The Methodical Measurement and Evaluation of Customer-relevant Perceived Quality

The Ford Research Centre Aachen has developed a method for reproducibly measuring the customer-relevant perceived quality of vehicle interiors. The most important new feature is the application of a measuring robot that serves as both a force/travel measuring device and a carrier of other sensor technologies. The findings are correlated with human perception in order to allow an evaluation of the measured data to be performed with regard to customer acceptance.

1 Introduction

The efforts of the automotive industry have always been focused essentially on the optimisation of safety, fuel consumption and production processes as well as on questions of the environmental compatibility of vehicles and their production. This correlates to a large extent with the purchase criteria that are crucial for customers, such as safety, comfort, fun to drive, acquisition costs, maintenance costs, quality and reliability as well as, to an increasing extent, environmental compatibility. In this context, a prioritisation of the various criteria has to be seen in a greatly differentiated way. In order to achieve truly sustainable customer satisfaction, numerous subjective and objective requirements have to be fulfilled. This objective can be achieved by a standardized and reliable method for the identification of customer-relevant product properties. In the following, a project in the area of the vehicle interior is presented for the development of a methodical approach to allow standardized measurement and evaluation of customer-relevant perceived quality in a holistic manner.

In this context, "holistic" means that the perceived quality is not reduced to a parameter or an attribute, but that the interaction of many sensory impressions and procedures is analysed.

2 Consideration of Customer Relevance

The importance of customer-relevant perceived quality is shown by an internal analysis of a large independent customer survey (JD Power). According to the survey, the attributes shown in the **Table** were seen as important by the end customer.

A helpful analysis method for the collection and structuring of customer requirements is the one developed by Dr. Noriaki Kano. The Kano method is briefly introduced here with reference to the vehicle interior. In the Kano diagram, **Figure 1**, the x-axis shows to which degree a desired function is fulfilled, while the y-axis shows customer satisfaction. Three different groups of characteristics are determined:

Basic Quality Features: The requirements that the customer wants the product to meet reflect the basic product characteristics ("As long as no problems arise I will not be dissatisfied!"). The customer's satisfaction decreases rapidly if the function is not or only insufficiently fulfilled. For this aspect, it is characteristic that customer satisfaction cannot rise beyond a certain range even with perfect fulfilment. Examples of basic quality in the vehicle interior are the absence of squeaks and rattling noises or trim defects, as well as exact fuel gauge readings or a smooth seat belt function.

Performance and Quality Features: The customer is aware of performance and quality criteria and the expectations of the customer are articulated. In this category, customer satisfaction increases almost proportionally with the increase in fulfilment and is not limited as is the case with basic quality features.

Examples of performance quality in the car interior are: low noise levels, stowage capacity, seat comfort and everything concerning the appearance of the interior.

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Table: Relevance of different vehicle characteristics according to JD Powers

1. Occupant Accomodation – **19.5%**
2. Styling – **16.5%**
3. **Perceived Quality – 11.4%**
4. Night and Weather Adaption – **10.8%**
5. Driving Dynamics – **8.8%**
6. Vehicle NVH & Sound Quality – **7.4%**
7. Controls and Displays – **7.1%**
8. Fuel Consumption – **6.5%**
9. Performance & Driving Perception – **6.3%**
10. Infotainment – **5.7%**

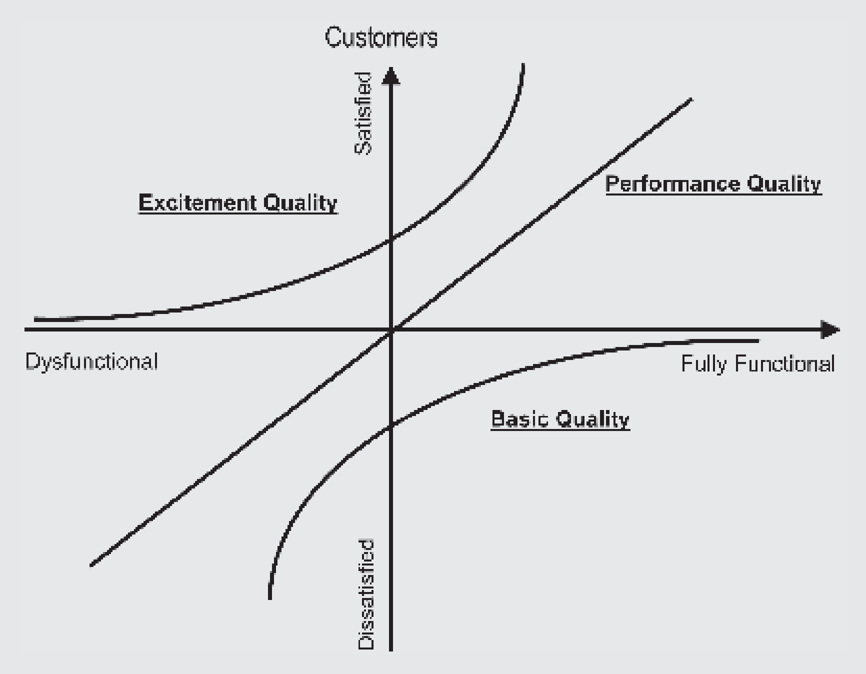

Figure 1: Kano diagram

Excitement Quality Features: Excitement quality represents the largest challenge, as even unexpressed customer expectations are exceeded. They set the product apart from the competition and have high-ranking purchase relevance. A small increase in performance can lead to a disproportionately high benefit. In this category, we find both surprising features and the superior execution of interior details.

Examples of excitement quality in the interior are: a particularly flexible interior design, new equipment or an exclusive choice of materials.

The Kano Diagram is therefore not a static viewpoint. On the contrary, a dependency on time, on the vehicle segment and on the car manufacturer can be recognized. A performance quality item can, over time, change into a performance quality feature, for example, and can later be found in the basic quality category.

Customer-relevant perceived quality therefore extends over all groups of characteristics specified here and contributes to a considerable degree to customer satisfaction.

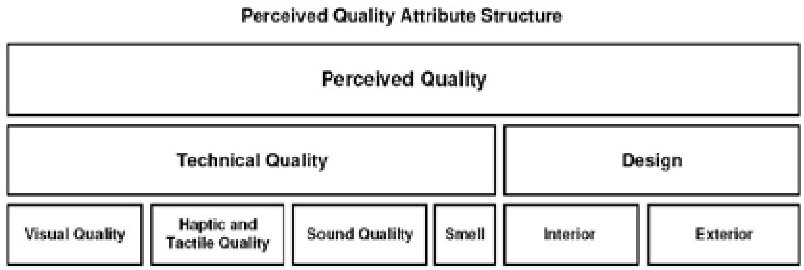

Figure 2: Attributes of customer-relevant perceived quality

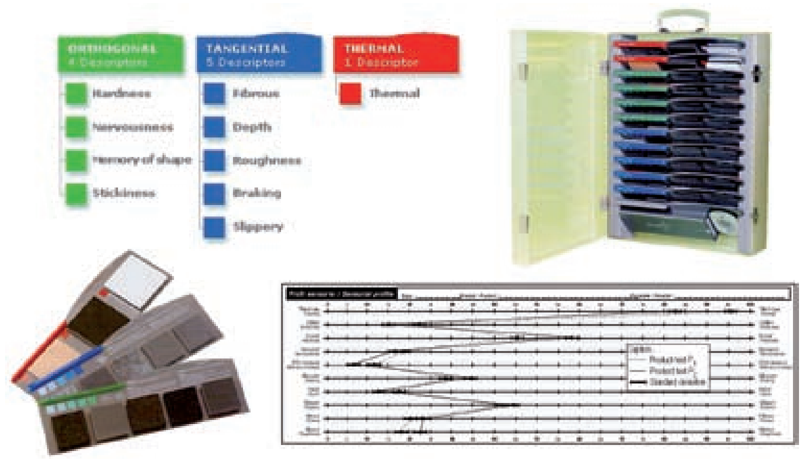

Figure 3: Tactile reference frame (source Sensotact)

3 Methodology for the Measurement of Customer-relevant Perceived Quality

Considering that one can methodically only improve what can be reliably measured, a description based on physical terms is mandatory for the communication of customer-relevant perceived quality throughout the entire product development process. This includes the areas of design, product development, supply chain, launch team and manufacturing. This approach therefore contributes to an increase in quality while at the same time reducing costs, as complex iteration cycles are significantly reduced.

Customer-relevant perceived quality is to be seen as a continuation of the purely functionally emphasised aspects of quality. The perception of quality is usually not a single sensory perception. The perception of quality develops in connection with physiological and psychological processes, on the basis of several linked sensory impressions that involve estimates, previous experiences, expectations, etc.

3.1. Attributes of Customer-relevant Perceived Quality

Customer-relevant perceived quality can basically be divided into technical and design qualities, **Figure 2**. In this project, the focus is on haptics and tactility as well as on visual quality.

3.2 A First Approach towards an Objective Evaluation: The Tactile Reference Frame

An initial approach towards an objectification of customer-relevant perceived quality can be a tactile reference box with surfaces that can be referenced very quickly and without high expenditure. By means of this tactile reference frame, various descriptors can be assigned to surfaces using five or eight reference surfaces, **Figure 3** . The tactile correlation is based on four orthogonal, five tangential and one thermal descriptor. Each of the reference surfaces was evaluated by an expert panel on a scale of 0 to 100.

A surface can be evaluated on the basis of the reference surfaces and then graphically analysed, thus making it possible to move from a purely verbal description to a referencing description. This procedure has the advantage of being fast, simple and economical. Only attribute-based discrete variables that are useful for the pure correlation are available. However, it is not a data-based method.

In research and in practical application, usage restrictions were observed concerning the applicability of the tactile reference box. For instance, a strong co-foundation was determined with other attributes, and the operational usage of the tactile reference frame as a development tool is restricted by material fatigue limits. Therefore, further efforts are necessary in order to obtain durable, repeatable, objective and continuous data.

3.3 Technology for the Measurement of Customer-relevant Perceived Quality

Measurements should also be possible in the vehicle. This allows a flexibility that makes it possible to measure, for example, mechanically linked systems in the vehicle interior, thus permitting a more meaningful analysis of the competition.

The requirements relevant for the project were best implemented in the form of a measuring robot that can measure precise force/travel and torque/angle characteristics and support further sensors in the vehicle interior.

The measuring tasks perceived by the robot, **Figure 4**, can be basically divided into the following categories:

Switch Haptics:
Measurement of the switch haptics on the basis of force and torque characteristics, free-play (wobble), friction, usage stereotypes (for example, usage under different angles) as well as tuning of the switch operation harmony.

– Surface Haptics and Tactility: In principle, the orthogonal parameters such as elasticity, recovery rate, stickiness or the compliance of components can be tested. It is rather complex to measure the tangential parameters such as friction, stick-slip behaviour, roughness and surface topography in such a way that it can be correlated to human perception. While the surface temperature behaviour only marginally depends on the actual component temperature, it often depends on other material parameters that may not be available. Examples are heat conductivity, density and specific thermal capacity.
– Visual quality: Examples are gap dimensions and their course, as well as flushness, gloss, colour or graining. In this case, the robot is used as a highly precise positioning device for supplemental sensors.

3.4 Different Stages of the Implementation

The selected method for the measurement of customer-relevant perceived quality can be performed in three stages:

The first is the determination of the parameters that potentially affect customer-relevant perceived quality. Suitable measuring devices are to be found and applied. This alone already represents a great benefit. For instance, sample and prototype parts can be characterised, perceived quality can be communicated on the basis of data and benchmarking can be improved.

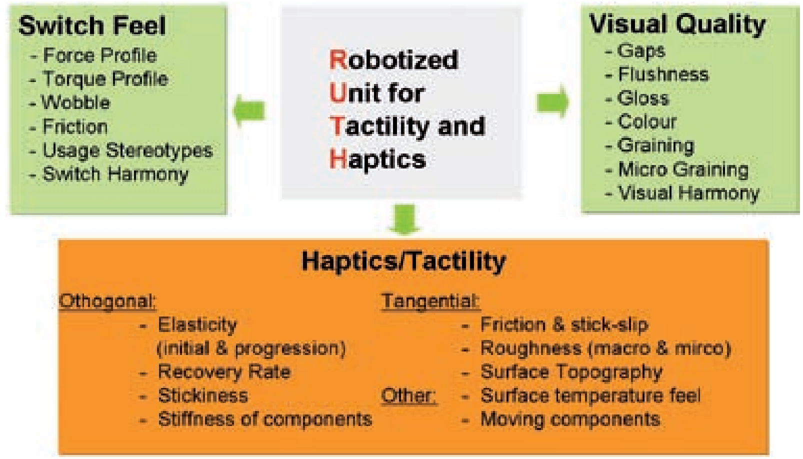

Figure 4: Overview of measuring tasks of the mobile haptics robot

The second step is the link to human perception. What do the data mean from the customer's point of view? The customer data are collected on the basis of internal or external customer opinion surveys or customer satisfaction statistics. A coupling of the two data sets is described in Section 3.5.

The third part is the prediction of customer-relevant perceived quality based

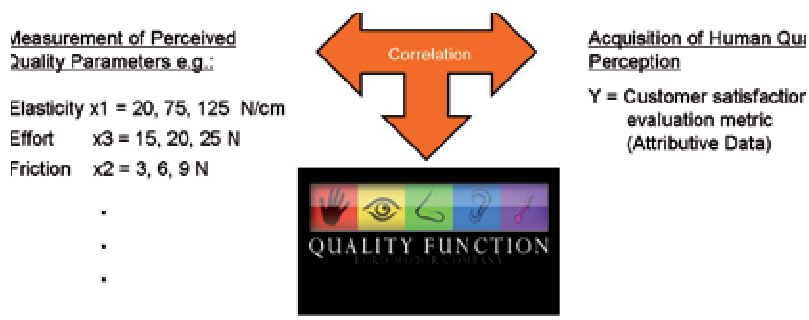

Figure 5: Determination of a quality function

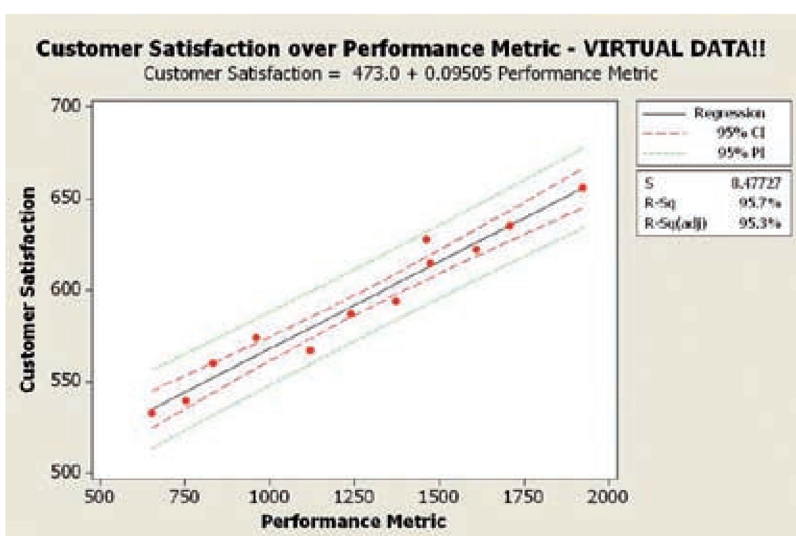

Figure 6: Example of a linear regression

Figure 7: Switch haptics simulator

on data. In this step, a data-based evaluation of the customer's perception of different component groups or certain surface types by means of optimisation algorithms is performed.

3.5 Correlation of the Measurements with the Customer's Evaluation

Usually a quality perception depends on several parameters, as schematically represented in **Figure 5**, on the basis of elasticity, effort and friction. These have to be determined if the component is to be examined.

Parallel to this, customer opinion surveys are carried out to determine the customer's evaluation of the respective component, usually as attributive data.

A correlation of the two data sets then records results in a quality function, in which the customer perception is represented as a function of different parameters.

A possible approach towards determining the quality function is the use of linear regression if a linear correlation is estimated. In most cases, the following intervals are set, **Figure 6**.

- The confidence interval (CI) is the range into which the regression line will fall with a certain probability.
- The prediction interval (PI) is the range into which the measurement values will fall with a certain probability.

The linear correlation was selected in **Figure 7** for better comprehension. Many other correlation functions can also be used depending on the application. For instance, a linear correlation could be assumed within certain limits for the temperature perception. For many other senses, a logarithmic correlation can be assumed, which is also expressed in the law of Weber Fechner:

$$E = c \ln\frac{R}{R_0}$$

E: Stimulus sensation
c: Constant, dependent on stimulus
R: Stimulus
R_0: Integration constant, usually stimulus threshold

Due to the linkage of several measured variables to form a sensory perception, there is a multi-dimensional dependence that needs to be analysed with multi-dimensional functions, so-called response surfaces, or the method of multi-dimensional scaling. Statistics and the methods of experimental design offer valuable assistance.

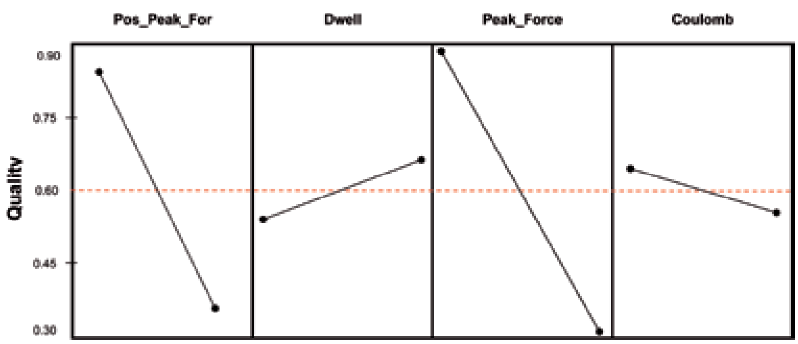

Figure 8: Effect plot switch optimisation

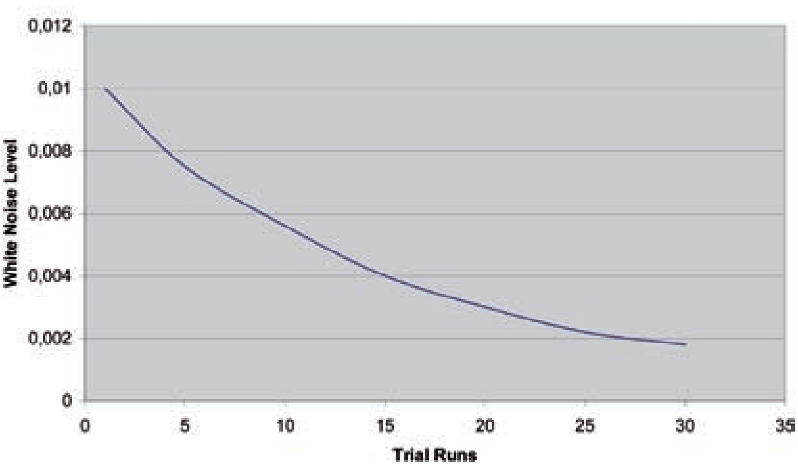

Figure 9: Threshold analysis

4 Haptics Simulation

The simulation of haptics, as developed by the Ford Research and Innovation Center in the USA (RIC), concentrates in particular on the simulation of moving control elements in the vehicle. For example, a switch haptics simulator consisting of a stepper motor and an encoder makes it possible to vary the entire switch haptics in order to develop the parameters correlating to the best possible customer perception.

4.1 Optimisation of a Switch by Means of Simulation

The objective of one study was the optimisation of an intensity switch, for example for volume or temperature. For this purpose, a full-factorial Design of Experiments (DOE) with 4 factors on 2 levels was selected with the following four factors:

1. Position of the peak force (Pos_Peak_For)
2. Dimension of a force plateau in the cam (Dwell)
3. Amount of peak force (Peak Force)
4. Coulomb friction (Coulomb)

As can be seen in **Figure 8**, under the given conditions the magnitude of the peak force and the position of the peak force were judged as significant. A force plateau or also the presence of Coulomb friction was less significant.

4.2 Threshold Value Analysis by Means of Switch Haptics Simulation

A further study within the simulation of switch haptics examined the perception threshold when a grinding signal is added to the initial switch signal. Here we identified the amount of the added signal at the point at which it is no longer perceived by the participants, i.e. a further reduction in the grinding effect no longer yields higher customer satisfaction.

For this purpose, the initial force/travel profile was overlaid with an amount of 1 % white noise, which leaves a strong rubbing and grinding haptic impression. The switch profile was then compared in a randomised manner with the genuine switching profile, and the participant indicated which the switch had the grinding effect. With every two correct estimations, the effect was reduced by 0.1 %. This distinction was very easy at the beginning, but it became increasingly more difficult, so that with each wrong choice a further 0.1 % of roughness was added.

These comparisons were conducted 30 times, **Figure 9**, so that, at the end, the perception threshold value of each participant could be seen. In this investigation, the threshold value was about 0.2 % of the peak switch force. Below this threshold, it was no longer possible to distinguish whether the friction was added or not.

5 Summary and Outlook

Within the project presented here, the customer-relevant perceived quality of vehicle interiors was examined methodically and holistically. This was mainly achieved by the application of a measuring robot that serves as a force/travel measurement device and also an exact carrier of other sensor technologies. The measuring robot was applied both in the laboratory and in the vehicle interior. The results obtained were correlated with the human perception that was gained, for example, from customer surveys, in order to allow an evaluation of the measured data with regard to customer acceptance.

Further work will be concerned mainly with an expansion of the measuring parameters as well as a further increase in the correlation and prediction capabilities. ■

IMPRINT

ATZ WORLDWIDE

www.ATZonline.com

02|2008 · February 2008 · Volume 110
Vieweg Verlag | GWV Fachverlage GmbH
P. O. Box 15 46 · 65173 Wiesbaden · Germany
Abraham-Lincoln-Straße 46 · 65189 Wiesbaden · Germany

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