

Perceived Quality Attributes Framework and Ranking Method.

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Perceived quality (PQ) is one of the most important product attributes in the automotive industry that defines successful automotive design. This paper presents a new approach regarding PQ assessment by examining PQ decomposed into a structure with the top-down approach to the level of basic (“ground”) attributes, covering almost every aspect of car quality perception from the engineering viewpoint. The paper proposes a novel method for PQ attributes relative importance ranking, resulting in the PQ balance of the vehicle, within the given conditions. The proposed method helps to reach the equilibrium of the vehicle’s quality equation from the perspective of design effort, time and costs estimations. The authors introduce the Perceived Quality Framework (PQF), which is the taxonomy system for PQ attributes and the core of the attributes importance ranking method. The research outcomes are based on findings of qualitative exploratory study that includes the European and North American premium and luxury automotive manufacturers. To validate the proposed method, an industrial pilot study was performed with one of the automotive companies to examine the PQ attributes importance ranking obtained from automotive industry professionals. The results can significantly improve PQ assessment during all stages of product development.

Keywords: perceived quality, premium, customer data, automotive, product development, quality evaluation, quality assessment, importance ranking

1. Introduction

Making a car with excellent perceived quality (PQ) is not an extremely difficult task for an automotive project today. Almost anything related to superior product quality can be achieved with increased product cost and time investments. The truly challenging task is to create optimal PQ based on given boundaries regarding technologies, development time, production systems capabilities and financial limitations. From the changes incepted by the fourth industrial revolution new technologies have emerged that combine the physical, digital and human worlds. These changes also create an industrial need for understanding the dimensions of perceived quality. For that reason, PQ must be predicted and reported during all stages of a development project. Ability to control PQ during product development process can be expressed in the single open question, *“Which PQ 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 PQ attribute or a group of PQ attributes for the customer?”* These questions define the course of this research article.

1.1 Background

Considerable research, including various definitions of perceived quality, has been conducted primarily to attempt to identify the dimensions and nature of product quality (Olson and Jacoby 1972; Gilmore 1974; Crosby 1980; Garvin 1984; Zeithaml 1988; Steenkamp 1990; Reeves and Bednar 1994; Mitra and Golder 2006; Aaker 2009). However, this body of work, represented mainly by the marketing science, has often depicted perceived quality as the antagonistic entity to the “real” or “objective” quality (i.e. not quantifiable, imaginary, subjective). In the engineering science, perceived quality has in turn become a part of bigger models: e.g., in the field of Robust Design (Taguchi, Chowdhury, and Wu 2005) and particularly in the area of Geometrically Robust Design (Söderberg and Lindkvist 1999). These research methodologies consider perceived quality from the engineering viewpoint (Wickman and Söderberg 2007; Wagersten et al. 2011). Robust Design (RD) 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 & 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 was 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, and Carlson 2006). This is a complex process where functional and quality aspects must be balanced against manufacturing constraints and cost limitations. With regard to early design phases (usually described as a “fuzzy front end”), product requirements have tended towards avoidance of being specific, with follow up difficulties in their quantification. This problem is a central issue for the automotive industry regarding PQ attributes definition. Overall, it is important to set robust target requirements to avoid quality loss induced by variation. To address these issues, Pedersen, Christensen, and Howard (2016) proposed the Robust Design Requirements Specification (RDRS) approach for quantification of the early stage requirements and developed Perceptual Approach to Robust Design (Pedersen 2017). Howard et al. (2017) introduced a Variation Management Framework (VMF), linking variation during production with its impact on product and customer perception regarding quality loss. Alas, the comprehensive engineering approach with a focus on perceived quality as a central point, together with questions regarding the importance of quantification of PQ attributes, PQ 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.

1.2 Perceived Quality approach in the automotive Industry

In the automotive industry, during the cycles of product development, desired performance of the vehicle is handled by various product attributes: e.g., fuel consumption, passive and active safety, noise, vibration and harshness (NVH), durability, and weight. A perceived quality is usually one of these product attributes. Consequently, a typical automotive Original Equipment Manufacturer (OEM), uses around 20-120 PQ sub-attributes, depending on organizational and attribute structure. The PQ attributes are responsible for the definition of requirements and requirement levels that determine perceived quality of the product. In the automotive industry, these attributes can be related to the complete vehicle requirements, but also to the system and component level requirements. Quite

often, the PQ attributes are also responsible for complete vehicle verification with the use of computer-aided engineering (CAE), as well as physical testing. Notably, the PQ, as it is defined in this paper, is not usually administered in the industry as a single global product attribute but rather as distributed among many, such as visibility, drivability, ergonomics, craftsmanship. However, alone or in combination, thoroughly or with limitations - these global attributes can be described in terms of a common framework.

1.3 Basic definitions for Perceived Quality

PQ is a multi-dimensional entity and can be seen differently by the different research schools of thought, so it is essential to set definitions. From the engineering point of view, *PQ 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 attributes – engineering tradition regarding PQ is to produce events at which the customer is aware about how things are done. A high perceived quality means attractiveness of the product to the customer. Yet attractiveness is a relative quality. It is based on our previous experiences and exists only in contrast to what does not attract attention (Falk et al. 2017). In industrial practice, PQ engineers are continuously challenged with a polylemma of choice between equally important PQ attributes and their performance; i.e., invest time and resources into a minimization of split lines gaps around rear lights or focus on a cut & sew execution of interior materials?

At this point, we define *engineering design intent* – a rationale for product attributes that convey the intrinsic requirements of the design. *The equation, where engineering design intent is meeting customer's expectations regarding the vehicle, has to reach an equilibrium*. Therefore, the correct perceived quality attributes prioritization for the complete vehicle will lead to a successful design and customers' appreciation.

From the engineering design perspective, PQ can also be divided into two main classes; *Technical Perceived Quality (TPQ)* and *Value-based Perceived Quality (VPQ)*. TPQ includes everything that is part of a product 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 judgements, hedonic or social values, impact from other global attributes, advertising, and marketing promotion techniques (extrinsic attributes). Such a distinction is essential, since PQ can be treated differently depending on the academic field.

Moreover, PQ attributes can also be defined differently by different OEMs, however, the overall goal of PQ attributes definition is to secure correct content and execution of the complete vehicle. All components and system solutions of the product shall be built in such a way that the product is perceived as one of high quality. This paper focuses on TPQ and its sub-attributes as it was defined in the theoretical description of the engineering approach to Perceived Quality (Stylidis, Wickman, and Söderberg 2015).

1.4 Scope of the paper

This paper presents the Perceived Quality Framework (PQF), defining taxonomy of PQ attributes within the global product attribute of Technical Perceived Quality. We consecutively described the set of terminology for PQ attributes based on the primary

human senses (see Section 3). This paper also presents a new method for relative PQ attributes importance ranking (see Section 4). The new method is aimed towards understanding how the engineering design intent decisions will impact on customer satisfaction, and consequently can be used to produce effective PQ attributes balancing within the global product attribute of TPQ.

1.5 Limitations

There are number of limitations in this work. Firstly, this paper focuses on the attribute Technical Perceived Quality (Stylidis et al. 2015) and only on automotive designs, however, the method can be applied to other product attributes with direct customer impact. The new method is used to understand how design decisions will impact customer satisfaction and consequently optimal balancing of PQ attributes. To apply this method for evaluation of PQ, a global attribute (the TPQ in our case) must be investigated and integrated into the heuristic structure prior to any evaluation studies. Secondly, our preliminary pilot study of PQ attributes importance ranking involved only industry professionals. Future work into obtaining data from both professionals and customers will help understand which assumptions must be relaxed to better represent the reality of perceived quality in the automotive industry.

2. Methodology

This research paper consists of a mixed methods design; a qualitative exploratory case study used for determination, definition and taxonomy of PQ attributes, enhanced with quantitative survey technique (Best-Worst Scaling) used for ranking of determined PQ attributes during the industrial pilot study.

2.1 Qualitative exploratory research

Eight European and two North American automotive OEMs were studied in terms of decomposition of perceived quality. All of the companies develop vehicles within different product types. All of the companies are global actors. We applied design research in the form of an exploratory case study, including case design, data collection techniques and approaches to data analysis (Yin 2013).

With the aim to investigate the contemporary phenomenon of perceived quality, information about PQ attributes was gathered through different channels. Semi-structured interviews with follow-up questions (Creswell and Clark 2007) served as the main source of information and were complimented with unstructured conversational interviews, together with informal conversations. We also studied the OEM's internal documentation regarding PQ attributes structure, including presentations, descriptions of organizational structure, attributes structure descriptions, lists of functional and technical requirements and working instructions. Several workshops have been arranged, where employees from the two participating companies have described the structures, processes and methods they use for understanding, defining and assessing perceived quality.

This information was used for composition of the PQF and the new taxonomy development of the PQ attributes. Since the specific structures and terminology of the companies must be kept confidential, a new universal framework of Perceived Quality is presented (see Figure 1).

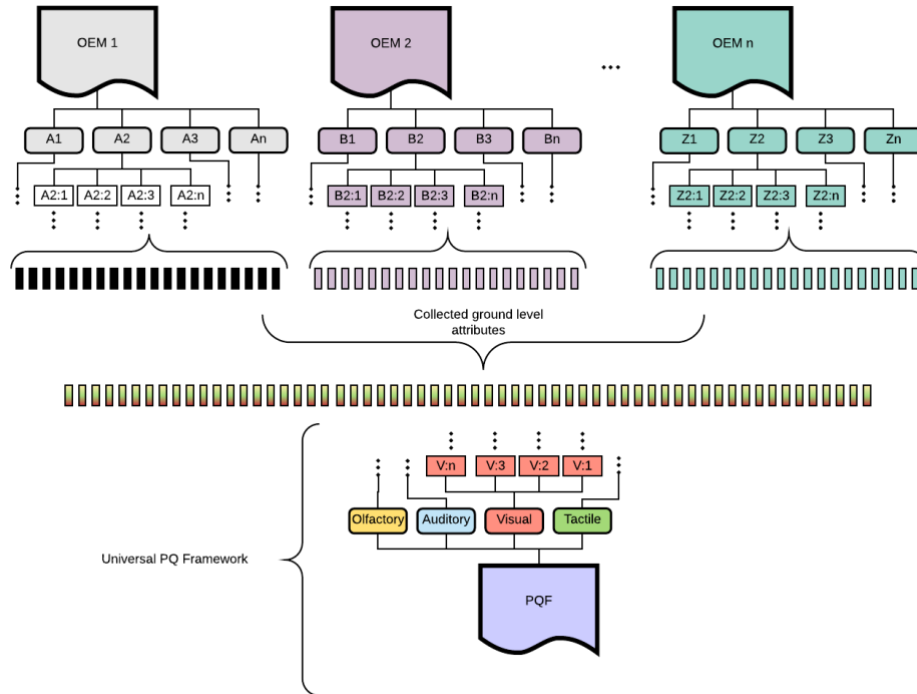


Figure 1. Procedure of the PQ attributes complete list collection and PQF composition based on industry Input.

2.1.1 Sampling

Our pool of interviewees included 13 high-ranked professionals with long track records in the automotive industry and experience in the global market. Their responsibilities include areas of perceived quality, product marketing, complete vehicle requirements definition, environment, branding, and strategy management. We also interviewed a substantial number of mid-level engineers who work within the attribute area of "Perceived quality." The selection of interviewees allowed a holistic view to be obtained on perceived quality as the industry sees it, and the current state of PQ attributes assessment working routine.

2.1.2 Data collection

Semi-structured interviews were completed in a place convenient for participants; in particular eleven face-to-face interviews and two phone interviews. During the semi-structured interviews we asked the same questions of professionals from all companies involved in the study. The subsequent questions focused towards mapping perceived quality attributes. Sometimes we had to ask additional questions to explore topics widely and elicit perceived quality ground attributes as clearly as possible.

Briefly describing the protocol design, at the beginning of each interview the questions were quite open and general, for example:

- *How would you define perceived quality?*
- *What are the prerequisites for a good perceived quality?*

The subsequent questions narrowed the interest to mapping perceived quality attributes, for example:

- *On what perceived quality attributes do you focus when assessing materials quality?*
- *What are perceived quality attributes that determine visual quality?*
- *On what perceived quality attributes do you focus when assessing sound quality?*

The unstructured interviews and informal conversations were also focused on knowledge distillation regarding PQ attributes. Following the initial data analysis, when categories and PQ attributes structure emerged, a series of workshops were organized with industry professionals to evaluate the relevance and accuracy of the PQ attributes structure and descriptions.

The mean semi-structured interview length was approximately 50 minutes. All semi-structured interviews were voice-recorded and transcribed verbatim. Unstructured and conversational interviews had a mean time of 30 minutes and were performed as a follow-up procedure for PQ attributes elicitation. The internal OEM's data, including customer clinics reports and internal attributes structures were also carefully examined. The exploratory study was performed between November 2013 and October 2017.

2.1.3 Data analysis

To analyse obtained data we implemented Grounded Theory (GT) methodology (Corbin and Strauss 1990). The analysis commenced with open coding where each of the interview transcripts were examined (Glaser 1992). The choice of methodology for data analysis was set to acquire perceived quality and manufacturing processes knowledge that automotive Original Equipment Manufacturers (OEM's) are unlikely to share with the public. The text was coded and analysed with the help of qualitative data analysis software. We used a bottom-up approach – i.e. reading the interview data and creating codes as they appeared. The coding procedure included two phases: 1) an initial phase of coding strategy discussion, followed by 2) a focused phase of data analysis and synthesis of nodes. The procedure included two intermediate workshops where the coding strategies and preliminary results were discussed and evaluated.

During the data analysis we obtained new information regarding dimensions of perceived quality that was previously unavailable to us; collected rich data regarding internal processes in the OEMs, viewpoints on perceived quality, and lists of existing methods for PQ assessment. Altogether, we revealed the need for more robust PQ evaluation methodologies. We were able to identify lists of perceived quality attributes from each OEM. All attribute structures, including ground attributes from the companies, have been documented.

2.1.4 Trustworthiness of data analysis

The rigor of data analysis was ensured through adherence to GT methodology (Corbin and Strauss 1990). Four independent coders analysed the content of the interviews to improve the internal validity of the work and minimize subjective discrepancy.

2.2 Pilot industrial survey design

To assess usability and rigor of the new ranking method, we designed and performed a pilot industrial study. The PQF and developed PQ Attributes Importance Ranking method (PQAIR) has been evaluated at one of the automotive companies included in the exploratory study. Three professionals within the attribute area of PQ have been asked to rank all defined ground (i.e. bottom level attributes of PQF) perceived quality attributes (GA) sequentially to evaluate the current flagship vehicle intended for the EU market.

For measurement of respondents' subjective preference, a best-worst scaling (BWS) elicitation method was used. This method was originally developed by Louviere (1993) to understand a respondent's or respondent group's relative valuations of different products or product attributes. 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 affect the consistency of the responses and can be easily understood by respondents. We designed an importance ranking study for 32 ground attributes of PQF. Prior to the survey, respondents were introduced to the descriptions of PQ modalities and PQ ground attributes (see Appendix 1 and 2). Average survey completion time was approximately 40 minutes.

3. Perceived Quality Framework and Ground Attributes

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 PQ-related technical elements in connection with the customer's sensorial experience. The vast majority of perceived quality relationships (attributes) can be described by one of these sensory categories, or by several in combination. In essence, the Perceived Quality Framework reflects human perceptual processing to delineate, test and explore automotive designs. The PQ attributes within the framework are organized with regard to primary human senses involved in their assessment; visual, tactile, auditory and olfactory (see Figure 2). In our case, quality perception based on primary senses forms the first level of PQ attributes; Visual Quality, Tactile Quality, Auditory Quality and Olfactory quality.

We acknowledge 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 motor vehicle behaviour and product attributes internal or external spatial relations (Newell 2004), i.e. split-lines and overall design. Thus, we focus only on TPQ, disregarding any affective perceptual issues related to VPQ.

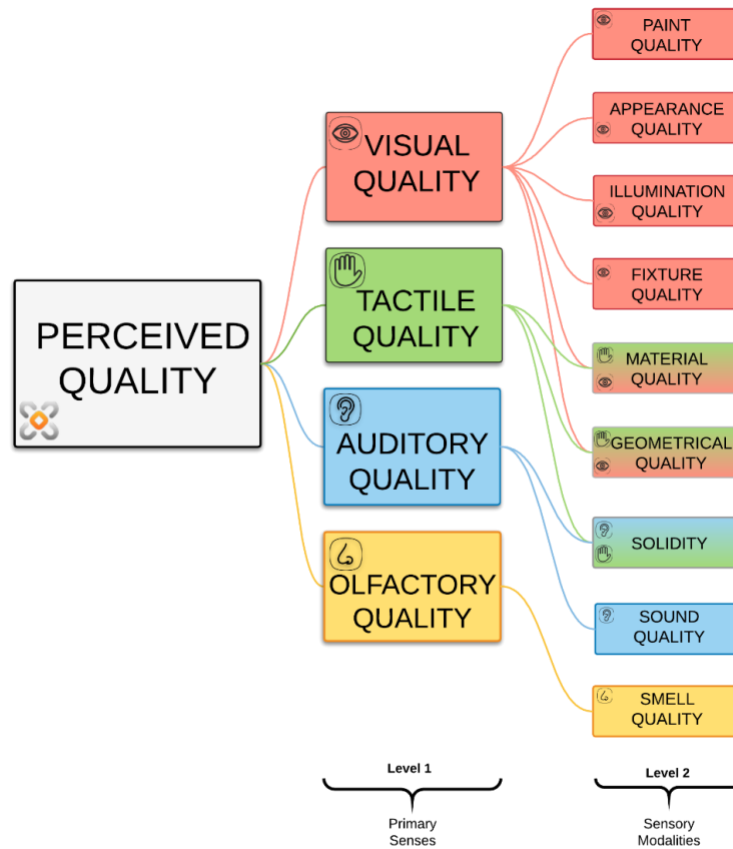


Figure 2. The first and second levels of PQF, based on primary human senses.

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 (primarily to the customers). Each of these sets has a description (see Appendix 1) and includes a number of GA.

The base (ground) level of attributes (see Figure 3) is the “lowest point” where the engineers can still communicate technical details to the customers and receive meaningful feedback. To avoid ambiguity, every GA has to be coherent to a customer’s experience, so the PQF can stand as a meaningful and accessible frame of reference for both – engineer and customer. Eventually, a customer must be able to understand the meaning of each GA and at the same time be able to rank and prioritize its importance among other GA. Such a customer’s feedback is the key for PQ equation balancing activity within the OEM.

It can be mentioned that the majority of GA could be delineated further into attribute characteristics (e.g., “Illumination Function” into light tolerances, colour temperature); however, it becomes then more a matter of engineering specifications rather than elements that customers can perceive, understand and explain. Each GA has been defined based on the data obtained during an exploratory study of the OEMs.



Figure 3. The Modalities and Ground Attributes of PQF.

During the PQF composition process, sometimes two or more of a company's specific ground PQ attributes identified during the exploratory study, have been merged into one or broken up into more GA of PQF. Each GA in PQF has been described and supported with real examples. The GA descriptions have been presented to the companies to verify that the data

has been interpreted correctly. A complete list of all identified Sensory Modalities, GA and their meanings can be found in Appendix 1 and Appendix 2.

 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. Affects Visual and Tactile Quality
Attribute Description	
Example	The gap between front and rear door is too big. Y relation between headlamp and bumper is greater on the right side than on the left side. Harmony of a split line in relation to the nearest split lines.
 GEOMETRICAL QUALITY  GAP  FLUSH  PARALLELISM  REFLECTION ALIGNMENT	

Figure 4. Descriptive and visual guidance regarding one of the GA.

To summarize, the PQF is not limited to its status as a descriptive framework. The PQF can be used widely to explore and test automotive designs with regard to perceived quality, at all product development stages with the implementation of the PQAIR method as it is described in the Section 4.

4. Perceived Quality attributes importance ranking method

The PQ attributes importance ranking method intentionally combines the objective, measurable information of PQ with the subjective customer's evaluation of product quality. The PQAIR was built to assist the engineer or designer in the decision-making process regarding evaluation of relative importance of PQ attributes for the complete vehicle.

The core of the new method for PQ attributes evaluation is that all identified GA are ranked (see Figure 5) with regard to their importance, using either knowledge obtained within the company and/or customer data (e.g., surveys, customers' clinics, interviews, internal customer feed-back systems and large data sets).

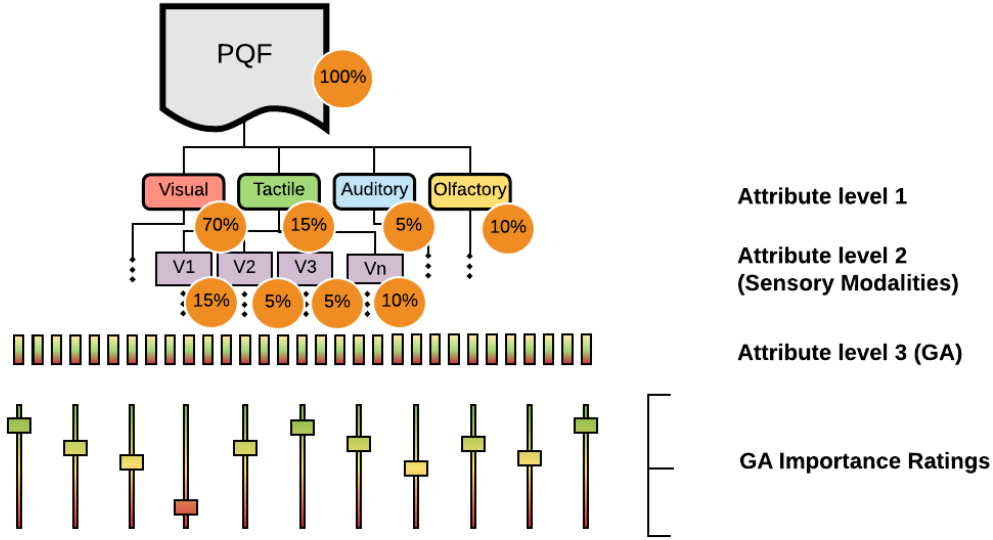


Figure 5. Each identified GA is mapped into the universal PQ framework and importance ratings can be calculated per attribute at every level.

These rankings, in combination with the presented attribute structure, contribute to the importance score for each branch of the structure at all levels. Consequently, each OEM can apply the importance ranking on their own, internal attribute structure. As a result, the company can obtain an importance score for each perceived quality attribute considering the PQF as a reference model for PQ assessment.

The importance of each level attribute must be calculated based on the ranking of all ground attributes. All (1, ..., k) GA's are ranked according to their importance, where the most important GA has the highest impact factor R. The impact factors are assigned at variance to the ranking of each GA. Hence, the relation between all impact factors is linear. However, one GA can have an impact on several second level attributes (e.g., affect Visual and Tactile Quality at the same time), therefore the number of occurrences 'o' must be specified, since the total impact from that specific GA 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 a single GA's impact on different modalities can be applied.

Below the following definitions are set:

- R: Impact factor based on ranking position (k, ..., 1)
- o: Number of multiple occurrences for a single GA
- m: Number of sub-attributes on the level above GA
- n: Number of GA in one sub-attribute 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,...,m) has an impact score S, where S is defined as:

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

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

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

Now, when the importance of each sub-attribute on the lowest level is known, it is possible to calculate the importance score for each sub-attribute on each level by summarizing all S_{rel} for each lower level attribute. On the final level for complete PQ the impact score will sum up to 100%.

5. Industrial pilot study of Perceived Quality attributes ranking

The PQ attributes importance ranking method has been evaluated in an industrial pilot study at one of the automotive OEMs. The initial task given to the respondents was to evaluate the company's flagship SUV vehicle, intended for the EU premium market segment, and rank perceived quality GA importance according to this target. The pilot study was set up as follows: specialists within the PQ attribute area were asked to rank all defined GA sequentially. The GA description (see Appendix 2) and examples, including visual references, were distributed among participants to ensure correct interpretation of each attribute.

In each task, the participants were asked to select the "most important" and "least important" attributes from subsets of GA. Survey design and results were subjected to data analysis using Microsoft Xlstat Software (Adinsoft, SARL 2010). The choice tasks were presented to the respondents with different permutations of the attributes listed in Appendix 2, and the number of choice tasks in each series was adjusted to the number of attributes. The results of the BWS rank-order are shown in Figure 6.

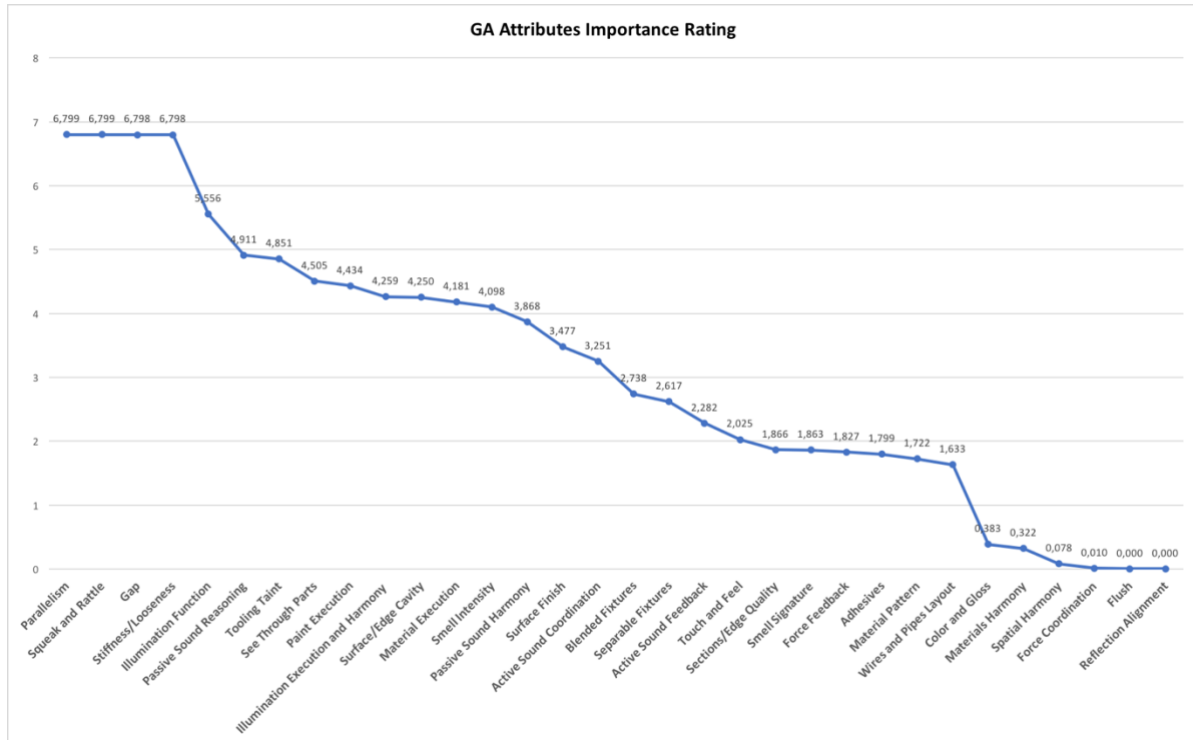


Figure 6. The GA importance ratings obtained during the industrial pilot study.

A linear impact factor has been assigned to each of the GA, where the most important has k (i.e. $R=32$) as its impact factor and the least important has 1 as its impact factor. With the application of the proposed importance ranking method, this resulted in the attributes importance ranking score presented in Figure 7.

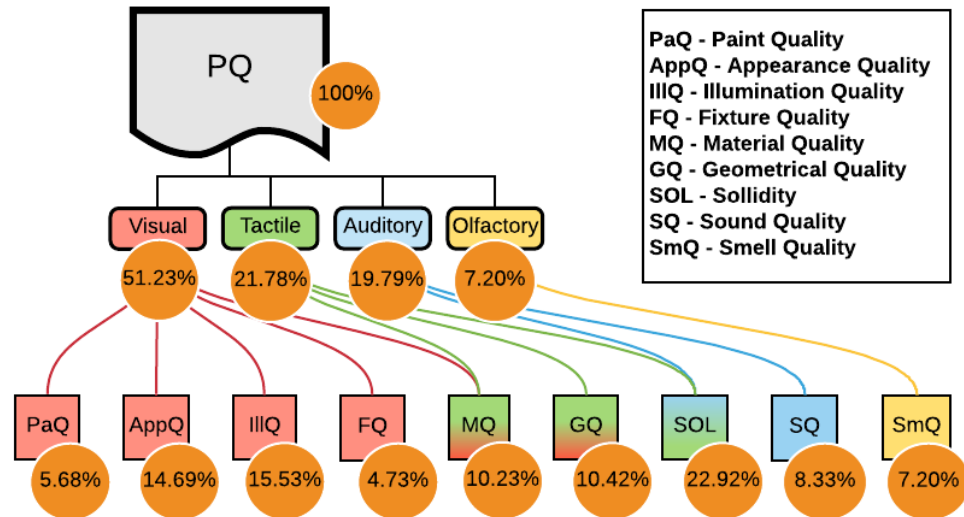


Figure 7. PQ attributes importance ranking distributed for relevant PQ areas regarding the flagship SUV, intended for EU premium market segment.

The importance ratings obtained among PQ attributes indicated great attention to modalities such as “Solidity”, “Illumination Quality” and “Appearance Quality.” At the same time modalities such as “Paint Quality” and “Fixture Quality” are less important contributors to overall perceived quality of the vehicle, according to our respondents. This means that in the real situation, to perform the initially required task *“evaluate the company’s flagship SUV vehicle intended for the EU premium market segment”*, the focus of the engineering team responsible for PQ design would to be on PQ modalities including “Solidity”, “Appearance Quality”, “Illumination” and their derivatives according to the internal OEM’s perceived quality attribute structure.

6. Results and Discussion

In this section we discuss a number of important questions regarding applicability and implementation of PQF and PQAIR, as well as future directions of this research.

6.1 Taxonomy and Definition of Perceived Quality Attributes

The PQF presents an engineering viewpoint on perceived quality, where PQ is seen as one of the working product attributes; an attribute that includes a wide spectrum of expertise areas. There is no doubt that PQ is one of the most important product attributes in the automotive industry for creation of a successful vehicle design, however, it is just one of many. Definitions of GA in our case are based on data we received from automotive OEM’s, and these GA surely could be defined differently. However, the same principles of product attribute decomposition as implemented in the PQF are valid for any set of GAs, regardless

of structure or number. The only requirement is that the same attribute structure for one set of GA is used for both benchmark and evaluation during the product development phase. The notion of PQ in this context can be seen as an integrated process of engineering endeavour with regard to product attributes that communicates quality to the customer. The scope of ground PQ attributes is to ensure the correct meaning, authenticity and execution of the complete vehicle. Consequently, the PQF and PQ attributes taxonomy is a step forward in understanding the engineering viewpoint on perceived quality.

6.2 Implementation of the Perceived Quality attributes importance ranking method in the automotive industry

The PQ attributes importance ranking method illuminates the interplay between technical characteristics of the product and customer perceptions. The successful implementation of the method can help to find an answer to the question we postulated in Section 1 *“Which PQ attributes do engineers have to focus on to receive the highest level of a customer’s appreciation?”*

In fact, ranking of GA importance produces indices where the respondents’ choice estimations allow metric comparisons of PQ attributes. This helps to translate subjective opinions of individuals into quantifiable measures and to avoid subjectivity in the assessment of PQ. Industrial pilot study demonstrated that the PQ attributes importance ranking method produced results and that there is a possibility for the method to be used in practice. However, a number of key points have to be addressed.

6.2.1 Impact Factors and PQ Attributes Importance Rankings

Firstly, we have used a linear model to assign impact factors for all GA, but other approaches can be adopted. For example, the Kano model (Kano et al. 1984) can be used to define a two-dimensional map for base, linear and exponential customer values regarding each GA. Importance scores could then be assigned based on coordinates of the GAs.

Secondly, additional aspects regarding perception of the GA by the customer could be included in the importance score. For example, the position of GA on the vehicle and its visibility to the evaluator could be implicitly included in the ranking (i.e. GA that are not so visible, or generally are hard to discover for an inexperienced customer are likely to be ranked as less important). However, this assumption has to be checked with the larger customer study.

Thirdly, “Why is it important to calculate importance score per sub-attribute on each level when you simply can prioritize the GA that is highest in the ranking?” Usually sub-attributes, or modalities in our case, have a corresponding unit within the OEM organisational structure, which means that overall balancing of resources can be conducted based on importance score per sub-attribute.

6.2.2 Important observations and feedback on the industrial pilot study

While performing tasks regarding importance ranking of GA, all respondents experienced difficulties finding good reference points for their judgements. They were provided with the modalities and GA descriptions, but without the visual, exact and detailed references for “bad” or “good” examples of GA execution it was nevertheless extremely

difficult even for the industry professionals to make decisions and rank importance of the given GA. This means that future BWS study designs, when displayed to respondents, have to be visually explicit and supported with precisely described examples of GA. These descriptions are the subject of current and future research.

6.2.3 PQ assessment process loop and the importance of customer feedback

Discussing the pilot study presented in Section 5, we have to admit that data received from the professionals within the company can indicate the engineering design viewpoint but cannot provide a holistic picture regarding the importance of GA for the customer. However, acknowledging the fact that only data from professionals has been used to rank all GA, we assume it was relevant to start implementation of the method based on the collected knowledge within the company.

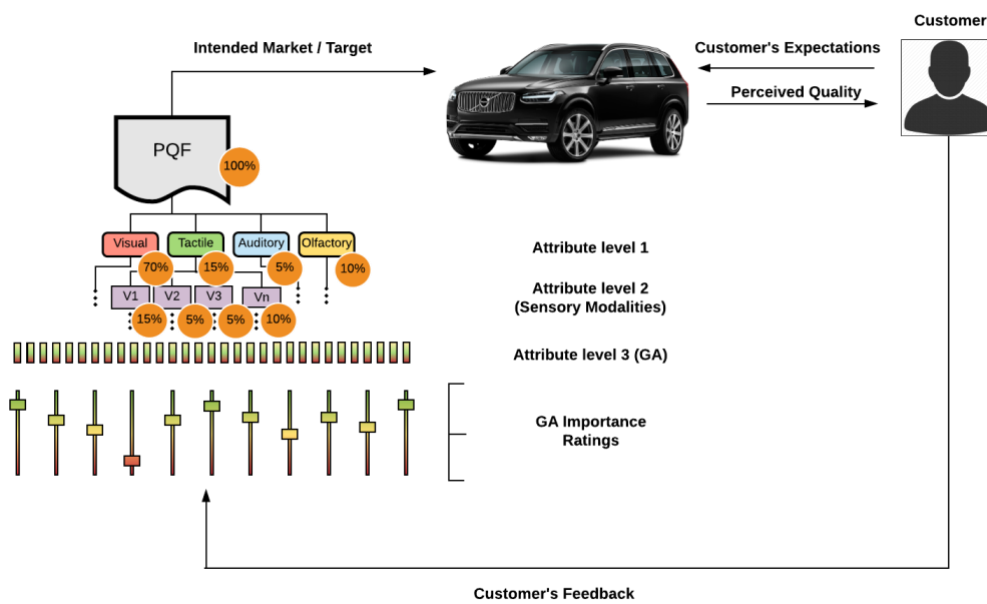


Figure 8. PQ assessment process loop for successful engineering design intent implementation with customer feedback.

Moreover, obtained knowledge can be used to compare GA ranking based on ranking by professionals compared with GA ranking based on customer data. This approach may also highlight discrepancies between the views of professionals and customers on perceived quality. Therefore, the customer's data acquisition is the key for successful implementation of POF and the ranking method for industrial use (see Figure 8).

As we mentioned previously, this process is not easy since the customers might not be familiar with the terminology and technical details. However, **only the customer's opinion can help to make correct estimations regarding the importance of PQ attributes.**

6.3 Obtaining better customer's data

One source of information to collect customer data is surveys conducted by third-party companies, such as JD powers, ADAC or internal surveys / customer clinics that each

OEM performs after a certain time of product use. One significant issue regarding customer surveys analysis is that it is hard to explicitly extract information about a single GA. This is very critical for PQ assessment. In JD powers for example, most questions that relate to PQ could also refer to product design (e.g. styling). For example, “What is the appearance of the instrument panel?” Of course, PQ will have a huge impact on the appearance of the instrument panel, but it is impossible to distinguish between PQ and product design in this case. Another example is the question in the “reason to buy” part of the JD Power surveys (i.e., the customer is asked to pick a number of reasons for purchasing a particular car.) One of the given options is good “workmanship”, the meaning of which is equivalent to PQ. Now the problem is that it is not possible to distinguish what sub-attributes within PQ are important. Consequently, other methods for data collection are needed to understand the impact of PQ and to prioritize within the attributes.

6.4 Future work

The future research suggests a design of exploratory studies including other automotive OEMs within different market segments. Further research is also warranted to validate the findings of the industrial pilot study using large customer response samples. Implementation of the PQAIR method regarding other products, e.g. in furniture design, also has a great importance and potential for establishing robust industrial practices regarding PQ assessment.

7. Conclusions

In this work we investigate the possibility to measure the relative importance of a single PQ attribute or a group of PQ attributes to the customer. Specifically, we studied ten automotive OEMs, defined perceived quality from the engineering viewpoint, introduced taxonomy of the perceived quality attributes with the Perceived Quality Framework, and proposed the PQ Attributes Importance Ranking method, based on data input from professionals and customers. Moreover, we performed a pilot industrial study to rank the importance of PQ attributes with specific design tasks.

Although there is still room for improvement in the proposed method and PQF architecture, our results show that the PQ Attributes Importance Ranking method can potentially provide the long-awaited answer to the question, “Which perceived quality attributes are most required for successful product design?”

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Appendix 1. Definition and description of PQ Modalities

Modality	Description
Appearance Quality	Uniformity and harmony of the car body components, trim and styling. Focuses on how components look. Affects Visual Quality.
Fixture Quality	Quality of attached or appended components including appearance and layout. Focuses on adhesives, blended and separated fixtures such as spot welds, rivets etc. Affects Visual Quality.
Geometrical Quality	Harmonious relations among and within visible components (e.g. split lines). Has impact on Visual Quality and Tactile 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.
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.
Paint Quality	Quality of automobile paint including components and absence of visible defects. This modality focuses on the painted components. Affects Visual Quality.
Smell Quality	Olfactory perception is an integrity of input regarding the smell inside of a vehicle. Affects Olfactory Quality.
Solidity	Perception of components' tactile or auditory properties as firm, solid. Affects Tactile and Auditory Quality.
Sound Quality	This modality refers to the adequacy of the sound induced by the product. An assessment of the accuracy, enjoyability, or intelligibility of sound output from components inside a vehicle. Affects Auditory Quality.

Appendix 2. List of identified PQ ground attributes

Modality	Ground Attribute	Description
Appearance Quality	See Through Parts	The degree to which gaps and holes are covered and free from see-through effect. 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 of how 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.
Fixture Quality	Wires & Pipes Layout	A visually balanced arrangement of wires and pipes.
	Adhesives	Appearance, number and placement of visible adhesives.
	Blended Fixtures	Appearance, number, and placement of visible joining techniques which are fused/merged components.
	Separable Fixtures	Appearance, number, and placement of visible joining techniques that can be fastened permanently (e.g. rivets) or re-assembled (threaded fasteners).
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.
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 like lights, displays, HMI, exterior light, etc.
Material Quality	Material Execution	A degree of manufacturing processes affection 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 is forming a consistent design: e.g., the appearance and direction of the intended texture on the surface.

Paint Quality	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 correspond to how it looks.
	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.
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.
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 of the controls, buttons and switches.
	Force Feedback	Characteristics of haptic feedback induced by driver/passenger controls operations.
Sound Quality	Stiffness & Looseness	Stiffness and fixation feeling induced by the component when applying a force.
	Passive Sound Harmony	Harmonious combination or interaction of the passive sound sources. A passive sound usually induced by component or system that has no purpose of a functional communication.
	Passive Sound Reasoning	Passive response or reaction on a sound that follows 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.