

THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Perceived Quality of Cars

A Novel Framework and Evaluation Methodology

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CHALMERS UNIVERSITY OF TECHNOLOGY
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“Σα βγεις στον πηγαιμό για την Ιθάκη,
να εύχεςαι νάναι μακρύς ο δρόμος,
γεμάτος περιπέτειες, γεμάτος γνώσεις...

*Τους Λαιστρυγόνες και τους Κύκλωπας,
τον άγριο Ποσειδώνα δεν θα συναντήσεις,
αν δεν τους κουβανείς μες στην ψυχή σου,
αν η ψυχή σου δεν τους στήνει εμπρός σου.”*

- «Ιθάκη» Κ.Π. Καβάφης

*“As you set out for Ithaka
hope the voyage is a long one,
full of adventure, full of discovery...*

*Laistrygonians and Cyclops,
wild Poseidon—you won’t encounter them
unless you bring them along inside your soul,
unless your soul sets them up in front of you.”*

- «Ithaka» C.P. Cavafy
(Translated by Edmund Keeley / Philip Sherrard)

Abstract

The supremacy of the automotive manufacturers today is no longer driven by them achieving a superior manufacturing quality but increasingly depends on the customer's quality perception. Average car consumers see a car's quality as a fancy mixture of design, aesthetics, their own previous experiences and performance characteristics of the vehicle, unlike a combination of mechanical parts, software pieces, advanced materials, cutting-edge manufacturing processes, with technical knowledge, skills and high production volumes – all ingredients involved in the modern car creation. Perceived quality is one of the most critical aspects for product development that defines successful car design.

Speaking of perceived quality, we are dealing with a complex, multifaceted adaptive system; a system where a human is the main agent. *“Which product characteristics require the most attention for successful car design?”* This is the question engineers and designers need to answer under the pressure of shrinking product development time, available technologies, and financial limitations, not to mention that the answer is expected to be given in numbers to sustain the fierce competition in today's automotive industry. For this reason, the perceived quality must be understood and controlled during all stages of product development.

The research presented in this thesis justifies the engineering viewpoint on perceived quality as an inevitable part of new product development. The core of this research is the Perceived Quality Framework (PQF), a taxonomy structure of perceived quality attributes and the Perceived Quality Attributes Importance Ranking (PQAIR) method, a novel method for perceived quality evaluation that can be applied to a variety of products, including cars. The PQF communicates the attribute-centric engineering viewpoint on quality perception, developed through cumulative studies in the premium and luxury market segment of the automotive industry. The PQAIR method equips engineers with practical tools for perceived quality evaluation. The proposed method helps to reach the equilibrium of the product's quality equation from the perspective of design effort, time, and costs estimations.

Altogether this introduces a new paradigm of perceived quality as the inevitable element integrated into the process of engineering endeavor regarding product attributes that communicates quality to the customer.

Keywords: perceived quality, automotive, product development, product quality, premium, luxury, knowledge management, design, aesthetics, engineering;

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Kostas Stylidis
Gothenburg, September 2019

Appended Publications

The following research papers form the foundation on which this thesis stands.

Paper A

Stylidis, K., Hoffenson, S., Rossi, M., Wickman, C., Söderman, M., Söderberg, R. (2019, *in press*). Transforming brand core values into perceived quality: A Volvo case study. *International Journal of Product Development*.

Distribution of work:

Stylidis and Hoffenson wrote the paper, performed the data collection and analysis. Rossi took part in qualitative analysis. Wickman, Söderman and Söderberg outlined the concept and contributed as reviewers. All authors contributed to creating the case scenario.

Paper B

Stylidis, K., Wickman, C., & Söderberg, R. (2015). Defining perceived quality in the automotive industry: An engineering approach. *Procedia CIRP*, 36, 165–170.

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Stylidis wrote the paper, conducted the literature review and analysis with the support of Wickman. Söderberg contributed as a reviewer.

Paper C

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Paper D

Stylidis, K., Bursac, N., Heitger, N., Wickman, C., Albers, A., & Söderberg, R. (2019). Perceived quality framework in product generation engineering: an automotive industry example. *Design Science*, 5.

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Additional Publications

AP1. Styliadis, K., Hoffenson, S., Wickman, C., Söderman, M., & Söderberg, R. (2014). Corporate and customer understanding of core values regarding perceived quality: Case studies on Volvo Car Group and Volvo Group Truck Technology. *Procedia CIRP*, 21, 171-176.

AP2. Styliadis, K., Wickman, C., & Söderberg, R. (2015). Perceived Quality and the Core Values in the Automotive Industry: A Corporate View. In *DS79: Proceedings of The Third International Conference on Design Creativity*, Indian Institute of Science, Bangalore, India.

AP3. Styliadis, K., Landahl, J., Wickman, C., Johannesson, H., & Söderberg, R. (2015). Structuring Perceived Quality Attributes for Use in the Design Process. In *DS 80-7 Proceedings of the 20th International Conference on Engineering Design (ICED 15) Vol 7: Product Modularisation, Product Architecture, systems Engineering, Product Service Systems*, Milan, Italy, 27-30.07. 15 (pp. 033-042).

AP4. Styliadis, K., Burnap, A., Rossi, M., Wickman, C., Söderberg, R., & Papalambros, P. Y. (2016). A preliminary study of trends in perceived quality design attributes in the automotive luxury Market segment. In *DS 84: Proceedings of the DESIGN 2016 14th International Design Conference* (pp. 2189-2196).

AP5. Styliadis, K., Rossi, M., Wickman, C., & Söderberg, R. (2016). The Communication Strategies and Customer's Requirements Definition at the Early Design Stages: An Empirical Study on Italian Luxury Automotive Brands. *Procedia CIRP*, 50, 553-558.

AP6. Stenholm, D., Styliadis, K., Bergsjö, D., & Söderberg, R. (2016). The Challenges of Different Roles with Engineering Knowledge Reuse. *DS 85-2: Proceedings of NordDesign 2016, Volume 2, Trondheim, Norway, 10th-12th August 2016*, 298-308.

AP7. Stenholm, D., Styliadis, K., Bergsjö, D., & Söderberg, R. (2017). Towards robust inter-organizational synergy: Perceived quality knowledge transfer in the automotive industry. In *DS 87-6 Proceedings of the 21st International Conference on Engineering Design (ICED 17) Vol 6: Design Information and Knowledge*, Vancouver, Canada, 21-25.08. 2017 (pp. 011-020).

AP8. Falk, B., Styliadis, K., Söderberg, R., & Schmitt, R. (2017). Shifting paradigm: Towards a comprehensive understanding of quality. In *DS 87-9 Proceedings of the 21st International Conference on Engineering Design (ICED 17) Vol 9: Design Education*, Vancouver, Canada, 21-25.08. 2017 (pp. 255-264).

AP9. Styliadis, K., Madrid, J., Wickman, C., & Söderberg, R. (2017). Towards Overcoming the Boundaries between Manufacturing and Perceived Quality: An Example of Automotive Industry. *Procedia CIRP*, 63, 733-738.

AP10. Styliadis, K., Striegel, S., Rossi, M., Wickman, C., & Söderberg, R. (2019). Perceived quality estimation by the design of discrete-choice experiment and best-worst scaling data: an automotive industry case. In *Research into Design for a Connected World* (pp. 859-870). Springer, Singapore.

AP11. Styliadis, K., Dagman, A., Almius, H., Gong, L., & Söderberg, R. (2019, July). Perceived quality evaluation with the use of extended reality. In *Proceedings of the Design Society: International Conference on Engineering Design* (Vol. 1, No. 1, pp. 1993-2002). Cambridge University Press.

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List of Acronyms

AI	Artificial Intelligence
CAE	Computer-Aided Engineering
DMAIC	Define, Measure, Analyze, Improve, Control
DPMO	Defects Per Million Opportunities
DRM	Design Research Methodology
DS	Descriptive Study
GA	Ground Attribute
EEG	Electroencephalography
EMG	Electromyography
EQFD	Enhanced Quality Function Deployment
HMI	Human-Machine Interface
HoQ	House of Quality
OEM	Original Equipment Manufacturer
PD	Product Development
PGE	Product Generation Engineering
PQ	Perceived Quality
PQAIR	Perceived Quality Attributes Importance Ranking
PQF	Perceived Quality Framework
PS	Prescriptive Study
QC	Quality Control
QFD	Quality Function Deployment
QMS	Quality Management Systems
RC	Research Clarification
RD	Robust Design
RDRS	Robust Design Requirements Specification
RQ	Research Question
SD	Semantic Differential
TQM	Total Quality Management
TPQ	Technical Perceived Quality
VPQ	Value-based Perceived Quality
VQA	Visual Quality Appearance
xR	Extended Reality (Augmented/Virtual Reality)

1 Introduction

“If we want things to stay as they are, things will have to change.” –

“Il Gattopardo” by Giuseppe Tomasi di Lampedusa

The world we live in is changing and changing fast. Product development is evolving as the customer’s expectations regarding products emerge. We are witnessing probably the most dramatic changes in the automotive industry since the last century. These changes are incepted by the rise of new global markets and competition that we likely haven’t seen before. New transportation paradigms have increased customer awareness regarding the vehicle’s quality, connectivity, safety, fuel economy and sustainability. This makes it important for automotive product development to fully understand the dimensions of perceived quality.

Traditionally successful automobile design is characterized by a combination of technical manufacturing quality (“hard” factors) and customer oriented perceived quality (“soft” factors) (Petiot, Salvo, Hossoy, & Papalambros, 2009). For example, the premium segment of the automotive industry has historically excelled in manufacturing quality, resulting in a vision of “zero defects” quality. Consequently, for the premium car market, product differentiation largely derives from the customer’s assessment of perceived quality (Schmitt & Quattelbaum, 2010), somewhat disregarding the “price tag.” In other words, high manufacturing quality for the premium automobile segment is not a primary determinant of customer choice, but rather it is only an entry ticket for this segment (Robinson, 2000). This vision is today widely adopted in other car market segments – sometimes just allusive, sometimes with earnest intent. Average customers, in turn, find themselves in a situation where the choice has to be made among technically excellent vehicles with similar functionality and design. Add on top of that the vastly changing trends, a cloud of possible technical and design solutions available for an average premium car, with countless quality allures. Altogether, this creates a “wicked problem” for any car manufacturer. From the automotive manufacturer’s point of view, the desired level of perceived quality is defined by the numerous product attributes. A typical automotive Original Equipment Manufacturer (OEM) uses around 20-120 perceived quality attributes, depending on organizational structure. The perceived quality attributes are responsible for the definition of requirements and requirement levels that determine the perceived quality of the product. In the automotive industry these attributes can be associated with the complete vehicle requirements, but also the component- and system-level requirements. The perceived quality attributes are also needed for complete vehicle verification with the use of computer-aided engineering (CAE), as well as physical testing.

However, there is an information gap between the customer’s perception of the vehicle’s quality and functionality and the engineering intent. This gap appears for a

reason; it is difficult for engineers to communicate advanced technical aspects to the customer, perform an unbiased assessment of the perceived quality and predict customers' opinion. Engineers often deal with ambiguous requirements in product development, especially at the early stages of design. The outcomes might be depicted in vehicle design that is poorly appreciated by the customers due to scattering of engineering focus regarding attributes that influence the perception of quality. Moreover, in the premium market segment of the automotive industry, some of the requirements are driven by the sectoral competitiveness among the players. Thus, evaluation of the perceived quality attributes is a highly challenging process because of the subjective nature of some attributes and the intuitive approach of the engineers (Eckert, Bertoluci, & Yannou, 2014). Quite often engineers responsible for the evaluation of the perceived quality attributes rely solely on their previous experience and intuition. This occurs mainly due to the lack of time, reliable perceived quality evaluation methods, tight deadlines within product development timelines and other factors, even though the decisions they make are critical to the product success on the market (Ranscombe, Ben Hicks, Mullineux, & Singh, 2012). Understanding the customer's perception of the quality is understanding the dimensions of perceived quality. At this point engineers usually face the problems of balancing the importance of perceived quality attributes with regard to a complete vehicle. Ability to manage perceived quality can be expressed in the single open question, "*Where should money be spent and which perceived quality attributes make a difference for the customer?*" (de Jongh Hepworth, 2007). This normative question is usually followed by the prescriptive question, "*How can we measure the importance of a single perceived quality attribute or a group of attributes for the customer?*" This work is motivated by the idea that engineering design intent of creating a vehicle, perfectly fit for intended purpose and market segment, can be managed and evaluated in a constructive manner. As a result, it will ultimately meet the customer's expectations for a high-quality product. Hitherto, no framework or methodology has been available which (i) can explicitly define perceived quality and its elements, and (ii) is able to assess quantitatively the impact of a single perceived quality attribute on the product design as a whole. This thesis introduces a coherent structure for a robust discourse around the perceived quality for establishing a shared basis for dialogue among engineers, practitioners and academic researchers. An extensive literature review draws on a historical timeline for concepts, methods, and theory regarding product quality evolution and ascent of the engineering approach to perceived quality. The major outcomes of this research are the Perceived Quality Framework (PQF), a taxonomy structure of perceived quality attributes, and the Perceived Quality Attributes Importance Ranking (PQAIR) method. The PQF illustrates the attribute-centric engineering viewpoint on quality perception, developed through reciprocated studies of the automotive industry. The PQAIR method equips engineers with the practical tools for perceived quality evaluation.

1.1 Research Focus

The purpose of the research presented in this thesis is to define perceived quality from the engineering viewpoint and develop a methodology for perceived quality evaluation. Special consideration is given to the structuring and establishing of a perceived quality attributes taxonomy system, making possible communication and quantification of the perceived quality. Better understanding of the perceived quality nature, supported by the attributes-centric frame of reference, helps companies to manage perceived quality-related issues. The new methodology for perceived quality evaluation helps to meet customer requirements and increase effectiveness of product development processes. The initial challenge in creating mutual understanding of the perceived quality theme was the absence of a language that would provide a common knowledge basis for academia-industry or industry-industry types of interaction. To address this gap, this thesis presents the development of PQF - the ontology system for perceived quality evaluation based on primary human senses. This attribute-centric framework can serve as a platform for robust discourse around the theme of perceived quality, not limited by the product type or production method. Furthermore, the PQF delineates perceived quality attributes prioritization regarding the desired engineering intent. This task can be fulfilled by the ranking of perceived quality attributes importance based on multi-sensory information related to a product, assessed with the help of the PQAIR method. The research presented in this thesis focuses on the concept of perceived quality in product development. This thesis addresses questions mainly related to the management of perceived quality in the automotive industry; however, the PQF and PQAIR method are not limited to use in the automotive industry alone. The PQF focuses on the product attributes that communicate quality to the customer - i.e., perceived quality attributes. Perceived quality attributes can be defined as characteristics that convey functional and psychosocial benefits of a product to the customer (Steenkamp, 1990). While the PQF carries information about perceived quality attributes applicable to the automotive industry, the same set, or a modified set of attributes can be used in a various domains of product development for evaluation of perceived quality. Research in this area indicates the full spectrum of opportunities regarding the use of the PQF and PQAIR method for evaluation of consumer products.

1.1.1 Scientific Goals

From the scientific point of view, the concept of perceived quality has been a topic of interest in several research disciplines for quite some time. However, previous research was quite polarized, converging either on the marketing science or on the manufacturing-based approaches, with little relation to product development at the early design phases. Philosophy, marketing, brand management, economics, operational management, neuroscience and psychophysics have been focusing on various perceived quality issues directly or incidentally. Alas, the engineering approach remains ambiguously defined. The “traditional” views on perceived quality give little space for objective evaluation of this complex matter. For quite a long time the measurability of perceived quality remained questionable, since, once defined by

Garvin (1984b) as an intangible part of product quality, it has always been seen as absolutely subjective, somewhat more related to the affective impression and advertising rather than to the precise and exact engineering. It is time to change that. In summary, the objectives of the research presented in this thesis are the following:

- **To define and characterize the taxonomy of perceived quality attributes suitable for evaluation of perceived quality on a complete vehicle.**
- **To develop models and describe processes within a new paradigm of perceived quality – realization of the engineering viewpoint on perceived quality in the automotive manufacturing sector.**
- **To initiate the transition from fragmented case/industry thinking to the holistic view of perceived quality as an inevitable part of product development; the utilization of process patterns and incorporation of perceived quality concerns in product design at all stages.**
- **To be able to capture customers' preferences for the importance of different perceived quality attributes under the specific context of a product's use.**

Thus, the primary purpose of this research is to initiate a fundamental change in the research related to the perceived quality of products; to coin explicit definitions of the perceived quality attributes; to address the communication issues interconnecting science and industry, and to support industry with reliable methods for perceived quality evaluation.

1.1.2 Industrial Goals

This research project has been carried out in close collaboration with Original Equipment Manufacturers (OEM) representing the premium and luxury market segment of the automotive industry. It is perfectly understood by automotive manufacturers that quality perception is at the forefront of customer's attention and has the highest influence on purchasing behavior. If a company wants to communicate quality aspects of the product, there is eventually a need to bring these characteristics into the measurable space of perceived quality attributes. Therefore, the identification and mapping of attributes that represent perceived quality was one of the primary goals. In reality, customers often have difficulties expressing their opinions about a product with a high level of complexity, such as a premium vehicle. Consequently, a composition of a universal taxonomy system with the purpose to communicate all aspects of quality perception has become necessary. This research aims at integrating customers' and companies' views on quality and therefore must introduce a faster and more resource-efficient way of realizing good quality from the customers' point of view. However, the fundamental industrial goal was defined unambiguously: **to develop a methodology, that can be easily adopted in industrial settings, able to provide trustworthy outcomes for the perceived quality evaluation of a complete vehicle or its components.** Ability to measure the importance of a single perceived quality attribute as a part of the bigger and extremely complex system gives a great advantage to automotive manufacturers. This also equips engineers with practical tools for perceived quality evaluation.

1.2 Research Questions

In this research, a number of questions were identified. The main research questions addressed in this thesis were:

RQ1. How can perceived quality be defined from the engineering perspective?

Discourse regarding perceived quality is an ongoing challenge and there is no comprehensive definition which would satisfy views that are different from the customer-oriented marketing science or “complete ignorance” from the manufacturing side. This research question aims to define perceived quality from the engineering perspective as an inevitable part of the product development process.

RQ2. What product attributes can be used to validate perceived quality on a complete vehicle?

To create a vehicle with perfect perceived quality is not a challenge today for a premium automotive OEM. Almost anything can be achieved with increased product cost and time investments. The challenge is to find perceived quality equilibrium with consideration of given boundaries, such as: existing technologies, product development time, production systems and financial limitations. Therefore, it is extremely important to delineate and describe perceived quality attributes that can serve best to fulfil desired engineering intent.

RQ3. How can meaningful perceived quality feedback be gathered?

There are different kinds of formal methods and approaches for gathering customers’ feedback in product design. However, not all of them fit for the use in product development processes regarding perceived quality evaluation. This research question addresses how perceived quality feedback can be collected and analyzed in the most efficient way for the automotive industry.

RQ4. How can perceived quality be balanced at the different product levels?

To create a balanced equation for the perceived quality of a vehicle, the connections between the product’s attributes and corresponding customer evaluations have to be drawn. This research question addresses the development of a methodology for the perceived quality evaluation and attributes importance ranking, resulting in controllable perceived quality propagation.

1.3 Delimitations

Although this project includes different topics related to product development and product quality, the basis of the research presented in this thesis stands upon the grounds that are intended for the automotive industry. In particular, the scope of the analysis was the premium and luxury market segment of the automotive industry. In

addition, only five premium and three luxury car manufacturers were studied. Production cost aspects, and the product's technical limitation was not considered. The research also focused on product attributes that can be controlled by engineering specifications, disregarding the impact of extrinsic attributes related to branding or hedonic values. The questions of sensory dominance, the product's familiarization was not considered.

However, it is the author's desire that the findings from this research will be adopted not only by a broad number of the automakers, but also by the researchers and practitioners in other areas of product design and development.

1.4 Thesis Structure

This thesis consists of five sections and the sections subsequent to the *Introduction* are outlined as follows:

Frame of Reference section presents the theoretical background of the thesis, describing the historical and methodological development of the product quality models.

Research Approach section presents the methodology applied in this research and rationale for its use.

Results and Summary of the Appended Papers section collects the results from the appended papers, introducing new definitions of perceived quality and summarizing the findings.

Discussion section elaborates on answering the research questions, validity of the results and success criteria.

Outlook section discusses advancements of current and future research.

1.5 Towards a New Understanding of Perceived Quality

In the past, a considerable amount of research, including various approaches to perceived quality, has been conducted primarily in an attempt to identify the dimensions and nature of product quality. However, this body of work, contributing mainly to the field of marketing and manufacturing science, has been depicting perceived quality as the antagonistic entity to the "real" or "objective" quality (i.e. not quantifiable, imaginary, subjective). These viewpoints are sometimes antagonistic since they are representing two different schools of thought. The marketing approach consolidates around the customer-centric perspective (e.g., brand, core values, service quality perception), and the manufacturing approach is established around achieving superior quality (e.g., producibility, robust design, design for quality). Alas, the engineering viewpoint remains ambiguously defined. This thesis introduces the engineering connotation, defining perceived quality as an equation, where the *engineering intent* of meeting customer's expectations regarding the vehicle has to be balanced. Hereafter, the thesis describes the evolution of the views on perceived quality in product development and engineering practice. Let us begin with a question: "*What is quality?*" §

2 Frame of Reference

This chapter presents a synopsis of the literature related to the research field of quality. It will familiarize the reader with the existing quality models, approaches and methods. Likewise, this chapter explains concepts, phenomena and the context to which the research of thesis relates.

*“Do not go gentle into that good night.
Old age should burn and rave at close of day;
Rage, rage against the dying of the light.” –
Dylan Thomas.*

2.1 What is Quality?

The definition of “quality” has a long history, and we are lucky to have the ability to trace its origin over the centuries. The word “quality” derives from the Latin translation of the Ancient Greek word “ποιότης” or “what-is ness”. Cicero discovered it in one of the Socratic dialogues. Before Cicero’s invention of “qualitas” European languages had no reference to the “what-is ness”. Nevertheless, the entire branch of philosophy – Aesthetics is concerned with the eternal question “What is beautiful?” and the definition of quality. Today it is hard to imagine science without a word like “quality” (Baars & Gage, 2010). Speaking about product development, the quality of produced goods was monitored either directly or indirectly probably since the time when “Homo” became “Sapience”. However, great interest in the definition and deployment of quality principles in the product development and production processes appeared after the Second World War, when Japanese industry experienced great difficulties regarding quality, and so attempted to overcome these issues. Today quality has become the essential characteristic for the success of any OEM in the highly competitive global market. The visceral experience of motion goes hand in hand with the excitement of quality perception ownership. Rephrasing the famous quote by Carroll Shelby, “Your favorite car (in terms of quality) is the next one!”

2.1.1 Historical Evolution of Product Quality Definitions

It is recognized by many authors that quality has a multidimensional structure (see Table 1). The well-known definition of quality as “*fitness for use*” is credited to Josef Juran. According to Juran, “*fitness*” is defined by the customer. Another view is held by Crosby (1980), defining quality as “*conformance to requirements*”. According to Crosby, requirements may not always fulfil customer’s expectations. This view was also supported by Gilmore (1974), who defined quality as “*...degree to which a specific product conforms to a design or specification*”. One of the first descriptions

of perceived quality was given by Shapiro (1970), describing purchasing behavior. As for the term of product quality, however, it has been identified at the macro level as a key variable for competitiveness (Steenkamp, 1990). At the micro level, product quality is the major driver for the manufacturers and the consumers. Olson & Jacoby (1972), defined quality perception as a two-stage process: the first stage includes consumer's judgment based on available cues and forms; later the user forms his quality impression based on his interpretation of those cues and forms. Pirsig introduced "Metaphysics of Quality" as a theory of reality and broke it into two forms: *dynamic quality* and *static quality* patterns. According to Pirsig (1999), "*Quality is a characteristic of thought and statement that is recognized by a non-thinking process. Because definition is a product of rigid, formal thinking, quality cannot be defined.*" Hence, there have been many independent approaches to defining quality. Probably one of the most complete and powerful was conducted by the Japanese engineer Genichi Taguchi. Taguchi, Elsayed, & Hsiang, (1989) defined quality as "*the losses to society caused by the product after its delivery*" and as "*uniformity around the target value*". Although quality loss represents rather non-quality, in practice Taguchi's definitions apply not only to the products but the quality of services (Bergman & Klefsjö, 2010). Product development, according to Taguchi, consists of Product quality (what consumers desire) and Engineering quality (what consumers do not want). In the first case, consumers desire functionality or appearance of the product and in the second consumers dislike high running costs, pollution or functional variability (Taguchi et al., 1989). Furthermore, Kano, Seraku, Takahashi, & Tsuji (1984), presented a model with two dimensions of quality: "*must be quality*" and "*attractive quality*". Kano used his definition in the model of customer satisfaction as the result of the company's performance.

Garvin (1984a), introduced five approaches to the quality definition: *transcendent*, *product-based*, *user-based*, *manufacturing-based* and *value-based*. A *transcendent* view is a philosophical approach that defines quality as "essential excellence". The roots of this approach lie in Plato's discussion on beauty and "platonic forms" where these forms cannot be defined. The same logic applies to the *transcendent* approach – it is hard to define what is excellent. The *product-based* approach sees quality as an explicit and measurable variable. It is possible to measure *product-based* quality according to the number of desired attributes that the product itself has. This type of quality can be assessed objectively. The *user-based* approach relies on the assumption that "beauty is in the eye of the beholder". It is based on the personal view of quality and is highly subjective. The "fitness for purpose" definition of quality perfectly fits into the *user-based* approach, where the user defines appropriate "fitness". The general agreement of views indicates that users often desire certain product attributes. However, this approach does not take into account the importance of the different product attributes in the overall customer impression. The *manufacturing-based* approach, as opposed to the *user-based*, is primarily focused on engineering and manufacturing issues. Practically this approach sees quality as "*conformance to the requirements*", which is the view presented by Crosby (1980). Once the requirements are set any deviations in terms of the fulfillment of specifications or time deadlines are

seen as a quality loss. According to the *manufacturing-based* approach, reducing the number of deviations leads to cost minimization and, as the results improve, quality.

Table 1. Quality definitions by the various authors.

Author	Quality Definition
Juran	“fitness for use”
Gilmore	“degree to which a specific product conforms to a specification”
Crosby	“conformance to requirements”
Shapiro	“value acquisition”
Steenkamp	“idiosyncratic value judgement”
Pirsig	“dynamic quality and static quality patterns”
Taguchi	“the losses to society caused by the product after its delivery” and “uniformity around the target value”
Kano	“must be quality” and “attractive quality”
Garvin	“transcendent, product-based, user-based, manufacturing-based and value-based”

The *value-based* views on quality act in terms of cost and price. According to the value-based approach to quality, the product provides the best ratio in terms of performance and cost or price. It is difficult to implement this approach in practice because there are no well-defined limits to measure the ratio of quality and value. Garvin claimed that the result of this approach is the hybrid concept – “affordable excellence”. It was also noted by Garvin (1984b), that views on quality are differentiated from the point of “marketing people” and “manufacturing people”. The first type usually prefers a user-based or product-based approach, because they see a customer as a referee of quality. Accordingly, “manufacturing people” see quality as “*conformance to the requirements*”. Garvin identified the clear existence of this conflict in these two views. Such a conflict can seriously affect communication strategies in product development. In order to avoid conflicts, it is suggested that companies must be fully aware of these different quality perspectives. The assumption that a single definition of quality is sufficient may cause a potential problem. As the solution, Garvin proposes a shift in the quality approach as a product moves from the early design stage to the production stage. The characteristics that represent quality first have to be identified by applying the user-based approach and translated into the product attributes using the product-based approach. Afterwards to fulfill the requirements set by the number of product attributes, the manufacturing-based approach is applied.

Finally, there are eight dimensions of product quality identified as a framework for quality: *Performance* (primary product characteristics, combination of user-based and product-based approaches); *Features* (secondary attributes that improve product performance and overall quality, including objective and measurable attributes); *Reliability* (frequency of failure, uptime); *Conformance* (match with the specifications, manufacturing-based related approach); *Durability* (closely linked with the *Reliability*, product lifetime); *Serviceability* (speed of repair); *Aesthetics* (“fits and finishes”,

related to the user-based approach, subjective); *Perceived Quality* (reputation and intangibles, related to the user-based approach, subjective). Consequently, the quality definitions mentioned above formed the basis for the ISO 9000 series of Standards and derivatives, defining quality as “fitness for purpose, conformance to the requirements, a product designed and made to do the job properly” (Rothery & Palacios, 1997).

2.1.2 Quality Engineering and Design

There have been many independent approaches to the implementation of quality in product development. Many of these approaches have derived from the definitions of quality mentioned previously. The development of quality assurance methodologies over recent decades clearly indicates a shift from activities of inspection towards process control, preferably at the early stages of product development. It is well known that the relative cost of a design change increases dramatically over the time of the production process. A change in the early stages of the product development is less expensive than a change in the later stages, or even if a product has already been produced (see Figure 1). This is a primary reason for why quality control is so important to implement in the early phase of design and production. Additionally, the fact that production timelines are getting shorter and shorter is another reason that quality controls should be implemented as early as possible. Often there is simply no time to test a product on the market, resulting in the necessity for highest quality standards from the launch.

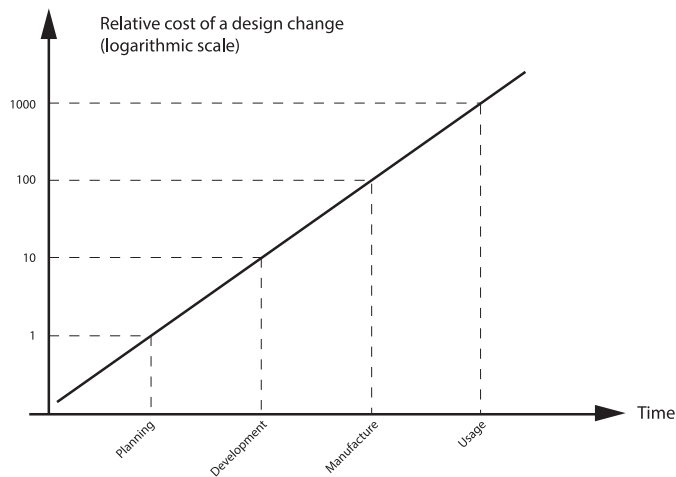


Figure 1 – The cost of design changes a function of time. Adopted from (Bergman & Klefsjö, 2010)

It is also necessary to mention, that the modern view on quality focuses on the customer. The customer is the one who evaluates the final product. To be able to satisfy customer demands and be competitive, companies implement different quality strategies. The strategies used during the early product development phase may vary significantly from the Fishbone (Ishikawa) Diagram to more complex methods e.g., Quality Function Deployment. Quality Circles, Kaizen philosophy, control charts and

experimental designs are used at the later stages of product development (Wankhade & Dabade, 2010). Quality control methods are in the process of continuous evolution, and change, and product quality requirements are also changing continuously. An additional aspect contributing to the variety of the existing approaches is the multidisciplinary nature of quality. Marketing science, economics, and manufacturing engineering have different views on product quality. Although such views often remain isolated, it is important to highlight them for the holistic understanding of quality.

2.1.3 The Taguchi System of Quality Engineering

An important methodology that has attracted considerable interest in the industry is Taguchi's philosophy. As mentioned in the previous section, Taguchi's view on product quality (or rather an absence of quality) is the quality loss and financial loss after the product is delivered to the customer.

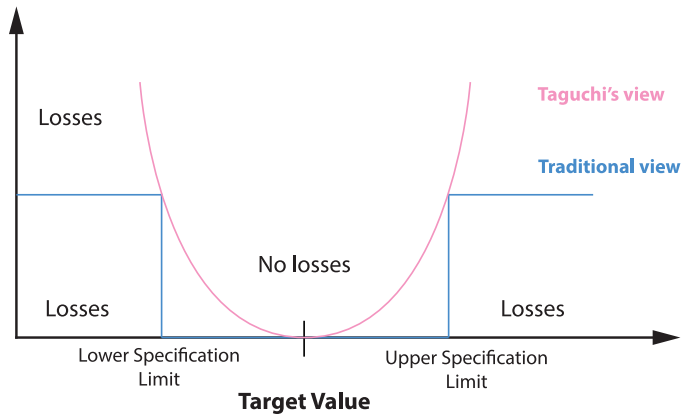


Figure 2 – Traditional approach, known as “Step function” and Taguchi’s Quality loss function.
Adopted from (Taguchi et al., 1989)

According to Taguchi et al. (1989), “quality loss is caused by deviations from ideal performance” and it is a loss to “society” including manufacturers and customers (see Figure 2). Taguchi clearly differentiates product characteristics from quality characteristics. The number and choice of product characteristics depend on the certain market segment. Quality characteristics, however, are a set of deviations from the ideal product quality in the same market segment (Bergman & Klefsjö, 2010). It is impossible to eliminate all deviations and disturbances, and Taguchi proposes that design has to be robust. Robust design is insensitive to the disturbances that can affect a product. The system of quality engineering using robust design has four activities according to Taguchi. The most significant improvement activity is the *product parameter design* that keeps performance close to the ideal value of customer satisfaction.

Other activities include *tolerance design*, *process parameter design* and *online quality control*. This paradigm represents total quality development (Clausing, 1994).

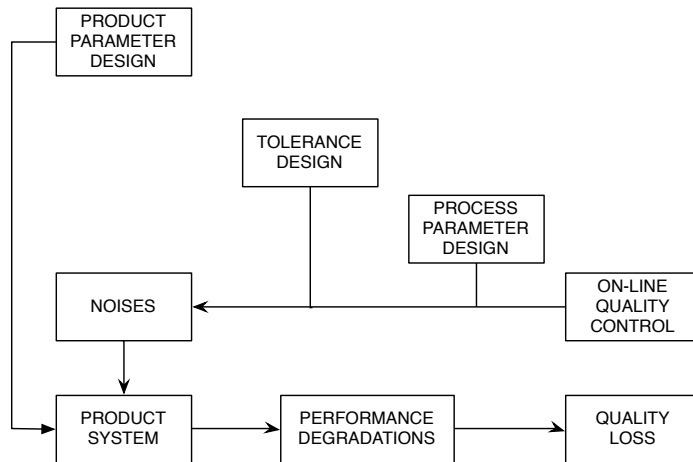


Figure 3 – Taguchi's system of quality engineering.

The essential elements of Taguchi's system of quality engineering are illustrated in Figure 3. Taguchi's views contributed significantly to the *robust design methodology* and can be generally divided into four categories – *quality philosophy*, *engineering methodology*, *experimental design* and *data analysis* (Nair et al., 1992). Söderberg, (1995) developed these ideas further, defining total loss as the sum of the functionality loss and the tolerance-dependent part of the product price. To be able to quantify and include customer needs in the process of assigning tolerances, the concept of functionality loss was introduced. Consequently, this elaborated the notion of Robust Design further.

2.1.4 Robust Design and Geometry Assurance

Robust Design is an engineering methodology related to reliability and quality engineering focusing on minimizing the effects of variation. Robust design methodology originates from Taguchi's statistical control methods (see Section 2.1.3), also known as quality engineering (Taguchi et al., 1989). The aim of the methodology is to reduce costs of production and increase quality of the products. However instead of variation elimination, the central idea of the method is making products insensitive to variation. Robust design can be described as a system (Phadke, 1995) with *input* performing transformation of the signal and the intended output. There are factors that influence the process of signal transformation. These factors are *control factors* and *noise factors*. The noise factors are usually difficult or expensive to control. This statement defines the ultimate goal of robust design as finding the settings of the

control factors that minimize the effect from the *noise factors* on the product or production system (see Figure 4).

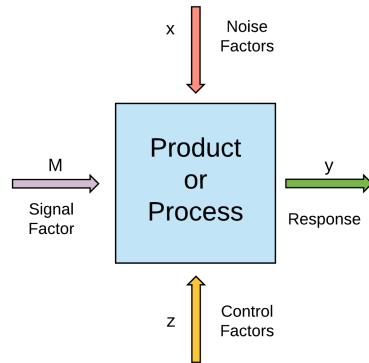


Figure 4 – Robust Design as a system; P-diagram (Phadke, 1995)

In a situation with a successful scenario, the effect of variation can be controlled and reduced without elimination of the source of variation. There are three stages in finding robust design (Phadke, 1995): (i) *Concept Design*, where in the early stage of product development a designer produces several concepts that can satisfy the design intention; (ii) *Parameter Design*, where various activities related to analysis and optimization are performed to find optimal settings for parameter control, and (iii) *Tolerance Design*, where there is allocation of input tolerances with the goal to optimize the system output.

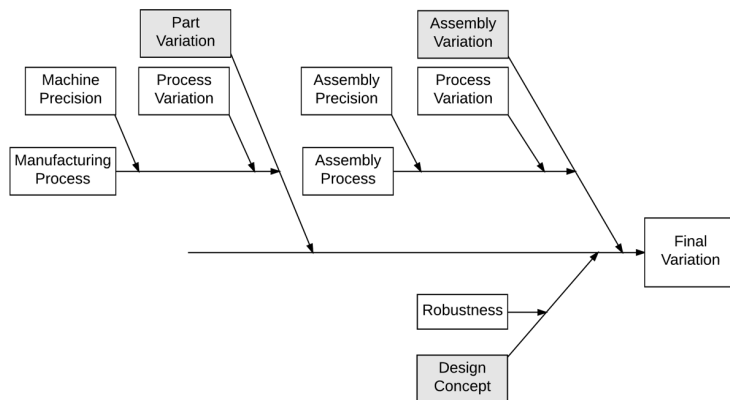


Figure 5 – Contributors to the final geometric variation (Söderberg, Lindkvist, & Dahlström, 2006b).

A geometrically robust design has been defined by Söderberg & Lindkvist (1999), as “a design that fulfils its functional requirements and meets its constraints even when geometry is afflicted with small manufacturing or operational variation.” Accordingly, *Geometry Assurance* is defined as a set of activities in the concept, verification and production phase aimed at reducing the effects of geometrical variation and increasing the precision of functional attributes of products (Söderberg, Lindkvist, Wärmefjord, & Carlson, 2016). This is a complex process where functional and quality aspects must be balanced against manufacturing constraints and cost limitations. Another key point is the fact that part variation comes from variation in the manufacturing process and manufacturing machine tools. Together with the fixtures variation and variation in the assembly process, this produces a geometric variation of the final product. The propagation and accumulation of the variation depend on the degree of design robustness for the particular solution (Söderberg, Lindkvist, & Dahlström, 2006). The major contributors to variation are illustrated in Figure 6. According to Söderberg & Lindkvist (1999), two of the most important Robust Design aspects are *assembly robustness* and *parts positioning robustness*.

In general, there are a number of actions included in a range of design activities from the concept phase until the production (see Figure 6). To conclude, problems related to geometry quality are quite often discovered only during pre-production, or even at the production phase. A change of the product design or production concept at late stages of product development will certainly result in a dramatic rise in costs and delays in product delivery to the market.

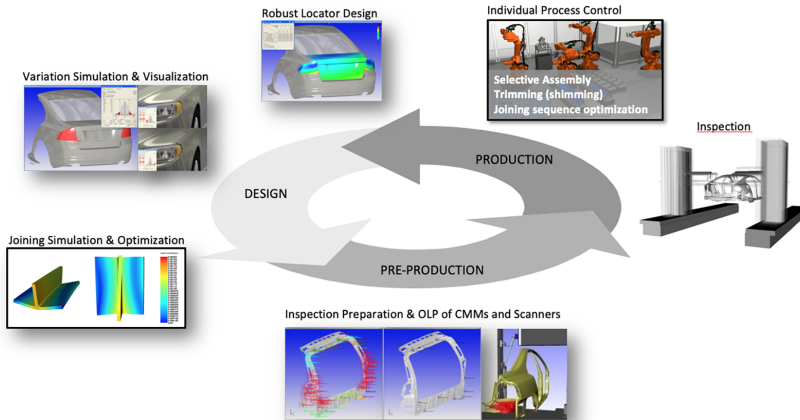


Figure 6 – Geometry Assurance activities (Söderberg, Lindkvist, Wärmefjord, & Carlson, 2016)

This is the reason for the existence and development of sets of integrated tools that can support geometry assurance process at the early stages of the product development.

2.1.5 Robust Design – Further Development and Implementation

The reliability and predictability of a product's functional performance has critical importance for any OEM. Robust Design (RD) is widely recognized as a consistent methodology for obtaining a high level of product quality. However, deployment of RD in industrial practice has produced very diverse outcomes – both successful and not. Göhler, Eifler & Howard (2016), in their work observed and reviewed RD methodology implications in industrial cases. They concluded that despite a large number of RD methods it is unclear how they are connected, in which order they must be used and how to translate the RD mindset into a set of activities. Göhler et. al. proposed the practical Robust Design process based on general design activities to support the design engineer during the product development process. This process includes four stages and can be applicable in all product development phases. Speaking about early design phases (usually described as a “fuzzy front end”), product requirements have a tendency towards avoidance of being specific, with follow up difficulties in their quantification. However, it is important to set robust target requirements to avoid quality loss induced by variation. Pedersen, Christensen & Howard (2016) proposed a Robust Design Requirements Specification (RDRS) approach for quantification of the early stage requirements. The RDRS approach introduces a new innovative use of Quality Loss Function along with capturing and communication of product requirements.

Generally speaking, there are few dominant models related to RD: (i) Quality loss function (Taguchi et al, 1989); (ii) Axiomatic Design (Suh & Suh, 2001), and (iii) Transfer function – a graphical representation of RD and its effects. Howard, Eifler, Pedersen, Göhler, Boorla & Christensen (2017) introduced a Variation Management Framework (VMF) linking variation during production with its impact on the product and the customer's perception regarding quality loss. In a word, VMF adopts the concept of the quality loss function along with the transfer function to represent variation for a single product characteristic across the four domains (i.e. customer attribute, functional requirement, design parameter and process variable) proposed in axiomatic design. To conclude, robust design in its current state is a well-established, although actively developing methodology with a focus on practical aspects of design processes and industrial implementation. RD methodology evolves in the symbiosis with other quality-oriented approaches, e.g., Design Structure Matrix methods or Quality Function Deployment.

2.1.6 Quality Function Deployment and Derivatives

The boost in global competitiveness over recent decades required an enormous number of decisions to be made. The primary approach to handle such decision making has been *Quality Function Deployment* (QFD) introduced by Hauser & Clausing (1988), and a further development of it: *Enhanced Quality Function Deployment* (EQFD) presented by Clausing & Pugh (1991). The basic idea of QFD is use of a matrix where customer requirements are listed on the page and the columns show the methods that can be used to meet these requirements. Furthermore, the matrix should be filled with the customer's most important needs and with the detailed product technical

specifications. The next step is the identification of relations between the customer's requirements and the technical specifications. Despite the simplicity of the QFD method, it was a significant step forward regarding existing design methods at that time (Franceschini, 2016). The QFD has several stages of implementation and during this process the customer's requirements are successfully translated into the technical specifications.

This approach forms the total quality development strategy and puts emphasis on quality loss prevention rather than a reaction to the problem at the later stages of product development. It is also a strongly customer-oriented approach, and uses team experience in decision making (Clausing, 1994). An essential part of the QFD visualization is the matrix form known as *House of Quality* (HoQ). This matrix allows arrangement of activities from the voice of the customer to the shop floor. The HoQ is a very effective way of product planning compared to traditional activities, mainly due to the elimination of rework that traditionally occurs in the late stages of the product development process. Overall, the HoQ consists of eight "rooms" as shown in Figure 7.

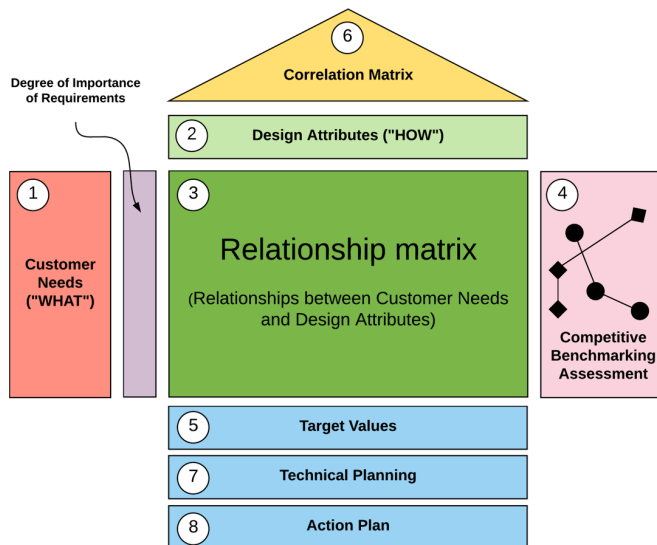


Figure 7 – Main components of the House of Quality (HoQ)

Room 1 is the voice of the customer, a series of activities to identify the customer needs. The customer attributes are usually determined by qualitative research with the different types of interviews and/or focus groups (Griffin & Hauser, 1993). It is critically important to translate customer attributes into technical requirements, and this is done in Room 2. The technical requirements are measurable and specified in the HoQ as "Hows". To overcome the issues that may appear during the process of a voice of the customer translation to the technical attributes, the HoQ includes a relationship matrix in Room 3. The benchmarking rooms, Rooms 4 and 5, fulfill the purpose of planning not only a new product but even a product with a better quality. Room 4 is for benchmarking of customer's perceptions and Room 5 is the company's targets

areas, including objective measures that reflect a link between customer attributes and technical requirements. The product development team compares two sets of benchmarks for consistency until results are coherent. Room 6 or “the roof matrix” is the correlation matrix where positive and negative correlations among technical requirements are indicated. Room 7 is where the project planning is done. The team usually estimates the difficulty in a change of the technical requirements, usefulness and cost of such changes. Room 8 is the final action plan, including the quantification of the company’s expectations regarding the new product. The process of determining the “whats” and “hows” is central for almost all QFD applications. Speaking about benefits of this method usage, Hauser & Clausing (1988) state that the QFD method was developed to solve three general problems: (i) the voice of customer often was ignored in PD; (ii) a considerable loss of information occurred during the PD phase, and (iii) different departments involved in PD often interpret the customer’s requirements and technical specifications differently. Furthermore, one of the main benefits of QFD is the ability to generate and maintain involvement and knowledge transfer/development within the work team over the whole PD cycle (Franceschini, 2016).

2.1.7 Total Quality Management

Total Quality Management (TQM) is an umbrella term for various quality management activities (including those described in the previous sections) and can be seen as part of the quality management philosophy. TQM has predecessors that form the foundation of the philosophy; these are *quality inspection* and *control*, *quality assurance* and *management*. The quality inspection paradigm appeared at the beginning of twentieth century as a method for cost reduction and the Ford T-model is a typical example of high product volume combined with reduced product variety in manufacturing.

The next step was understanding that identification of errors and their subsequent correction was less efficient than addressing the source of the error itself. As a result, *quality inspection* activities were augmented with *quality control*. *Quality assurance* appeared due to further development of manufacturing process analysis, particularly with the idea of not just control of the quality of product and application of countermeasures but rather to assure quality by identification and prevention of possible risks. The increased complexity of product development processes and rise of customer-oriented approaches in manufacturing resulted in the arrival of quality management policies, such as the ISO 9000 family of standards. Finally (see Figure 8), the continuous globalization of the world market, continuous time to market shortening combined with incremental increases in product complexity resulted in total quality management concepts (Weckenmann et al., 2015). Today TQM is gradually evolving into what is known as “intelligent TQM” and focuses on data mining to create new knowledge regarding quality issues. The ascendance of TQM brought the notion of perceived quality to the forefront, since one of the challenges for quality management has become the determination of quality from a customer’s viewpoint.

However, the approach to perceived quality in TMQ remains in the boundaries of marketing science.

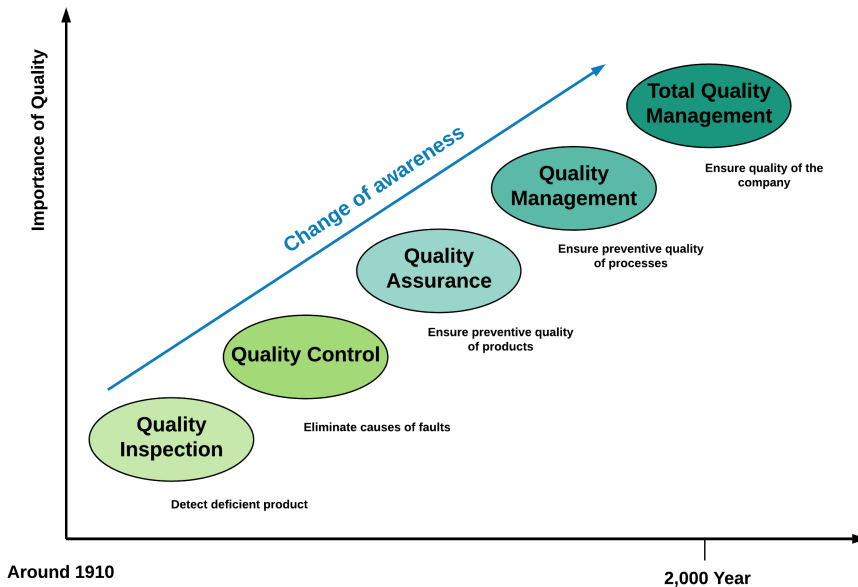


Figure 8 – Development of concepts in quality management. Adapted from Weckenmann, Akkasoglu, & Werner (2015)

2.1.8 The Six Sigma Quality Approach

Another methodology worth mentioning within Total Quality Management is Six Sigma. The history of Six Sigma is well documented and known as a quality improvement approach introduced in the 1980s by Motorola. The name “sigma” derives from a statistical measure related to the capability of the process to produce non-defective products. In statistics “sigma is a measure of process variation referred to as the standard deviation and “six sigma” generally implies occurrence of defects at a rate of 3.4 defects per million opportunities (DPMO) for defects to arise” (Klefsjö, Wiklund, & Edgeman, 2001). Therefore, in Six Sigma statistical techniques are used in a systematic way to reduce variation and improve quality control processes. Six Sigma, as with other approaches within the concept of Total Quality Management, is customer oriented and focused on the results. Snee (2000), stated that “Six Sigma should be a strategic approach that works across all processes, products, company functions and industries.” However, the Six Sigma method has not only a statistical approach but also a business viewpoint (Kwak & Anbari, 2006). According to this approach, Six Sigma is defined as a “business strategy used to improve business profitability, to improve the effectiveness and efficiency of all operations to meet or exceed customer’s needs and expectations.” (Antony & Coronado, 2001). Six Sigma has several essential key steps that can be generally described as a data-driven approach using the *define, measure, analyze, improve, and control* (DMAIC) process (see Table 2).

Table 2. Key steps of the Six Sigma DMAIC process. Adapted from McClusky (2000)).

Six Sigma steps	Key processes
Define	Define the requirements and expectations of the customer. Define the project boundaries. Define the process by mapping the business flow.
Measure	Measure the process to satisfy the customer's needs. Develop a data collection plan. Collect and compare data to determine issues and shortfalls.
Analyze	Analyze the causes of defects and sources of variation. Determine the variations in the process. Prioritize opportunities for future improvement.
Improve	Improve the process to eliminate variations. Develop creative alternatives and implement an enhanced plan.
Control	Control process variations to meet customer requirements. Develop a strategy to monitor and control the improved process. Implement the improvements of systems and structures.

2.1.9 QC-Circles and the Kaizen Philosophy

An important factor in quality improvement is the quality management within the organization. The quality policy deployment is an important element of the *Total Quality Management System*. Such a policy may contain various components and strategies. Historically one of the first organized approaches to involving employees in the quality improvement process was the activity usually referred to as *QC-circles* (Quality Control Circles). The idea of *QC-circles* was developed in Japan in the 1960s. A *QC-circle* is usually a study group consisting of 6-10 members having the goal to study literature regarding quality control. The self-development of the employees is the primary objective of the *QC-circle*. As a result, group members can discuss, analyze and solve different problems regarding product quality and the product development process. It is essential that *QC-circles* get support from the management teams in their quality activities and results. However, it is necessary to mention that the *QC-circles* approach had certain problems with the adaptation to Western companies (Blair & Whitehead, 1984). “*Kaizen*” is a term derived from the Japanese and means “change for the better.” “*Kaizen*” is presented as one of the fundamental principles of the *Total Quality Development* process. The ultimate goal of the “*kaizen*” philosophy is the awareness of customer satisfaction to keep the business profitable. “*Kaizen*” is based on the employee’s commitment and participation in a continuous improvement of the workflow. Unfortunately, “*kaizen*”- based activities are often misinterpreted either as “an endless ‘free lunch’ of improvements which emerge magically from the workers” or as “the mundane application of suggestion schemes and quality circles (QCs)” (Paul Brunet & New, 2003). Nevertheless, the “*kaizen*” philosophy can be described as a continuous path through the checkpoints Plan-Do-

Study-Act. A comprehensive description of the “*kaizen*” philosophy is also provided by Masaaki (1986).

2.1.10 The Kano Model of Customer Satisfaction

Professor Noriaki Kano has developed a very useful model for customer satisfaction. The quality dimensions in the Kano model are separated into three groups as perceived by the customers’ must have needs, expected needs and delights or exciting experiences (see Figure 9). The basic needs are the requirements represented by the bottom line and the customer simply expects them to be there. If those requirements are not fulfilled, the customer will be very dissatisfied. The expected needs are such needs that the customer is aware of and expects to be fulfilled. The delights are not expected by the customer; however, the absence of the delights often leads to the customer’s dissatisfaction. One way to surprise the customer is to present technologically advanced attributes, another is the services (Kano et al., 1984). Hence, customer requirements change over time. As an example, the seat comfort was an excitement in the automotive industry a few decades ago. Today, in the premium segment, the seat comfort is a necessary prerequisite. Later, Kano added another three

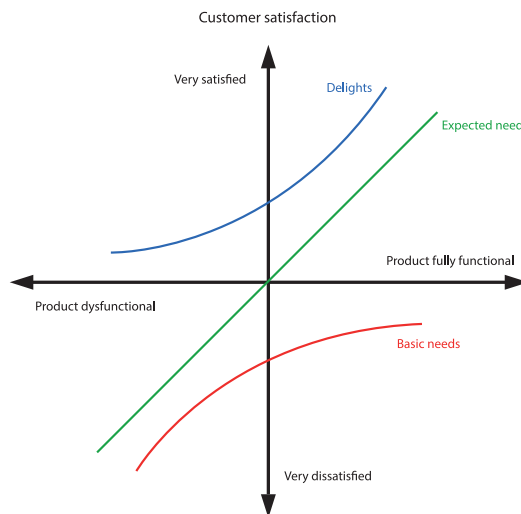


Figure 9 – The Kano model of customer satisfaction

categories of customer requirements: indifferent, reverse, questionable. Indifference means that customers do not care if the requirement is fulfilled or not. This has no influence on the satisfaction level. Reverse indicates customers’ dislike of the requirement, and questionable indicates contradictory customer opinions.

The degree of customer satisfaction that is on the one hand influenced by the customer’s expectations and awareness, and on the other hand by brand loyalty and heritage, plays a significant role in the customer’s satisfaction. For the preparation of

the Kano diagram data collection is needed. Usually the data is obtained from the customers with the help of a questionnaire. The questionnaire is designed so that two questions are asked for each customer need. The need is stated in a negative and positive way.

Table 3. Kano interpretation.

		Negative statement				
Positive statement		1.Like	2.Must be	3.Neutral	4.Live with	5.Dislike
	1.Like	Q	D	D	D	E
	2.Must be	R	I	I	I	M
	3.Neutral	R	I	I	I	M
	4.Live with	R	I	I	I	M
	5.Dislike	R	R	R	R	Q
		D-delighter; M-must have; R- reverse; E- expected; Q- questionable; I-indifferent.				

The responses to both questions are analyzed, and customer requirement is classified as one of the six Kano categories. The Kano evaluation table is the key to the interpretation of the answers. (see Table 3).

2.1.11 The ISO 9000 Quality System

The previous sections discussed methods and strategies for improvement of product quality. Many companies had a demand for a documented quality system. Such a system was introduced by the International Organization for Standardization in 1987 and is known as the ISO 9000 family of standards. Since then ISO 9000 standards have been translated into the national standards of quality in more than 50 countries (Rothery & Palacios, 1997).

The ISO 9000 family has the following standards:

- ISO 9001:2015: Quality Management Systems - Requirements
- ISO 9000:2015: Quality Management Systems - Fundamentals and Vocabulary (definitions)
- ISO 9004:2018: Quality Management - Quality of an Organization - Guidance to Achieve Sustained Success (continuous improvement)
- ISO 19011:2018: Guidelines for Auditing management systems

The ISO 9000 group of standards is a combination of the concepts and principles that can be applied in organizations. Despite the important role of the ISO 9000 requirements in the implementation of quality standards, there are some deficiencies – the system is defensive and product-oriented rather than progressive and process-oriented. Quoting Dr. Juran, “There is nothing in ISO 9000 about continuous quality improvement, customer satisfaction or employee participation.” (Bergman & Klefsjö, 2010). At least, there is no definition of perceived quality in the ISO 9000 family of standards.

2.2 “Early” Perceived Quality Research

As has been noted previously, perceived quality has been addressed with a variety of approaches in different research disciplines. Despite important research on perceived quality, the engineering viewpoint has not been defined explicitly in any related discipline. However, the “early” approaches to perceived quality paved the way towards understanding of the interrelation between designer and customer in terms of quality impression.

2.2.1 Perceived Quality from a “Marketing people” perspective

In the field of marketing science, perceived quality has often been depicted as the antagonistic entity to “real” or “objective” quality (i.e. not quantifiable, imaginary, subjective). Monroe & Krishnan (1985), defined perceived quality as “Perceived ability of a product to provide satisfaction relative to the available alternatives.” Steenkamp (1990), admitting inconsistency and lack of empirical proof for the existing (at that time) definitions of perceived quality, proposed a framework for developing a new definition. His framework presented the following quality dimensions in the context of value: perceived quality involves preference; perceived quality is neither objective nor subjective; perceived quality exists in the product consumption. There are also several “marketing-oriented” definitions of perceived quality that focus mainly on the consumer. For example, Mitra & Golder (2006), interpreted perceived quality as “perception of the customer” and opposed it to the term “objective” quality. Such a view of perceived quality derives from the earlier research of Zeithaml (1988). She defined perceived quality as a subjective customer’s judgment regarding overall product superiority. Perceived quality is different from objective quality, according to Zeithaml. A similar view is expressed by Aaker (2009), with the definition of perceived quality as “the customer’s perception of the overall quality or superiority of a product or service with respect to its intended purpose, relative to alternatives.” Castleberry & McIntyre (2011), discussed the nature of perceived quality as, “... a belief about the degree of excellence of a goods or service that is derived by examining consciously and/or unconsciously, relevant cues that are appropriate and available, and made within the context of prior experience, relative alternatives, evaluative criteria and/or expectations.” Only recently Golder, Mitra & Moorman (2012), proposed an integrative quality framework as a prominent approach to link the connections between objective and subjective quality domains.

Nevertheless, probably the most important finding for the automotive industry was presented by Aaker & Jacobson (1994), establishing the direct link between perceived quality and financial performance.

2.2.2 “Manufacturing people” Strike Back

In engineering science, the notion of perceived quality similar to this research appeared as part of bigger models; i.e., in the field of Robust Design (Taguchi et.al., 1989), and particularly in the area of Geometrically Robust Design (Söderberg & Lindkvist 1999). These research methodologies were among the first to consider perceived quality as an aftereffect of manufacturing processes. Robust Design is widely recognized as a consistent methodology for obtaining a high level of product quality. Consequently, a Geometrically Robust Design has been defined by Söderberg and Lindkvist (1999), as “a design that fulfils its functional requirements and meets its constraints even when geometry is afflicted with small manufacturing or operational variation.” With regard to early design phases (usually described as a “fuzzy front end”), product requirements have a tendency towards ambiguity, with follow up difficulties in their quantification. This problem is a central issue for the automotive industry with regard to the definition of perceived quality attributes. For this reason, it is important to set robust target requirements to avoid quality loss induced by variation. For the most part, Robust Design recognizes the need to control perceived quality, as geometrical variation can significantly influence visual and tactile perception of the product. The author sees Geometrically Robust Design as a cornerstone of the engineering approach to perceived quality (Wickman & Söderberg, 2007; Wagersten, Forslund, Wickman & Söderberg, 2011); despite it focusing mainly on the visual (e.g., split-lines). Moreover, Lieb et al. (2008), presented a retrospective review about the evolution of perceived quality definitions and how they influence purchase behavior. Lieb et al. proposed regarding perceived quality as “a scalable input factor for a company’s product development.”

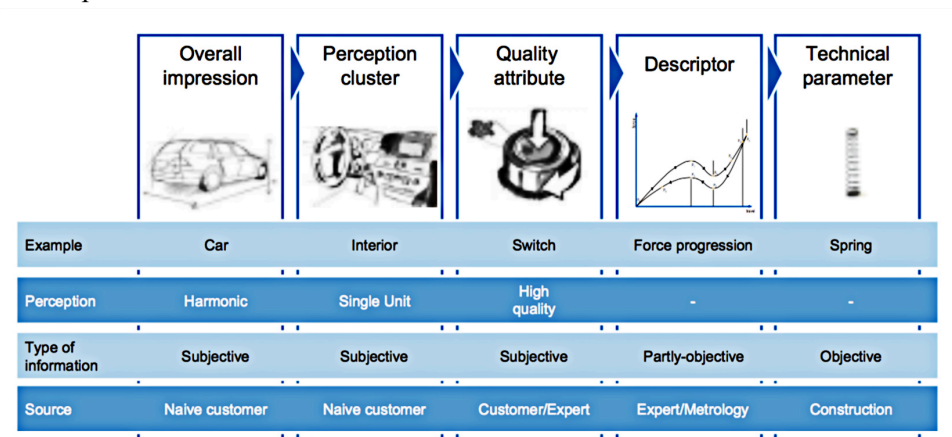


Figure 10 – The five-stages framework according to R. Schmitt, Quattelbaum, & Falk (2010)

The development of this approach is the research presented by Schmitt & Quattelbaum (2010), where perceived quality is defined as “the result of a cognitive and emotional comparison process between customer’s conscious and unconscious expectations regarding criteria like price, design, brand image or product experiences and the realized technical product features in specific situations of use.” In contrast to the

“traditional” view of perceived quality as a subjective factor, the approach mentioned above points towards objectification of the perceived quality attributes (Schmitt & Neumann, 2013). Lieb et al. (2008), developed a methodology that provides a structured approach to quantification of the customer’s overall impression and transformation into the technical parameters. Schmitt et al. (2010), introduced a five-stage framework for integrating perceived quality-related information into product development (see Figure 10).

However, Eckert et al. (2014), stated that in such complex situations as car design the existing methods for quantification of product attributes do not work correctly. As for the latest research, there are a number of scholars investigating the topic of perceived quality also from the manufacturing and marketing-oriented points of view (Quattelbaum, Knispel, Falk, & Schmitt, 2013; Amini, Falk, Hoth, & Schmitt, 2016).

2.2.3 Don't Go Wasting Your Emotion

Another approach, widely recognized in the literature as Affective or Emotional Engineering, sees perceived quality as an affective impact of a product on the customer. This emotional impact is consequently analyzed as a result of the composition of the various product attributes (Schütte, Eklund, Axelsson, & Nagamachi, 2004). Examples of methodologies that aim to measure the impact of affect caused by the product on the customer are Kansei Engineering, Positive Design, and Pleasure-based approaches in product design.

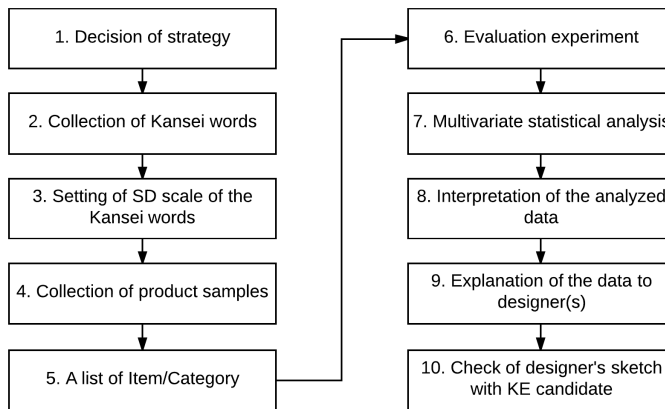


Figure 11 – The process of Kansei Engineering Type I (Nagamachi, 2016)

Nagamachi developed Kansei Engineering as a consumer-oriented technology for new product development. “Kansei” is a Japanese word describing a consumer’s psychological feeling and image about a new product. Nagamachi gives a particular example: “When a consumer wants to buy something, he or she has an image of the product as ‘luxurious, gorgeous and strong’. Kansei Engineering enables his or her image and feeling to be used in the new product.” (Nagamachi, 1995). In other words, Kansei Engineering translates the customer’s feelings about new product into the

design specifications. There are four points that need to be taken into consideration when applying Kansei methodology: 1) understanding the consumer's emotions regarding the product in terms of psychological estimation; 2) identification of design characteristics for the product; 3) establishing the connections between the customer's feelings and design characteristics in order to maximize customer satisfaction; 4) product design adjustments to the current trends. A wide variety of methods are in use to capture customer feelings: semantic differential (SD) method, conjoint analysis, eye-tracking and gaze analysis methods, even electromyography (EMG) and electroencephalography (EEG). There are six types of Kansei Engineering: Type I means category classification, Type II uses a computer system, Type III utilizes a mathematical model or engineering modelling to reason an appropriate design, Type IV is a hybrid Kansei Engineering, Type V is virtual Kansei Engineering and Type VI is collaborative Kansei Engineering (Čok, Fikfak, & Duhovnik, 2013; Nagamachi, 2002). One of the well-known examples of use of Kansei methodology is the development of some ergonomic aspects for Mazda Miyata (Nagamachi, 1995).

Kansei Engineering Type I is a fundamental technique of the Kansei method which uses the process-ruled means. A procedure for this method is shown in Figure 11. Alas, despite the attractiveness, Kansei methodology it is quite challenging in practice. It is limited to the analysis of words (usually adjectives) and their emotional representation of a customer's perception. The difficulties in extracting and transforming customer emotions into technical specifications often leads to weak results; e.g., the technical and functional complexity of a car and its components usually exceeds the knowledge, imagination and verbal apparatus of an average customer. Moreover, engineers are usually poorly trained in the data analysis used in Kansei Engineering; there is a lack of support systems and guidelines (Nordgren & Aoyama, 2007). In addition, a typical Kansei study is quite a time-consuming process (even if it is performed by an experienced engineering team), and this fact often plays a negative role due to a continuously shrinking time period for the product development processes.

Desmet & Pohlmeier (2013) introduced the Framework for Positive Design, which comprises three major pillars: design for virtue, design for pleasure, and design for personal significance. Positive Design is a customer-centric approach and focuses on deep understanding of the customer's context, lifestyle, values and goals related to the design process. However, this particular framework needs to be elaborated further towards development of practical methods and tools for product development, especially during its early stages. Jordan (2002) proposed linking product benefits or "pleasures" to product attributes, moving human factors in design beyond the usability-based approaches. Jordan adopted a framework for addressing pleasure issues - "The four pleasures: a framework for considering pleasure with products." This framework defines four types of pleasures: (i) Physio-pleasure (ii) Socio-pleasure (iii) Psycho-pleasure, and (iv) Ideo-pleasure. However, the challenge to "fit" the product perfectly to the customer needs remains open. Therefore, with the plethora of available methodologies for the translation of "pleasures" into design decisions, fitting can be applied only in the specific personal or usability context. Jordan divides these methods into empirical and non-empirical, describing advantages and limitations for each method. In essence, this new approach to human factors in design gives a broad

overview of the existing methodologies. If applied in practice, an exceptional skills and knowledge of the qualitative and quantitative approaches are required from the design team, which in turn is rarely the case.

Zöller and Wartzack (2017) proposed a methodology of Application for Computer-Aided Design of Emotional Impressions. (ACADE) that integrates interdisciplinary knowledge into the product development process by addressing the subjective needs of a customer. ACADE was designed as a system to support subjective quality creation based on customers' individual attitudes. The system's workflow consists of three major phases: product context, user context and processing. The subsequent data analysis includes numerical methods, such as multivariate statistical analysis, fuzzy set theory and artificial neural network processing and analysis. At this point the applied data analysis techniques are similar to those used in Kansei Engineering. However, the authors admit that only visual sensory perception factors have been considered to date and the possibility of particular methodology use for assessment of other sensory systems is a question for future research.

2.2.4 Towards the Quantification of Perceived Quality

The quantification and ability to measure perceived quality or its elements has recently become a prominent theme in research. Hazen, Boone, Wang, & Khor (2017) presented a methodology for evaluation of the perceived quality of remanufactured products (PQRP), admitting that no attempts to measure perceived quality of remanufactured products were made in the past. Li, Liu & Li (2014), proposed a method for customer satisfaction evaluation using an Entropy weight and Analytic Hierarchy Process (Saaty, 1990). This methodology combines the Kano model with the Entropy weight determination for product evaluation criteria, which in turn is assigned with the use of AHP. Thus, the industry professionals' knowledge utilization, combined with the use of statistical methods, forms a new path in perceived quality quantification methodology. Wiesner & Vajna (2018) argued for low measurability of industrial design in the context of new product development, bridging the cognitive gaps between designers and users regarding the perception of wearable devices. Furthermore, several methods have been proposed for the evaluation of single attributes. Duraiswamy, Campean, Harris & Munive-Hernandez (2018) developed a methodology for robust evaluation of the perceived quality of vehicle body panel gaps or split lines. Pan et al. (2016) presented a quantitative model for prediction of visual attraction design regions related to automotive styling, where the customer's response to product design was modelled with the use of a deep convolutional neural network and crowdsourced Markov chain. Overall, the research mentioned above shapes the current trend towards quantification of perceived quality and facilitates development of the new approaches regarding the evaluation of entities that have previously been seen as highly subjective and non-measurable.

Generally speaking there are few major flows in product development related to perceived quality (see Figure 12): the "old school" manufacturing approach – not taking account of perceived quality; the "marketing" approach – broadly customer-centric; the Emotional (Affective) engineering approach – a subjective notion of

perceived quality; the Robust Design and Geometrically Robust Design approach – although the engineering approach was introduced, it focuses mainly on visual quality.

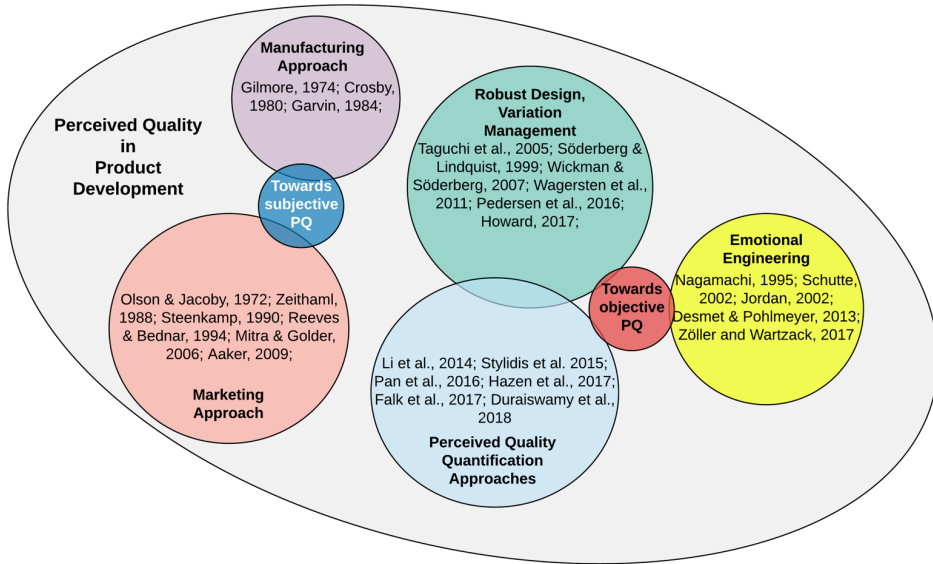


Figure 12 – The major views on product and perceived quality in the literature.

Alas, the comprehensive engineering approach, with a focus on perceived quality as a vantage point for new product development, together with questions regarding the importance of quantification, perceived quality attributes design impact on the customer - have not been widely covered in the literature, leaving a significant knowledge gap in applied and theoretical engineering science.

2.3 The “Intangibles” of Perceived Quality

The research regarding the “intangibles” related to perceived quality and applicable to the automotive industry is fragmented and mainly focused on areas such as brand image, brand heritage, perceptions of aesthetics, and craftsmanship. Here we can observe the existing pattern of a “marketing” vs “manufacturing” approach similar to the one described above. The research related to branding, core values, luxury and premium product domains is usually “marketing”-oriented, while the research on craftsmanship, aesthetics and core values usually focuses on the areas where the product-based or even manufacturing-based approach is applicable. Eventually, the demand of customers today is not only zero defects quality but rather the expectation for products to be error-free. This is very important for the automotive industry. Cars are becoming more and more heterogeneous systems of systems with a high level of integration among various functions. Design and aesthetics factors are also becoming an inevitable, integrated part of product development. These facts are forcing the

industry to find new areas of differentiation (Schmitt & Neumann, 2013) and academia to perform research in these areas.

2.3.1 The Brand, Brand Image and Brand Heritage

Compared to the past, nowadays brand managers are facing extensive market fragmentation, various channel dynamics, and globalization. To be able to deal with these changes and complexities, brand managers have no other choice but to create aggressive brand extensions, complex structures with a number of sub-brands. According to Aaker & Joachimsthaler (2000), sub-brands are playing the role of co-drivers that increase Perceived Quality of a brand. Styliadis, Hoffenson, Wickman, Söderman, & Söderberg (2019), confirmed this trend of the sub-brands use in the case study of Volvo Car Group and Volvo Trucks. Homer (2008), describes the relationship between brand image and quality, bringing attention to cases with a conflict between product quality and its perceived image. Homer concludes that the brands with a low perceived image are in a worse position regarding the customer's judgment than brands suffering from low actual product quality. Homer claims that "data suggests that strides in quality are not as powerful as efforts aimed to enhance brand image, at least for some product categories such as cars." Lobschat, Zinnbauer, Pallas, & Joachimsthaler (2013), in their study structured multifaceted formative construct, social currency, and investigated further how the social currency influences brand equity in the case of the automotive industry. They found that social currency has a positive influence on the Perceived quality of the brand. Akdeniz & Calantone (2017), presented a longitudinal study of the US automotive market on quality perception gaps. In marketing science, a quality perception gap is described as the difference between perceived and objective quality. Akdeniz empirically tested if the quality perception gap of a brand affects its market performance. Key findings from this research showed that "relationship between the quality perception gap and brand sales has a non-monotonic relationship, implying that only up to a certain level will the gap favoring a higher perceived than objective quality have a positive impact on brand performance." It was also revealed that the quality perception gap has a trend to decrease over time.

It should be noted that the brand heritage is a very important influencer on the vehicle purchase decision as well. An extensive methodology regarding consumers' perception of the heritage of brands restricted to the automotive industry is presented by Wiedmann, Hennigs, Schmidt, & Wuestefeld (2011). The evolution of the brands together with the future of brand management presented in the research of Wiedmann (2015) acknowledges the complexity of the current and future challenges.

2.3.2 Luxury and Premium: Walking a Fine Line

A clear understanding of which factors form the foundation of the premium automotive brand and the difference from the luxury brand is essential. The terms "luxury" and "premium" are widely used in the communication strategies of the automotive manufacturers and in the glossary of the executives. However, these terms are often misinterpreted or bring confusion both to the manufacturer and to the customer. There is a lack of understanding about which components comprise luxury or premium:

where should the money be spent, which perceived quality attributes make a difference (de Jongh Hepworth, 2007). In general terms - premium is a prerequisite to luxury. However, there is no clear borderline or clear measurement scale to distinguish premium from luxury. Hennigs, Wiedmann, Behrens, & Klarmann (2013), define the concept of luxury as “highly subjective, situational contingent and depending on the experience and individual needs of the consumer.” Wiedmann, Hennigs, Klarmann, & Behrens (2013), state that “...*key characteristics of luxury brands include a Perceived high price; excellent quality; exclusivity and uniqueness in the sense of scarcity or severe availability; aesthetics of form and color; a long history and the reputation of a holistic and continuous brand presence; and non-necessity, as symbolic values which dominate over the functional characteristics.*” Quoting Andrew Smith, Director of Design at GM, “*In the car industry, there is always room to become more perfect but also the risk to run of “sterility”, and “sterility” tends to push towards premiumness versus luxury.*” The key difference between luxury and premium is the fact that premium is more about product quality and functionality. Luxury communicates a more personal approach while premium is all about a product that exceeds customer expectations. A good example of misinterpretation of the concept of quality in terms of luxury/premium is the case of the Volkswagen Phaeton. “Volkswagen pulled its Phaeton from the U.S. market because American consumers were not willing to buy the 6-figure “best car in the world” if it had a VW nameplate.” (Homer, 2008). Lesson learned - two years later Volkswagen successfully launched the Bentley Continental GT on the platform of VW Phaeton. The automobile luxury market segment has focused historically on an emotional and personalized approach to design (Bastien & Kapferer, 2013). In the luxury industry the focus of the design process has been placed on prioritizing design attributes (Hauser & Clausing, 1988) most related to symbolic values such as aesthetics and brand image (Wiedmann et al., 2013). Less emphasis has been placed on measurable manufacturing quality design attributes, such as gap and flush metrics of vehicle body split lines, or other perceptual design attributes, such as squeak and rattle. However, recent studies revealed new trends: (i) customers of luxury vehicle manufacturers now expect the same level of perceived quality amongst design attributes as in the premium segment, (ii) luxury vehicle manufacturers benchmark their products to the premium (Stylidis et al., 2016). This fact means that the luxury OEMs will invest resources into the product quality attributes they ignored for quite some time, focusing to the hedonic values instead. Hennigs, Karampournioti, & Wiedmann (2017), investigating the luxury wine market defined the existence of four latent value dimensions: the *financial value* of wine, the *functional value* of wine, the *individual value* of wine and the *social value* of wine. These four consumption values are expected to drive purchase attitude and behaviour. A similar approach can be applied to other luxury products, such as automobiles. However, if the engineering design intent for the premium segment is limited by factors such as cost and time to production, the luxury segment is relatively free from these boundaries. As a result, successful design for the luxury segment can be implemented by correct balancing of the perceived quality attributes to meet customer expectations in the context of consumption values.

These findings only indicate that the thin borderline between the premium and luxury domains regarding functional values may fade away in the nearest future. However, it is likely that differentiation regarding financial and social values will last.

2.3.3 Perception of Aesthetics and Visual Quality

The discussion about the relationship between form and function, the ability to measure subjectivity of the aesthetic qualities, dates back to the Plato Dialogues (Beardsley, 1975). Various researchers have investigated aspects of the aesthetics and visual quality of vehicles. Aesthetics, and aesthetic judgment in particular, is often seen as highly subjective elements of quality, comprising intangible notions such as pleasure, beauty and taste. In contrast, aesthetic judgment is quite often referred to as processes that have particular outcomes with certain triggering characteristics (Xenakis, Arnellos, Spyrou, & Darzentas, 2012). Visual quality is not limited to appearance, rather it is a complex phenomenon which includes interaction with the product. The quantification of the product attributes, referred to as visual quality, is the primary goal of the research majority. Crilly et al. (2004), presented a conceptual framework for consumer perception of the visual product form. Crilly et al. adopted Shannon's model of communication (Shannon, 1949) for the product design, concluding that "product form may provide for unarticulated consumer requirements and suggest product qualities that are otherwise difficult to ascertain." Young & Warell (2008), developed the *Perceptual Product Experience* (PPE) framework. This particular framework provides a structure to support design work in terms of validation of the perceptual product experiences. Ranscombe et al. (2012), observed the influence of different aesthetic attributes on the customer's brand perception. Proposed visual decomposition strategy of the vehicle image can improve vehicle appearance evaluation. Burnap, Hartley, Pan, Gonzalez, & Papalambros (2016), investigated dependency of the changing vehicle visual attributes and brand recognition by the customer. This contributed to the knowledge about the extent of design freedom using quantitative models for aesthetic related attributes evaluation. Reid, MacDonald, & Du (2013), attempted to quantify subjectively perceived quality attributes regarding vehicle silhouette design. Quite often a customer has no indicators to signal durability of the product. As a result, the focus will be on the aesthetic impression of the product. For this reason, connection uniformity or consistency (e.g., of gap dimensions) is important (Schmitt & Quattelbaum, 2010). The design of the vehicle consists of some components that are in structural relation to each other (Dagman, Wickman, & Söderberg, 2004). A split line is defined as the relation between two parts over a specified distance. The split line may have some parameters and characteristics such as gap, flush, level of parallelism or curvature. Gap and flush as a characteristic of a split line is a factor that influences perception of the aesthetics by the customer. (Wickman & Söderberg, 2007). Stoll & Paetzold (2008), presented results of gap and flush evaluation in terms of visual quality in a virtual environment. Nonetheless, visible controversy regarding the definition of aesthetics and visual quality still exists. Maxfield, Dew, Zhao, Juster, & Fitchie (2002), defined aesthetic quality by stating that, "*Aesthetic quality* has no precise definition, since it is a qualitative attribute that

is perceived by a customer through visual inspection and comparison. It may be loosely defined as the ‘look’ of the product.” Juster et al. (2001), discuss the term “cosmetic” quality and describe this as, “*Cosmetic quality* has no precise definition. It is a customer-perceived product attribute. It may be loosely defined as the ‘look’ of the product.” Such an approach complies with the “marketing” view on aesthetics as one of the quality dimensions, but also contributes to some confusion in terms of the exact definition of visual quality.

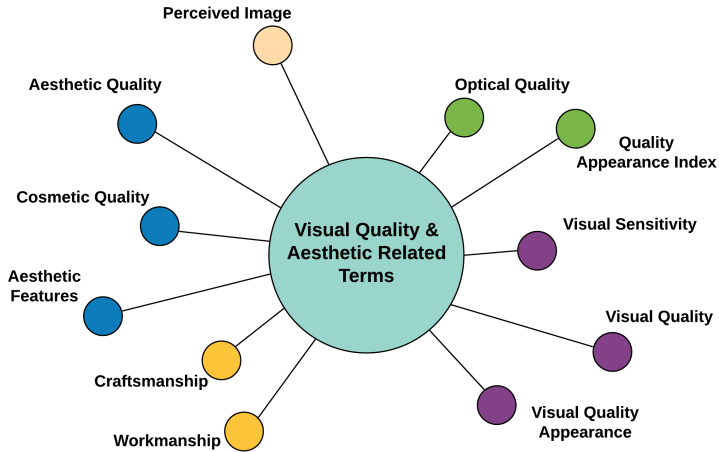


Figure 13 – Schematic illustration of the terms range related to visual aspects of perceived quality

Hazra, Roy, Williams, Aylmore, & Hollingdale (2013), introduced an inspection method for evaluation of the *cosmetic quality* of automotive skin panels. Penzkofer, Wittmann, & Winter (2008), presented a visual analysis method for non-ideal assemblies, since tolerance values have an impact on aesthetic requirements. Forslund & Söderberg (2007); (2008); and Forslund, Dagman, & Söderberg (2006), provided noteworthy papers regarding visual sensitivity, effects of geometrical variation on Perceived quality and *optical quality* as the product attribute. Dagman et al. (2004), introduced *Visual Quality Appearance (VQA)* in an empirical case study investigating the relationship of the *VQA* and the split lines of the vehicle. Wickman & Söderberg (2001), defined a *Quality Appearance Index* as a part of a visual quality evaluation. Wagersten et al., (2011), developed a framework supporting evaluation of split lines perceived quality at the early stage of product development.

The great interest in the area of visual quality can be explained. The visual assessment of the vehicle is considered as one of the early and critical aspects for the perceived quality (Pan et al., 2016). Visual information processing is also influencing other sensory processes. For example, numerous studies show that visual cortical processing is common during tactile perception, especially during macro spatial tasks (Sathian, Prather, & Zhang, 2004). To sum up, despite the quite extensive research in the area of visual perceived quality evaluation, there are certain gaps and overlaps in the definitions (see Figure 13).

2.3.4 Craftsmanship

Craftsmanship is often referred to as the perception of quality experienced by a customer. Craftsmanship is associated with four critical elements, which are the customer's perception of quality, the ability to stir emotions, sensory interaction and skillful manufacture or workmanship (Turley, Williams, & Tennant, 2007). Craftsmanship requires attention to the details in such areas of product development as: appearance – in terms of exterior/interior execution; solid function - functional operational fitness; superior fit and finish, and choice of material – authenticity. Consequently, craftsmanship combines not only a quality of design but even quality of the design execution. Wang & Holden (2000), developed a craftsmanship evaluation method that calculates an overall craftsmanship score for the vehicle. The score is a sum of individual product attributes assessed subjectively. With a similar approach Ersal, Papalambros, Gonzalez, & Aitken (2011), developed a procedure for analysis of vehicle interior characteristics and Perceived attributes of craftsmanship. Previously, Turley et al. (2007), discussed a final vehicle product audit methodology, which includes craftsmanship evaluation. Petiot et al. (2009), illustrated the customer's craftsmanship perception of the vehicle interior with a cross-cultural case study. An effort to develop a comprehensive methodology regarding quality perception measurement of interior material was presented by Bhise, Hammoudeh, Nagarajan, Dowd, & Hayes (2005). In essence, the concept of craftsmanship is very similar to the notion of the perceived quality. It includes involvement of many skills, serves to express quality and can be measured objectively. The author believes that the craftsmanship from the engineering perspective can be seen as a synonym for several elements of perceived quality in relation to the automotive industry.

2.4 Current Industrial Practices

In the automotive industry, during the cycles of product development, the desired performance of the vehicle is handled by various product attributes, such as fuel consumption, passive and active safety, noise, vibration and harshness (NVH), durability, and weight. The perceived quality is usually one of these product attributes. Consequently, a typical automotive OEM uses around 20-120 perceived quality attributes, depending on organizational structure. The perceived quality attributes are responsible for the definition of requirements and requirement levels that determine the perceived quality of the product. In the automotive industry these attributes can be associated with the complete vehicle requirements, but also the component and system-level requirements. Quite often the perceived quality attributes are also responsible for complete vehicle verification with the use of computer-aided engineering, as well as physical testing. The need for robust assessment techniques and evaluation methods of the perceived quality attributes is evident. Despite the continuous pursuit and far-reaching progress in terms of quantification and objectification of the intangible perceived quality attributes, the overall picture often remains diffuse.

The perceived quality evaluation is the ongoing process throughout the new car development project and typically consists of several stages. Initially the marketing department delivers a sort of product attribute description illustrating the future vehicle with target values and positioning the new car to the product category with regard to intended market segment. The marketing department also decides where the car should be positioned within its product category (i.e., taking competitors within the market segment into consideration). This gives the perceived quality evaluation group one or more cars to use in a set of benchmarks. The benchmarks result in generated target values for the complete vehicle. The perceived quality group defines requirements for engineering and design, and then predicts issues, verifies engineering and design status and validates target values and status in production throughout the product development phases. This is an iterative process, as one issue can be solved while a new may occur at a new design release. The work on issues continues until all decisions are taken. Every new decision effecting perceived quality of a component can become a potentially new issue. The evaluation of perceived quality attributes for a vehicle is usually performed by inspection of a physical vehicle or by virtual studies using physical product simulation. It is important to add that a new product today is rarely an outcome of new developments. The focused modification of existing proved solutions to realize new product functions and attributes seems more practicable due to the economic risks (Stylidis, Bursac, Heitger, Wickman, Albers, & Söderberg, 2019). The assessment is carried out by the groups of experts. Every possible defect receives a certain amount of points, which in the end are weighted and added to obtain an overall score for the vehicle. Typically, the OEM uses a global scale for measuring and comparing the results of its own and competitors' vehicles. The single received scores are translated or adjusted to this global scale for assessing the total quality of a car.

There are a number of methods for gathering customer requirements and translation of those requirements into technical specifications. One of the most popular is the Kano method (Kano et al., 1984). However, the Kano model does not include the customer's sensorial perception. Some of the customer's requirements have a subjective or unconscious character and cannot be captured by this method (Tsiotsou, 2006). The Kansei Affective Engineering (Nagamachi, 2016) approach is the method of translation of emotional feelings and image perceptions of people into physical design parameters. Kansei methods support the understanding of subjective perceived quality attributes, but the process of translating these into physical properties is time-consuming and the expression of customers' views is limited to the spoken words (termed "kansei words") (Eckert et al., 2014; Schütte et al., 2004). Another source of information for perceived quality evaluation are the surveys conducted by third party companies, e.g., JD Power, ADAC, or the internal customer clinics that each OEM performs after a certain period of use of the product. One major issue regarding the analysis of customer surveys is an inability to explicitly extract information about a single perceived quality attribute. Certainly, a variety of statistical techniques for marketing research are highly applicable to the studies of perceived quality: conjoint analysis (Wu, Liao, & Chatwuthikrai, 2014); combination of the semantic differential method with the Best-Worst Scaling method (Louviere, 1993). However, this is

difficult to incorporate into the difference modelling of the subjective perceptual attributes e.g., regarding visual quality (Ren, Burnap, & Papalambros, 2013). To design a survey in the proper way the set perceived quality attributes have to be identified and structured. This is a very demanding task due to the nature of information regarding the perceived quality: it is disseminated across various departments in OEMs, the knowledge is often subjective and classified (Stenholm, Styliadis, Bergsjö, & Söderberg, 2016). Qualitative methods such as structured and semi-structured interviews, and focus groups are also widely in use. Alas, the rich data acquired by these methods is often evaluated subjectively. A relatively new method for gathering customer perceptions is eye-tracking. Eye-tracking is a method for capturing eye gaze and fixations while a person is observing visual stimuli. These methods allow the capture of direct feelings and responses of the consumer to be analyzed later with a scientific and quantitative method (Chang, Chiung-Pei, & Min-Yuan, 2013). A combination of eye-tracking with the qualitative research methods is a very promising technique in terms of capturing customers' requirements and their translation to the technical specifications. One of the important limitations to be considered is the question of time that needs to be allocated for customer studies. With the continuous shortening of the production lifecycle, the demand for robust methods of perceived quality evaluation will only increase. The integration of customer requirements into the product development process have to be structured, systematic and supported with robust methodology (Falk & Schmitt, 2014).

With this in mind, it is important to stress that despite the accumulated experience, long-term goals and working culture, advanced methods for quality control – the perceived quality evaluation for the majority of the automotive OEMs often remains a “hit or miss” action. Therefore, industry requires not only theoretical descriptions and delineation of perceived quality attributes, but also a “toolbox” of assessment methods (preferably that are not time-consuming and that are easy to understand).

2.5 Design as a Communication and Information Asymmetry

Not so long ago automotive industry professionals operated with simple brand structures, few endorsed brands, and straightforward business strategies. Today, the situation has changed dramatically, as brands have become more complex, the business environment has grown more difficult to navigate, and challenges now reach a global level (Aaker & Joachimsthaler, 2000). To communicate quality almost every OEM has a need to create a strong identity and express this identity through consistently managed and relevant “touch points” with customers. When speaking about the premium/luxury segments of the automotive industry, the OEMs communicate many of these touch points with the customer through perceived quality attributes (e.g., material, surface finish, and split lines). Perceived quality also involves many aspects of customer cognition and product properties, including emotions, aesthetics, semiotics and semantics, and gestalt perception of the design. However, there is an obvious gap between engineering intentions and customer expectations. This situation

usually appears due to absence of direct contact between designers/engineers and customers.

One of the theoretical frameworks (see Figure 14) explaining these communication discrepancies is a *model of design as a communication process* (Crilly, Maier, & Clarkson, 2008; Crilly, Moultrie, & Clarkson, 2004; Forslund & Söderberg, 2007; Monö, Knight, & Monö, 1997).

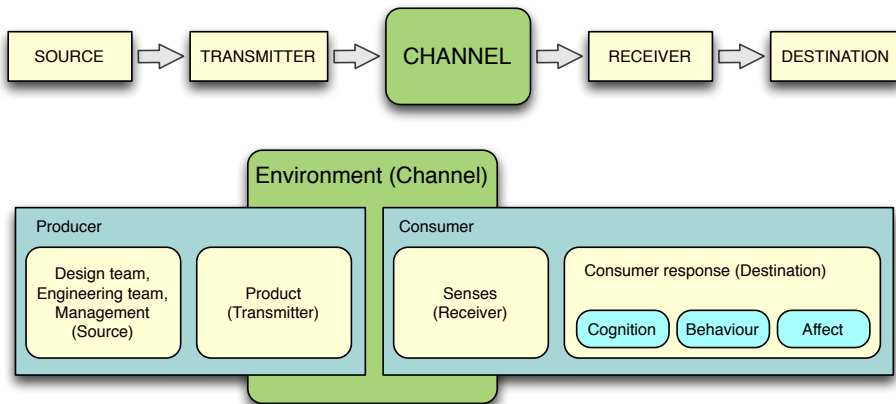
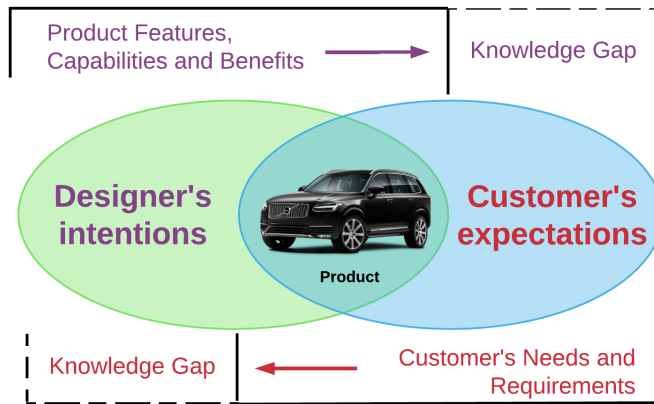


Figure 14 – Framework for design as the process of communication, adapted from Crilly et al. (2004)

The gap between engineering intent for high quality and the customer's perception of the quality can be defined as a state of *information asymmetry*.

Information asymmetry as a notion developed initially in economics (Spence, 1973) and biology (Zahavi, 1975), and was originally explained in signaling and marketing theory as a behavior of two parties when they have access to different information (Akerlof, 1970). There are two broad types of information where asymmetry is particularly important (Stiglitz, 2000): information about quality and information about intent. In the context of product attributes, information asymmetry is caused by misinformation due to existing differences in background knowledge of and available information to the designer and user (Christozov, Chukova, & Mateev, 2009). Information asymmetry works both ways, for example, from an engineering perspective, limited knowledge about user preferences and values can result from time-critical development processes. From a user perspective, information asymmetry can be caused by the limited communication capacities of products and various human factors, including different epistemologies during observation and interpretation (Krippendorff, 2009). Information asymmetry also can appear if the actual quality of the product is not apparent due to its complexity, or if the perception of the brand was affected by negative images in the past, which is a common phenomenon in modern cars (Homer, 2008). Generally speaking, information asymmetries are naturally related to any process of information exchange, and they create a risk of misinterpretation and miscommunication (Christozov et al., 2009).

Premium/Luxury Car Market Segment



Information Asymmetry

Figure 15 – Information Asymmetry from the Product Development Perspective

Information asymmetry is detrimental to a product's success (Stylidis et al., 2016). The ultimate design process goal should be to reduce it, so that designers and customers are considering the same set of design attributes with the same priority when evaluating perceived quality of the complete vehicle or part of it (Figure 15).

2.6 Reflections on the Frame of Reference

Retrospective evaluation of the existing body of literature highlights the deficiency and fragmentation of methods and approaches to perceived quality. The multifaceted nature of perceived quality is recognized in research as well as in industrial practice. A derivative of product quality, perceived quality, has an anthropocentric character and therefore is often seen as a subjective matter. The subjective nature of human judgments predefined the evolution of evaluation methodologies for perceived quality. This has been addressed in different disciplines with a plethora of views and approaches. In this research, the author identified major exploration pathlines in the area of perceived quality:

- (i) Manufacturing-based
- (ii) Marketing-based
- (iii) Emotional engineering
- (iv) Robust design and its derivatives
- (v) Industrial practices.

Alas, in the comprehensive engineering approach, with a focus on perceived quality as a vantage point for new product development, together with questions regarding the importance of quantification, the perceived quality attributes design impact on the

customer have not been widely covered in the literature, leaving a significant knowledge gap in applied and theoretical engineering science.

The existence of this void incepted the development of the perceived quality attributes framework (PQF) and taxonomy of perceived quality attributes. Subsequently, the absence of a comprehensive methodology regarding perceived quality evaluation, primarily inspired by the current industrial needs, shaped the new method (PQAIR) for perceived quality attributes relative importance ranking. After all, the need for introduction of an engineering-based concept regarding perceived quality has become evident.

§

3 Research Approach

A body of knowledge that is the foundation for a discipline is produced through research. To obtain scientifically transparent and credible research results different disciplines use a variety of approaches. The research presented in this thesis is conducted within the discipline of design science. This chapter describes the reasons why this particular approach was chosen, and how it was adopted to fit the boundaries of the research.

“One methodology cannot be more true than another; it can only be more convenient. Methodology is not true, it is advantageous.” –

Paraphrased from Henri Poincaré on Geometry.

3.1 Design Research and Science

Many definitions of design exist. Engineering Design is usually referred to as a set of activities that results in developing a product or knowledge. The particular product or knowledge has to fulfill a customer's need and the needs of other stakeholders. The design as a process includes activities such as requirements specification, concept phase and detailed design, process planning and manufacturing systems design and optimization system analysis. Blessing & Chakrabarti (2009), describe design as “...not only a knowledge-intensive activity, but also a purposeful, social and cognitive activity undertaken in a dynamic context. Design is a complex, multifaceted phenomenon, involving people, a developing product, a process involving a multitude of activities and procedures; a wide variety of knowledge, tools and methods; an organization; as well as micro-economic and macro-economic context.” According to Hubka & Eder (1987), design science is “... the problem of determining and categorizing all regular phenomena of the systems to be designed, and of the design process. Design science is also concerned with deriving from the applied knowledge of the natural sciences appropriate information in a form suitable for the designer's use.” Design research evolution consisted of three phases: Experimental, Intellectual and Empirical (Wallace & Blessing, 2000). The Experimental phase, which existed until the late 1950s, included activities of the senior designers. They wrote about their experiences in the design process and the results. These observations were not placed within any framework and were specific to the domain they described. The Intellectual phase that followed lasted about 20 years. During this stage, the emphasis was placed on the creation of a design basis using a variety of methodologies and principles of a design process. The Empirical phase started in the 1980s with the empirical studies. Its purpose was to understand how the designers perform a process of design. The

Empirical phase investigated what impact new methods and tools had on this processes (Blessing & Chakrabarti, 2009).

3.2 Available Theoretical Frameworks

This research was conducted in the context of product development. However, the nature of perceived quality draws support from various domains including mechanical engineering, material science, marketing and economics, ergonomics, cognitive and social sciences. It should be mentioned that there are differences between explanatory models of science and design science: explanatory models in science tend to determine what causes a particular phenomenon in nature, whereas design science is pragmatic and results oriented. Generally, there are three categories of scientific disciplines: (i) the *formal sciences*, e.g., philosophy and mathematics; (ii) the *explanatory sciences*, e.g., the natural sciences and major sections of the social sciences; and (iii) the *design sciences*, e.g., the engineering sciences, medical science and modern psychotherapy (Aken, 2004).

Speaking about theoretical schools of thought there are two major approaches; *theory-driven* and *data-driven* approaches (Blessing & Chakrabarti, 2009). In the first case, the process starts with the problem statement and hypotheses formulation, followed by the validation and verification processes. The best example of the second approach is the Grounded Theory. Grounded Theory is the general method for systematic generation of theory from empirical data (Corbin & Strauss, 1990). Consequently, numerous discussions about the differences between *qualitative* and *quantitative* research can be found in the literature. Often quantitative research is described as deductive, where the hypothesis is derived from the theory and tested by systematic statistical analysis. Qualitative research is a rather inductive process utilizing data collection and analysis to formulate the hypothesis, test it and attempt to create theory (Frankfort-Nachmias & Nachmias, 1996; Kelle, 1997; Flick, 2008; Given, 2008;). Research that utilizes both quantitative and qualitative approaches is called mixed-methods research. There are several different methods and frameworks that provide a useful theoretical basis for researchers in the product development domain. In particular, the theoretical framework of the design includes the following research methodologies: TRIZ (Altshuller, Shulyak, & Rodman, 1999), Domain Theory (Andreasen, 1991), Mathematical Theory of Design (Braha & Maimon, 2013), Function-Behavior-Structure framework (Gero & Kannengiesser, 2004), CK-Theory (Hatchuel & Weil, 2003), Theory of Technical Systems (Hubka & Eder, 1987), Axiomatic design (Suh, 2001) and others.

The complexity of the perceived quality notion has resulted in synthesis of the available approaches and methods used in this research. A qualitative approach was applied to understand the nature of perceived quality, utilizing such methods as observations, interviews, study of internal documents, and third-party surveys reports. The quantitative approach in this research applies in the form of surveys, questionnaires to obtain statistical data with the main purpose of validation of the hypotheses derived from the qualitative data analysis. The ultimate goal of this

research was the development of a valid and reliable body of knowledge, to be used further in product development processes, i.e., to have applicability to real world problems.

3.3 Design Research Methodology

The methodology of this research project was based on the Design Research Methodology (DRM), a framework developed by Blessing & Chakrabarti (2009). The DRM focuses not only on aiding the process of providing understanding of design but provides a rigorous path to more effective and efficient design research. On the first hand, the research methodology choice should be grounded concerning the identified research gap and research questions. The research methodology must help in collecting the data to answer research questions. In this research the author applied DRM for several reasons: (i) this research into design science is based on the research tradition of the university department and research group, (ii) it has strong relevance to the mechanical engineering field and product development, and (iii) DRM is intended to fulfill two purposes, first to understand the object being studied and then to propose the tools, methods or guidelines that can be applied in practice. Therefore, DRM allows the researcher to find new ways to deal with the phenomena previously uncovered as a creative part of the research process.

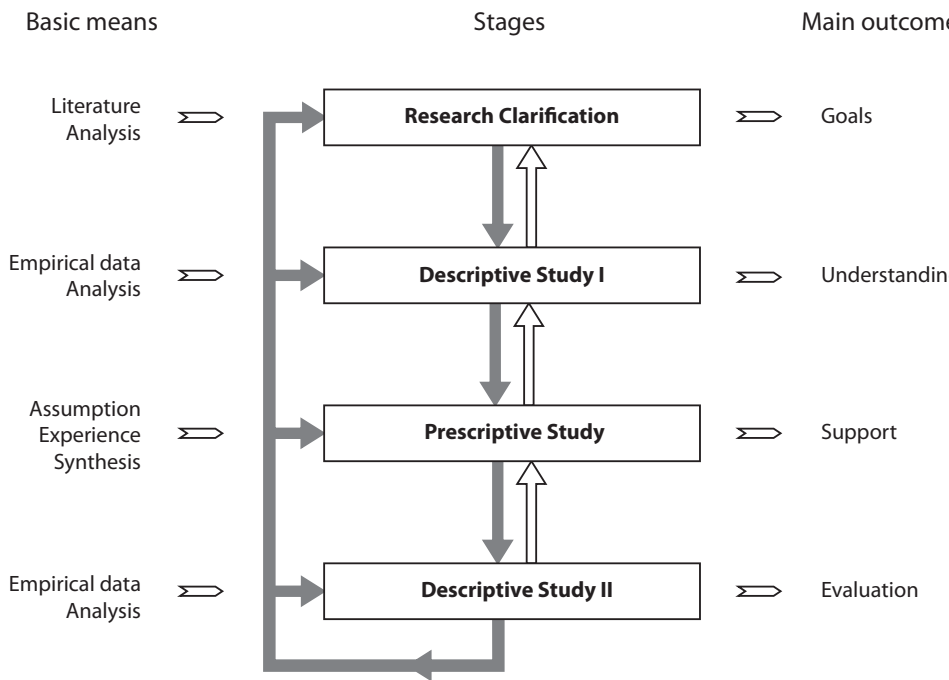


Figure 16 – DRM Framework by Blessing & Chakrabarti (2009) applied this research

The DRM consists of four main phases (see Figure 16) and it is iterative methodology, which means implementation of the phases is not necessarily executed in chronological order. Additionally, it may not be possible to perform all stages of the framework within the boundaries of one research project (Blessing & Chakrabarti, 2009). Phase 1 is the research clarification (RC) and the main goal is to define a success criterion that will evaluate success of the research. The main method and source of information regarding this stage is the literature study. In the next phase, known as the Descriptive Study I (DSI), the researcher usually tries to clarify the situation and detect possible problems and research gaps, if any. At this point an extensive literature review is performed, together with empirical studies if needed. Normally DSI acts as a basis for the third phase – Prescriptive Study (PS). The PS addresses those problems, depicting how to affect them to improve the existing situation with development of new methods and tools. The next phase, Descriptive Study II (DSII) aims at evaluating the true effects of the support implemented. To sum up, each phase stage contains a pool of activities and deliverables to aid the researcher. To determine the focus of the research, it is necessary to identify the success criteria in relation to the main research question. Success criteria according to Blessing and Chakrabarti (2009) relate “to the ultimate goal to which the research project intends to contribute and usually reveal the purpose of the research.” The aim of research presented in this thesis is a creation of ontology and methodology for perceived quality evaluation from the engineering perspective. The ultimate goal of this research is to develop a robust methodology to equip engineers with the practical tools necessary for perceived quality evaluation. The research approach is represented by a mix of methods, such as a combination of qualitative and quantitative research methodologies.

3.4 Methodology Applied in this Thesis

This chapter describes how the research methodology has been applied in this thesis. As foundation of this process the following aspects will be considered: research questions, DRM phases, published papers and types of result, methods used, and case studies performed.

3.4.1 Research Questions and the DRM Phases

The ultimate goal of this research project is to generate new knowledge regarding the perceived quality evaluation methods applicable to the automotive industry. To achieve this, a number of research questions were generated.

RQ1 (*How can perceived quality be defined from the engineering perspective?*) deals with the complete understanding of perceived quality nature and explicit definition of perceived quality attributes. The initial attempt to define perceived quality from the engineering viewpoint was performed in **Paper B**. Over the years of this research the theme was developed further, and, as result, **Paper C** presented an innovative perceived attribute structure (PQF) with the method for perceived quality evaluation

(PQAIR). This work also presents a new definition of perceived quality and its elements. Paper C also provides a comprehensive literature review along with the description of existing gaps in research regarding perceived quality. An enhanced literature review is also presented in Chapter 2 of this thesis.

RQ2 (*What product attributes can be used to validate perceived quality on a complete vehicle?*) is important mainly because in practice the industry has a certain need of robust methods for collection and analysis of the customer's requirements. The production time in the automotive industry has a tendency towards decrease and this fact necessitates the search for effective user-centered but also "engineer-friendly" methodology. **Papers A, C, and D** present methods and tools that answer RQ2. In **Paper A**, a procedure of semi-structured interviews as a part of the qualitative study is presented. The results of the interviews are the list of the perceived quality attributes, which were evaluated by the customers with the use of survey and semantic-differential scale, together with the Maximum-Difference Scaling method. **Paper C** presents the Perceived Quality Framework (PQF), a taxonomy structure of perceived quality attributes and the Perceived Quality Attributes Importance Ranking (PQAIR) method. The PQF illustrates the attribute-centric engineering viewpoint on quality perception, developed through reciprocated studies of the automotive industry. The PQAIR method equips engineers with the practical tools for perceived quality evaluation. The data derived from previous research published in the additional publications, as well as from the internal OEM's documentation of customer clinics and current design practices or third-party companies i.e., JD Powers, ADAC. **Paper D** presents the use of the PQF and PQAIR methods in combination with Product Generation Engineering (PGE) as a holistic approach for designing new generations of products with a desired level of perceived quality. **Paper D** presents an analysis of a retrospective case from the premium car market segment, and specifically the development of haptic input systems in the centre console for the Porsche Panamera automobile.

RQ3 (*How can meaningful perceived quality feedback be gathered?*) deals with the internal and external factors that form the meaning of the perceived quality and its attributes. **Papers A, C and D**, with the use of a mixed method approach, provide insights into the genesis of the perceived quality attributes. The ability to convey a meaning of the perceived quality attributes, as engineers see it, to the customers is critical to the success of a car.

RQ4 (*How can perceived quality be balanced at the different product levels?*) is a primary question of this research. The ability to manage perceived quality can be expressed in the single open question, "*Which perceived quality attributes do engineers have to focus on to receive the highest level of a customer's appreciation?*" This normative question is usually followed by the prescriptive question, "*How can we measure the importance of a single perceived quality attribute or a group of attributes for the customer?*" To address these questions, **Paper C** proposes a new method for perceived quality evaluation.

Notably, DRM is not to be interpreted as a rigid and linear research process (Blessing & Chakrabarti, 2009). The allocation of the research questions in the DRM framework has a particular reasoning. In this research extensive exploratory studies were conducted and reflected not only in the major but in the additional publications too. The reason for such a diverse research approach is the multidimensional nature of perceived quality. Many of the perceived quality elements have a fuzzy construct, and little previous research exists. Visible controversy and redundancy in the terminology and definitions was detected too. Industrial practices related to perceived quality also vary to a great extent. The distribution of the appended papers in the context of DRM phases is depicted in Figure 17.

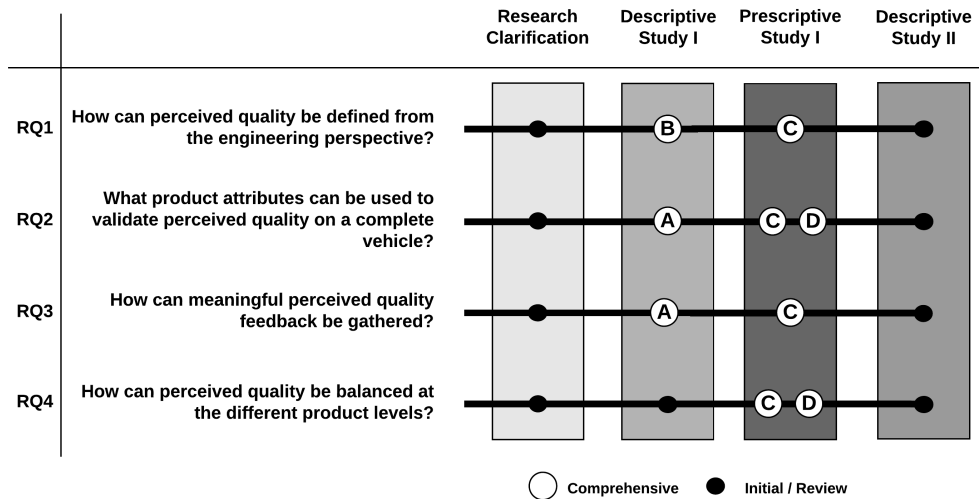


Figure 17 – Distribution of papers A-D in the context of the DRM Framework.

3.4.2 Type of Results

There are several types of results that form the basis of the current research presented in this thesis.

- Descriptive results: **Papers A, C, and D** provide empirical and statistical data leading to a better understanding of how the design processes relates to the perceived quality evaluation.
- Prescriptive methods and tools: **Papers C and D** present methods for data collection and further analysis.
- Phenomenology of perceived quality: **Papers A, B, C, and D** investigate the phenomenon of perceived quality.
- Major research findings: in **Papers B and C** the ontological frameworks of perceived quality (PQF) and perceived quality evaluation method (PQAIR) are presented.

3.4.3 Methods Used

There are numerous approaches for collecting data within design research, such as samplings, interviews, group interviews, surveys and observations. Methodologies can also be combined, such as case study and action research. In this research a variety of methods were used.

Case study is one of the commonly used approaches within research design. Yin (2013), defines a case study as a process of “investigation of a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident.” To understand the phenomenon of perceived quality, record existing methods for evaluation of perceived quality, and determine basic perceived quality attributes, several case studies were performed. **Paper A** presents the case of Volvo Car Corporation and Volvo Trucks, where the communication strategies of these companies were investigated in relation to the core values they share. A list of the perceived quality attributes that companies use in communication with the customers was compiled. A combination of qualitative and quantitative methods was applied to this research. **Paper B** introduces the sensorial approach to the taxonomy of perceived quality elements and sets up the course for the further research. A literature review and the analysis of the industrial cases composes the methodological core of this paper. **Paper C** demonstrates the results from the four-year study of eight European and two North American automotive OEMs that have been examined with regard to understanding and decomposition of perceived quality attributes. This research defines perceived quality from the engineering viewpoint, introduces the sensory-based taxonomy approach covering every aspect of the product’s perceived quality, and presents the robust methodology for perceived quality evaluation. **Paper D** investigates the use application of PQF and PQAIR in the context of Product Generation Engineering (Albers, Bursac, & Wintergerst, 2015). This paper presents how these two lines of research combined to design the central console of the Porsche Panamera automobile and discusses the opportunities and challenges posed in the practical implementation of this research.

Interview is one of the most widely used methods in qualitative research (Yin, 2013). Interview studies are typically classified as structured, unstructured and semi-structured interviews. **Papers A, B, C and D** include qualitative evaluation of the selected industry professionals using semi-structured interviews. The semi-structured interview normally include elements from both structured and unstructured interviews. Cachia & Millward (2011), describe semi-structured interviews as, “A fixed set of sequential questions is used as an interview guide, but additional questions can be introduced to facilitate further exploration of issues brought up by the interviewee, thus almost taking a form of a managed conversation.” Additionally, in **Papers A and C** the transcribed interviews were coded and analyzed with the use of NVivo – a qualitative data analysis computer software package (Welsh, 2002). The material was organized into topic areas or nodes. To ensure reliability of data and minimize possible discrepancy, the content analysis of the interviews was performed by two or more independent coders (i.e. **Paper A** – two coders, **Paper C** – four coders). To measure observed agreement between coders in **Papers A and C** the agreement coefficient (Kappa) was calculated (Cohen, 1960).

In some exploratory case studies during the data analysis a Grounded Theory (Corbin & Strauss, 1990) methodology was implemented. The rationale for the methodology choice was the fact that automotive OEMs involved in the studies are unlikely to share data regarding perceived quality evaluation methods or related manufacturing processes with the public. This fact did not allow conducting prior analysis of the available information. However, during the case studies process we obtained new knowledge regarding perceived quality that was previously unavailable to the public. As mentioned previously, this research utilizes a mixed methods approach, including quantitative methods. Particularly to capture the customer's perception of Perceived quality attributes, **Papers A and C** include quantitative survey. One of the methods used in the surveys is the Best-Worst Scaling (BWS) method, which is the quantitative choice-based technique used for understanding a respondent's or respondent group's relative valuation of different products or product attributes. BWS was used together with questions using the more common semantic-differential scaling, which is one way to avoid lack of discrimination and confounding among respondents (Magidson, Thomas, & Vermunt, 2009).

To understand the existing body of knowledge, a literature study was performed in **Papers B, C and D**. Literature study is an essential prerequisite in order to map the proposed methods and definitions, as well as to determine any existing gaps in the knowledge related to perceived quality. Moreover, the internal documentation available from the automotive OEMs involved in the case studies was systematically studied. Examples of internal documents that have been studied are presentations describing organizational structure, attribute structure descriptions, lists of functional and technical requirements, and working instructions. The author participated in international customer clinics performed by the car companies, observing the behavior of both parties, customers and professionals.

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4 Results and Summary of the Appended Papers

*“Every act of creation is first an act of destruction”–
Pablo Picasso.*

This chapter presents the results from the papers that are appended to this thesis (see Figure 18). Some of the papers provide answers to the research questions while some contribute with relevant information and significant elements of this research. The summary presented in this chapter focuses mainly on the results, hence not all the papers will be described equally in terms of detail. The full descriptions can be found in the appended papers. Certainly, the work presented in this thesis is not derived solely from the four appended research papers, but rather must be seen as a consolidated result, and is also expressed in other publications (see List of Additional Publications).

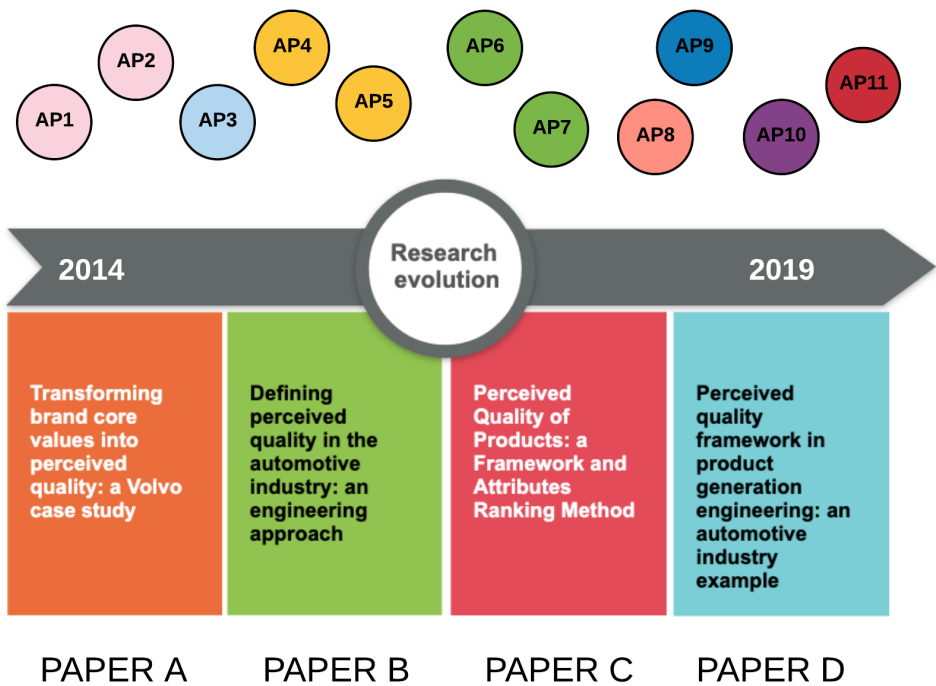


Figure 18 – Evolution of the research presented in this thesis depicted as the appended papers.

4.1 Summary of the Appended Papers

In brief, the results of all papers can be summarized as follows:

- The extensive literature review performed, depicting certain confluences and disengagements in the definitions and terminology of perceived quality. The existing quality models and systems were carefully examined.
- The “*model of design as a communication*” applied to the process of perceived quality evaluation. A proposition to see the gap between *engineering design intent* for high perceived quality and the actual customer’s perception of the quality as a state of *information asymmetry*.
- The communication strategies and trends regarding perceived quality are investigated. Demonstration of how the customers perceive and prioritize perceived quality attributes is presented. The key discrepancies are identified and discussed regarding their implications on communication and perception differences between industry professionals and customers.
- New trends regarding definition of customers’ requirements and perceived quality in the premium and luxury market segments are revealed. These trends confirm the hypothesis that perceived quality is becoming a frontier for successful automotive design.
- Definition of perceived quality domains from the engineering perspective. Inclusion of the new terms *Technical Perceived Quality* (TPQ) and *Value-based Perceived Quality* (VPQ) in the process of perceived quality assessment.
- Development of the taxonomy structure for the perceived quality attributes – Perceived Quality Framework (PQF).
- Development and implementation of the Perceived Quality Attributes Importance Ranking (PQAIR) methodology.
- Coordination of the PQAIR method with already established product development methodology, such as Product Generation Engineering (PGE).
- Assessment of usability and rigor for the PQAIR method in practice.

4.1.1 Paper A - Transforming Brand Core Values into Perceived Quality: A Volvo Case Study

Paper A presents a study performed in cooperation with the leading Swedish vehicle manufacturers Volvo Car Group (VCG) and Volvo Trucks (VT). Core values are an important part of the Volvo Car Group and Volvo Trucks strategic development plans. These two companies share the same core values (quality, safety, and environmental care), but they approach these values in different ways. The study has revealed current trends regarding the vision of Volvo professionals of their core values, and has demonstrated how customers also perceive and prioritize those values and the attributes through which they are expressed. Key discrepancies have been found and discussed regarding their implications for communication and perception differences among professionals and customers. During this study the phenomenon of

“information asymmetry” was observed by the author for the first time. The systematic approach presented in this paper to elicit customers’ preferences served as a model for consecutive studies.

4.1.2 Paper B - Defining Perceived Quality in the Automotive Industry: An Engineering Approach

Paper B is the first attempt to define perceived quality taking into account the engineering viewpoint on the subject. The paper presents an analysis of existing research related to the automotive industry in terms of definition and evaluation of perceived quality attributes. This research presents PQF in its earliest form, solely as an idea of an attribute-centric system based on the primary human senses. The authors make a first attempt to define perceived quality as, “Perceived quality itself in the automotive industry has a dualistic nature.” The authors also propose definitions of *Value-based Perceived Quality* (VPQ) and *Technical Perceived Quality* (TPQ). The main outcome of this paper is the conclusion that in the automotive industry application of the user-based approach to quality (through marketing research and identification of product related requirements that represent quality) is hardly manageable on the stage of translation of requirements into the product attributes. This is mainly due to the subjective origin of some product attributes and the lack of information regarding the importance of such attributes to the customer. For this reason, correct definition of the perceived quality attributes is essential, especially for highly complex processes such as car manufacturing. Dissemination of the perceived quality attributes to manageable areas is also important for the objective evaluation and quantification of the areas previously subjectively assessed.

4.1.3 Paper C – Perceived Quality of Products: A Framework and Attributes Ranking Method

Paper C contributes to the product development approach by introducing the Perceived Quality Framework (PQF) in its current state. This attribute-centric framework can serve as a platform for robust discourse around the theme of perceived quality that is not limited by the product type or production method. To achieve this, the authors performed data-collection studies over a four-year time span, examining ten global automotive companies from five different countries. This paper also presents a method to evaluate the perceived quality of a product (PQAIR). This study builds on the assumption that multi-sensory information related to a product, assessed with the help of an attribute-centric framework and mixed methods, is a promising approach for tackling the complexity of the perceived quality evaluation. The PQAIR method can potentially provide the long-awaited answer to the question, “*Which perceived quality attributes are most required for successful product design?*”

4.1.4 Paper D – Perceived Quality Framework in Product Generation Engineering: An Automotive Industry Example

Previous research defined a taxonomy of perceived quality and provided understanding about how engineering design decisions impact customer satisfaction. It is known that the development of new products is frequently based on carrying over attributes of existing products, either from the same producer or from competitors. Product Generation Engineering (PGE) offers a new product development methodology combining variations of subsystems to carry over from existing products (Albers et al., 2015). **Paper D** presents how these two lines of research (PQAIR and PGE) combined to design the central console of the Porsche Panamera automobile and discusses the opportunities and challenges posed in the practical implementation of this research. **Paper D** has several important conclusions:

- Perceived quality phenomenon is as complex as human nature and systematic decomposition of perceived quality into manageable areas is the way to bridge the gap between engineering intent and customer appreciation of the vehicle. The PQF can serve as a core for the methodology intended to help automotive designers and engineers to link technical characteristics with the customer's perceptions and successfully design vehicles for the intended purpose.
- The analysis of the reference products of the product generation in the context of the initial development of the system of objectives shows which attributes have to be improved, disregarded or carried over. From this, the corresponding subsystems of the product can be identified that are critically responsible for realizing these attributes. Furthermore, reference products provide an indication of the perceived quality-critical aspects.

4.2 Understanding the Engineering Viewpoint on Perceived Quality

Perceived quality is a multi-dimensional entity, an outcome of designer/customer convention, and can be seen differently by the different research schools of thought (e.g., philosophy, marketing science, engineering, manufacturing). There are several interpretations of perceived quality (see Section 2.6) in science. However, existing models do not consider the engineering part in the equilibrium of perceived quality. As a result, it is hard to start meaningful discussion about quantification of quality perception. Therefore, the author proposes an approach to perceived quality from the position of applied engineering research. ***From the engineering point of view, the perceived quality domain is a place where the product meaning, form, sensorial properties and their execution intersect with human experience.*** Such an experience is driven by the interplay between product quality and its context. For example, in contrast to a rigid, formal definition of manufacturing quality – engineering tradition regarding perceived quality is to produce events that make the customer aware of how things are done. However, even this statement can be interpreted differently. One of the luxury car manufacturers intentionally adds imperfections into the consistency of

the sew-lines and stitches to reflect “human touch and craftsmanship.” On the other hand, the absence of visible welding spots on the car body is considered a sign of good perceived quality. This means a customer is not even aware of their presence. A high perceived quality means attractiveness of the product to the customer. Yet attractiveness is a relative degree. It is based on our previous experiences and exists only in contrast to what does not attract attention. In industrial practice, engineers are continuously challenged with a polylemma of choice between equally important attributes and their performance; i.e., in the automotive industry should time and resources be invested in the minimization of split lines gaps around the rear lights of a car, or focused on a cut & sew execution of interior materials? In other words, a reasonable trade-off between design capacity and customer requirements must exist. ***The equation, where engineering design intent is meeting customers’ expectations regarding the product, has to reach an equilibrium.*** Therefore, the correct perceived quality attributes prioritization for the new product will lead to a successful design and customers’ appreciation.

4.3 Definition of Perceived Quality

Taking into the account the findings of this research a new definition of perceived quality unfolded. The author proposes the two-dimensional typology of perceived quality: *Technical Perceived Quality* (TPQ) and *Value-based Perceived Quality* (VPQ). ***TPQ includes everything that is part of a product (or service) and can be controlled by engineering specifications together with the functional product requirements (intrinsic attributes).*** ***VPQ is more related to brand image, brand heritage, affective customer judgments, hedonic or social values, the impact from other global attributes, advertising, and marketing promotion techniques (extrinsic attributes).*** Such a distinction is essential, since perceived quality can be seen differently depending on the academic field. The attribute-centric approach to TPQ at the “bottom” level, is expressed with the *Ground Attributes* (see Table 5). ***The Ground Attributes are measurable variables, isolated for a specific product as they depict a borderline for meaningful discussion between the designer/engineer and customer.*** The nature of *Ground Attributes* can be composite and may include materials, shapes, joining methods or parts; however, its primary purpose is to communicate engineering design intent effectively to the customer. The *Ground Attributes* have a further advantage - ability to convey a meaning of the perceived quality attributes, as engineers see it, to the customers. It is only uninformative (for the customer) technical specifications that are left out of the *Ground Attributes* level. It is important to stress that perceived quality attributes can also be defined differently by different OEMs, however, the overall goal of attribute definition is to secure correct content and execution of the final product. All components and system solutions shall be built in such a way that the product is perceived as being one of high quality.

4.4 Perceived Quality Framework (PQF)

The quality perception process is a physical and cognitive event, usually triggered by a physical signal received by our sensory apparatus. The information obtained through the human senses forms the basis of human experience. Thus, it is possible to communicate perceived quality-related technical elements in connection with the customer's sensorial experience. The majority of perceived quality relationships (attributes) can be described by one of these sensory categories, or by several in combination. In essence, the PQF reflects human perceptual processing to delineate, test and explore product designs. The perceived quality attributes within the framework are organized with regard to the primary human senses involved in their assessment; visual, tactile, auditory, olfactory and gustatory (see Figure 19). In the case described in PQF, quality perception based on primary senses forms the first level of the attributes *Visual Quality*, *Tactile Quality*, *Auditory Quality*, *Olfactory Quality* and *Gustatory Quality*.

The author acknowledges the fact that perception is not a fixed concept, as it is significantly modulated by many contextual factors such as multi-sensory information, past experiences, internal predictions, associations, ongoing product behavior and internal or external spatial relations (Newell, 2004), i.e. split-lines and overall design. Thus, PQF today focuses only on TPQ, disregarding any affective perceptual issues related to VPQ. The second attributes level of PQF, based on industry knowledge input, is organized into *Sensory Modalities*. In our case, *Sensory Modalities* are the nine distinctive sets of product attributes encoded for presentation to humans. Each of these sets has a description (see Table 4 and Table 5) and includes a number of *Ground Attributes*. The performed studies revealed none of the attributes associated with gustatory perception or taste. For this reason, there are no modalities linked to Gustatory Quality. However, gustatory-based perceived quality attributes can play an important role in the automotive industry, e.g., use of breath alcohol ignition interlock devices or alcolocks. These devices are likely to become a mandatory feature for new vehicles in the near future.

The *Sensory Modalities* ($m=9$) and *Ground Attributes* ($n=32$) are also color-coded, depicting the human sensory system involved in their assessment. For example, if the "Gap" can be evaluated not only by the visual sensory apparatus but also by haptic sensations, in the PQF this *Ground Attribute* is depicted by the color codes associated with "*Tactile Quality*" and "*Visual Quality*." The base (ground) level of attributes is the "lowest point" where the engineers can still communicate technical details to the customers and receive meaningful feedback. To avoid ambiguity, every *Ground Attribute* has to be coherent to a customer's experience, so the PQF can stand as a meaningful and accessible frame of reference for both the engineer and customer. Eventually a customer must be able to understand the meaning of each *Ground Attribute* and at the same time be able to rank and prioritize its importance among other *Ground Attributes*. Such customer feedback is key for the optimal perceived quality equation-balancing activity within the OEM.

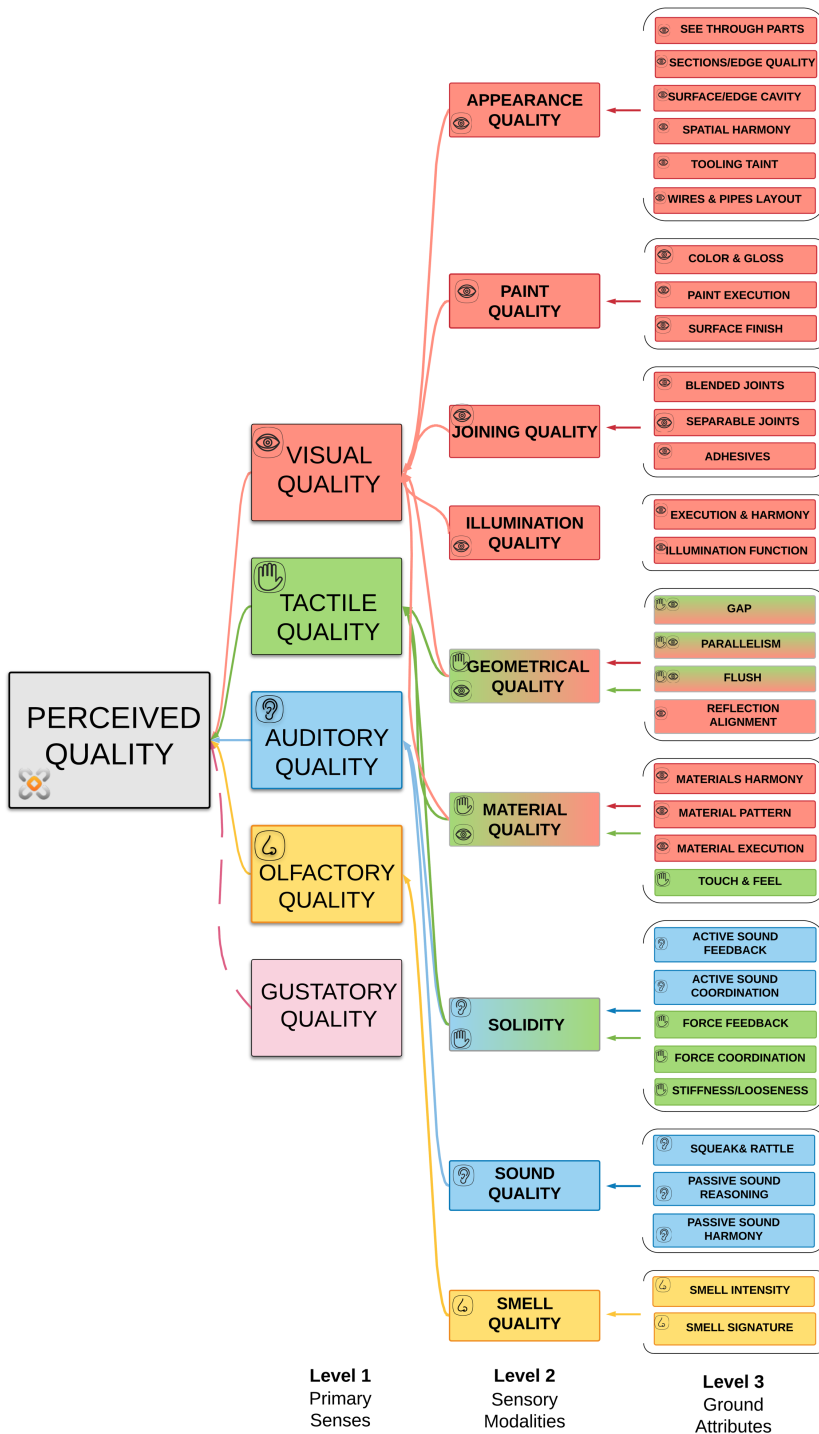


Figure 19 – Attributes Levels of the PQF

Table 4. Definition and Description of the Perceived Quality Sensory Modalities

Modality	Description
Smell Quality	Olfactory perception is integrity of input regarding the smell inside a vehicle. Affects Olfactory Quality.
Sound Quality	This modality refers to the adequacy of the sound produced by the product. An assessment of the accuracy, enjoyability, or intelligibility of sound output from components inside a vehicle. Affects Auditory Quality.
Solidity	Perception of tactile or auditory properties of components as firm, solid. Affects Tactile and Auditory Quality.
Paint Quality	Quality of automobile paint including components and absence of visible defects. This modality focuses on the painted components. Affects Visual Quality.
Geometrical Quality	Harmonious relations among and within visible components (e.g., split lines). Has impact on Visual Quality and Tactile Quality.
Material Quality	A modality that represents a measure of the quality of materials, their execution, and outlook. Evaluates the material of a component. Focuses on genuineness of materials, visual harmony and haptic feedback. Affects Visual and Tactile Quality.
Joining Quality	Quality of attached or appended components including appearance and layout. Focuses on adhesives, blended and separated joints such as spot welds, rivets etc. Affects Visual Quality.
Illumination Quality	Experience of light for a customer. A quality of light provided so the customer can perform visual tasks. Components of illumination quality are determined by visual performance, visual comfort and the visual atmosphere inside and outside a vehicle. Affects Visual Quality.
Appearance Quality	Uniformity and harmony of the car body components, trim and styling.

Table 5. List of Identified Perceived Quality Ground Attributes

Modality	Ground Attribute	Description
Smell Quality	Smell Intensity	Quality and strength of smell in a vehicle
	Smell Signature	A distinctive set of characteristics that represent smell inside a vehicle.
Sound Quality	Passive Sound Harmony	Harmonious combination or interaction of the passive sound sources. A passive sound usually induced by a component or system that has no purpose in functional communication.
	Passive Sound Reasoning	Passive response or reaction to a sound that follows an action/operation in a systematic pattern without any apparent defects in logic.
	Squeak & Rattle	Short, sharp-pitched sound with high or low frequency as a consequence of agitation and repeated concussions while driving, pressing on panels, etc.

Solidity	Active Sound Coordination	Harmonious combination or interaction of the active sound sources, as of functions or parts.
	Active Sound Feedback	Response or reaction sounds of active communication induced by the interaction with driver/passenger primary and non-primary controls.
	Force Coordination	Harmonious combination or interaction of different forces feedback from the controls, buttons and switches.
	Force Feedback	Characteristics of haptic feedback induced by driver/passenger controls operations.
	Stiffness & Looseness	Stiffness and fixation feeling induced by the component when applying a force.
	Wires & Pipes Layout	A visually balanced arrangement of wires and pipes.
Paint Quality	Colour & Gloss	The attractiveness of paint regarding colour, gloss, and matching.
	Paint Execution	Paint has no visible defects, such as visible marks, difference in thickness, unevenness or unwanted process signatures.
	Surface Finish	Surface finish is a measure of a visible deviation from the nominal surface on painted ungrained parts. The nominal surface has no irregularities.
Geometrical Quality	Flush	A perceived step between visible components due to real step size and size of radii. Includes flush symmetry between right- and left-hand side and alignment relations.
	Gap	The perceived distance between visible components due to real gap size and size of radii. This includes gap symmetry between right- and left-hand side.
	Parallelism	The gap or flush has an agreement in direction and tends towards being parallel along a complete split-line.
	Reflection Alignment	Alignment of highlights casting back from split lines between parts.
Material Quality	Material Execution	A degree of effect of manufacturing processes on materials at the micro level (within the material) that can influence its perception.
	Materials Harmony	A proper adjustment of the materials and their components regarding harmonization of colours, textures, gloss, etc.
	Material Pattern	A regular sequence of material properties to form a consistent design, e.g., the appearance and direction of the intended texture on the surface.
	Touch & Feel	The quality of material touched that imparts a sensation. How exclusive the material feels when touching? Also, includes sharp edges. Includes that the material T/F corresponds to how it looks.
Joining Quality	Adhesives	Appearance, number and placement of visible adhesives.
	Blended Joints	Appearance, number, and placement of visible joining techniques that are fused/merged components.

	Separable Joints	Appearance, number, and placement of visible joining techniques that can be fastened permanently (e.g., rivets) or reassembled (threaded fasteners).
Illumination Quality	Illumination Function	The logical function of the illumination. Timing patterns. Timing synchronization. Ramping up of light signature/function. Coordination of light sources.
	Execution & Harmony	An arrangement of the light sources designed to show their mutual relations. Uniformity, intensity, consistency within the ramping of light sources. Execution is relevant for all different types of light sources, such as lights, displays, HMI, exterior light, etc.
Appearance Quality	See-through Parts	The degree to which gaps and holes are covered and free from see-through effects. A non-disturbing visual impression of an arrangement of elements or parts that can be visible through gaps, splits, etc.
	Surface/Edge Cavity	Hollow space on surface or irregularity of edge that occurs due to the way that components and split-lines are arranged and size of ball corners.
	Sections/Edge Quality	Visibility of the inner side of a component at the edge or the quality of the edge.
	Spatial Harmony	A harmonized layout of components that creates an appearance of natural relations among the components, car silhouette, underbody, etc. Visual balance of functional parts/knobs etc. All components and parts create a composition that results in visual stability. Volumes and spatial relationships of surfaces are harmonious. The goal is to minimize visual imbalance induced by manufacturing or technological restrictions.
	Tooling Taint	Appearance, number, and placement of visible defects, traces and signatures from tools.
	Wires & Pipes Layout	A visually balanced arrangement of wires and pipes.

The PQF is not limited to its status as a descriptive framework. The framework can be used widely to explore and test product designs with regard to perceived quality at all product development stages with the implementation of the PQAIR method described in the next section.

4.5 Perceived Quality Attributes Importance Ranking (PQAIR) Method

The Perceived Quality Attributes Importance Ranking (PQAIR) method was created to assist the engineer or designer in the decision-making process with regard to evaluation of the relative importance of perceived quality attributes for the final product. The PQAIR method intentionally combines the objective, measurable information of perceived quality with the subjective customer's evaluation of product quality.

The core of the new method for perceived quality attributes evaluation is that all identified *Ground Attributes* are ranked with regard to their importance (see Figure 20). The ranking can be obtained by utilizing knowledge within the company (e.g., expert's opinion) and/or analyzing customer data (e.g., surveys, customers' clinics, interviews, internal customer feedback systems, and large data sets). These rankings, applied to the PQF order, contribute to the importance score for each branch of the structure at all levels.

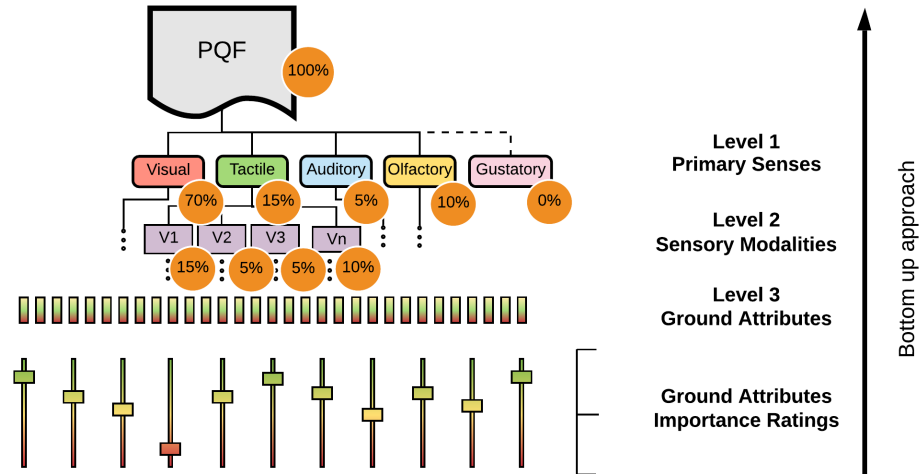


Figure 20– Each identified *Ground Attribute* is mapped into the PQF and importance ratings can be calculated per attribute at every level

The PQAIR method analysis procedure (see Figure 21) begins with the initial stage - target definition for the desired level of perceived quality. Usually, the design intent includes identification of the critical perceived quality attributes for the complete product or just for the specific product's area. Consequently, before the PQAIR method is applied, each OEM has to map their product attributes to PQF. If the OEM already has an internal product attribute structure, the existing perceived quality attributes have to be associated with the relevant *Ground Attributes* of PQF. Alternatively, the OEM can elicit perceived quality attributes of a product in coherence with the PQF principles. After that, the application of the PQAIR method will result in the obtaining of an importance score (ranking) for each attribute, considering the PQF as a reference model for perceived quality assessment. For example, initial ranking of *Ground Attributes* can be performed by the design of discrete-choice experiments and utilization of a quantitative survey technique called Best-Worst Scaling (BWS) (Louviere, 1993). The BWS is not the only methodology which can be employed to rank *Ground Attributes*; e.g., choice-based conjoint (CBC) is another popular discrete choice experiment method for acquiring information on customer preferences for individual product attributes (Louviere & Islam 2008).

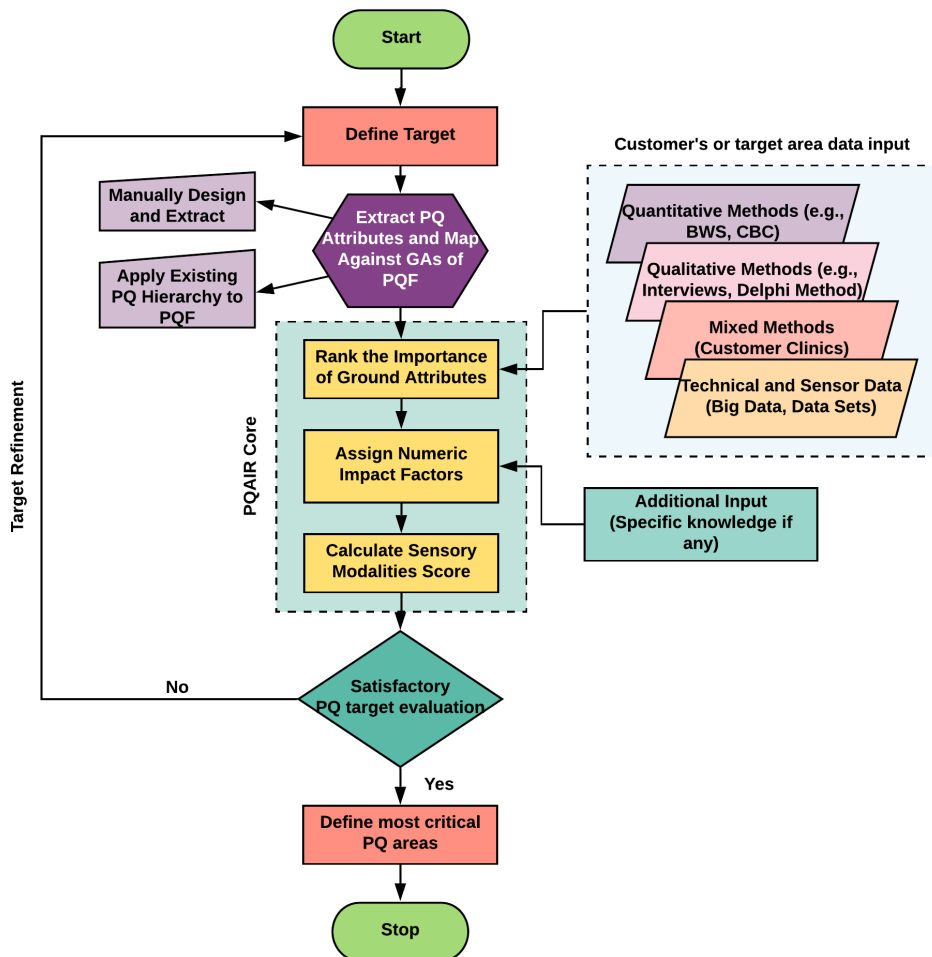


Figure 21 – PQAIR method analysis procedure

The author suggests that the strategy for the choice of methodology regarding obtaining rankings of *Ground Attributes* should be based on the current company needs and available resources. For example, in the case of luxury automotive manufacturers the data obtained from the relatively small group of the car experts or car distributors (e.g., Delphi study), as an additional input, can be more informative compared to the data obtained from the surveys (Stylidis et al., 2016).

The importance of each level attribute must be calculated based on the ranking of all *Ground Attributes*. As long as all $(1, \dots, k)$ *Ground Attributes* are ranked according to their importance, the impact factors are assigned at variance to the ranking of each *Ground Attribute*. The most important *Ground Attribute* is assigned with the highest impact factor, R . Hence, the relation between all impact factors is linear. However, a single *Ground Attribute* can have an impact on several Level 1 attributes (e.g., one *Ground Attribute* can effect *Visual* and *Tactile Quality* at the same time), therefore the

number of occurrences, ‘ o ’, must be specified, since the total impact from that specific Ground Attribute shall be distributed in different modalities with the impact of R/o . Equal distribution of importance between modalities is assumed as a starting point. However, any distribution of the impact of a single *Ground Attribute* on different modalities can be applied. The following definitions are set:

R : Impact factor based on ranking position ($k, \dots, 1$)

o : Number of multiple occurrences for a single *Ground Attribute*

m : Number of sub-attributes on the level above *Ground Attributes* (Sensory Modalities level)

n : Number of Ground Attributes on the lowest sub-attribute level

S_{sum} : Summary of impact score for all sub-attributes on the lowest level.

It can be derived that on the lowest level, above GA level of the attribute structure, each sub-attribute ($1, \dots, m$) has an impact score S , where S is defined as:

$$S_{p=1, \dots, m} = \sum_{i=1}^n \frac{R_i}{o_i}$$

This means that each sub-attribute on the lowest level has a relative importance of $S_{\text{rel } 1, \dots, m}$

$$S_{\text{rel } p=1, \dots, m} = \frac{S_p}{\sum_1^k R}$$

When the importance of each attribute on the lowest level is known, it is then possible to calculate the importance score for subsequent attribute levels by summarizing all S_{rel} for each lower level attribute.

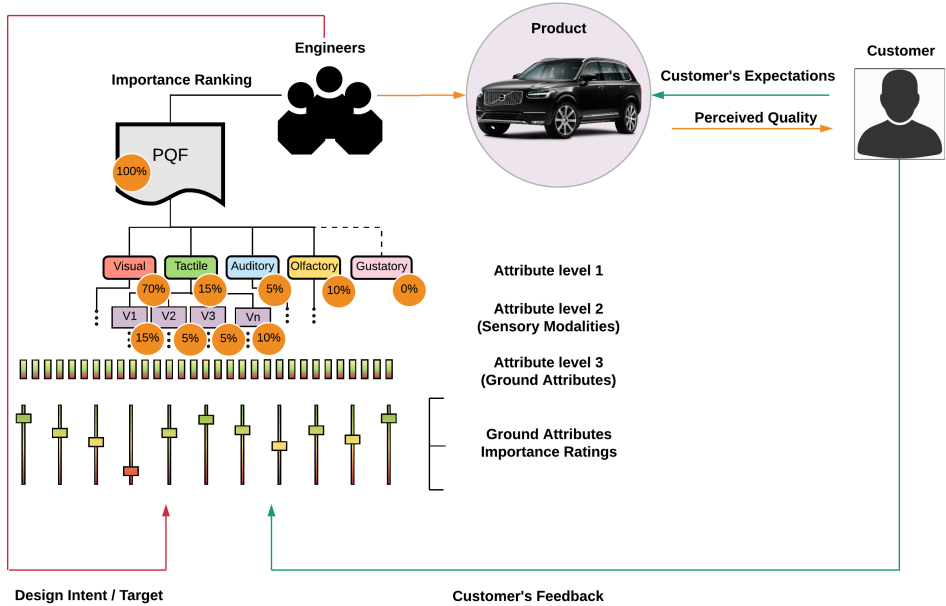


Figure 22– Perceived quality evaluation process loop for successful engineering design implementation with customers' feedback

On the top level for complete perceived quality the impact score will sum up to 100%. The modalities and *Ground Attributes* with the highest score indicate product areas where engineers have to focus in order to achieve the desired level of perceived quality. Overall, the process can be “single stage” or iterative until the OEM is satisfied with the outcomes (see Figure 22).

The PQAIR method illuminates the interplay between technical characteristics of the product and customer perceptions. Successful implementation of the method can help to find an answer to the question postulated earlier, “*Which perceived quality attributes do engineers have to focus on to receive the highest level of a customer’s appreciation?*”

This is after all a very “expensive” question. Billion-dollar decisions in the automotive industry often rely on predictions and assumptions about how a customer will perceive and evaluate such a complex product as a car. The successful implementation of PQF and its principles shifts the perceived quality evaluation processes towards the objective and reproducible side. In fact, ranking of the relative importance of *Ground Attributes* produces indices where the respondents’ choice estimations allow metric comparisons of perceived quality attributes. This helps to translate subjective opinions of individuals into quantifiable measures and to avoid subjectivity in the assessment of perceived quality.

§

5 Discussion

This section aims to consider the obtained results in connection to the research questions. Additionally, the quality of the results in relation to the research approach, practical implementation of the PQAIR method, generalizations and the future research will be discussed.

“If we want to solve a problem that we have never solved before, we must leave the door to the unknown ajar...doubt is not to be feared, but welcomed and discussed.” –

Richard Feynman

5.1 Answering research questions

RQ1: How can perceived quality be defined from the engineering perspective?

To answer the first research question, Chapter 4 presents the results from the four appended papers and multiple case studies that allowed the engineering approach to perceived quality to be defined. The first part of **RQ1** includes existing definitions of perceived quality, which is also covered by the literature analysis presented in Chapter 2. Outcomes of this analysis show that the previous research in the area is incomplete, fragmented and has not been revised for quite some time. The marketing science approach to perceived quality prevails in the literature, but does not really provides help or guidance to the automotive engineers about how to capture and evaluate customer expectations. The majority of the existing methodologies are positioned at the level of capturing customers' requirements and translations of those into the technical specifications. Among those methods are Product Semantic Analysis (Landauer, Foltz, & Laham, 1998), Semiotic Product Analysis (Oppenrud, 2004), Kano methods (Kano et al., 1984), Kansei Affective Engineering (Nagamachi, 2002), House of Quality (Hauser & Clausing, 1988), Focus Groups (Kitzinger, 1995), Conjoint Analysis (Green & Srinivasan, 1978), internal methods, derivatives and combinations of the above, as well as many others. However, there are a few weak points in the current approaches to defining customers' requirements. First, there is the question of smooth implementation in product development and production timeline. The majority of existing methods are rather time-consuming or have quite complicated procedure rules. In the automotive industry, the production cycle time shows an obvious trend to decrease. This fact is the possible source of the conflicts. Second, it is hard to capture customer preferences with such a complex product as a modern car. Because of the high complexity, the customer is most often not aware of a majority of the product attributes that comprise perceived quality. As a result, it is hard to describe perceived quality attributes to the customer, for the opportunity to evaluate these later. Third,

there are a limited number of players in the premium and luxury market segments of the automotive industry. Consequently, some of the requirements are driven solely by internal competitiveness and are only moderately related to the customer's actual needs. Finally, perceived quality is expressed with the overall impression of the vehicle. It is a combination of many factors, attributes - tangibles and intangibles that form the customer's opinion. The biggest question at the stage of requirements definition is how to extract a single attribute and measure with an objective means its input to the overall quality impression. As has been noted, the majority of approaches to perceived quality are either driven by market research or represent the manufacturing side of product development. They provide no ideas about elicitation and/or objective assessment methodology regarding product attributes that comprise perceived quality. It is not obvious how different engineering design decisions will impact on the customer experience of the product. Seeing that, the transition from case/industry thinking to the vision of product development as utilization of process patterns and incorporation of perceived quality concerns in product design at all stages is a difficult but necessary shift. At the end of the day, to create a car with intentionally high perceived quality is not a challenge in a developing project. Almost anything can be achieved with increased product cost and investments. The truly challenging task is to create optimal balance for perceived quality attributes based on given boundaries in terms of technologies, development time, production system and financial limitations. For that reason, perceived quality must be defined and reported during all stages of a development project.

To implement this transformation of the perceived quality connotation, the author proposes to regard the process of perceived quality attributes balancing within the classic model of *design as a communication process* with the addition of the *engineering design intent* (see Chapter 4.2) notion. Hence, the gap between *engineering design intent* for high perceived quality and the actual customer's perception of the quality is characterized by a state of *information asymmetry* (see Chapter 2.5). Often the state of *information asymmetry* can appear if the actual quality of the product is not apparent due to its complexity, which is a common phenomenon in modern vehicles. At this point, the answer to the second part of **RQ1** – “*what is the engineering perspective on perceived quality?*” can be expressed as follows: *Perceived quality domain is a place where the product meaning, form, sensorial properties and their execution intersect with human experience. Such an experience is driven by the interplay between product quality and its context. The equation, where engineering design intent is meeting customers' expectations regarding the product, has to reach an equilibrium.*

Finally, the author proposes a two-dimensional typology of perceived quality: Technical Perceived Quality (TPQ) and Value-based Perceived Quality (VPQ) (see Chapter 4.3). This definition contributes to the multi-disciplinary integration of the quality-related issues. The TPQ and VPQ can bridge “hard”- defined conformance-to-design specifications of manufacturing operations with the “soft” marketing-oriented approaches. Consequently, the PQF attributes taxonomy can fill the void of conceptual ambiguity about quantification of the perceived quality that obviously exists today.

RQ2: What product attributes can be used to validate perceived quality on a complete vehicle?

Based on the results of Chapter 4.4 and research presented in the appended papers, the first part of the **RQ2** can be answered by the list of *Sensory Modalities* and *Ground Attributes* included in the PQF. One can ask, “How inclusive is this set?” In brief, the PQF represents an engineering viewpoint on quality perception, including a wide spectrum of expertise areas. Definitions of *Ground Attributes* are based on the data received from the four-year study of ten premium and luxury market segment automotive OEMs. During the study it was identified that a number of “low level” attributes can significantly vary from one OEM to another. Some companies can effectively manage perceived quality issues with less than a dozen attributes, while others use more than a hundred. In the composition of the PQF, the author’s intention for *Ground Attributes* was to make these attributes to serve as a “filter” or “sway” communicating perceived quality in product development. Therefore, the PQF contains a significant amount of *Ground Attributes* to manage perceived quality requirements for a complete vehicle. The only condition is that the same attribute structure for one set of *Ground Attributes* is used for both benchmarking and evaluation during the product development phase. The notion of perceived quality in this context can be seen as an integrated process of engineering endeavor with regard to product attributes that communicate quality to the customer. The idea of *Ground Attributes* existence is to ensure the correct meaning, authenticity and execution of the final product. After all, several industrial studies with the PQAIR method application proved the ability of PQF to convey perceived quality issues to the customer successfully, and therefore the capacity of the method to validate the perceived quality of the car or specific car component.

RQ3: How can meaningful perceived quality feedback be gathered?

A plethora of methods regarding data collection suitable for collecting feedback on the perceived quality-related attributes exist in the qualitative and quantitative research. However, these methods need to be applied at the right time, in the right place and, most importantly, within the right context. One significant issue regarding customer feedback analysis is that it is hard to extract information about a single product attribute explicitly. This is also very critical for perceived quality evaluation, not only in the automotive industry but also in other product domains. The PQF architecture allows handling products with the highest level of complexity. A holistic approach to the methodology for feedback collection is essential. The mixed methods approach has so far appeared to be a robust technique for gathering and analyzing the feedback. Papers A and C are good examples of a mix of qualitative and quantitative methods. Notably, one of the quantitative methods used in the majority of the studies by the author is the Best-Worst Scaling (BWS) or Maximum-Difference Scaling (MaxDiff) method, which is a quantitative choice-based technique used for understanding a respondent’s, or a respondent group’s, relative valuation of different product attributes (Louviere, 1993). Its main purpose is to aggregate and estimate rank-order information when there are too many attributes for a normal rank-order survey task. According to Marley and Louviere (2005), best-worst tasks positively effects the consistency of the responses

and can be easily understood by respondents. Paper C includes a pilot study intended to test feasibility of the PQAIR method. Despite the “illustrative” nature of the experiment, its outcomes were quite interesting since it is modelled on the real-life situation. Later, similar results were obtained with the full-scale industrial studies at the automotive OEMs. The meaning of *Ground Attributes* and PQF as a sensory attribute-centered framework were well understood not only by the automotive industry experts but also by the general public. The analysis of the post-experimental specific competence measures (with the help of the feedback forms) indicated an acceptable level of the *Ground Attributes* descriptions (Table 5). With the subsequent industrial studies some of these descriptions were simplified even more. So far, the sets of static images in digital format were used in the design of the initial ranking studies. The major drawback using the static images is the poor dynamics of perception (physical stimuli and past experiences), i.e., just one viewing angle and exploration of the attribute is possible. As a designer of a perceived quality assessment experiment, one needs to be very careful and accurate to provide the “best” picture for the specific *Ground Attribute* to ensure that the right thing is assessed.

Analysis of the studies with the use of PQAIR method demonstrated an apparent bias related to the perceived quality attributes importance ranking by industry experts. Automotive industry professionals tend to overestimate the importance of the attributes they are currently working on. At the same time, they may rank low the attributes where the OEM is performing relatively well (according to the internal benchmarking). For example, the premium market segment automobile usually has a high level of materials quality across all competing OEMs (e.g., uniformity of “*Material Pattern*”). However, analysis indicated that materials sometimes had a low level of importance for professionals, while the “squeak and rattle” issue was usually ranked high. This can be explained by the fact that high materials quality is somehow “expected” in the premium market segment, contrary to the “squeak and rattle” which today can be an important differentiator for the specific market segment. This must be taken into consideration with the analysis of the studies involving automotive industry professionals. Speaking of customers, the PQAIR methodology can deliver reliable results if screening questions are implemented prior the main ranking exercise. During pilot and industrial studies, a significant variance in the customers’ subjective preferences was identified to be related to their age, previous experience with cars, and financial status. Henceforth, to validate a spectrum of the tendencies that were spotted, further research is warranted.

The answer to the **RQ3** would be incomplete without mentioning the importance of the perceived quality attributes context awareness during any PQAIR method study design. The instances of *Ground Attributes* can be displayed to the customers in different ways: physical objects, graphical images, CAD models visualizations or extended reality (xR). The study design must be focused on elimination of the “noise” – any possible distraction of the customer from the specific instances of the *Ground Attributes* involved in the study. Currently, there is an obvious tradeoff between the accuracy of the *Ground Attribute* representations and the statistical validity of the customer group sample size (large customer population studies with the real products or in a virtual reality environment are expensive and time-consuming). Nevertheless,

the use of extended reality (xR) has great potential for the design of meaningful perceived quality attributes ranking studies, if the amount of “information loss” for each communication channel is known. Recently a series of studies were performed in that direction (Stylidis, Dagman, Almius, Gong, & Söderberg, 2019; Horvat, Škec, Martinec, Lukačević, & Perišić, 2019).

Equally important in the imminent future may be the use of Artificial Intelligence (AI) approaches (Bickel, Spruegel, Schleich, & Wartzack, 2019), and Machine Learning tools for objective perceived quality data collection and evaluation (Mittal, Khan, Romero, & Wuest, 2019). The incremental role of big data analysis means it is also a possibility to use crowdsourcing in the modeling and quantification of the perceived quality attributes (Ren et al., 2013). The customers’ feedback analysis can include large data sets (which can be customer clinics as a separate entity or output of big data derived from sensors installed in the vehicle). Quite often cross-disciplinary methods can bring valuable results. One example is the photo-elicitation method (Schaeffer & Carlsson, 2014), originally derived from ethnological research, which can be successfully used in customer studies along with sets of structured or semi-structured interviews. A combination of semi-structured interviews with eye-tracking (Duchowski, 2007) is one of the promising methods for evaluation of the perceived quality attributes. Eye-tracking was successfully used for the assessment of Human-Machine Interfaces (HMI) and with the evolution of hardware it can be used for the vehicle’s interior/exterior assessment.

RQ4: How can perceived quality be balanced at the different product levels?

The core of this research is the PQAIR method. The PQAIR method is a decision-making support tool in the first hand, rather than a “replacement” of an experienced engineer or designer. One has to consider all available information managing the perceived quality of a product before taking a decision and is costly by all means. The challenge for the automotive industry is to find a balance for perceived quality that accounts for existing technologies, product development time, capacity of production systems, and financial limitations. *“Which perceived quality attributes do we have to focus on to receive the highest level of a customer’s appreciation?”* – that is the question for any automotive company today, surrounded by fierce competitors, overwhelmed with the environmental crisis, and facing an obscure autonomous mobility future. The PQAIR method gives a “freedom” to every OEM to use their attribute structure alongside the PQF taxonomy and Sensory Modalities so they can balance perceived quality at any product level.

It all starts with the design target definition. In the case of complete vehicle evaluation all 32 *Ground Attributes* will be involved in the process of perceived quality evaluation. However, in industrial practice this is usually not the case. A new car today is rarely an outcome of new developments. The focused modification of existing proved solutions to realize new product functions and attributes seems more practicable due to the economic risks (Deubzer & Lindemann, 2009; Eckert, Alink, & Albers, 2010). Newly developed subsystems of a new product generation should create functions and attributes that enable differentiation of the new product from the reference product(s) and therefore efficiently improve customer value (Albers et al.,

2015). Therefore, studies performed according to the PQAIR methodology in the automotive industry often become area, or even component, focused (e.g., evaluation of Geometry & Appearance related attributes, or design of the new top tether component for the specific vehicle model). The PQAIR method can be applied to the isolated *Sensory Modality* in order to correctly define requirements for the specific product attributes and achieve a high level of perceived quality.

The use of PQF and PQAIR methodologies can be propagated to the area of their origin – Robust Design. When considering design decisions affecting manufacturing processes, there is a clear view of manufacturing quality aspects to secure outcome and manufacturing variation. Therefore, such decisions can affect perceived quality, which has to be controlled during the design process in a similar manner as manufacturing quality is controlled today (Stylidis, Madrid, Wickman, & Söderberg, 2017). Understanding the level of manufacturing variation acceptability by the customer can not only improve car design but also decrease production time and cost.

To summarize, the dilemma of choice - which perceived quality attributes engineers need to amplify without compromising brand values or market segment positioning, has been seen as a highly subjective task. With the implementation of the PQF approach in combination with the PQAIR method this conundrum becomes quantifiable, even reasonable. Engineers can estimate a customer's appreciation of the particular design. This way a quantitative link between the product's design space and customers' perceptions can be established.

5.2 Validation of Results

To establish the quality of research, it is important to validate and verify it. In the case of this research, as an example of engineering design, verification refers to internal consistency, whereas validation refers to justification of knowledge claims (Barlas & Carpenter, 1990). Nanda, Rivas, Trochim, & Deshler (2000), stated the need for an interdisciplinary approach to address complex problems in the research. Perceived quality in the context of the automotive industry is an outstanding example of a highly complex and diverse research topic.

The validation of research findings can be performed by *Validation by acceptance* and verification by *Logical verification*. *Validation by acceptance* focuses on having new scientific contributions accepted by experts within the field. Research can be considered logically verified when it is *complete*, *internally*, and *externally consistent*.

5.2.1 Validation by acceptance

All papers included in this thesis (as well as the additional publications) have been a subject of the rigorous peer-review process. **Paper B** and additional publications were submitted to international conferences where the content was peer-reviewed by the experts in the particular field. The results have been the subject of review and discussions, followed by the podium presentations required to be published in the

proceedings of each conference. **Papers A, C, and D** have been published in scientific journals, i.e., International Journal of Product Development (Inderscience Publishers), Journal of Engineering Design (Taylor & Francis), and Design Science (Cambridge University Press).

Another key point is the acceptance of the PQF and PQAIR methods by industry professionals. This is a continuous process, however, it can be divided into two major phases; PQF acceptance and PQAIR method practical implementation. Speaking of the PQF acceptance by the industry, it is important that the descriptions of the *Ground Attributes* are defined explicitly. To verify descriptions, several workshops were arranged, where employees from the three premium market segment automotive companies described the structures, processes, and methods they use for understanding, defining, and assessing perceived quality. During these workshops, PQF and its structure were assessed and feedback regarding form, meaning, and descriptions of perceived quality attributes was received. Examination of available internal documentation also contributed to verification of the descriptions of perceived attributes. Analysis of the received information allowed us to define 32 *Ground Attributes* and 9 *Sensory Modalities* comprising the PQF taxonomy. All of the above mentioned allowed a general agreement on PQF structure and the description of its elements to be achieved. **Consequently, the PQAIR methodology was applied in practice**, to date at two premium car market segment OEMs:

- (i) Design of the top tether component for the premium car market segment (Volvo Cars);
- (ii) Investigation of users' preferences regarding perceived quality of geometry appearance attributes on the complete vehicle (CEVT);
- (iii) Evaluation of car illumination on the complete vehicle (CEVT).

Furthermore, the results of the research have been presented at the Wingquist Laboratory seminars with discussions that have included the industry. The theme "*Perceived Quality and The Future Cars: A Paradigm Shift*" after the rigorous selection process was accepted for presentation at the Design Society Young Members Event, ICED'15, Milan. The popular science presentation was presented to the general public on the 6th of February 2017 with the theme "Perceived Quality," receiving positive feedback from the audience. Two workshops were performed consecutively at the main events during Design Conference 2018 in Dubrovnik, Croatia, and at the ICED 2019 Conference in Delft, Netherlands.

The author was a recipient of the University of Michigan, USA grant to serve as a Visiting Scholar at Optimal DEsign Laboratory, University of Michigan, USA, 2015. The author was also a recipient of the Erasmus+ Staff mobility grant to serve as a Visiting Lecturer at Vilnius Gediminas Technical University, 2019. A series of presentations to the researchers and students regarding the PQF and PQAIR method were held during this time outside of Sweden.

5.2.2 Logical Verification

External consistency

The results can be considered externally consistent if they agree with established literature. The current research is based on known models and literature. However, due to its novelty, in terms of relation to the automotive industry, sometimes it is difficult to compare the results with different research centers. One of the markers can be citations. So far, there has been a positive trend. The author sees the proposed Perceived Quality Framework as an evolution of existing quality models and the PQAIR method as a logical derivative with the particular application to the premium and luxury market segment of the automotive industry. There is also a positive trend in acceptance of proposed terminology of PQF by other researchers, which can be tracked from the analysis of the citing papers.

Internal consistency

There are no conflicts between individual elements in theory.

5.3 Research Quality in Descriptive Results

A qualitative approach and case study have been used in descriptive elements of this research. To ensure validity Yin (2013), proposes the following steps:

- **Internal validity:** ensuring the conclusiveness of the results. That is certain conditions are presented to lead to other conditions. The case studies presented in this thesis aimed to capture the perspective of the interviewees. The internal validity comes from the ability of the interviewee to communicate certain opinions to the researcher.
- **External validity:** establishing the domain of the results that can be generalized. The findings in the presented studies relate to the particular companies and cannot be fully transferred to other companies.
- **Construct validity:** establishing correct operational measures for the concepts being studied. The subject of analysis related to the studied companies and, with the use of structured coding techniques, presented descriptive information associated with the collected data.
- **Reliability:** a demonstration that the operations of study can be repeated with the same results. The semi-structured interview procedure to some extent can be influenced by the researcher, as well as the coding procedure. However, the main outcomes would likely be similar to the outcome presented in the thesis because of the descriptive nature of the study.

Additionally, taking Maxwell's (2012), approach of triangulation for results verification the following statements can be made:

- The research was conducted at ten different automotive companies, manufacturing a wide range of vehicles.

- The interviewees were from various departments and have had different roles in the companies. However, they had a holistic view of the processes due to their position in the company.
- Apart from interviews, numerous discussions with industry professionals were performed, together with a study of extensive literature and technical papers.
- The results were presented in writing to peer-reviewing conferences and journals, as well as to experts at workshops and presentations.
- The customers' feedback analysis performed during pilot and industrial studies indicated correlation with the research outcome.

5.4 Clarification of Results and Success Criteria

The definition of research success is a subject of debate, as many factors influence success. According to the DRM there are no established metrics to measure success. It is advised to set up Measurable Success Criteria that are linked to the chosen Success Criteria. The term "measurable" refers to the possibility of evaluation criteria during the research project, i.e., mixed methods can be used in this case (Blessing & Chakrabarti, 2009).

In this research the *Success Criteria*, according to the Research Questions, were set as follows:

- Possibility to define perceived quality and perceived quality attributes from the engineering viewpoint.
- Ability to convey meaning of the perceived quality attributes to the customers.
- Composition of methodology capable of evaluating perceived quality of a complete vehicle or its components.
- Cutback of time and cost for product development processes.
- Implementation of the developed methodology in industrial practice.

Consequently, the *Measurability of the Success Criteria* is expressed as follows:

- The notion of perceived quality defined as an integrated process of engineering endeavor with regard to product attributes that communicate quality to the customer. The sensory-based, attribute centered PQF provides precise and exact definitions of product attributes involved in the perceived quality evaluation.
- The TPQ and VPQ definitions bridge manufacturing operations with "hard"-defined conformance to design specifications and marketing-oriented approaches with the customer's perception of quality in focus. The PQF attributes taxonomy fills the void of conceptual ambiguity regarding the perceived quality in product development that obviously exists today.
- The PQAIR method can be used to collect professional's and customer's data for consecutive evaluation of *Ground Attributes* impact on perceived quality

- of a vehicle. This fulfills a condition for successful implementation of engineering design intent
- Use of PQF as a shared platform regarding taxonomy of perceived quality attributes and sharing knowledge about perceived quality between industrial and academic organizations. The Ground Attributes serve as a “filter” or “sway” to perceived quality communication in product development.
 - Acceptance of PQF and PQAIR method by other researchers, i.e., scientific impact. Ability to manage perceived quality requirements for a wide range of products.

For most of the criteria, it is possible to acknowledge their fulfillment. Certainly, evaluation of efficiency for PQAIR method in large-scale industrial practices and projects is a question of time. However, the current status of academic and industrial acceptance only promises further development of the Framework and Methodology.

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6 Outlook

*“There are things known and there are things unknown,
and in between are the doors of perception.” –*

Aldous Huxley

The increasing importance of perceived quality urges the automotive industry to focus globally on customer-oriented product development. The average consumer sees a car's quality as a fancy mixture of a design, aesthetics, their own previous experiences, and performance characteristics of the vehicle, rather than a combination of mechanical parts, software pieces, advanced materials, cutting-edge manufacturing processes coupled with technical knowledge, engineering skills and high production volumes – all concealed ingredients that have involved into modern car creation. For this reason, one of the major challenges the automotive industry will face tomorrow is the development of a quantitative model that conforms with human intuitive perception.

The Perceived Quality Framework and Perceived Quality Attributes Importance Ranking method presented in this thesis are a step towards a structured and objective approach to a better execution of engineering design intent. It is a basis for developing new metrologies for measuring quality perception and finding the equilibrium of the importance among various perceived quality attributes. Adaptation of the existing and well-known *model of design as a communication* to the perceived quality evaluation process is a step towards explanation of the engineering viewpoint on quality perception. This author, believes that the *model of design as a communication* can be augmented with a controllable creation of a product's meaning by design, involving semiosis - the semiotic term of meaning-making (Waltersdorfer, Gericke, Desmet, & Blessing, 2017). It is known that perception of a product's meaning occurs before or concurrently with the perception of the product as an object. We see a product's intended meaning as fast or faster than we see what it is (Peterson, 2018).

Inclusion of *Information Asymmetry* into the “engineer vs customer” equation allows us to build mathematical and statistical simulation models behind processes of product evaluation. This opens a variety of possibilities to predict outcomes of engineering design intent and serves to fulfil the success criteria for the perceived quality evaluation.

Many of the *Ground Attributes* and *Sensory Modalities* are multisensory in terms of their assessment by the customer. This fact raises the immediate question, “*Which Sensory Modalities effect the customer the most and to what extent?*” Following the course of this research, the answer is expected to be given by the numbers. Currently, the PQAIR methodology applies a linear model to assign numeric impact factors for all *Ground Attributes*, but other approaches can be adopted. The research on sensory dominance and methods for capturing/eliciting sensory experience is represented

mainly by the field of experimental psychology (Fenko, Schifferstein & Hekkert, 2010; Carbon, 2015). This research also considers the relation of time and product appreciation regarding sensory dominance and product familiarization issues. The author's intention is to adopt such methods in the future development of the PQAIR method to increase the accuracy of results. Other aspects regarding perception of the *Ground Attributes* by the customer must be included in the overall importance score. For example, the position of a *Ground Attribute* for the product and its visibility to the evaluator could be implicitly included in the ranking (i.e., *Ground Attributes* that are not so visible, or generally hard to discover for an inexperienced customer, are likely to be ranked as less important). However, this assumption has to be confirmed with a larger customer study.

Future research has to investigate the concept of perceived quality more deeply than it is explored in this thesis, with the continuous verification of current assumptions in industrial contexts and extending the aspirations with the ambition to create an all-encompassing, uniform model for the definition and evaluation of the perceived quality experience. This includes finding approaches to the *Value Perceived Quality* (see Chapter 4.3) which is in quite a vague state today, and therefore equally important as *Technical Perceived Quality*. In other words, we need to address *Value Perceived Quality* – extrinsic attributes of quality perception.

The increasing role of the Human Machine Interfaces (HMI) will certainly influence perceived quality evaluation processes. The number of perceived quality variables will only grow over time and the complexity of the systems to assess this will probably increase. The emerging technologies, such as autonomous driving and electric powertrains, may change the perception of quality from the customer's side significantly.

The author's intent with this research was to create an open-ended and flexible approach to the phenomenon of perceived quality in product development that can serve as a shared platform for critical discussion of this undertheorized research subject. Future work into the application of the PQAIR method with full-scale studies including all *Ground Attributes* and obtaining a larger amount of real data from both designers and customers (represented by the various geographical and market segments) will help understand which assumptions must be relaxed to better represent the reality of perceived quality in the automotive industry.

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“Design must be functional and functionality must be translated into visual aesthetics, without any reliance on gimmicks that have to be explained.” –

Ferdinand. A. Porsche

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