

5.2.7 Limitations

This experiment has revealed that five design parameters of an automotive part have statistically measurable influence upon the automobile’s expressed character. It is able to provide a recommendation that these parameters can be shifted into a certain value range to statistically emphasize a targeted product character as an experiment. However, since the character of hardly any object (including human beings) is caused mono- or oligo-factorially but rather multi-factorially the experiment is incapable of ensuring that these five parameters are optimal to describe an object’s character. This set of parameters is five out of a plethora of other (obvious or hidden) parameters that might even have stronger influence upon the targeted product character. Additionally, against the background of the first theoretical chapter and because of expectable cross-interaction effects between the design parameters it is clear that this experiment cannot provide the exact parameter values that might ensure the perfect design and therefore maximum product success. Furthermore, the alterations of the five parameters affect or generate other unstudied parameters (such as light ring center position, light ring thickness or newly-occurring spaces and surfaces between the objects when shifting or scaling them), that again either can be studied scientifically or have to be adjusted with the designer’s eye.

5.2.8 Can Design Effects be coupled with Cost Effects?

Of course it would be very worthwhile to couple the production costs of e.g. a headlamp with its objective design parameters and therefore indirectly with the perceived character they cause. Ideally, one would be able to say how much a certain character attribute would cost in development or production. But as is well known it is already a challenge to pre-estimate absolute production costs a few years in advance since the costs fluctuate strongly due to commodity prices, supplier changes, supplier competition, quantity effects and last but not least lucky price negotiations. The link between the design parameters and their induced character is even more fragile and non-mechanical and still even more fragile is the link “around two corners” between design parameters and their production costs. Thus, it seems not advisable to rely on the fragile catena from product character to design parameters to production costs.

5.2.9 The Benefit of Using FACS

It should be reviewed where FACS was actually used fruitfully: It turned out to be useful in 5.2.1.3 where the Design Parameters and the Facial...
Action Units equivalent yield a very good match: 4 out of 5 Design Parameters match the Facial Action Unit equivalents, whereas the Design Parameters correspond to a combination of two to four Facial Action unit equivalents directly and indirectly.

This good match is taken as a confirmation of the perceptive relevance of the Design Parameters. The match between character and emotion (cf. the homomorphic mapping in the left part of Figure 5.5) is still not yet well understood. The approach was pushed forward as far as possible under the given resource constraints. The interdependency of character and emotion provides a topic for future research. Ideally it would be possible to follow the full commuting diagram of Figure 5.4 and thus have an alternative check or even prediction of the outcomes of the experiment. One speculative example is given to show a possible way ahead: Consider the scale *Attentive Expression – Relaxed Expression*. In order to relate *attentive* and *relaxed* to one of Ekman’s six emotions, it is noted that *relaxed* seems closest to a moderate *happiness* (this was confirmed by a small trial with several TU/e researchers) in Ekman’s circle representation of the six emotions, which is used in social robotic research (Bondarev, 2002). In this representation anger, *sadness and fear* are negative emotions, more or less opposite to *happiness*. *Anger and fear* share one property: They have high arousal (Russell, 1980). *Attentive* goes at least with some level of arousal. However, *anger* and *fear* are different concerning their direction: *Anger* is directed towards the object and *fear* moves away from it. *Attention* is also directed towards an object. Therefore it is an educated guess that *attentive* resembles a moderate form of *anger*. Now Ekman’s FACS tells that Action Unit 4 (Brow Lowerer) should be activated for *anger* and, in this case study, *attentive*. This corresponds to Average Eyelid Coverage. And indeed, in Figure 5.35 (Expression vs. Average Eyelid Coverage) the experiment shows that a high Average Eyelid Coverage corresponds to a high score of *Attentive Expression*.

5.3 Making Changes

The experiment was successful and demonstrated the possibility to discover statistical correlations between rather complex and interacting design parameters within a headlamp on the one hand and on the other hand character terms that are induced within the viewers mind. This was achieved by shifting the parameter values and observing a correlative shifting of the test persons’ evaluation. A verification test was conducted with a design from extrapolated data in order to test if a) the results are correct and b) if the product character can be enforced by means of parameter extrapolation. The verification test showed that the tendencies discovered in the first analysis were correct in most cases and that the design from the extrapolated data achieved a higher preference.

After all this work, a change can be proposed and design management can take a decision. In this case, the proposal is to expand and partially redesign the construction solution (Figure 5.39) and to create a headlamp according to the extrapolated design (Figure 5.38), which in 2 out of 3 criteria and with respect to preference outperforms the design solution (Figure 5.40). In other words, the carry-over-part strategies influencing LRD, ELD and AEC are to be reconsidered. Furthermore, the use of LED and fiber optics is justified (see Figure 5.2).

The explicit knowledge generated through analyses and models provides a decision basis in the product development process in order to allow well-founded product configuration changes.
6. Chapter: DPSE in Action
Park Distance Control Interface
6.1 Sixth Chapter Target

The second experiment in this chapter six is relevant for the DPSE method’s applicability in the field of acoustic interface design and interaction design, which means that also man-machine interaction is able to induce the subjective sensation of a character (and this is not too strange, since we create and adjust a subjective character impression of a person to a large extent by interacting with this person).

To facilitate acceptance in the intended professional environment, the steps and justifications elaborated in the previous chapters are again embedded into a fictive but believable scenario that might occur in a business setting. Besides the validation of the DPSE method, also the limitations are pointed out.

6.1.1 Annotation

It is emphasized that the aim of the following experiment is not to find the best acoustic interface design per se but to test a method that is capable to find those designs that are optimized to contribute to an agreed product character. The concrete product character terms developed for the experiments are suitable for BMW but fictive.

6.2 Experiment No. 2:

Park Distance Control Interface

It is not purely the visual design of automotive exteriors or interiors that contribute to the perceived product character. Since the presence and importance of embedded electronic interaction devices is increasing rapidly, also the interaction quality with them increasingly contributes to the product character. The second scenario deals with the acoustical man-machine interface of the Parking Distance Control (PDC).

6.2.1 Case Analysis

6.2.1.1 Object, Parameters and Metrics

When parking or backing the vehicle at low speeds, the PDC with its eight ultrasonic distance sensors – four within each bumper – continuously measure the distance to obstacles in front or behind the vehicle and informs the driver about obstacles within the closer environment that can be seen difficultly or not at all from the driver’s position (see Figure 6.1).

Figure 6.1: The PDC ultrasonic sensors measure obstacle position and distance.
The information about obstacle distance and location is primarily provided to the driver by auditory encoding. Nowadays, the distance is encoded by an impulse frequency (25-425 milliseconds). The closer the vehicle approaches the obstacle, the higher the impulse frequency becomes. When the distance falls below 25 cm, a continuous tone is played (see Figure 6.2).

The recent BMW PDC tone is a pure sine wave with a frequency of 1500 Hz (front) and 1000 Hz (rear). In the recent version, a slight amplitude envelope modulation was added in order to make the sound appear more pleasant and natural. The tone envelope onset is zero and the offset is 19 ms (see Figure 6.3). The amplitude envelope is the loudness development of a signal over the time and influences for example the sound’s “percussivity”. The envelope is described through the envelope onset (or envelope attack), envelope sustain and envelope decay.

The exact definition of the acoustic parameters for the analysis is done after consideration of the fields of psychoacoustics.

The obstacle location is encoded by panoramic distribution of the tone signal between four in-car speakers (front left, front right, rear left, rear right) in the vehicle. Recently, visual encoding was added: As it can be seen on Figure 6.4, obstacles are displayed abstractly on the central information display.
6.2.1.2 Innovation and Optimization Demand

Since the PDC was introduced in the mid 1990s, its auditory interface had been optimized and modernized only slightly. The major innovation was the change from buzzer-like tones towards pure sine-waveforms, the introduction of decent amplitude envelope modulation and the visual interface explained above. Anyhow, the sound is still generated by means of a sound-synthesizer instead of a costly sample-player.

Customer feedback and web forum research reveal that some users tend to be irritated by the PDC beeping sound acoustical interface. An automotive component that might cause irritation barely contributes to a pleasant product character. Furthermore, since operating a vehicle is a safety relevant task, the operator should not be irritated, especially in maneuvering situations with high cognitive load. Finally, the PDC acoustical interface is similar with most vehicle brands; the possibility of brand differentiation is not given at present. Under this aspect, the acoustical interface is an interesting research field. Two cardinal requirements exist:

1. The interface usability and reliability has to be retained or optimized (which means that the encoded information has to be interpretable through the user as well or better than with the recent PDC).
2. The interface should be designed to be pleasant in its use and to express a maximum of an agreed brand specific product character.

Therefore, the experimental targets are:

- Interface modernization and functional optimization.
- Product character optimization.
- More interface pleasantness and therefore interior pleasantness.

6.2.1.3 Subjective Metrics

The PDC tone in first instance has an informatory and indicator function and occurs with every front or rear approach towards an obstacle, which is often given in everyday use. Personal communication and internet investigation showed that users often feel bothered by this PDC tone. It seems appropriate to prefer a pleasant and natural sound as long as the system has no urgent warning function. In this fictive scenario the aspired product character attributes concerning the vehicle interior including its electronic soundscape were agreed as usual about 60 months before start of serial production. They are:

- Calculated Modernity
- Polite Attentiveness
- Natural Clarity

Furthermore, the interior soundscape should of course be perceived as pleasant and should only appear urgent when necessary. Again, qualitative semantic differentials are used to measure the subjective impressions.

<table>
<thead>
<tr>
<th>Modernity</th>
<th>calculated</th>
<th>daring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attentiveness</td>
<td>polite</td>
<td>direct</td>
</tr>
<tr>
<td>Clarity</td>
<td>natural</td>
<td>bold</td>
</tr>
<tr>
<td>Pleasantness</td>
<td>pleasant</td>
<td>unpleasant</td>
</tr>
<tr>
<td>Urgency</td>
<td>non-urgent</td>
<td>urgent</td>
</tr>
</tbody>
</table>

These fictive attributes were elaborated with the BMW Group Design Strategy Department and are considered by Hands to suit the context of this dissertation (Jeffrey Hands, personal communication January 19, 2006).
6.2.1.4 Analogous Fields of Research

With auditory perception certain functional attributes and psycho-acoustical effects – particularly maskability and localizability effects – have to be considered when defining the design parameters for the PDC acoustical interface. In this case, masking means that tones are physically masked by other tones or ambient noise in a certain frequency band so that they simply cannot be heard anymore. More exactly, this is given when the sound pressure level of e.g. a pure sinusoidal tone of 1100 Hz lies beneath the sound pressure level of another tone or ambient noise within the sinusoidal tone frequency band of 1100 Hz. The schematic diagram (see Figure 6.5) shows a signal at 1100 Hz that is just above the auditory threshold of 50 dB SPL. This signal is audible. The signal at 3000 Hz is just below the auditory threshold of 40 dB SPL, thus masked and inaudible.

![Figure 6.5: Auditory signal masking.](image)

To forestall masking and in order to improve localizability, Edworthy & Adams (1996) suggest that pure sinusoidal tones of frequencies around 1000 Hz without any overtones should be avoided. At least four harmonic overtones between 500-4000 Hz are required to design a tone that is more difficult to mask and well localizable.

Fundamental frequencies around 200 Hz improve the localizability of the tone. Interestingly, the recent BMW PDC acoustics with pure sinusoidal tones between 1000-1500 Hz fulfill the parameters to be easily maskable and difficult to localize. A possible reason therefore will be discussed at the end of the experiment.

Because acoustic parameters are known to have strong interaction effects, in the second experiment a factorial ANOVA is conducted. So every possible parameter combination will be presented to the test persons. To limit the amount of sound samples the experiment focuses on four design parameters that assumedly have strong influence upon the perception of a sound character.

Considering the targeted character of the PDC interface, Hermes suggested the following influential parameters for the factorial generation of samples. (Dik Hermes, personal communication, February 2007):

- Fundamental Frequency (f =400 Hz, 800 Hz or 1600 Hz)
- Harmonics (1st, 3rd, 5th and 7th)
- Roughness (Modulation Depth h=0.8, Frequency f=70 Hz)
- Amplitude Envelope (abrupt, trapezoid or exponential)

Furthermore, Edworthy & Adams (1996) suggest Fundamental Frequency, Harmonics and Amplitude Envelope as influential upon *Perceived Urgency*.

These parameters are preset to two respectively three values as can be seen in the following Table 6.1. Variant 13 and 25 are close to the recent BMW PDC sounds.
It is known that especially complex sounds obtain their character through countless (dynamic) parameters and parameter combinations as well but with the factorial analysis, a combinatorial problem occurs: Already 36 possible parameter combinations are reached with the quite limited parameter combinations listed above.

According to Houben, Kohlrausch & Hermes (2005), other parameters that, for example, have strong influence on the sound-associated material (skin, rubber, wood, stone, metal or glass) are the distance between the harmonics, harmonic register and harmonic range. Surely, they would be an interesting field of research but investigating these parameters in detail within this context would extremely dilate the possible parameter combinations.

6.2.1.5 Sample Generation

The 36 sound samples were generated in Matlab (MatWorks) according to the specifications in Table 6.1. The programming was done with friendly and generous help of Dr. Ir. Dik Hermes at the Technische Universität Eindhoven Department for Human-Technology Interaction.

Due to psycho-acoustic effects concerning perceived loudness, the following adaptations were applied to the PDC signals. Through Root Mean Square (RMS) normalization the energy in each PDC signal was equalized. Next, to compensate for the loudness increase for signals whose harmonics are spread out over a large frequency range (i.e. loudness summation), the signals with four harmonics were divided by the square root of the number of harmonics, which is 1 (\(\sqrt{1}\)) or 2 (\(\sqrt{4}\)). This guaranteed that all PCD signals were perceived as about equally loud, which was verified by informal listening.

| Table 6.1: Objective Alterations of the 36 PDC Signal Variants |
|-------------------|-------------|--------------|-------------------|--------------|
| Sample Variant    | Fundamental Frequency | Harmonics (1st, 3rd, 5th, 7th) | Roughness (h=0.8; f=70 Hz) | Amplitude Envelope |
| 01                | 400 Hz       | No           | No               |                |
| 02                | 400 Hz       | No           | No               |                |
| 03                | 400 Hz       | No           | No               | exponential   |
| 04                | 400 Hz       | No           | Yes              | abrupt        |
| 05                | 400 Hz       | No           | Yes              | trapezoid     |
| 06                | 400 Hz       | No           | Yes              | exponential   |
| 07                | 400 Hz       | Yes          | No               | abrupt        |
| 08                | 400 Hz       | Yes          | No               | trapezoid     |
| 09                | 400 Hz       | Yes          | No               | exponential   |
| 10                | 400 Hz       | Yes          | Yes              | abrupt        |
| 11                | 400 Hz       | Yes          | Yes              | trapezoid     |
| 12                | 400 Hz       | Yes          | Yes              | exponential   |
| 13                | 800 Hz       | No           | No               | abrupt        |
| 14                | 800 Hz       | No           | No               | trapezoid     |
| 15                | 800 Hz       | No           | No               | exponential   |
| 16                | 800 Hz       | No           | Yes              | abrupt        |
| 17                | 800 Hz       | No           | Yes              | trapezoid     |
| 18                | 800 Hz       | No           | Yes              | exponential   |
| 19                | 800 Hz       | Yes          | No               | abrupt        |
| 20                | 800 Hz       | Yes          | No               | Trapezoid     |
| 21                | 800 Hz       | Yes          | No               | exponential   |
| 22                | 800 Hz       | Yes          | Yes              | abrupt        |
| 23                | 800 Hz       | Yes          | Yes              | trapezoid     |
| 24                | 800 Hz       | Yes          | Yes              | exponential   |
| 25                | 1600 Hz      | No           | No               | abrupt        |
| 26                | 1600 Hz      | No           | No               | trapezoid     |
| 27                | 1600 Hz      | No           | No               | exponential   |
| 28                | 1600 Hz      | No           | Yes              | abrupt        |
| 29                | 1600 Hz      | No           | Yes              | trapezoid     |
| 30                | 1600 Hz      | No           | Yes              | exponential   |
| 31                | 1600 Hz      | Yes          | No               | abrupt        |
| 32                | 1600 Hz      | Yes          | No               | trapezoid     |
| 33                | 1600 Hz      | Yes          | No               | exponential   |
| 34                | 1600 Hz      | Yes          | Yes              | abrupt        |
| 35                | 1600 Hz      | Yes          | Yes              | trapezoid     |
| 36                | 1600 Hz      | Yes          | Yes              | exponential   |
6.2.2 Data Collection

6.2.2.1 Test Group

To achieve statistical reliability, a neutral group consisting of 50 test persons was asked to evaluate the 36 sound samples concerning the five character components *Modernity*, *Attentiveness*, *Clarity*, *Pleasantness* and *Urgency*. BMW employees were excluded to ensure that the result is influenced through expertise knowledge as less as possible. Due to limited time and budget, a convenience sample group was preferred instead of a representative BMW client group – the average BMW buyer in Germany, Great Britain, France, Italy and Spain is male and aged 48 (Josef Köster, personal communication August 27, 2007). The underlying assumption here is that the result from this convenience sample predicts the results that would have been obtained from a sample of average BMW buyers. The convenience sample comprised 50 students and employees addressed at the Universität Hamburg in March 2007; according to Hattula (Marcus Hattula, personal communication, October 22, 2007) n=50 is the statistical basis of the law of large numbers and is considered to be sufficient. The test group was constituted as follows:

**Gender:**
- 54% of the test persons were male
- 46% of the test persons were female

**Age:**
- 72% of the test persons were between 20-30 years old
- 20% of the test persons were between 31-40 years old
- 4% of the test persons were between 51-60 years old
- 4% of the test persons were between 61-70 years old

**Culture:**
- 80% North-Western European
- 8% Eastern European
- 8% Asian
- 2% US-American
- 2% Latin-American

6.2.2.2 Stimulus Presentation

The stimuli were presented in two different manners to ascertain whether a laboratory test provides different results compared to a real parking test. 10% of the tests were conducted in a demonstrator car and its real environment and 90% were conducted as a laboratory test. The laboratory test was conducted with stereo headphones and manually triggered sound samples. To avoid order effects, the stimuli order was completely randomized for each test person. To achieve a realistic parking situation during stimulus evaluation, a PDC prototype was built and implemented into the demonstrator car. The demonstrator is able to simulate a regular stereo rear PDC while its acoustical behavior can be changed between the 36 preset sound variants and sensitivity characteristics. The stimuli were presented through the in-car stereo system in real-time while the test person was backing the car close to an obstacle (see Figure 6.6).

![Figure 6.6: Experimental setup (re-enacted).](image)

6.2.2.3 Demonstrator

The demonstrator was built using Max/MSP 4.5 (Cycling ’74) and sensor kits from Phidgets Inc. This software and hardware combination is a highly efficient visual programming tool since it is extremely flexible, modular and easy-to-learn. It allows rapid hardware and software prototyping: The first prototype was built within three days and the fine tuning until the final patch (see Figure 6.7) took another week.
The software programming was done by the thesis author with friendly help from Ir. Philip Ross at the TU/e (in practice, this meant that Ross introduced the thesis author into many functions of Max/MSP 4.5, provided edifying “extra lessons” and that both did initial programming together. The further structural development of the software and software parameter optimization was done by the thesis author. The first field tests on a parking space where conducted by Ross and the thesis author and are documented on video).

The Phidget kits contain a broad selection of sensors, actuators and displays which can be connected to USB computer interfaces. Two Phidget infrared distance sensors mounted on the rear bumper provide the signals to the Max/MSP patch (see Figure 6.8).

6.2.2.4 Questionnaire Design

The questionnaire design is analogous to the first experiment’s questionnaire which was designed in dialogue with a BMW psychologist (Sarah Rehmann, personal communication, June 2006) and optimized by means of three pretests with BMW employees. It contained a short introduction into the study, the assignment, an evaluation example, 36 blank evaluation scales for the evaluation of five character components per variant and one page including several questions concerning personal statistics. The questionnaire is displayed on the next two pages (Figures 6.9, 6.10 and 6.11). A German questionnaire translation was also available for the test persons.
Survey about the automobile product character

Introduction
Products, especially automobiles, exude a character that is primarily generated through its visual design but also through the information it provides to the driver, e.g., the acoustical feedback of a Parking Distance Control PDC that informs the driver about the obstacles distance behind or in front of the car.

Assignment
In the following, you will hear 36 PDC “test sounds” always in comparison with a “reference sound”. Please evaluate the character you sense with each “test sound” relatively to the “reference sound” by marking the scale with a cross (see example). Please evaluate without hesitating, the first intuition usually is representative. If you do not notice any character difference between test and reference, please place the cross in the middle.

Character Component “Modernity”
Please evaluate, if the “modernity” of the test sound appears rather calculated or daring to you in comparison with the reference sound.

Character Component “Attentiveness”
Please evaluate, if the “attentiveness” of the test sound appears rather polite or direct to you in comparison with the reference sound.

Character Component “Clarity”
Please evaluate, if the “clarity” of the test sound appears rather natural or bold to you in comparison with the reference sound.

Character Component “Urgency”
Please evaluate, if the “urgency” of the test sound appears non-urgent or urgent to you in comparison with the reference sound.

Character Component “Pleasantness”
Please evaluate, if the “pleasantness” of the test sound appears pleasant or unpleasant to you in comparison with the reference sound.

Example:

Thank you for your attendance!

Figure 6.9: Questionnaire design.

Figure 6.10: Subjective evaluation scales.

Please provide some relevant data concerning your person. Person-related data will be appraised anonymously:

Age:
<20 ☐ 20-30 ☐ 31-40 ☐ 41-50 ☐ 51-60 ☐ >60 ☐

Gender:
female ☐ male ☐

Which culture has influenced you most, where did you grow up?
Northwestern Europe ☐ Eastern Europe ☐ Southern Europe ☐ Asia ☐ North America ☐ Latin America ☐ Other ☐

Occupational Grouping / Study Discipline: __________________________

Are you familiar with the PDC system? If so, how often do you use it?
not familiar to date ☐ seldom ☐ often ☐

Figure 6.11: Personal statistics questionnaire.
6.2.2.5 Relative Evaluation

When evaluating objects, it is easier for the test persons to evaluate relatively to a reference or to generate a ranking order with at least two positions than evaluating on an absolute scale. For calibration reasons the test persons hear two sound sample triplets one after another. One is a neutral reference sound sample and the other one a variant sound sample. As can be seen in the questionnaire assignment, the test persons were asked to evaluate the second sound sample compared to the first reference sound sample on the left side. On the evaluation scale the reference sound sample was used as a reference in the middle, so the test persons had to decide whether – for example – the second sound sample expressed a rather Polite Attentiveness or a rather Bold Attentiveness compared to the reference sound sample. The reasons for relative evaluation are the same as in the first experiment.

6.2.2.6 Data Results

The 50 test persons reported their subjective impression and affection towards the 36 variants concerning each character component. All scales of subjective reports are encoded as followed: Subjective reports on the left part of the scale obtain negative values (down to -10) and subjective reports on the right part of the scales obtain positive values (up to +10). Thus, neutral reports are encoded with zero (0).

6.2.3 Data Analysis

Also within the second experiment the data analysis was conducted with friendly help from Prof. Peter König, Hans-Peter Frey and Selim Onat at the Universität Osnabrück Institute for Cognitive Sciences. The software used for this purpose was the same used in the first experiment: Matlab (MatWorks).

6.2.3.1 Variability of Subjective Reports

As a first step, the variability of subjective report in the five different questions (Modernity, Attentiveness, Clarity, Urgency and Pleasantness) was surveyed. The subjective assessment differs considerably across prototypes and the standard deviation of all subjective assessments approaches the range of an equal distribution. This is an important aspect for the further evaluation. However, the variability across subjects is large which might be reasoned in the high level of the product character judgments. Hence, care has to be taken, that the results do not depend on individual outliers. For that purpose a qualitative overview is obtained of the combined dependence of the subjective report on prototype and subject identity.

<table>
<thead>
<tr>
<th>Subjective Reports (n=50)</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modernity</td>
<td>1.481</td>
<td>5.324</td>
</tr>
<tr>
<td>Attentiveness</td>
<td>1.184</td>
<td>5.507</td>
</tr>
<tr>
<td>Clarity</td>
<td>1.317</td>
<td>5.220</td>
</tr>
<tr>
<td>Urgency</td>
<td>1.631</td>
<td>5.476</td>
</tr>
<tr>
<td>Pleasantness</td>
<td>0.699</td>
<td>5.733</td>
</tr>
</tbody>
</table>

6.2.3.2 Influence of Individual Features on Subjective Report

In the following 20 tables and plots, the influence of the individual features (Fundamental Frequency, Harmonic Overtones, Roughness and Amplitude Envelope) on the subjective reports (Modernity, Attentiveness, Clarity, Urgency and Pleasantness) is displayed. Nearly all dependencies between them are significant. Some are however weak.
Modernity

The perceived Modernity is most strongly dependent (positively correlated) on the parameters Fundamental Frequency (FF), Harmonics (HA) and Roughness (RO). A weak negative correlation with Amplitude Envelope (AE) is observed.

Table 6.3: ANOVA of FF – Dependent Variable: Modernity

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fundamental Freq.</td>
<td>4431.01</td>
<td>1</td>
<td>4431.01</td>
<td>171.07</td>
<td>0.0001</td>
</tr>
<tr>
<td>Error</td>
<td>46570.35</td>
<td>1798</td>
<td>25.90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>51001.36</td>
<td>1799</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6.4: ANOVA of HA – Dependent Variable: Modernity

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harmonic Overt.</td>
<td>7507.21</td>
<td>1</td>
<td>7507.21</td>
<td>310.34</td>
<td>0.0001</td>
</tr>
<tr>
<td>Error</td>
<td>43494.15</td>
<td>1798</td>
<td>24.19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>51001.36</td>
<td>1799</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6.5: ANOVA of RO – Dependent Variable: Modernity

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roughness</td>
<td>1824.08</td>
<td>1</td>
<td>1824.08</td>
<td>66.69</td>
<td>0.0001</td>
</tr>
<tr>
<td>Error</td>
<td>49177.28</td>
<td>1798</td>
<td>27.35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>51001.36</td>
<td>1799</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6.6: ANOVA of AE – Dependent Variable: Modernity

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplitude Envel.</td>
<td>244.80</td>
<td>1</td>
<td>244.80</td>
<td>8.67</td>
<td>0.0033</td>
</tr>
<tr>
<td>Error</td>
<td>50756.55</td>
<td>1798</td>
<td>28.23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>51001.35</td>
<td>1799</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 6.12: Bivariate fit of “Modernity” by “Fundamental Frequency”.

Figure 6.13: Bivariate fit of “Modernity” by “Harmonic Overtones”.

Figure 6.14: Bivariate fit of “Modernity” by “Roughness”.

Figure 6.15: Bivariate fit of “Modernity” by “Amplitude Envelope”.

175
Attentiveness

The perceived Attentiveness is most strongly dependent (positively correlated) on the parameters Fundamental Frequency (FF) and Harmonics (HA), less on Roughness (RO). A weak negative correlation with Amplitude Envelope (AE) is observed.

Table 6.7: ANOVA of FF – Dependent Variable: Attentiveness

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fundamental Freq.</td>
<td>6299.00</td>
<td>1</td>
<td>6299.00</td>
<td>234.69</td>
<td>0.0001</td>
</tr>
<tr>
<td>Error</td>
<td>48257.13</td>
<td>1798</td>
<td>26.84</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>54556.13</td>
<td>1799</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6.8: ANOVA of HA – Dependent Variable: Attentiveness

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harmonic Overt.</td>
<td>8145.13</td>
<td>1</td>
<td>8145.13</td>
<td>315.55</td>
<td>0.0001</td>
</tr>
<tr>
<td>Error</td>
<td>46411.00</td>
<td>1798</td>
<td>25.81</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>54556.13</td>
<td>1799</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6.9: ANOVA of RO – Dependent Variable: Attentiveness

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roughness</td>
<td>483.61</td>
<td>1</td>
<td>483.61</td>
<td>16.08</td>
<td>0.0001</td>
</tr>
<tr>
<td>Error</td>
<td>54072.53</td>
<td>1798</td>
<td>30.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>54556.14</td>
<td>1799</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6.10: ANOVA of AE – Dependent Variable: Attentiveness

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplitude Envel.</td>
<td>1559.52</td>
<td>1</td>
<td>1559.52</td>
<td>52.91</td>
<td>0.0001</td>
</tr>
<tr>
<td>Error</td>
<td>52996.61</td>
<td>1798</td>
<td>29.48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>54556.13</td>
<td>1799</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Clarity
The perceived Clarity is most strongly dependent (positively correlated) on the parameters Fundamental Frequency (FF) and Harmonics (HA) as well, less on Roughness (RO). A weak negative correlation with Amplitude Envelope (AE) is observed.

Table 6.11: ANOVA of FF – Dependent Variable: Clarity

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fundamental Freq.</td>
<td>4976.89</td>
<td>1</td>
<td>4976.89</td>
<td>203.16</td>
<td>0.0001</td>
</tr>
<tr>
<td>Error</td>
<td>44046.61</td>
<td>1798</td>
<td>24.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>49023.50</td>
<td>1799</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6.12: ANOVA of HA – Dependent Variable: Clarity

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harmonic Overt.</td>
<td>7921.21</td>
<td>1</td>
<td>7921.21</td>
<td>346.51</td>
<td>0.0001</td>
</tr>
<tr>
<td>Error</td>
<td>41102.29</td>
<td>1798</td>
<td>22.86</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>49023.50</td>
<td>1799</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6.13: ANOVA of RO – Dependent Variable: Clarity

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roughness</td>
<td>1203.77</td>
<td>1</td>
<td>1203.77</td>
<td>45.26</td>
<td>0.0001</td>
</tr>
<tr>
<td>Error</td>
<td>47819.73</td>
<td>1798</td>
<td>26.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>49023.50</td>
<td>1799</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6.14: ANOVA of AE – Dependent Variable: Clarity

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplitude Envel.</td>
<td>771.20</td>
<td>1</td>
<td>771.20</td>
<td>28.74</td>
<td>0.0001</td>
</tr>
<tr>
<td>Error</td>
<td>48252.30</td>
<td>1798</td>
<td>26.84</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>49023.50</td>
<td>1799</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Urgency

The perceived Urgency is most strongly dependent (positively correlated) on the parameters Fundamental Frequency (FF) and Harmonics (HA). A negative correlation with Amplitude Envelope (AE) is observed.

Table 6.15: ANOVA of FF – Dependent Variable: Urgency

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fundamental Freq.</td>
<td>7542.91</td>
<td>1</td>
<td>7542.91</td>
<td>292.35</td>
<td>0.0001</td>
</tr>
<tr>
<td>Error</td>
<td>46390.41</td>
<td>1798</td>
<td>25.80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>53933.32</td>
<td>1799</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6.16: ANOVA of HA – Dependent Variable: Urgency

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harmonic Overt.</td>
<td>7519.47</td>
<td>1</td>
<td>7519.47</td>
<td>291.29</td>
<td>0.0001</td>
</tr>
<tr>
<td>Error</td>
<td>46413.85</td>
<td>1798</td>
<td>25.81</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>53933.32</td>
<td>1799</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6.17: ANOVA of RO – Dependent Variable: Urgency

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roughness</td>
<td>7.35</td>
<td>1</td>
<td>7.35</td>
<td>0.25</td>
<td>0.621</td>
</tr>
<tr>
<td>Error</td>
<td>53925.97</td>
<td>1798</td>
<td>29.99</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>53933.32</td>
<td>1799</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6.18: ANOVA of AE – Dependent Variable: Urgency

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplitude Envel.</td>
<td>1950.75</td>
<td>1</td>
<td>1950.75</td>
<td>67.47</td>
<td>0.0001</td>
</tr>
<tr>
<td>Error</td>
<td>51982.57</td>
<td>1798</td>
<td>28.91</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>53933.32</td>
<td>1799</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 6.24: Bivariate fit of “Urgency” by “Fundamental Frequency”.

Figure 6.25: Bivariate fit of “Urgency” by “Harmonic Overtone”.

Figure 6.26: Bivariate fit of “Urgency” by “Roughness”.

Figure 6.27: Bivariate fit of “Urgency” by “Amplitude Envelope”.

181
Pleasantness

The perceived Pleasantness is most strongly dependent (positively correlated) on the parameters Fundamental Frequency (FF), Harmonics (HA) and Roughness (RO). A weak negative correlation with Amplitude Envelope (AE) is observed.

### Table 6.19: ANOVA of FF – Dependent Variable: Pleasantness

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fundamental Freq.</td>
<td>7559.33</td>
<td>1</td>
<td>7559.33</td>
<td>263.54</td>
<td>0.0001</td>
</tr>
<tr>
<td>Error</td>
<td>51573.46</td>
<td>1798</td>
<td>28.68</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>59132.80</td>
<td>1799</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 6.20: ANOVA of HA – Dependent Variable: Pleasantness

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harmonic Overt.</td>
<td>8183.47</td>
<td>1</td>
<td>8183.47</td>
<td>288.79</td>
<td>0.0001</td>
</tr>
<tr>
<td>Error</td>
<td>50949.33</td>
<td>1798</td>
<td>28.34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>59132.80</td>
<td>1799</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 6.21: ANOVA of RO – Dependent Variable: Pleasantness

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roughness</td>
<td>1938.57</td>
<td>1</td>
<td>1938.57</td>
<td>60.94</td>
<td>0.0001</td>
</tr>
<tr>
<td>Error</td>
<td>57194.23</td>
<td>1798</td>
<td>31.81</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>59132.80</td>
<td>1799</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 6.22: ANOVA of AE – Dependent Variable: Pleasantness

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplitude Envel.</td>
<td>910.02</td>
<td>1</td>
<td>910.02</td>
<td>28.10</td>
<td>0.0001</td>
</tr>
<tr>
<td>Error</td>
<td>58222.78</td>
<td>1798</td>
<td>32.38</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>59132.80</td>
<td>1799</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 6.28: Bivariate fit of “Pleasantness” by “Fundamental Frequency”.

Figure 6.29: Bivariate fit of “Pleasantness” by “Harmonic Overtones”.

Figure 6.30: Bivariate fit of “Pleasantness” by “Roughness”.

Figure 6.31: Bivariate fit of “Pleasantness” by “Amplitude Envelope”.
6.2.3.3 Overall Summary
Most subjective reports are positively correlated with Fundamental Frequency, Harmonics, somewhat less with Roughness and very little or negative with Amplitude Envelope.

6.2.3.4 Multivariate Analysis of Dependent Variables
The multivariate analysis demonstrates a close positive relation of the subjective reports of all dependent variables with at least ($r = .95$ $p<.05$). Only the correlation of Urgency with the other subjective reports is (just) below ($r = .9$ $p<.05$).

6.2.3.5 Generative Model
Modeling the subjective report with five hidden nodes leads to a reasonable prediction based on the given parameter set in form of the 36 prototypes (predictability: Modernity 94%, Attentiveness 96%, Clarity 95%, Urgency 94% and Pleasantness 96%). Five nodes seem suitable considering the amount of degrees of freedom (modeling with less than five nodes lead to bad fits, six and seven nodes do not yet reach the point of overfitting).

Given the limitations of the experimental design, for feature combinations outside the parameter space tested, additional experimental data should be obtained to validate these predictions. Nevertheless, parameter values of means and weights allow predicting the effect of arbitrary feature combinations in order to reach targeted values of the subjective reports.

6.2.4 Data Interpretation
Compared to the first experiment the second PDC experiment provided very clear data. Due to the previous detailed data analysis, the following conclusions can be drawn for each character component. To provide the agreed product character tending to Calculated Modernity, Polite Attentiveness and Natural Clarity to the acoustic interface and to achieve low perceived Urgency and high perceived Pleasantness in the interface, the design parameters of the PDC acoustic interface should tend as described in the following.

**Modernity**
Figure 6.32 indicates that a lower Fundamental Frequency, the absence of Harmonics, the absence of Roughness and an exponential Amplitude Envelope contribute to the perception of a rather Calculated Modernity.

![Figure 6.32: Modernity vs. Fundamental Frequency, Harmonics, Roughness and Amplitude Envelope.](image)

**Attentiveness**
Figure 6.33 indicates that a lower Fundamental Frequency, the absence of Harmonics, the absence of Roughness and an exponential Amplitude Envelope contribute to the perception of a rather Polite Attentiveness.
Figure 6.33: Attentiveness vs. Fundamental Frequency, Harmonics, Roughness and Amplitude Envelope.

Clarity
Figure 6.34 indicates that a lower Fundamental Frequency, the absence of Harmonics, the absence of Roughness and an exponential Amplitude Envelope contribute to the perception of a rather Natural Clarity.

Figure 6.34: Clarity vs. Fundamental Frequency, Harmonics, Roughness and Amplitude Envelope.

Urgency
Figure 6.35 indicates that a lower Fundamental Frequency, the absence of Harmonics and an exponential Amplitude Envelope contribute to the perception of a rather low Urgency.

Figure 6.35: Perceived Urgency vs. Fundamental Frequency, Harmonics, Roughness and Amplitude Envelope.

Pleasantness
Figure 6.36 indicates that a lower Fundamental Frequency, the absence of Harmonics, the absence of Roughness and an exponential Amplitude Envelope contribute to the perception of a rather high Pleasantness.

Figure 6.36: Pleasantness vs. Fundamental Frequency, Harmonics, Roughness and Amplitude Envelope.
6.2.5 Conclusion

According to the results of the previous data interpretation, a conclusion can be drawn. In order to let the acoustical PDC interface express Calculated Modernity, Polite Attentiveness, Natural Clarity, low Urgency and high Pleasantness, the Fundamental Frequency has to be low, Harmonics and Roughness have to be absent and the Amplitude Envelope should be exponential, as it is in tone variant No. 3. The four suggested parameters had measurable influence on the five character components. Figure 6.37 shows all cumulated design parameters that contribute to the product character.

Figure 6.37: Cumulated design parameters and expressed character.

6.2.6 Differences between Laboratory Tests and In-Car Tests

No differences between the 45 laboratory tests and the 5 in-car-tests were observed. It can be assumed that the evaluations of test samples via headphone and in-car are very similar.

6.2.7 Verification Test

The results in the second experiment were lucid and the extrapolation of the design parameters to optimize parameters was not necessary or it was impossible (the amount of Harmonics and Roughness is already zero within the latest BMW PDCs). These parameters were chosen correctly because of the following reason: The parameters do have influence upon the targeted product character. The experiment showed that, in order to achieve the targeted character, these parameters have to be kept adjusted to zero and the Amplitude Envelope requires an exponential characteristic. The Fundamental Frequency should be as low as possible but should still consider functional aspects such as localizability and maskability. By those reasons, no parameter extrapolation and verification test was conducted.

6.2.8 Limitations

In order to keep the analysis manageable, all tested parameters as well as their ranges have to be predefined in order to limit the amount of sample variants and test persons. It is self-evident that especially more complex sounds contain countless interdependent parameters like fundamental frequency, harmonics, harmonic register, harmonic range and amplitude envelope etc. The complex sounds of musical instruments like strings, woodwinds or brass instruments even have characteristic temporal modulation changes of all these parameters. Without the temporal modulation aspect many instruments would not be distinguishable. Again, the conclusion is that the complexity of an object leads to a fast growing amount of parameter combinations.

6.2.9 Annotation

It was mentioned before that the recent PDC signals are not perfect concerning their maskability and localizability since their fundamental frequencies are at 1000 Hz and 1500 Hz and do not contain any harmonic overtones or roughness. Under aspects of localizability and maskability the current sound design is questionable but since those parameters are
strongly responsible for the perceived pleasantness as well their adjustment is a trade-off between functionality and pleasant use. However, since the PDC is only used in engine idle where the background noise and therefore the masking threshold remain low, the maskability aspect does not preponderate.

6.2.10 Implementation of an Adaptive PDC

The information that is obtained within this experiment can be used to advance the PDC. On the one hand, the PDC is a warning device that should appear urgent in order to prevent collisions. On the other hand, it should sound pleasant and non-irritating.

Anyhow, functionality and pleasantness do not have to exclude each other: It might be very useful to develop a system that is able to adapt its behavioral character depending on the situation. This would enable a PDC that appears non-urgent (and less irritating) in less urgent situations and – vice versa – highly urgent in situations where the driver risks a car damage and an immediate driver reaction is required.

According to the experimental results, the most pleasant and character-targeted standard PDC sound should be around 400 Hz, with an exponential amplitude envelope and without harmonic overtones and roughness (Sample Variant No. 3). But with increasing situational urgency, for example when the obstacle distance or the approaching speed (and therefore the resulting “time to contact”) reach critical levels, the PDC signal becomes more urgent in its acoustical appearance. This is visualized below (see Figure 6.38).

Figure 6.38: Time to Contact controls Perceived Urgency.

The increase of perceived urgency, for example, can for example be achieved by increasing the signal roughness and/or amount of harmonic overtones and/or fundamental frequency. A further experimental development and testing of the adaptive PDC appears worthwhile.

6.3 Making Changes

Also the second experiment was successful and demonstrated the possibility to discover correlations between rather complex and interacting acoustical design parameters on the one hand and targeted character terms that are induced within the viewers mind on the other hand.

These insights can be used in product development to achieve a product character optimization, to increase interface pleasantness and to achieve differentiation to competitors without raising production costs: Still, the sound-synthesizer instead of a costly sample-player is used.
7. Interviews & Conclusion
7.1 From Action to Reflection

Following Swann (2002), Action Research arises from a problem, dilemma or ambiguity in the situation in which practitioners find themselves. Three conditions apply to Action Research:

- The subject matter is situated in a social practice being changed.
- Action Research is a participatory activity.
- The project proceeds through a spiral of cycles of planning, acting, observing and reflecting.

In order for DPSE to be successful, it has to be acceptable and adapted optimally to the social practice for which it is intended. Therefore, most of this chapter is devoted to interviews with a number of stakeholders. This is essential for the evaluation of the Action Research at process level (see section 2.1.1). Most of the evaluation of the work at product level has been done already in Chapters 5 and 6.

Note the participatory nature of that evaluation: Designers are involved with the generation of variants, others are involved in evaluating them; design strategists generate character terms. Several categories of test subjects participated, such as students and employees of Universities of Hamburg and Munich and for the extra verification step in Chapter 5, TU/e students and BMW designers.

To complete the abovementioned cycle, Section 7.4 is devoted to reflection and, finally, Section 7.5 is about the next cycle of the spiral, options for future research.
7.2 Designer Opinion

In the previous chapters, the DPSE method functioning was developed and experimentally tested. Since DPSE should be able to support designers in their work, the following interviews with BMW Group Design employees where conducted for three reasons: a) to identify business conditions that might hinder practical applicability, b) to elaborate DPSE optimization potentials with experienced experts and c) to obtain a nuanced expert opinion about such a method in general.

All interview partners agreed that their personal opinion may be published within this dissertation. The interview partners were (in chronological order):

- Oliver Heilmer, Interior Designer of the BMW X5 (E70) and X6 (E71)
- Michael Markefka, Exterior Designer of the BMW 3 Series Coupé (E92) and Convertible (E93) and Rolls-Royce Exterior Designer
- Daniel Wechner, Transportation Designer at the BMW Group Advanced Design Studio, currently Requirement Manager at Design & Perceived Quality Management
- Jeffrey Hands, Industrial Designer at BMW Group Design Strategy

The abstract method principle was explained to the designers. They were asked to imagine a fictive method that is able to create a link between design parameters (e.g. proportions, surface language, material texture, color etc.) and the product character as a subjective impression that these parameters induce within a viewer. Subsequently, they were asked the following four questions as an interview compendium:

Do you think that such a method could help you in your everyday business as a designer? If so, please explain how. Please differentiate between the pure designing (e.g. sketching, modeling) and the process work (discussing, arguing for the design solutions in the design-engineering-convergence process).

Concerning the authentic use and design of materials, Heilmer (2007) recommends that the method might help reducing struggles within the design-engineering-convergence process if it was able to provide a booklet or database with material appropriate edge radii (this means that, for example, the edge radii on a leather-grained dashboard have to be appropriate to authentic edge radii that leather would adopt; and not rather appropriate to tooling possibilities. The same applies upon metal parts, textile parts etc.).

Figure 7.1: Interview partner Oliver Heilmer.
Wechner (2007) sees the most feasible advantage in a database that contains explicit knowledge about the worldwide common understanding of certain character terms, e.g. “boniness” within their context. This database should not be seen as an imperative but more as a helpful reference book (like e.g. Wikipedia) to gather validated assertions. This database has to be revised continuously in order to grasp the current zeitgeist as well.

Hands (2007) constitutes that such a method would form a bridge between the understanding for different people who are involved in design, e.g. marketing, project and design management. It can create a unifying language and enable targeted creativity in order to achieve more clearly articulated goals.

Do you think that such a method could have disadvantages for you as a designer? If so, please mention them.

Heilmier (2007) states that the method would not be able to help within sketching and modeling since this phase is distinctively coined with “gut instinct”. Furthermore, this method could restrict the creative space. But nevertheless, it would be interesting to engage the method in order to explain and investigate design solutions retrospectively.

Markefka (2007) quotes that such a method would not be helpful within the design process: The process requires a certain amount of creative space since there are numerous legal, technical and economical constraints and necessities anyway. The designer’s personal experience is one of the richest sources of design innovation. Without the designer’s personal experience, the design would not advance throughout the years. Markefka mentions that the designer has to reconsider his work continuously.

Wechner (2007) claims that no method should be forced upon the design process and cites the information database Google as an example: Google figuratively contains merely the knowledge of the whole world but only a novel creative idea is capable of creating something completely unprecedented and this is necessary for progress and advance.

Hands (2007) finds important that people who are involved with this method have to be enlightened what the method is able to do and what it is unable to do: It is a fallacy to expect that the method is able to give all answers and that creative exploration is no longer needed. Design is not a formula. However this method could optimize the practices of creativity and free thinking.
If such a method would exist, where do you think it would work best (e.g. proportions, surface language, details, graphic materials etc.)?

Heilmer (2007) suggests that mainly exterior proportions, wheel sizes or interior proportions could be treated with such a method. In the interior it might be worthwhile to test where certain materials should be placed or how the contrasting surfaces might be arranged.

Markefka (2007) imagines that, for example, the field of acoustics can be analyzed successfully. Since acoustics are not among his core competences, he emphasizes that this is an assumption.

Wechner (2007) assumes that the method can be applied best to issues that are disconnectable from their context (see Figure 7.5).

According to Hands (2007), the method might be able to increase the general understanding of issues like surface language and proportions. Also the arrangement and juxtaposition of different kinds of materials could be treated with the method: How, for example, is the perception of a higher value material being influenced by surrounding inferior materials. Moreover, associations are important in design perception. With the method, designers can make themselves aware what associations are induced within a non-designer perceiving a design.

Where would the method never work because design is so complex and subtle that no method could ever find out the reasons why e.g. a Rolls-Royce expresses grace and wisdom, why a BMW appears dynamic already when standing still and why a MINI expresses sexiness?

According to Heilmer (2007), the surface language lives on extremely subtle nuances and on the designer’s individual sense for forms and cannot be treated sufficiently with statistical methods.

Markefka (2007) finds that the method is not applicable to the pure design process, since one design requirement admits a thousand design solutions. The ultimate design solution is depending on the whole design team including the designers, modelers and design managers.

Prized input from Markefka (2007) is also that designers do not just react on changes, they define them as well. Since the method can only be tested with existing test person knowledge, it is difficult to obtain useful test results with completely new design stimuli that might “overstrain” the test persons during the first test but might still be successful design stimuli after product launch when people begin to “understand” the design.
Figure 7.4: Interview partner Michael Markefka.

Markefka (2007) concludes: Design democratization holds problems. Concerning the most design issues it is a “Center of Competence”-responsibility since the emotions elicited by designed stimuli cannot be mapped in their whole complexity and, furthermore, emotions are highly individual.

Wechner (2007) quotes that it is beneficial for the method if issues and objects are clearly dissoluble and consults examples from automotive interior and exterior. But the more integrated and organic an object is and the higher the object complexity is, the more difficult it becomes to find stand-alone parameters that are responsible for certain subjective impressions. The parameters become interdependent within this conglomerate. One example is the evolution of headlamps: They were mostly mounted as separate reflector lamps in a chrome housing in the 1930’s, then became slightly integrated into the fender since the 1940’s and nowadays they are often geometrically not distinguishable any longer from the car body (see Figure 7.5). Probably, in the future, they won’t be recognizable as lamp when switched off.

Figure 7.5: Integration of parts, e.g. headlamps, over the time. The more integrated parts are into the sculpture, the more difficult their analysis might be.

Wechner concludes: When countless factors that result from decades of learning and experience come together and originate a Michelangelo artwork, one is not able to reliably trace or cluster all necessary factors.

Also Hands (2007) describes limitations: Design and product perception also deal with historical perception. For example, concerning Rolls-Royce, “homage & heritage for innovation” are major aspects. It would be difficult for such terms can be grasped, described or mapped by methods. Or concerning “youth”, a product can express youth in different manners, since the BMW 1 Series and 3 Series both appear young: The 1 Series – shown in Figure 7.6 – creates the appeal to youth, amongst others, through “unexpectedness” or
“mischievous” which helps differentiate young people, however it may not be experienced as attractive by others. This is done by its physical design but also by its historical brand context.

Conversely, the 3 Series – shown in Figure 7.7 – accentuates physical fitness and athletic appearance and therefore creates the impression of youth. With these conditions it is attractive to middle-aged drivers who feel young and value a healthy, youthful appearance.

Although both models express youth, a sense of deliberate difference between the 1 Series and 3 Series is obvious. And this impression is achieved through completely different parameters.

7.2.1 Interview Conclusion

The main results of the designer interviews are the following:

- A method like DPSE has to preserve creative space.
- The method should not and cannot substitute the creative design phase, in which a design progress has to be generated.
- However, the creative design phase can profit by a knowledge database which contains information about how objects or certain design parameters are perceived in general.
- It can be used to achieve a more common understanding and a unifying language between people from different professional fields.
7.3 Neuro-Scientist Opinion

Another interview was conducted with neuro-scientist Prof. Dr. Dr. Gerhard Roth (Gerhard Roth, personal communication, July 16, 2007). Roth’s research focus lies in the fields of cognitive and emotional neuro-biology, theoretical neuro-biology and neuro-philosophy.

The DPSE method’s basic principle was explained and discussed and Roth’s following contributions should be considered with further experiments and method application.

Roth states that purchasing decisions are highly intuitive and mostly unconscious. The decision is extremely difficult to verbalize and to justify since verbalizing brain areas have limited access to emotional brain areas.

In order to obtain information which is induced through a stimulus (e.g. a product) within a test person the conscious disturbances should be suppressed as far as possible.

In an experiment, this can be achieved by forcing quick answers using promptness-depending rewards. Therewith, cogitation is somewhat suppressed. Another possibility to “bypass” conscious disturbances is to use masked stimuli: The relevant stimulus (e.g. a product) is presented for just a few milliseconds followed instantly by a longer and neutral masking stimulus. Although the masked relevant stimulus is not processed consciously it still biases polled answers or opinions.

Neuro-marketing pretends to give detailed answers to the fundamental questions that companies have about their products and their customers.

Indeed, Functional Magnetic Resonance Tomography is able to detect product-induced strong and basic emotions like joy or disgust. However, the spatial and temporal resolution of these methods is not fine enough to grasp more subtle information. And, again, this subtleness is what is of interest for us.

Roth concludes that neuro-scientists, and therefore neuro-marketers as well, are far from reading thoughts.
7.4 Final Conclusion

7.4.1 What can be achieved with DPSE?

The two experiments showed that DPSE provides a powerful approach to find interdependencies between graspable design parameters or rather complex character design issues such as facial expression, gesture, surface language etc. and the induced perception within the viewer.

The following main advantages are given through DPSE:

- DPSE can help to substantiate design (parameter) decisions, since an officially agreed target product character is mapped to design parameters.
- DPSE helps to adjust the design parameters in a way that a targeted product character is enforced.
- DPSE is a methodical approach that helps in the understanding of what makes people characterize products as, for example, polite or bold, what leads to a product exuding an Incisive Mindset and an Attentive Expression.

The main contribution of this research might not only be in the details of the experiments in Chapters 5 and 6, but in the intervention done at process level. The essential steps are the blocks “Elements of Interest”, “Analogous Fields of Research”, “Objective Parameters” and Objective Metrics” as seen in Figure 4.7. The DPSE process offers a slot for plug-ins. The nature of this plug-in is a body of knowledge and lingo chosen especially for a specific problem. This allows the usage of modularized knowledge.

As in modern engineering disciplines like electronics and software engineering, complexity management is a major issue in automotive development. Earlier work on complexity management addressed the systematic analysis of requirements (Suh, 1990), the systematic clustering of problems and sub-problems (Alexander, 1964) and the theory of black-box and glass-box correctness of components and assemblies thereof (Feijs, 1990). These works belong to the tradition of scientific objectivity and positivist formulas mentioned by Swann (2002) in his paper on Action Research and in Section 2.2.1 of this thesis. These works offer a modularization but do not address subjective aspects. The process intervention of this thesis helps in complexity management while still addressing subjectivity. The relevance of this intervention will grow when more cultural knowledge, perception theory, emotion theory, design knowledge etc. becomes available. Already now, the piled-up literature on visual perception is huge. The method supports the mindset of opening the doors to integrate more types of knowledge. For example, the theory relevant to Chapters 5 and 6 has by far not been exhausted, which is not a limitation of this thesis, but there is more research done on visual and auditory perception than any single person could possibly study. But exploiting a part of the available knowledge can be done in an engineering approach.

7.4.2 Limitations

Although DPSE provides insight into the connection between objective design parameters and subjective impressions, it cannot always be guaranteed that a) all and b) the optimal parameters are treated. A simple example (see Figure 7.9) clarifies the limitations: Whereas the silverness, roundness, heaviness and glossyness of the ball on the left side can be described by means of a few significant parameters (e.g. diameter, gloss level and...
color) an iPod (excluding interaction) needs much more parameters to be described sufficiently – for example in its *cleanness* – although it still has one of the most simple geometries and less than ten perceivable materials. However, the number of parameters that form for example the car’s *aggressiveness*, *sexiness* or *astuteness* shown on the right side tends to infinite. Finding exactly that one optimal parameter setup that delivers the statistical maximum of agreement concerning a character term is impossible; too “many roads lead to Rome”. Therefore, DPSE is not a *synthesis method* as soon as high complexity and strong parameter interaction is involved. Nevertheless, the two experimental analyses showed that certain sub-aspects (e.g. headlamp or PDC interface) of a complex object are analyzable with certain accuracy. DPSE is an *analysis method*.

Figure 7.9: Rising complexity in geometry and material.

Especially current automobiles often are markedly complex concerning their design: Their gestures are similar to human or animal body language, their surface geometry or cut line graphics are supposed to tell a semiotic and evolutionary story of the form. The contents of these stories often are about speed, eolian erosion, pulling, dragging and running the claws into the asphalt. And these stories are already readable with a parked car. The information is encoded in their geometry. The language that a well designed object speaks often is extremely subtle and subliminal and it is fine art to bring this content into sketches and to model this information into clay. It is interesting that this formal subtleness seemed to decrease or vanish with some products between 1970-1990, when Computer Aided Styling (CAS) had prevailed but virtual surface modeling tools and computer performance still were poor. The virtual tools were not capable to generate or handle “organic” surface complexity but they were capable to process rather simple mathematic geometries like cylinders, cuboids or extrusions with simple fillets. That is how many cars and other products looked like in those times (and, surprisingly, even until quite recently).

Nowadays computers are fast enough to process extremely complex, organic geometries real-time in photographic quality whereas the software modeling tools still are not able to completely replace physical hands-on and eyes-on 1:1 clay modeling (see Figure 7.10). But clay modeling and CAS perfectly complement one another.

Figure 7.10: Clay modeling of the Rolls-Royce Phantom.
An analogous performance condition can be seen in DPSE. Nowadays, no statistical model or method is sufficient to grasp and map all four-dimensional, complex and interdependent parameters of the subtle interplay between object (product) and subject (viewer). The data mesh is not woven finely enough to grasp the subtleness that is causing subjective qualia within the viewer’s mind. Character terms as well as fascination stay emergent mental concepts and processes (see Figure 7.11). It is questionable whether and when this complexity will be manageable and emergence will be less emergent. It is probably easier to anticipate the anthill out of the single ant.

Figure 7.11: Character terms are emergent phenomena within our brains and as difficult to predict as the anthill out of the ants.

7.4.3 Discussion

Emergence as well as neuro-sciences are highly contributory fields for understanding product perception.

Concerning this matter, a group of leading neuro-scientists around Monyer et al. (2004) conclude: “In the foreseeable future – within the next 20 to 30 years – neuro-sciences can explain the interdependency between neuro-electrical and neuro-chemical processes on the one hand and perception, cognitive, psychic and motor activities on the other hand to that degree, that these bi-directional interdependencies can be predicted with a high probability. According to Monyer et al. (2004), this means that mind, consciousness, emotions, acts of volition and freedom of action can consistently be seen as natural events since they bear on biological processes. Anyhow, a complete explanation of brain functioning – a consistent decoding on cellular level or even molecular level – is not achieved. Especially the explanation of the individual brain and the prediction of individual behavior will remain extremely constricted. This is because the individual brain organizes itself after individual genetic disposition and non-reproducible environmental imprinting, namely according to individual needs and an individual value system. Therefore, it is generally impossible to deduce individual mental events from the registration of brain activity.”

Psychologist Rösler (2004) concludes that the precise prediction of individual human behavior and evaluation stays impossible due to individuality and plasticity of the human brain as a matter of principle. Even if the brain functions deterministically, it will never be explainable in its full complexity. Anyhow, this does not exclude the possibility that behavioral tendencies beyond randomness can be explained.
However, the individual brain and individual evaluation is involved with DPSE. To achieve DPSE analysis robustness and reliability, a factorial analysis of as many parameters as possible is worthwhile, this means that every possible parameter combination is generated and tested.

Since designed objects are described by many parameters and again sub-parameters concerning geometry, color, material, sound and haptics the amount of possible feature combinations easily assumes such alarming proportions that they become simply unmanageable. Due to limited time and budget, limitations in the analysis setup have to be considered. If these limitations are not well-founded, the analysis becomes insignificant. As things are now, the DPSE method is applicable when the majority of parameters or possible degrees of freedom are fixed (the design is given through a design framework) and only sub-aspects (of the design) with a few parameter variables are treated with the analysis. The fewer variables are treated simultaneously the more reliable the treatment becomes due to less possible interaction effects.

Also, to provide reliable output, every new product context requires its own analysis. The new context might already occur with another product color (e.g. black, silver or white car), other materials, other leather or wood grains (e.g. wooden, piano black or aluminum trim strip), within other cultural groupings (e.g. European, US-American or Asian). Also analyses in different temporal contexts might provide even oppositional results: If one is asked about the character of an innovative design as it rolls on the asphalt for the first time, he might give another evaluation than what he would say after half a year when he is used to this new stimulus. Hence, an infinite set of interdependent, conglomerated parameters that is neither available at the beginning of the product development nor at product launch should be considered within the optimum analysis. This is why design parameterization is so extremely sensitive and fragile. Furthermore, the interaction effects might also hinder the design parameterization. A good example for the interaction effects is the surface language: Of course, the radii of several creases, cambers, sweeps or splines might be used to determine if a car appears sinewy and athletic or rather brawny. Analogies with skin that is tauten over bones, sinews or fat are articulate or also fabrics that are tauten over different kinds of rods (see Figure 7.12).

![Figure 7.12: Visualization of fat, bony and sinewy surface language of drapery.](image)

However, the complex and aesthetic interplay between those countless geometry details and the perceiving brain is too complex to be parameterizable in a sufficient granularity that would also ensure aesthetic appearance. The following three Figures 7.13, 7.14 and 7.15 basically show the same BMW M5 Touring concerning proportions and details. Merely the surface characteristics are modified and shifted into a rather athletic (Figure 7.15) and a rather brawny (Figure 7.14) appearance. These changes would already be difficult to parameterize and it would take a creative person’s eye to adjust all possible parameters sensibly by visualizing them in a drawing or by modeling them into clay.
However, the two experiments showed that, in many cases, this design analysis method DPSE is able to substantiate design decisions with hard, quite scientific facts.

DPSE is not a design synthesis method that can provide a (wholehearted and professional) design according to verbal specification, but it is a design analysis method that can provide important explicit information and inspiration for the design synthesis.

The creative hands-on design process can be complemented by this scientific design analysis method but in case of doubt, trust the person skilled in the art, since the holistic design effect is – especially with complex designed objects – an emergent phenomenon. In order to let a clearly defined design effect emerge and in order to ensure a continuous design progress, creativity is mandatory and according to Lotter (2007), “pure creativity is not scalable and it lives on freedom and reliance”.

Figure 7.13: BMW M5 Touring with its original surfaces.

Figure 7.14: BMW M5 Touring with modified surface language to appear brawny.

Figure 7.15: BMW M5 Touring with modified surface language to appear athletic.
7.5 Options for Future Research

Adaptive Product Character
As a design parameter within a designed object is identified to have major influence upon the perceived product character, this design parameter can be designed to be adaptive. Therefore the product character – coupled to the design parameter – will also be adaptive. This, for example, can be used to achieve adaptive facial expression or bodily gestures of a car (or robotic products), depending on the mode of use (see Figures 7.16). Both the theoretical research and the technological and material research provide exciting and promising options for future research.

Adaptive Product Behavior
Also non-visual design aspects provide a vast field of application: For example speech synthesis that is depending on the driver’s mood or driving situation (e.g. the car’s speech prosody adapts) or steering wheels, pedals and pushbuttons that behave “unruly” in order to minimize driver mistakes and accidents. Also driving assistants and comfort devices can be made adaptable from dominant to diffident.

Advanced Product Configurator
Certain customer groups tend to prefer individual “bespoke” products rather than mass produced articles. This especially applies to cars. Therefore, it would be worthwhile to advance the “product configurators” (known from car manufacturer websites) where not only color, carpeting and wheel rims can be configured but where the car obtains its appearance through adjustment on semantic scales according to the intended specific use or according to the customers’ individual preferences. The semantic scale poles might, for example, be: dynamic/stable, sprinting/crouching or offensive/sovereign.

Therefore, every configuration scale slider has to be mapped upon one or more continuous design parameters (e.g. car proportions, surface language, surface graphics etc.) as it can exemplarily be seen in the previous Figures 7.13, 7.14 and 7.15.

This, as a matter of course, requires markedly new product development and production methods which are not broadly available yet. However, research has to be conducted to provide answers for these possible future technologies and methods.
Rapid Virtual Modeling
A perfect match is DPSE combined with Rapid Virtual Modeling (e.g. polygon modeling). This combination allows rapid 3D variant generation and real-time parameter modification via simple mouse-dragging and therefore shortens the DPSE procedure considerably. Polygon modeling and rendering software, like e.g. Cinema 4D, provide photo-realistic variants for evaluation (see Figure 7.17).

Although the Rapid Virtual Modeling is perfectly useful for DPSE, it is clear that the main challenges to be addressed are in the multi-modal aspects where not just form is important, but where all senses play a role.

Figure 7.17: Exemplary wheel rim made with polygon modeling.

Design Parameters of Environmental Friendliness
Every time environmental friendliness becomes present in the media and fossil fuels rise in price, the consumer goods industry reacts upon this by offering eco-friendly and sustainable (looking) products. Next to achievement of physical eco-friendliness and sustainability it would be worthwhile to analyze what customers perceive as eco-friendly. For example, observable tendencies in eco-friendly design concepts are painted grilles, aerodynamically closed rims, light-blue LED decor auxiliary or the visible use of renewable fiber composites. The parameters could, for example, also be located in wheel diameter, tire width, packages, car concepts, colors or surface language.

Influence of Electronic Components upon Product Character
Oftentimes, the characteristics of electronic components are decided rather under functional and monetary aspects than under design aspects, although they might have strong influence upon the product character. For example, the perceived quality of acoustic signals is depending on the different kind of signal processors (i.e. synthesizers or sample-players) used in the central car computer. Another example is the LED driver in instrument lighting or automotive taillights. The LED brightness usually is controlled via the duty cycle of the pulse width modulation. However, flicker sensitive people might be irritated when having “dimmed” LEDs in their parafoveal and peripheral field of view. This irritating flicker appears obsolete and inharmonic but can, for example, be reduced with higher pulse frequencies, which however might raise costs since the high-frequency electronics need electromagnetic shielding. Finding interdependencies between electronic components (that do not seem design relevant) and the product character helps achieving products that are perceived as modern and harmonious.
7.6 Management Summary

Premises

- The consumer products industry, especially the automotive industry – not necessarily its designers – demands a method to grasp and control subjectively perceived product qualities, such as product character, perceived effect etc. in order to align product development strategically.

- Subjective qualities, such as the design effect, always and exclusively emerge in the viewers’ minds. Therefore all evaluations and analyses have to consider the subjects’ reports.

Functioning of Design Parameter Shift Evaluation (DPSE)

- According to the targeted character terms semantic differentials are generated. They provide a subjective evaluation scale.

- Out of an existing design framework a limited amount of relevant physical design parameters (e.g. concerning proportions, surfaces, materials, details etc.) is elaborated and defined. Usually the parameters of interest are those that a) show divergence between design models and the feasible solutions and b) assumedly have strong influence upon the relevant subjective impression. This assumption is supported by analogous fields of research (e.g. facial expression, perception psychology etc.).

- Within a given parameter range, the design parameters are altered (shifted) deliberately and design variants are generated as a medium for altering design parameters. These design variants serve as stimuli for the subjects.

- The altering design variants are evaluated on the semantic scales.

- Through statistical analysis, possible correlations can be found between the objective design parameters and the viewers’ subjective response and therefore subjective product qualities (the design effect) can be grasped and controlled to a certain degree via the object’s physical design.

Limitations

- The analysis should not be narrowed down to the object (e.g. car) but ideally has to consider the subject (e.g. buyer), temporal and socio-cultural aspects (e.g. vogue) and perception psychological aspects (e.g. facial expression) as well. However, in order to reduce complexity, the object analysis requires separation, clustering and focusing of parameters.

- In certain cases it might be deficient to separate, cluster or focus design parameters since:
  a) The holistic subjective quality (design effect) emerges from complex interaction effects between the design parameters.
  b) The subjective qualities (design effect) are always depending on the object’s and subject’s context.

- Consequently, the analysis might provide less reliable results with ascending object complexity and/or question complexity.

- DPSE is unable to find the thin optimum line between a design that is “democratic” (and probably quickly becoming unprepossessing) and a design that remains attractive for years (but might “overstrain” the viewer in the first instance).

Recommendation

- General design research is done by leading consumer products industry (computer software and hardware, consumer electronic devices and automotive industry). Since it has an increasing importance under aspects of competition, it should continuously be expanded.

- On a theoretical and scientific level, DPSE can – under favorable circumstances – evidentially provide insight into the dependencies between a design and its effect upon the viewer. Important design decisions must not exclusively be based on this statistical expertise but should consider it as an auxiliary process input.
Curriculum Vitae

Julian Eichhorn was born on November 21st 1978 in Stade near Hamburg (Germany) where he also obtained his university-entrance diploma at the Vincent-Lübeck-Gymnasium in 1999. After an internship in tool-making and precision-engineering at the writing instruments and accessory manufacturer Montblanc Simplo GmbH in Hamburg he studied Industrial Design at the Burg Giebichenstein – University of Art and Design in Halle/Saale. In 2004 he completed his study with the conceptual design of a car-sharing service including the zero-emission car powered by an electrical flywheel-based drivetrain.

Since January 2005 he assisted the BMW Group Design Strategy Department and subsequently worked for BMW Group Design & Perceived Quality Management and Platform Management for BMW, MINI and Rolls-Royce projects. In summer 2005 he also started his doctoral research on product perception and design analysis. This thesis is the result.
Literature

A

B

C

D
Desmet, P.M. (2002) *Designing Emotions.* Technische Universiteit Delft
Desmet, P.M., Hekkert, P., Hillen M.G. (2004) *Values and Emotions.* Delft University of Technology, School of Industrial Design

E

F

G

H

J
Internet Sources

B

I

M

W

Personal Communication

B
Bangle, Christopher E., BMW Group Design, München (February 19, 2006; August 07, 2007; September 17, 2007)
Bech, Dr. Søren, Bang & Olufsen, Struer/Denmark (March 28, 2006)
Breidbach, Prof. Dr. rer. nat. Dr. phil. Olaf, Max-Planck-Forum München (January 16, 2006)

H
Hands, Jeffrey, BMW Group Design Strategy, München (February 16, 2006; July 19, 2006; January 19, 2007; June 12, 2007; September 17, 2007)
Hartula, Marcus, BMW Group, München (August 08, 2006; October 22, 2007)
Heilmann, Oliver, BMW Design Studio, München (May 07, 2007)
Hermes, Dr. Dik J., Technische Universität Eindhoven (February, 2007)

K
König, Prof. Dr. Peter, Universität Osnabrück (December 19, 2005)
Koester, Dr. Josef, BMW Market and Trend Research, München (August 27, 2007)

M
Markefka, Mare-Michael, Rolls-Royce Design, München (May 09, 2007)

R
Roth, Prof. Dr. Dr. Gerhard, Henn Akademie, München (July 05, 2007); Hanse Institute for Advanced Study, Delmenhorst (July 16, 2007)

W
Wagner, Dr.-Ing. Ulrich, BMW Group, München (August, 2005)
Wechner, Daniel, BMW Group Design, München (May 08, 2007)