Perceived Quality Estimation with the Design of Discrete-Choice Experiment and Best-Worst Scaling Data: An Automotive Industry Case

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Abstract. The abstract is a mandatory element that should summarize the contents of the paper and should contain at least 70 and at most 150 words.

Keywords: We would like to encourage you to list your keywords here. They should be separated by middots.

1 Introduction

There would be no company without customers. And there is not a sale transaction if the customer does not perceive the product of enough quality that makes it worthy to buy. The concept of quality is strongly linked to both manufacturing quality and perceived quality. Leaving manufacturing quality out of the scope of this research, being a maturely discussed topic in literature, this paper discusses instead how perceived quality (PQ) influences product design. Providing an example of automotive industry, with the main idea that PQ is one of the most essential global product attribute, which has the direct impact on the success of the automobile's design.

PQ attributes are responsible for the definition of requirements that determine design and behavior of the vehicle. These PQ attributes can be related to the complete vehicle requirements, system and component level requirements. Moreover, PQ attributes taxonomy inside of organization is responsible for complete vehicle verification and physical inspection.

One of the most challenging tasks in the automotive industry today is to achieve "optimal" perceived quality within the given boundaries, such as available technology, product development time, production systems capacity and financial limitations. The goal of proper PQ attributes definition is to secure correct content and execution of complete vehicle. All components and system solutions have to be executed in a way that product will be perceived by the customer as one with the high quality. From the other side, PQ has multi-dimensional nature and engineers –under high time and cost pressure - are continuously challenged with the question of choice between equally important product attributes: e.g., to invest time and resources into a minimization of split lines gap around a rear lamp or focus on cut & sew quality of car seats? Therefore such a billion-dollar design decisions have to be supported with the robust and reliable methodology.

In this study we adopt communication model of design process - design as a communication process between designers and customers {Crilly:2004dv, Crilly:2008ts, Forslund:2006vs, Mono:1997um}. We use this communication model to capture information asymmetry {Akerlof:1970ua, Stiglitz:2000tg} between designers and customers, and therefore maximize PQ (see Fig.1).

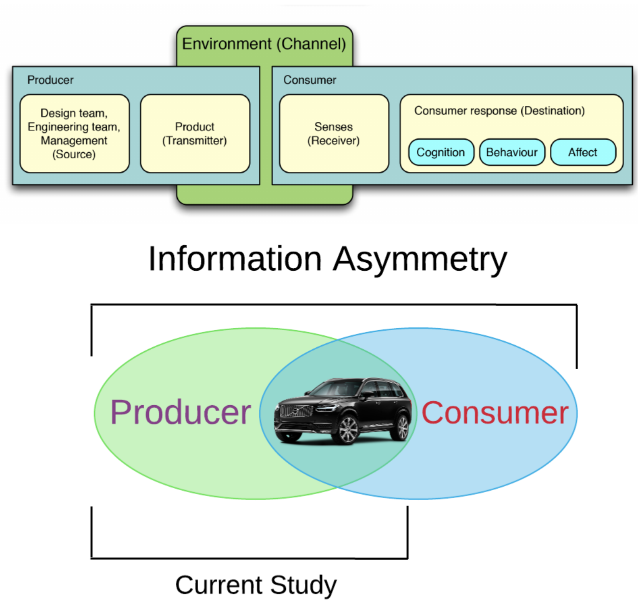

Fig. 1. Design as a process of communication and information asymmetry in the context of current study (adopted {Crilly:2004dv}).

To measure the importance of PQ attributes from the designer's viewpoint, we used Perceived Quality Attributes Framework (PQF) and ranking method (PQAIR) {Stylidis:2018vz}. The use of PQF as a common taxonomy system for PQ attributes allowed us to design and conduct experiments with two automotive Original Equipment Manufacturers (OEM) operating in the premium and economy automotive sectors.

Following this approach with the final aim to be able to rank PQ attributes importance, we asked the professionals within the two global automotive OEM's, to evaluate their flagship vehicle. For measurement of respondents' subjective preference, we used a combination of the discrete-choice experiment (DCE) and best-worst scaling (BSW) elicitation. We estimated PQ attribute-level importance for 32 ground attributes of PQF with the BSW data and obtained information regarding relative importance for 9 attributes of higher hierarchy level of PQF (i.e., PQ modalities).

Our results suggest that use of DCE and BSW for ranking PQ attributes can be an effective solution for estimation of PQ level in product design. Powerful implications possibly follow this statement. For example, thanks to the PQ ranking methodology it will be possible not only to highlight which PQ attributes are most important for successful product design, but also to perform this analysis for different vehicles design so to increase PQ perception under any given market target boundaries.

The remainder of the paper is structured as follows: Section 2 reflects on background and previous research; Section 3 introduces methodology; Section 4 discusses these results, as well as additional qualitative findings that suggest further research; Section 5 concludes this work.

2 Background

PQ attributes assessment would not be possible without clear definitions and taxonomy. No methodology can be applied to the dubious entity. Hitherto PQ was not clearly defined and views on its notion varied significantly.

2.1 Perceived Quality as a Part of Product Quality Models

Extensive amount of research into the quality perception models and definitions, has been conducted primarily to identify the dimensions of product quality {Olson:1972ul, Gilmore:1974um, Crosby:1980un, Garvin:1984ue, Zeithaml:1988wo, Steenkamp:1990ue, Reeves:1994vi, Mitra:2006uv, Aaker:2009vg}. Alas, this significant body of work, represent mainly the marketing science viewpoint on PQ. Consequently, PQ depicted as the antagonistic entity to the "real" or "objective" quality, i.e. hardly quantifiable, imaginary, subjective.

In the engineering science, PQ traditionally was the part of bigger models: e.g., in the area of Robust Design (RD) {Taguchi:1986vc, Taguchi:2005vz}. Particularly, Geometrically Robust Design {Soderberg:1999vi} considers PQ from the engineering viewpoint {Wickman:2007tj, Wagersten:2011tv, Wickman:2014tl}. Conceptually RD is widely recognized as a consisting methodology for obtaining a high level of product quality. Consequently, a Geometrically Robust Design has been defined by {Soderberg:1999vi} as "a design that fulfils its functional requirements and meets its constraints even when geometry is afflicted with small manufacturing or operational variation." Following this, the area of 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 {Soderberg:2006vf}. 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 {Pedersen:2016ux} proposed the Robust Design Requirements Specification (RDRS) approach for quantification of the early stage requirements and developed Perceptual Approach to Robust Design {Pedersen:2017tq}. Howard et al. {Howard:2017tt} introduced a Variation Management Framework (VMF), linking variation during production with its impact on product and customer perception regarding quality loss. Therefore geometry assurance and geometrical variation management processes become interdisciplinary, involving variety of activities such as inspection, assembly design and manufacturing {Schleich:2017vr}.

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.

2.2 Perceived Quality Framework (PQF)

A typical automotive OEM operates with 20-120 PQ attributes depending on organizational structure and internal PQ assessment procedures. PQ attributes are responsible for the definition of requirements and requirement levels that determine perceived quality of the product. The identification and mapping of attributes that represent PQ is ongoing challenge for researches and practitioners {Burnap:2015ww, Pan:2016vl, Striegel:2017wi}.

In this research we used PQF {Stylidis:2018vz} as a platform for PQ attributes importance assessment and exploration. The PQF constitutes primary human senses: olfactory, visual, tactile and auditory. The vast majority of PQ attributes can be described by one of these categories or several in combination (see Fig.2). Quality perception connected to the primary senses is forming the first level of PQ attributes: Visual Quality, Tactile Quality, Auditory Quality and Olfactory quality. The second attributes level of PQF organized in 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 and includes number of Ground Attributes (GA). The GA is the "lowest point" where the engineer can still communicate with the customer to receive feedback. To avoid ambiguity, every GA has to be coherent to a customer's experience. Therefore, the PQF can stand as a meaningful and accessible frame of reference for both the engineer and the customer. Eventually, a customer must be able to understand the meaning of each GA and at the same time be able to rank particular PQ attribute and prioritize its importance among other GAs. Such a customer's feedback is the key in search of equilibrium for a quality equation within the OEM's design and assessment activities regarding PQ. The complete list of Sensory Modalities and GA can be found in Table 1.

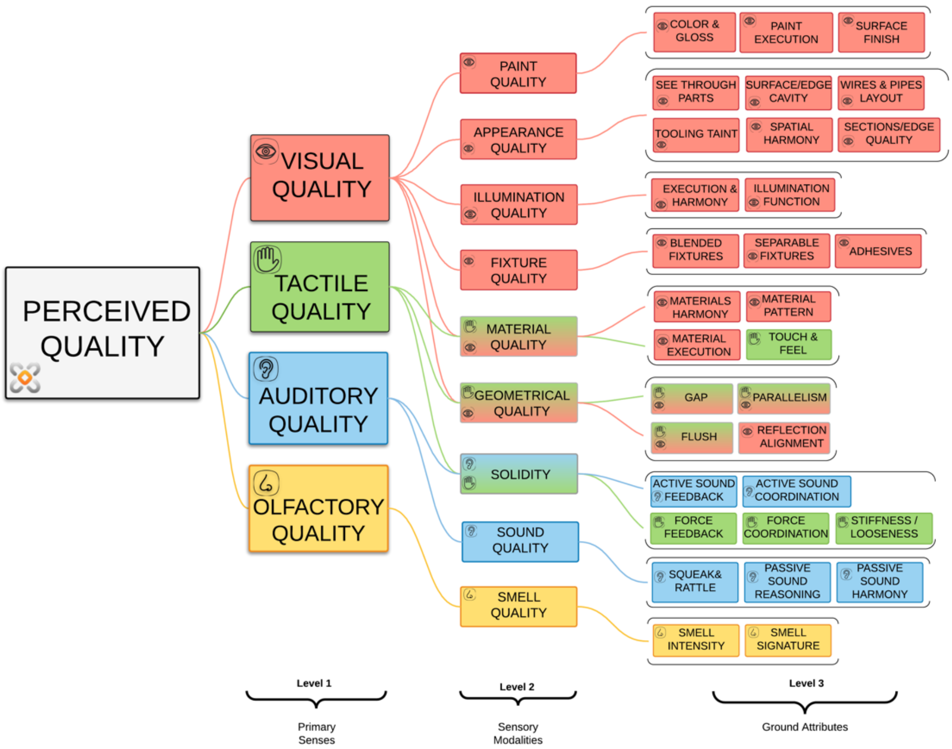

Fig. 2. Perceived Quality Framework: Modalities and Ground Attributes

PQF is not limited to its status as a descriptive framework – it can be used widely to explore and test automotive designs with regard to perceived quality, at all product development stages.

2.3 Perceived Quality Attributes Importance Ranking Method (PQAIR)

The PQ attributes importance ranking method {Stylidis:2018vz} 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 Fig.3.) regarding 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).

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.

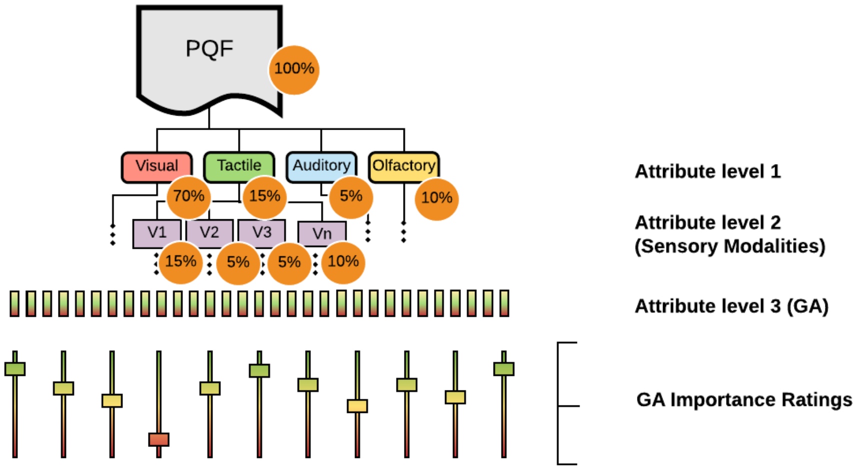

Fig.3 PQ attributes importance ranking structure.

3 Methodology

To understand subjective preference regarding PQF sensorial modalities and relative importance of GA, respondents were asked to complete a series of DCE and a series of BWS questions. We choose this strategy in our experimental design for the reason that analysis of DCE data provides attribute level (i.e. sensory modalities in case of PQF) preference parameters, while BWS data analysis reveals overall relative importance of each attribute (i.e. GA for PQF) {Zhang:2015vd}. This allowed to receive holistic views on PQ and PQ attributes relative importance. In fact, discrete choice models were applied widely in various econometric studies from the 1970s {BenAkiva:2002vg}. A theoretical foundation for discrete choice theory and conjoint analysis was provided by {Louviere:1983wd}.

In our case, a stated choice web survey (DCE) was designed for 9 sensorial modalities and X GA (see Table 1) within the PQF. The DCE experimental design was constructed with the use of CBC Sawtooth Software module {Unknown:vw}. For this study we have chosen the asymmetric design, i.e. modalities have different number of GA, since it's naturally derives from the PQF logical composition.

Table 1. List of PQF sensory modalities and GA involved in the study design.

Sensory Modality	Ground Attributes
Appearance Quality	See Through Parts
	Section/Edge Quality
	Spatial Harmony
	Surface/Edge Cavity
	Tooling Taint
	Wires and Pipes Layout
Fixture Quality	Adhesives
	Blended Fixtures
	Separable Fixtures
Geometrical Quality	Flush
	Gap
	Parallelism
	Reflection Alignment
Illumination Quality	Execution and Harmony
	Illumination Function
Material Quality	Material Execution
	Material Harmony
	Material Pattern
	Touch and Feel
Paint Quality	Color and Gloss
	Paint Execution
	Surface Finish
Smell Quality	Smell Intensity
	Smell Signature
Solidity	Active Sound Feedback
	Active Sound Coordination
	Force Feedback
	Force Coordination
	Stiffness/Looseness
Sound Quality	Passive Sound Harmony
	Passive Sound Reasoning
	Squeak and Rattle

For the estimation of PQ attributes relative importance, a quantitative survey technique was used called Best-Worst Scaling (BWS). Best-Worst Scaling is a discrete choice modelling method which offers to respondents a series of “best-worst” tasks, where they identify the “best” and “worst” option from the list of 4-7 alternatives. BSW is based on ranking and paired comparison models along with discrete choice modelling (DCM) which allows the simultaneous presenting of several items to respondents. This method originally was developed by

{Louviere:1993wo} 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:2005tu} best-worst tasks also positively affect the consistency of the responses and can be easily understood by respondents. Consecutively, BWS exercises result in better precision and discrimination of item scores in comparison to the typical rating scales (e.g. Likert scales). There is to mention that BWS method often also called maximum-difference scaling (MaxDiff). However, "*BWS name is to be preferred – as Louviere and others indicate there is no empirical evidence of humans using a maximum difference measure in a choice process*" {Lipovetsky:2014wy}. Consequently, we use term Best-Worst Scaling method throughout this paper.

With the use of Sawtooth Software, we designed BWS study for 32 ground attributes of PQF (see Table 1). Prior the survey, respondents were introduced to the descriptions of PQ modalities and PQ ground attributes {Stylidis:2018vz}.

The initial task given to participants was to rank given GA sequentially to evaluate their company's current flagship vehicle. Two automotive OEM's were studied: Swedish leading premium car manufacturer and Turkish subsidiary of an Italian automotive manufacturer producing passenger's van. Our pool of participants included X professionals with the long track record in the automotive industry. Their responsibilities include such areas of competence as of perceived quality, complete vehicle requirements definition and assessment. The survey was administered via web interface. Average survey completion time was approximately 40 minutes.

4 Results

4.1 Structuring Your Paper

Author Names and Affiliations. ICoRD uses double blind review process. **Please do not include any of your personal information** (e.g., name, affiliation) anywhere within the full paper which you are uploading. However, **authors must ensure that the papers will be within the 10 pages limit when the author information will be entered** in the final submission stage.

Headings. Headings should be capitalized (i.e., nouns, verbs, and all other words except articles, prepositions, and conjunctions should be set with an initial capital) and should, with the exception of the title, be aligned to the left. Only the first two levels of section headings should be numbered, as shown in Table 1. The respective font sizes are also given in Table 1. Kindly refrain from using "0" when numbering your section headings.

Table 1. Font sizes of headings. Table captions should always be positioned *above* the tables.

Heading level	Example	Font size and style
Title (centered)	**Lecture Notes**	14 point, bold
1st-level heading	**1 Introduction**	12 point, bold
2nd-level heading	**2.1 Printing Area**	10 point, bold
3rd-level heading	**Run-in Heading in Bold.** Text follows	10 point, bold
4th-level heading	*Lowest Level Heading.* Text follows	10 point, italic

Words joined by a hyphen are subject to a special rule. If the first word can stand alone, the second word should be capitalized.

Here are some examples of headings: “Criteria to Disprove Context-Freeness of Collage Languages”, “On Correcting the Intrusion of Tracing Non-deterministic Programs by Software”, “A User-Friendly and Extendable Data Distribution System”, “Multi-flip Networks: Parallelizing GenSAT”, “Self-determinations of Man”.

Lemmas, Propositions, and Theorems. The numbers accorded to lemmas, propositions, and theorems, etc. should appear in consecutive order, starting with Lemma 1. Please do not include section counters in the numbering like “Theorem 1.1”.

4.2 Length of Papers

Papers should be strictly within the 10 pages limit.

4.3 Page Numbering and Running Heads

There is no need to include page numbers or running heads; this will be done at our end. If your paper title is too long to serve as a running head, it will be shortened. Your suggestion as to how to shorten it would be most welcome.

4.4 Figures and Tables

It is essential that all illustrations are clear and legible. Vector graphics (rather than rasterized images) should be used for diagrams and schemas whenever possible. Please check that the lines in line drawings are not interrupted and have a constant width. Grids and details within the figures must be clearly legible and may not be written one on top of the other. Line drawings are to have a resolution of at least 800 dpi (preferably 1200 dpi). The lettering in figures should not use font sizes

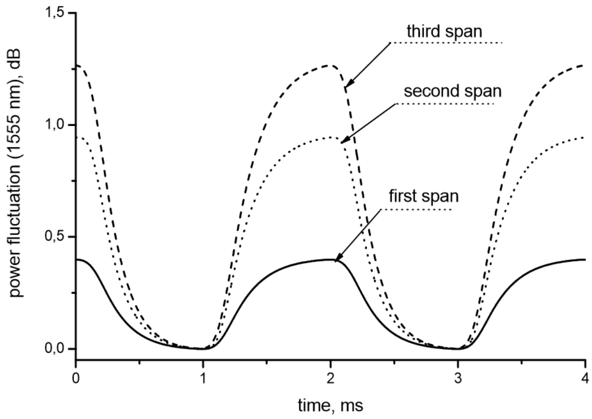

Fig. 1. Power distribution of channel at 1555 nm along the link of 383 km (Source: LNCS 5412, p. 323)

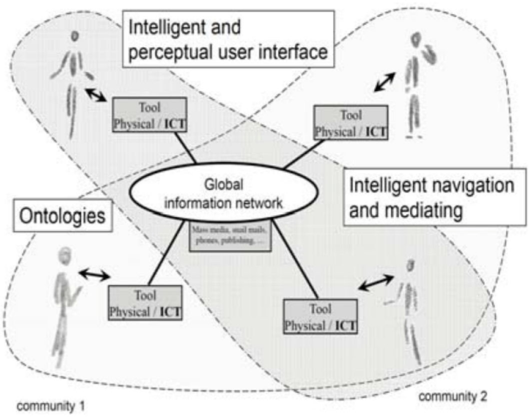

Fig. 2. Artifacts empowered by Artificial Intelligence (Source: LNCS 5640, p. 115)

smaller than 6 pt (~ 2 mm character height). Figures are to be numbered and to have a caption which should always be positioned *under* the figures, in contrast to the caption belonging to a table, which should always appear *above* the table.

Captions are set in 9-point type. If they are short, they are centered between the margins. Longer captions, covering more than one line, are justified (Fig. 1 and Fig. 2 show examples). Captions that do not constitute a full sentence, do not have a period.

Text fragments of fewer than four lines should not appear at the tops or bottoms of pages, following a table or figure. In such cases, it is better to set the figures right at the top or right at the bottom of the page.

If screenshots are necessary, please make sure that the essential content is clear to the reader.

Remark 1. In the printed volumes, illustrations are generally black and white (halftones), and only in exceptional cases, and if the author or the conference organization is prepared to cover the extra costs involved, are colored pictures accepted. Colored pictures are welcome in the electronic version free of charge. If you send colored figures that are to be printed in black and white, please make sure that they really are also legible in black and white. Some colors show up very poorly when printed in black and white.

4.5 Formulas

Displayed equations or formulas are centered and set on a separate line (with an extra line or half line space above and below). Displayed expressions should be numbered for reference. The numbers should be consecutive within the contribution, with numbers enclosed in parentheses and set on the right margin. Please do not include section counters in the numbering.

$$x + y = z \tag{1}$$

Equations should be punctuated in the same way as ordinary text but with a small space before the end punctuation mark.

4.6 Footnotes

The superscript numeral used to refer to a footnote appears in the text either directly after the word to be discussed or – in relation to a phrase or a sentence – following the punctuation mark (comma, semicolon, or period).[1]

4.7 Program Code

Program listings or program commands in the text are normally set in typewriter font:

```
program Inflation (Output)
  {Assuming annual inflation rates of 7%, 8%, and
  10%,...   years};   const
MaxYears = 10;   var
Year: 0..MaxYears;
         Factor1, Factor2, Factor3: Real;
begin     Year := 0;
    Factor1 := 1.0; Factor2 := 1.0; Factor3 := 1.0;
WriteLn('Year 7% 8% 10%'); WriteLn;     repeat
      Year := Year + 1;
      Factor1 := Factor1 * 1.07;
      Factor2 := Factor2 * 1.08;
      Factor3 := Factor3 * 1.10;
```

[1] The footnote numeral is set flush left and the text follows with the usual word spacing.

```
      WriteLn(Year:5,Factor1:7:3,Factor2:7:3,
Factor3:7:3)     until Year = MaxYears end.
```

[Example of a computer program from Jensen K., Wirth N.: Pascal User Manual and Report. Springer, New York (1991)]

4.8 Citations and Bibliography

For citations in the text, please use square brackets and consecutive numbers. We would write [1,2,3,4,5] for consecutive numbers and [1], [3], [5] for non-consecutive numbers.

Acknowledgements. This should always be a run-in heading and not a section or subsection heading. It should not be assigned a number. The acknowledgements may include reference to grants or supports received in relation to the work presented in the paper.

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