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Perceived Quality Attributes Importance Ranking Methodology in the Automotive Industry: A Case Study on Geometry Appearance Attributes at CEVT.

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Abstract

Implementation of methods for perceived quality evaluation is an integral part of the automotive manufacturers' strategic development plans. The correct definition of perceived quality requirements is one of the significant factors influencing customer's purchase intention. This study seeks to understand how customers perceive and prioritize attributes that are associated with the geometrical and materials quality of a premium car market segment. We applied the Perceived Quality Attributes Importance Ranking (PQAIR) methodology to understand the importance of different perceived quality attributes form a customer perspective. Such an understanding can contribute to the effectiveness of the design processes in the early product development phases. This approach is tested on 144 respondents representing customer's target group and performed in collaboration with China Euro Vehicle Technology (CEVT) technical experts. Our results verify the rationality and feasibility of the applied method and indicate the improvement of engineering practices regarding complex product development.

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Keywords: perceived quality; product development; design; automotive; pqair;

1. Introduction

For a long time, high manufacturing quality was one of the success factors for industrial companies, but today, technical excellence is an essential requirement in the premium car market segment. Hence, new success factors must be determined to differentiate one car manufacturer from competitors. Previous research shows that only a balanced combination of manufacturing quality and subjective factors related to customers' perception (i.e., quality impression, brand value perception, design factors, aesthetics) can make a difference in the highly competitive market [1-3]. To achieve the optimal balance between available technologies, product development time, the capacity of production systems, cost limitations, and product quality, the automotive manufacturers must correctly define perceived quality requirements. The goal of formal perceived quality attributes definition is to secure correct content and execution of the specific car part or a complete vehicle. All components and system solutions must be produced so that the customer will perceive the product as one with high quality [4]. However, perceived quality is a complex, multifaceted adaptive system - a system where a

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human is the main agent. Therefore, deviation from a design intent for many perceived quality attributes is hard to define explicitly, i.e., the same dimensional variation of the split line's gap located at the A-pillar or around a rear lamp of the vehicle can be perceived by the customer very differently. This fact creates a "wicked problem" for any automotive manufacturer, and the "typical" solution of this problem is usually expressed in the creation of "another" subjective measurement scale. In other words, the critical issues with any subjective empirical method regarding the evaluation of the perceived quality in the automotive industry are positioned within space of perceptual, information, design, and semantic gaps between designer and customer [5], [6]. In most cases, the perceived quality evaluation of vehicles is still performed manually and facing the following problems: (i) the absence of any equipment able to detect and assess all anomalies which can occur due to various manufacturing processes; (ii) perceived quality experts could provide only the subjective feedback, often solely based on their experience in the industry, that is not a problem-free; (iii) the perceived quality evaluation methods which are currently in use in the automotive industry are very refined.

In this paper, we describe the implementation of perceived quality evaluation based on the Perceived Quality Framework (PQF) and performed with the Perceived Quality Attributes Importance Ranking (PQAIR) method [7]. We test this approach on 144 respondents representing China Euro Vehicle Technology (CEVT) target group. The obtained results exposed critical (in terms of their importance to the customer's perception of a "premium quality") geometry and appearance attributes. Specifically, we studied attributes related to the Geometry Appearance of a vehicle, such as: "Separable Fixtures," "Blended Fixtures," "Wires & Pipes Layout." And "Tooling Taint." The data analysis resulted in the CEVT professionals gaining knowledge about their customers' perception of the geometry and appearance attributes. They distributed and prioritized the perceived quality attributes into different subcategories quantified their impact on the overall quality perception. This resulted in the perceived quality improvement for the next generation of vehicles and better communication of requirements at CEVT.

This paper is structured as follows: Section 2 discusses related work and motivation for this study. Section 3 describes a methodology applied in this study. Section 4 experiments on evaluating perceived quality attributes related to the geometry and appearance of the vehicle. Section 5 discusses implications and opportunities for future work. Section 6 offers conclusions.

2. Background

2.1. Perceived quality in engineering design and manufacturing quality

The complex nature of product quality is recognized by many [8]. A variety of approaches to the perception of quality have been established in the past. In this study, we applied an “engineering” approach to perceived quality [7]. In contrast to a rigid, formal “manufacturing” approach to the product and perceived quality or idiosyncratic “marketing” cases – engineering tradition in the automotive industry regarding perceived quality has been about producing events that make a customer aware of how things are done [9]. This concept in industrial practice, often called “craftsmanship” includes methods for elicitation and definition of perceived quality requirements and incorporates the process of perceived quality communication to the customer. There is to say that the link between “engineering” and “manufacturing” viewpoints exists. Our previous work emphasized a need to see product quality as an integrated system. For example, the spot welds quality is critical for the key performance characteristics fulfillment of the vehicle, such as stiffness or crash behavior. While various types of spot welding are well established, the verification methods for the perceived quality evaluation are absent in most cases. As a result, most premium and luxury automobile manufacturers hide attributes derived from the manufacturing process (e.g., Blended Fixtures) as non-compliable to the appearance quality of the vehicle. However, one of the primary targets for the manufacturers is to reduce production time and cost. With the application of PQAIR methodology at the early stage of product development, it is possible to optimize manufacturing processes and continuously control perceived quality.

2.2. Origin of the perceived quality gap between engineering design intent and customer's perception of a product

Often there is an apparent gap between a designer's intentions and customer's expectations about a product. In fact, car manufacturers often have incomplete information regarding the customer's sensory perception of the perceived quality attributes [10]. The customers, in its turn, find it challenging to express a meaningful opinion about a product with a high level of complexity, such as a premium car. For example, customers' perception of quality often conflicts with the brand's perceived image.

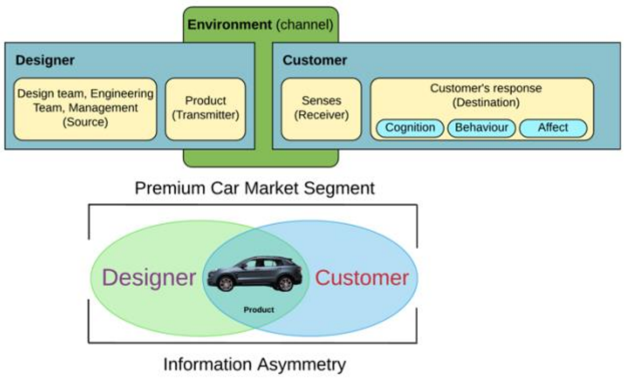

Figure 1. Framework for design as the process of communication, adapted from Crilly et al. [11] and state of the information asymmetry in product development.

One of the theoretical frameworks explaining this phenomenon is a communication model of the design process - design as a communication process between designers and customers [10], [11]. In the automotive industry (as well as in many other domains of product development), a designer plays the role of a communicator creating a range of forms (e.g., perceived quality attributes), and it is useful to view his or her relationship with the customer as part of the communication process (see Fig 1). We use this communication model to identify information asymmetry [12] or the "perceived quality gap" between designers and customers. In product development, information asymmetry can appear if the actual quality of the product is not apparent due to its complexity or misunderstanding of design intent, which is a common phenomenon in modern vehicles. Information asymmetries affect both – designer and customer. The "perceived quality gap" can significantly influence the interpretation of a product's quality; therefore, it should be minimized during the design process to avoid an informational imbalance between designers and customers.

2.3. Background to the China Euro Vehicle Technology (CEVT) and research objectives

China Euro Vehicle Technology (CEVT) is an innovation centre for the Geely Auto Group founded in 2013 to develop automotive technology for all the Geely Auto Group brands, including Volvo Cars, Lynk & Co, and Geely Auto. As Geely Group has the ambition to compete within the premium vehicle segment, there is a need to ensure that the products developed by CEVT are among the leaders within all quality aspects. The objectives and research questions of the CEVT regarding this study were as follows:

- How can perceived quality aspects related to the visual appearance be categorized?
- How can the end customer preferences regarding the visual appearance of perceived quality attributes be measured and quantified?
- How can the results be implemented into the product development process at CEVT?

2.4. Perceived quality at CEVT

CEVT describes the area of Perceived Quality as "looking to the complete product experience from a customer perspective to realize the full potential of the design." The perceived quality evaluation is the ongoing process throughout the project. The evaluation of visual appearance attributes for a vehicle is performed by visual inspection of a physical vehicle or by virtual studies using physical product simulation. The CEVT experts carry out the assessment. For this type of control, the evaluator should detect any appearance imperfection of a product, categorize this anomaly, and then evaluate it. The procedure follows a structured approach where the experts have a checklist document. All vehicle areas are visually inspected in the scan for demerits. The checklist document provides guidelines for rating every type of appearance imperfection found, assigning a demerit score. The guidelines are followed relatively strictly, although minor adjustments can be made. The evaluators primarily carry out the evaluation in pairs to decrease the possible bias. Every appearance defect receives a certain number of points, which, in the end, are weighted and added to an overall score for the vehicle. The scale ranges from 1 to 10 and indicates how a car stands against the competition and can be used to identify necessary improvements. The highest grade corresponds to the "perfect" car, and lowest corresponds to a car that cannot be sold.

2.5. Perceived Quality Framework (PQF) and Perceived Quality Attributes Importance Ranking (PQAIR) methodology

The number and taxonomy of the perceived quality attributes may vary depending on the organizational structure of a car manufacturer. In most cases, the information about perceived quality attributes, even the terminology, must be kept confidential. The Perceived Quality Framework (PQF) helps overcome this issue reflecting human perceptual processing to delineate, test, and explore product designs [7]. The PQF serves as a communication channel, where the specific car manufacturer's attributes are mapped against PQF attributes. The "Ground Attributes" of PQF cover the complete vehicle. (see Fig. 2).

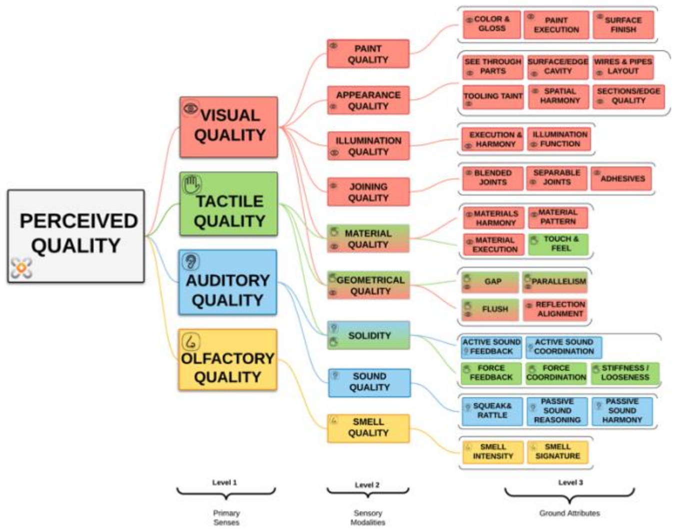

Figure 2. The attributes levels of the Perceived Quality Framework [11]

Perceived Quality Attributes Importance Ranking (PQAIR) methodology is designed to assist in the decision-making process regarding evaluating the perceived quality attributes relative importance for the final product design (i.e., a complete vehicle or part of it). The core idea of the method is that all identified ground attributes are ranked regarding their importance to the customer. Eventually, aggregated rank-order information from customers is augmented with the impact factors (assigned at variance to the ranking of each ground attribute) and integrated into the PQF, resulting in an importance score for each branch at all levels. The modalities with the highest score indicate product areas where engineers must focus on achieving the desired level of perceived quality.

3. Methodology

One of primary objectives of this study was to capture customer preferences regarding the visual appearance of geometry appearance attributes. In the final analysis, the expected results indicate the *perceived quality gap* between the designer's intent and customer's opinion. For this reason, we adopted Mixed Methods, implemented in a form of explanatory sequential design [13]. The study procedure (see Fig. 3) first listed the CEVT's internal perceived quality attributes primarily responsible for the vehicle's visual appearance. Secondly, the CEVT internal perceived quality attributes mapping was performed against the Ground Attributes of PQF. The identified attributes were analyzed further regarding the possible appearance, positioning, and execution variations according to the current design and manufacturing capabilities of CEVT / Geely Auto Group. As soon as all possible variations were listed, CEVT designers created a set of photo images depicting each perceived quality attribute. To eliminate the "noise" (possible customer distraction) from factors other than the intended, the design elements that could distract the test person were avoided. This included brand associations, unusual shapes, and materials. All graphic images were also taken from the same vantage point, one image with a closer look to the attribute and one from a typical customer position/viewpoint and under similar lighting conditions. The perceived quality attributes of interest were pointed out with arrows to avoid confusion regarding the subject of evaluation.

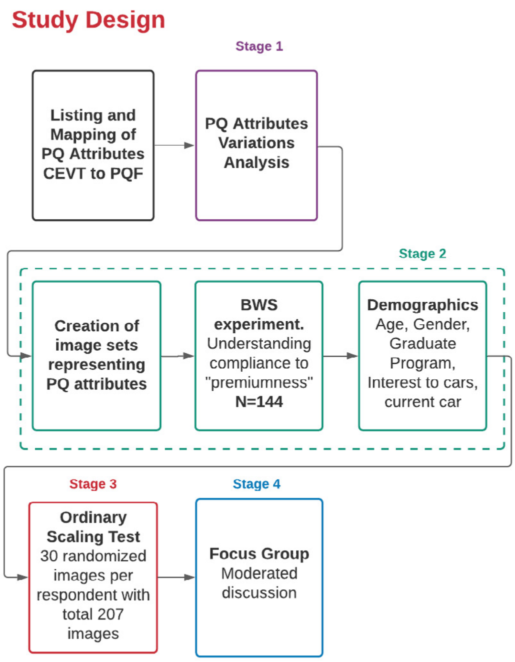

Figure 3. Study flow and procedure

Subsequently, to understand the relative importance of attributes involved in this study, we designed a quantitative survey implementing the Best-Worst Scaling (BWS) method [14]. The survey was conducted among the target group of respondents (N=144). We performed the ordinal scale rating test to measure the intensity of different variations within each category of attributes. Finally, to understand the quantitative results in-depth, post-survey focus group interviews were performed at the CEVT premises.

3.1. Target group and background information

According to CEVT's analysis, the target group consists of young, educated persons living in urban areas. The generation is often referred to as millennials, Gen Y, Echo Boomer, or NetGen, born between 1977 and 2000 [15]. Background questions (we captured parameters such as age, income, car interest, etc.) were created to identify if answers from respondents outside the target group differed from those insides. Other questions investigated if experience or price segment would affect the opinion.

3.2. Best-Worst Scaling study

Respondents were presented with three (3) images at a time in thirty (30) sets with total number of thirty (30) images. They were asked to select the most preferable and the least preferable of the 3 images in every set.

3.3. Ordinal scale rating test

We displayed thirty (30) randomized images per respondent out of two hundred and seven (207) in total, one a time, and asked to select from 6 different options of acceptance, from "Unacceptable" to "Good".

3.4. Focus group interviews

The results from the two tests were discussed with participants in a focus group. Data from interviews earlier in the project were also used to explain and understand the results.

4. Results and Discussion

4.1. PQF application in practice – Stage 1

While composing attributes list related to the geometry appearance, the company's specific perceived quality attributes have been broken up into more attributes. This was done since doubts were raised whether the entire attribute would have the same impact on the perceived quality or not. For example, clips and screws within the "Separable fixtures" attribute were separated. Every attribute, in addition, has several variants depending on one or more variation factors. Each variant of the specific attribute might not necessarily have the same impact on the overall perceived quality. For that reason, a method describing and quantifying the impact of the specific attribute and a tolerance limit within each attribute needs to be developed. In this study, variant factors have been defined according to the current evaluation tools and expert knowledge. The variant factors help with a relevant description that enables characterization and evaluation of the attribute items using a corresponding scale of intensity. Variant factors must be easily understood by evaluators and support the differentiation among attribute variants. Each variant factor should represent a specific characteristic of the attribute item. The variant factors characterize a specific variant within perceived quality attributes belonging to PQF. The identified variant factors were: area, exposure, size, shape, quantity, and distribution (see Fig.4). The size factor characterizes the size of the deviation. The shape factor characterizes the shape of the demerit. The quantity is the number of the same demerits within an area. The car can be divided into different areas, and the same demerit can have a different impact depending on where it was found - the area factor describes this. Exposure is how exposed the customer will be to the anomaly; this depends on orientation and the user scenario in which the demerit is seen. Distribution is how well the demerit aligns with the surrounding objects

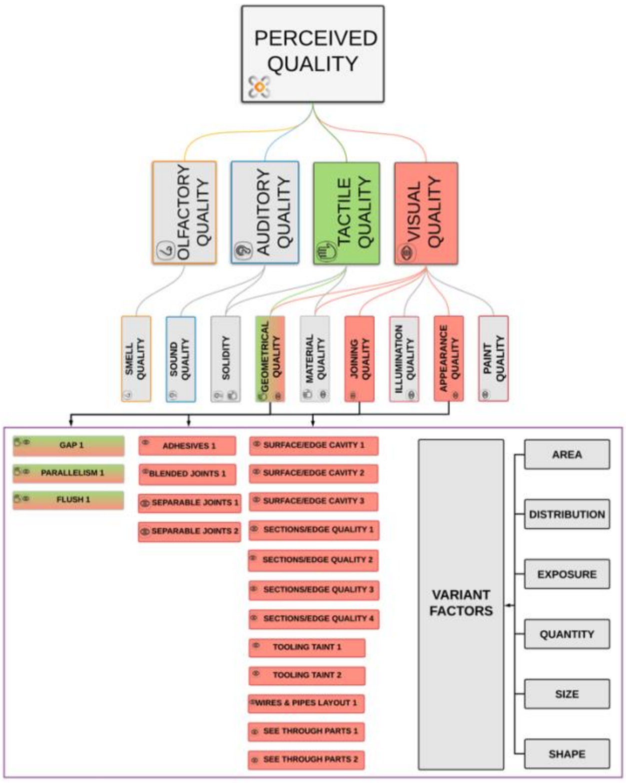

Figure 4. The relationship between the PQ Area, the Geometry & Appearance attributes and their variants.

4.2. Best-Worst Scaling study outcomes – Stage 2

N.B.: The attribute variants were coded due to confidentiality reasons. The P.Q. attributes are depicted as attributes 1-9, and the three main areas (interior, exterior, and DLO) are coded as area A-C. The vertical axis values represent the likelihood that the attribute would be more preferable than the others. An attribute with the value 5 is five times more likely to be chosen as preferred than an attribute with the value 1.

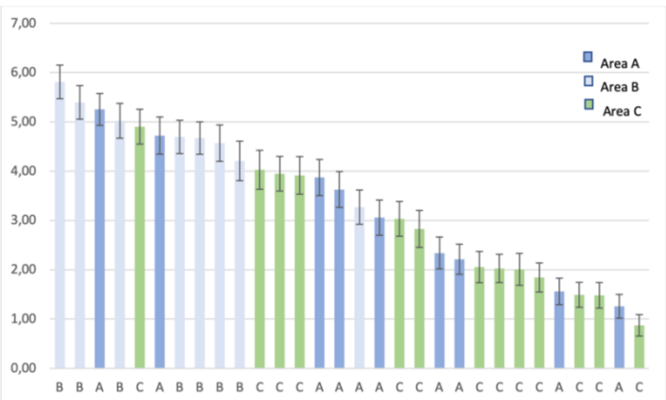

Figure 5. Interior, Exterior and DLO ranking, color coded by the area

Overall, the demerits in Area A and B are more likely to be preferred than the demerits present in Area C. In other words, demerits in Area C are generally seen as more disturbing than the ones in Area A and B. The pattern is observable among the extreme values >4 and <2. Among the demerits with a value over four are nine out of ten found in Area A and B and only one demerit found in Area C. Among the examples with a value below 2 are seven out of nine found in Area C and two in Area A. This data is presented in Fig 5. As we mentioned above, the selection of attributes for the BWS study was made together with the CEVT experts, influenced by the results from the explorative user studies. The feedback from the respondents indicates that they thought the choice was hard. Several respondents mentioned that none of the items were OK but perhaps would not notice them in an actual situation. Some thought that choosing the most preferable was not adequate for items that were all interpreted as problems. The feedback indicates that the items selected for the BWS study were on a similar severity level due to the difficulty of choosing between them. However, to draw general conclusions with any certainty, the representativeness of the items in the BWS study for the entire category need to be evaluated every time.

4.3. Ordinal scale rating test results – Stage 3

The selection of the images representing PQ attributes variants with different execution level usually is difficult. It is hard to establish reference points, especially when all items seen as unwanted. In other words, we should not compare extremes (in terms of execution) in the same attribute category. To receive a meaningful result about PQ attributes involved in the study the images of attribute variants must be within the same severity segment.

Table 1. Response distribution from individual reports. The mean for all respondents and the max value represents how many times a certain individual selected the options.

Option	Unacceptable	Very Disturbing	Slightly Disturbing	OK, this is not a problem	OK, I would'nt notice	Good
Mean	2,22	3,86	8,26	6,75	3,93	1,0
Max (Individual)	14	14	18	21	15	11

Overwise, respondents strongly tend to choose better execution.

The ordinal scale rating test should be designed and implemented to give further insights into the impact of variation factors. The results confirm that the PQ is very subjective. For none of the images/questions, the results were conclusive. Only three out of 207 categories were judged as OK or Good by all respondents, and nine out of 207 were judged as disturbing/unacceptable. When looking at individual reports, summarized in Table 1, some respondents had most of their selections on the disturbing/unacceptable side while others were on the good/OK side and another group in the middle with few selections on the extremes. One respondent found 14/30 images unacceptable while another rated 21/30 as OK - this is not a problem. The average distribution was focused in the middle; the most common selection was “Slightly disturbing.”

The results show that using an ordinal scale to assess images of attribute variants, and it is possible to discriminate between variants within an attribute and their effect on the PQ.

Figure 6. Ratings of three examples within the same attribute.

The example in Fig. 6 illustrates the variation within the same attribute and the distribution of the responses. The mentioned informational asymmetry between designers and customers is expected to increase when offering digital designs models. For the future, it has to be evaluated if digitized design models can offer items designed on different severity levels. These digitized items open the chance to show the customers a wider range of designs and bring the challenge that customers may not be able to judge on simulated/rendered images.

4.4. Focus Group Outcomes – Stage 4

The focus group consisted of four individuals. Out of the four, three completed both surveys, and one individual had completed the BWS survey only. The focus group confirmed that the interpreted cause and effect influence the judgment when evaluating a defect. There were discussions about the design intent: "The design intent is not really good," "This just seems to be bad design." Production issues "Seams like it should not be approved in production, and it is not produced well," as well as the effect and the potential risks associated with the defect.

Further, it strengthens the results from the main study about the area's importance. During the discussions in the focus group, the area was mentioned when discussing the impact of the demerit in every image. "Not at all bothering because of the area" and "Overall issues that come really in front of you is more severe."

5. Conclusions

Understanding attribute preferences contribute to the effectiveness of the design processes in the early product development phases and help prioritize the company's efforts in the competitive automotive industry. The PQAIR methodology was applied to understand the importance of Geometry Appearance PQ attributes from a customer perspective. It can also be extended to other visual attribute areas of PQ. It is essential to establish an uninterrupted communication channel from designers to customers and back. Correctly prioritized PQ attributes can lead to a successful design and eventually highest customers' appreciation.

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