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Towards overcoming the boundaries between manufacturing and perceived quality: an example of automotive industry.

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Abstract

Automotive manufacturing enterprises face many challenges today. Remaining as one of the biggest among them is delivering value to the customers through product quality. Moreover, good manufacturing or technical quality does not always result in high perceived quality from a customer perspective. At the same time, perceived quality is a property that has to be incorporated into the product during the whole product lifecycle, from design to production. Throughout the production stage, every manufacturing operation contributes to the building of final product's perceived quality. Thus, there is a need to control manufacturing operations related to this matter. This paper addresses the connection of the perceived quality framework, which defines dimensions of the perceived quality, to a manufacturing model that represents the manufacturing variation and propagation during different assembly operations. The aim of the study is to overcome boundaries between manufacturing and perceived quality. An industrial example, within the automotive premium sector, has been used to draw this connection illustrating the case of welded assemblies.

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Keywords: automotive, perceived quality; manufacturing quality; spot welding; product development; product quality, product value

1. Introduction

Delivering value to the customer through superior quality is one of the greatest challenges for manufacturing enterprises today. The success of the product on the global market can be achieved only with the fulfillment of customer requirements. In the premium and luxury segment of the automotive industry, this challenge takes another dimension with the constant battle against cost pressure and shortening the production lifecycle [1]. Thus, successful premium vehicle design characterized by excellence as a combination of both manufacturing and perceived quality.

As for manufacturing quality, it is well understood and described in Literature - e.g. [2]; that perceived quality often refers to customers emotional responses, to a particular product design [3] or associated with the craftsmanship [4], [5]; thus - perceived quality remains a somewhat fuzzy concept.

For quite a long time manufacturing quality aspects were isolated from the perceived quality and vice versa. To a great extent these two clusters of product quality remain isolated even today, with regards to product development.

Therefore, in the case of premium and luxury segments, the automotive industry situation can be seen from a different angle. Historical evolution of the premium and luxury automobiles arose with the vision of excellent or "zero defects" manufacturing quality. Consequently, product differentiation in these segments often derives from the customer's assessment of the perceived quality [6]. As a result, premium and luxury vehicles cannot be assessed today only by taking into consideration "perfect" technical quality; rather "zero defects" quality is just an entry ticket to the particular market segment.

One of the primary targets for the manufacturers is to reduce production time and cost. When considering design decisions that can affect manufacturing, there is a clear view of

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manufacturing quality aspects to secure outcome and manufacturing variation. Therefore, such a decision can affect perceived quality which has to be controlled during the design process as well as manufacturing quality is controlled today.

This fact calls for the amendment of existing product quality models, at least for the premium and luxury automotive sector. There is a need to see product quality as an integrated system and most importantly – an amount of integrated methods for successful product development. There is a need for methods that could incorporate the customer's holistic quality perception into the engineering practice.

In this study, we illustrate the link between product attributes related to the manufacturing quality and perceived quality with the example of weld spots. We propose a theoretical model that incorporates manufacturing quality with the perceived quality into the seamless process. We believe it can help to bridge the gap between current product quality views and "engineering" explicit approach to the perceived quality in the context of product development.

The remainder of the paper is structured as follows: Section 2 introduces the theoretical background regarding manufacturing and perceived quality; Section 3 presents an illustrative case from the premium automotive sector regarding spot welds as product attributes; Section 4 proposes a comprehensive product quality model; Section 5 discusses quality paradigm change and provides recommendations for further research; Section 6 offers conclusions.

2. Background

A brief Literature overview is provided below to describe the context of the proposed quality model with relation to manufacturing and perceived quality.

2.1. Historical evolution of product quality models

It is recognized by many authors that quality has a multidimensional structure. Traditionally perceived quality has been seen as one of the dimensions of the product quality. One of the first descriptions of Perceived Quality was given by Shapiro [7], describing purchase behaviour. As for the term "product quality," though, it has been identified at the macro level as a key variable for competitiveness [8]. At the micro level, product quality is the major driver for the manufacturers and the consumers. Olson [9] defined quality perception as a two-stage process: the first stage includes consumer's judgment based on available cues and forms; later the user forms his quality impression based on his interpretation of those cues and forms. Another view is held by Crosby [10], defining quality as "conformance to requirements." However, according to Crosby, requirements may not always fulfill the customer's expectation.

Hence, with the many independent attempts to define quality, probably one of the most remarkable was performed by Taguchi [11]. Taguchi defines quality as "the losses of society caused by the product after its delivery" and as "uniformity around the target value." Furthermore, Kano [12] presented a model with two dimensions of quality: "must-be quality" and "attractive quality."

Garvin [13] introduced an inclusive model of quality with the five approaches: transcendent, product-based, user-based, manufacturing-based and value-based. Additionally, Garvin noticed that views on quality are differentiated from the point of "marketing people" and "manufacturing people." The first type usually prefers user-based or product-based approach, because they see a customer as a referee of quality. Accordingly, "manufacturing people" see quality as "conformance to requirements." The clear existence of the conflict is identified in these two views. Finally, he defined eight dimensions of quality: performance, features, reliability, conformance, durability, serviceability, aesthetics and perceived quality. According to Garvin, Perceived Quality is a subjective dimension, which derives from incomplete information about product attributes and cannot be adequately assessed. Monroe and Krishnan [14] define perceived quality as "perceived ability of a product to provide satisfaction relative to the available alternatives". Steenkamp [8], admitting inconsistency and lack of the empirical proof for the existing (by that time) definitions of perceived quality, proposed a framework for developing a new definition of perceived quality. His framework presents the following quality dimensions in the context of value: perceived quality involves preference; perceived quality is neither objective nor subjective; perceived quality exists in the product consumption. There are several "marketing – oriented" definitions of perceived quality that focus mainly on the consumer. Namely, Mitra and Golder [15] interpret perceived quality as "perception of the customer" and oppose it to the term "objective" quality. Such a view on perceived quality derives from the earlier research of Zeithaml [16]. She defines perceived quality as a subjective customer's judgment regarding overall product superiority. Perceived quality is different from objective quality, according to Zeithaml. The similar view expressed by Aaker [17] with the definition of perceived quality as "the customer's perception of the overall quality or superiority of a product or service with respect to its intended purpose, relative to alternatives". As for the latest research there are a number of scholars that investigate the topic of perceived quality also from the manufacturing and marketing oriented point of view [18-19].

As shown above, the majority of quality models and views on perceived quality are either driven by market research or represent the manufacturing side of product development. They provide no ideas about elicitation and/or objective assessment methodology regarding product attributes that comprise Perceived Quality.

2.2. Design for Quality

Design for Quality (DFQ) can be considered as the methodology that links the two views on quality together, the customer perspective and manufacturing point of view [20]. DFX methodologies connect the design with a certain property or discipline. Design for Quality (DFQ) appeared during the 2000´s as a method that explicitly focuses on the quality as objective [21-23]. Mørup [20], when he first introduced DFQ, differentiated between big Q and little q because quality means different things to different stakeholders of a product realization process, customer inclusive. Q-quality represents the product function, the quality perceived from the external customer, whereas q-quality represents the quality perceived by the internal customer, manufacturing. In his research, Mørup reasons how quality is synthesized through product design properties and how these quality carriers are realized through the manufacturing process. Therefore, DFQ established a connection between the characteristics of the product that carries quality, designed to satisfy the external customer, and the manufacturing process that builds those product's characteristics.

2.3. Perceived quality challenges for the premium segment of the automotive industry

To ensure the success of their products in the competitive global market, automotive manufacturers had to ensure highest standards of both manufacturing quality and perceived quality. In the premium and luxury segment of the automotive industry, the ideas of "zero-defects" and highly functional products are followed by the majority of the players in the segment. Therefore, it is perfectly understood by automotive manufacturers that quality perception is at the forefront of customer's attention and has a strong influence on purchasing behaviour. There is a clear understanding that differentiation between manufacturers can be achieved only by the products perceived as high quality by the customers. However, identification and mapping of attributes that represent perceived quality is the ongoing challenge for researchers and practitioners [24-25]. This process is arduous due to the subjective nature of many attributes and absence of robust methodologies for translating the voice of the customer into technical specifications. Additionally, customers often have difficulties expressing their opinions about a product with a high level of complexity such as a premium vehicle. Given these points, designers and engineers need to strike a balance in representing perceived quality attributes while ensuring that the product is perceived by customers as possessing high quality.

Such a fuzzy background often creates a phenomenon of information asymmetry. Information asymmetry was adopted in signalling theory and explained as a behaviour of two parties when they have access to a different amount of information [26]. With the application of the product development process, information asymmetry can cause misprioritization of perceptual design attributes between the designer and the customer.

The information asymmetry can appear due to different terminology, organizational structure, divergent knowledge or internal manufacturing culture used in various OEM's. Previous studies [27] showed that information asymmetry is detrimental to a product's success on the market and reduction of such asymmetry should increase perceived quality of the vehicle.

3. Illustrative case of existing boundaries between manufacturing and perceived quality.

In this section, we illustrate how product attributes related to the manufacturing and perceived quality can be interconnected, providing the example of the weld spots. We claim the need to establish a connection regarding an assessment of manufacturing and perceived quality.

The spot welding as a part of a manufacturing process is probably one of the most dominant methods for joining sheet metal in the automotive industry. The spot welds quality is a crucial factor regarding the key performance characteristics fulfillment of the vehicle; such as stiffness and crash behavior [28]. While various types of spot welding e.g. resistance spot welding (RSW) and laser spot welding (LSW) are well established, the verification methods for the perceived quality and appearance prediction is absent in most cases. As a result, the majority of premium and luxury automobile manufacturers simply hide attributes derived from the manufacturing process (e.g. spot welds) as non-compliable to the visual quality of the vehicle.

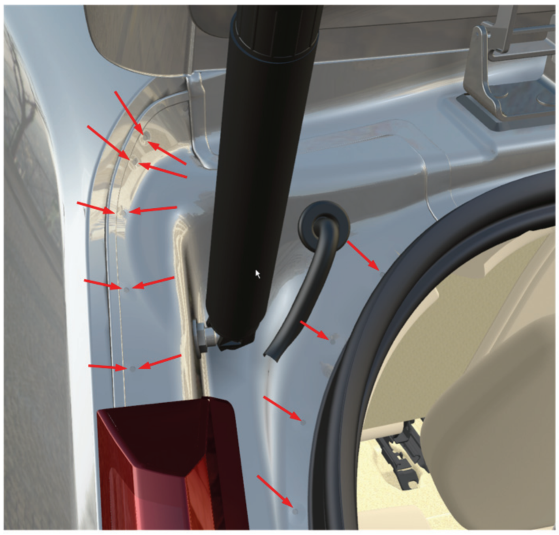

Fig. 1. Illustrative example of visible weld spots on the complete vehicle

The particular illustration (see Fig.1) shows a CAD model at the early design stage with the visible weld spots. The dilemma of choice between keeping a laser brazing as joining technique or its replacement with spot welding appears here.

As we can see, spot welds (type RSW) are visible and might create problems to the visual appearance of the vehicle. The solution, in this case, will be to hide those spots just because they do not communicate "good quality".

Such an approach works most of the times in the premium segment; however, recent studies showed [27] that in some cases automotive manufacturer intentionally wants to highlight product attributes previously assessed only from the manufacturing perspective (e.g. rivets, KB welding, spot welding). Today the existing paradigm of product quality where manufacturing quality is detached from perceived quality, does not allow flexibility in setting up customer's requirements.

4. Connecting manufacturing and perceived quality.

Here we explain an approach to the product quality assessment by the use of Producibility Assessment Framework (PAF) [29], together with the Perceived Quality Framework

(PQF) [30]. In this case, PAF stands as an integral part of the manufacturing quality assessment and PQF respectively contributes to the objective evaluation of the perceived quality.

4.1. Producibility Assessment Framework

A producibility model that represents the product quality creation during the manufacturing process made by Madrid et. al. [29], see Fig. 2. has been adapted from previous studies, to exemplify the specific case of the assembly process within the automotive sector, where welded sheet metals are predominant. This model first represents the manufacturing operations chain, see Fig 3., composed of three

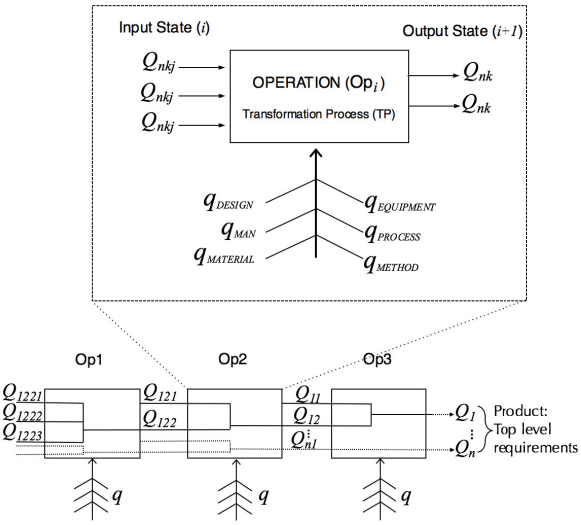

Fig. 2. *Producibility* assessment framework [33]

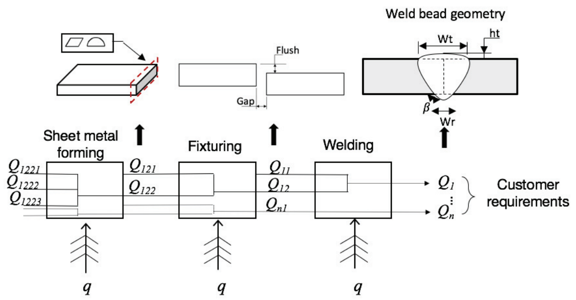

Fig. 3. *Producibility* framework adapted to automotive sheet metal assembly

main manufacturing operations: 1) Sheet metal forming processes are used to produce sheet metal parts that will later constitute the car body. 2) Fixturing: the sheet metal parts are placed in a fixture to be locked and aligned in optimal position. 3) Welding: the joining of the two sheet metal parts is executed by fusing the materials either through spot welding or continuous welding.

Each of these operations transforms the product from raw material to the final state. In the final state, the output of the welding operation, the final product is constituted by certain key product characteristics and properties that need to fulfill the external customer's requirements, including perceived quality. In this model, key characteristics are represented as (Q), with regards to Q-quality concept developed by Mørup [20], since those are the key product characteristics that carry the final product quality. For example, a key product characteristic output of the welding operation is the weld bead geometry. The weld bead geometry will determine a strength of the product but also the appearance of the weld, which influences the perceived quality.

Furthermore, in the producibility model (Fig.2) the product key characteristics (output of the welding operation) are decomposed into product key characteristics at each of the previous operations. The purpose is to decompose final product requirements into subsystem requirements, so that for each operation system, the output requirements are defined. In this case (see Fig.3.), the quality of the weld bead geometry is influenced by the output of the fixturing operation, where good alignment conditions for the parts to be welded needs to be guaranteed. Therefore, the product key characteristics output of fixturing are gap and flush. Before that, during sheet metal forming, the flatness of the surfaces to be welded and the weld interface profile need to be assured to deliver good weld alignment conditions while fixturing. In this producibility model, each operation represents a transformation process where input key product characteristics (Q_{ij}) are being created and transform to output key characteristics (Q_i), thus building the product Q-quality operation by operation throughout the manufacturing process.

At the same time, each manufacturing operation can act as an isolated system, where control parameters can be set to ensure the specific output of the certain operation. These parameters act as control parameters for the manufacturing quality. Thus, they are related to the concept q-quality developed by Mørup [20]. The control parameters (q) (see Ishikawa diagram), can be classified under design aspects or manufacturing aspects. For example, related to design, during fixturing operation, the design of the locating schemes, which represent the physical contact between the parts and the fixtures, will affect the quality of the alignment conditions, the gap and the flush [31]. With regards to manufacturing, control parameters during welding are welding speed and welding power, which will influence the welding quality outcome, that is the weld bead geometry [32].

All of the above create interconnections with perceived quality attributes, e.g. gap and flush, as a part of geometry quality.

4.2. Perceived Quality Framework

From the engineering point of view, Perceived Quality domain is a place where the product space, form, sound and material intersect with human experience. In the automotive industry during the product development phase, the vehicle architecture space is handled and described by product attributes; e.g. fuel consumption, active safety, noise, durability and many others. A typical automobile manufacturer uses around 40-120 attributes depending on organization structure. The product attributes are responsible for the requirement definition, as well as for requirement's levels construct which defines the desired vehicle behaviour and design. Product attributes involved in both – complete vehicle requirements, also in system and component requirements set up. Perceived Quality can be defined differently at different automotive original equipment manufacturers (OEM), though the scope of the Perceived Quality definition is to secure correct meaning and execution of the complete vehicle. The ultimate goal to execute all components and system solutions of the vehicle in a way that the final product will be perceived by the customer as one with the high quality.

It is important to mention, that creation of a vehicle with high perceived quality is not the biggest challenge for the premium and luxury segment of the automotive industry. The high perceived quality can be achieved with increased product cost. The initial challenge is in balancing perceived quality attributes regarding existing technologies, innovations, product development time cycle, production systems and project budget.

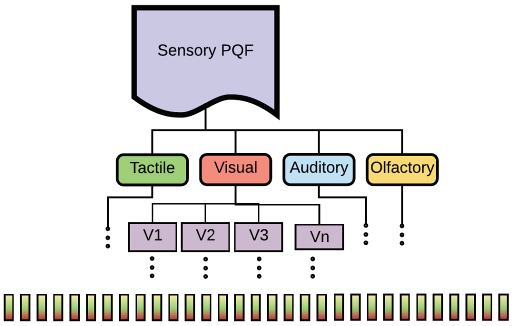

Fig. 4. Schematic representation of the sensory based PQF

The PQF [30], presents clear heuristic structure for robust discourse around the theme of product quality. The PQF establishes a shared basis for dialogue towards shifting quality paradigms with the decomposition and objective assessment of perceived quality attributes (previously seen as subjective). PQF illuminates the interplay between technical characteristics of the product and customer's perceptions.

The PQF is based on primary human senses: olfactory, visual, tactile and auditory. The vast majority of perceived quality relationships (attributes) can be described by one of these categories or several in combination (see Fig.4).

4.3. Integrated Quality Framework

We propose to see product quality formation as an integrated process of engineering regarding product attributes that communicate quality to the customer (see Fig.5). Such attributes form the set of cues in the environment that is perceived and evaluated by the customer. This process of attributes creation and definition, including assessment models regarding manufacturing and perceived quality, has to be seen as an organized whole. A principal cause is the fact that a customer judges a product on the grounds of its quality and product quality is the major determinant of the product's success. Therefore, customer's requirements have to be properly assessed and defined at early stages of the product development including manufacturing and design.

In the premium and luxury segment of the automotive industry high manufacturing quality (MQ) is the prerequisite to the high perceived quality (PQ). In other words, manufacturing quality in the premium and luxury automobile segment is not the primary determinant of customer satisfaction. Consequently, customer's requirements have to be transferred seamlessly from PQ to MQ and vice versa.

With the proposed Integrated Quality Framework (IQF) the MQ is decomposed to a set of product characteristics and can be assessed objectively with the PAF.

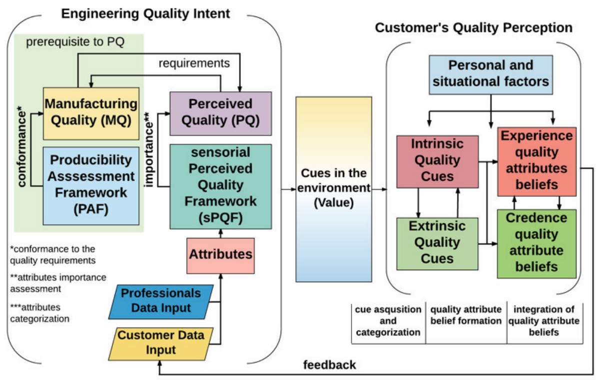

Fig. 5. Integrated Quality Framework.

Consequently, the product attributes or cues created with the engineering intent for high quality are evaluated by the customer, the feedback is captured and used as one of the input parameters in PQF. The Customer's Quality Perception model is described by Steenkamp [8]; however, our research interest focuses on the engineering intent and quality attributes assessment.

5. Discussion and results

With the challenges that the automotive industry faces nowadays, manufacturing and perceived quality becomes an inevitable part of the "total" quality impression for the customer. There is to say that automobile manufacturers empirically address these issues for a quite long time. However, there is a lack of the methodology and theory that could support engineering decisions. The paradigm of "conformance to requirements" has to be extended for the manufacturing quality since it may affect customer's quality impression. For example, weld spots sequence can deliver the goal of joining two metal sheet parts ultimately, therefore if the particular sequence does not fulfill aesthetic or geometry requirements from the perceived quality perspective - it might affect customer's judgment. At this point, engineers who work with such a requirement need robust methods for product attributes

assessment. The Perceived Quality has to be incorporated at the early stages of design, as an integral part of the product development.
This can be done with the precise translation of the customer's requirements into the technical specifications, followed by the subsequent decomposition of the customer's quality impression into objectively assessable product attributes. Such requirements have to contribute to the output of each manufacturing operation. Hence, we assure the high product quality and quality impression; deliver the value to the customer with the fulfilment of the requirements operation by operation, during the manufacturing process.

6. Conclusions

The proposed Integrated Quality Framework incorporates manufacturing quality with the perceived quality into the seamless manufacturing process. It can serve as a basis for future methods development that incorporates customer's holistic quality perception into the engineering practice. The proposed framework allows to see product quality as an integrated system; a combination of manufacturing and perceived quality approaches with the purpose to deliver the highest quality impression to the customer. The manufacturing systems can also benefit from the robust customer value creation in product development.

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