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Data acquisition for quality loss function modelling

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Abstract

Quality loss functions can be a valuable tool when assessing the impact of variation on product quality. Typically, the input for the quality loss function would be a measure of the varying product performance and the output would be a measure of quality. While the unit of the input is given by the product function in focus, the quality output can be measured and quantified in a number of ways. In this article a structured approach for acquiring stakeholder satisfaction data for use in quality loss function modelling is introduced.

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Keywords: Quality loss functions; data acquisition; modelling

1. Introduction

Quality loss functions (QLFs) are used in many different fields for describing the correlation between quality and its underlying parameters. Inspired by the Taguchi method [1] QLFs have especially found their use in fields such as tolerancing, design optimization, and production economics [2, 3]. However, even though these fields are related and often overlapping many different definitions of quality exists. Many contributions have been proposed to structure and clarify the diversity of the quality term, but little have been written on how the definition of quality influences the use and applicability of QLFs. In this contribution a top level overview of how QLFs can be approached with basis in five different definitions of quality, presented in section 1.1, is proposed.

How to define quality very much depends on the intended use of the QLF. Will the model be used as a visualization tool or will it only serve as an analytical tool? Will it be used for optimizing production economics, user satisfaction, or maybe production time? It is also important to consider the accuracy needed from the model and what parts of the model that is of interest. For instance, we might not be interested in the absolute values of the output, but rather the input values for optima or the relative change in output value as we move away from these optima (sensitivity). These are all important considerations when deciding which definition of quality to use in ones QLF modeling.

1.1. Product Quality

The output of a QLF is a measure of quality. However, many definitions of product quality exist and while some operate on a high abstraction level and could be described as general definitions [4, 5, 6, 7] others specifically targets, for instance, the quality of medical care [8] or education [9]. For the purpose of this article the five definitions of product quality proposed by David A. Garvin [4] in “What does “Product Quality” really mean” will be used to address the broadest and most appropriate quality definitions. As mentioned earlier these definitions were chosen as product quality in particular is the focus of this article, as opposed to process quality or a more general semantic understanding of the term. Also, David A. Garvin approaches the definition on a high abstraction level, which was deemed appropriate for this article. Another obvious choice could have been the Kano model [10], but with a strong focus on product attributes this model could be

said to mainly focus on a product-based quality definition, which is one of the five definitions covered by David A. Garvin's categorization.
All of the five approaches to defining quality proposed by David A. Garvin can be summarized by the following [1]:

1. **The Transcendent Approach**
   Quality is synonymous with "innate excellence". It "cannot be precisely defined, rather, it is a simple, unanalyzable property that we learn to recognize through experience".

2. **The Product-Based Approach**
   Quality is a precise and measurable variable. "Differences in quality reflect differences in the quantity of some ingredient or attribute possessed by the product".

3. **The User-Based Approach**
   Quality "lies in the eyes of the beholder". "Individual consumers are assumed to have different wants or needs, and those goods that best satisfy their preferences are those that they regard as having the highest quality".

4. **The Manufacturing-Based Approach**
   Quality is "conformance to requirements". "Once a design or a specification has been established, any deviation implies a reduction in quality".

5. **The Value-Based Approach**
   A quality product is one that provides performance at an acceptable price or conformance at an acceptable cost.

The above mentioned five quality approaches will form the basis of the discussion on quality and the scales used to evaluate the quality of a product as a function of one or more input variables. The mathematical description of this relationship between input variables and the chosen measure of quality is what we call a quality loss function.

1.2. Quality loss functions

In this article we will use a definition of QLFs as a function that describes the relationship between one or more input variables and a measure of product quality. Here the input variables can be any product function, feature, or attribute, but usually it would be a function, feature, or attribute that is thought to have a decisive impact on the quality, regardless of how quality is defined. The measure of quality depends on the definition of quality, where five alternative approaches to defining quality have been presented in the previous section.

One of the most widespread uses of QLFs was introduced by Genichi Taguchi as a tool for assessing the quality loss incurred by varying product performance from the nominal [11]. As such, the Taguchi definition is mostly based on the Manufacturing-Based quality approach where quality is defined in monetary terms as a measure of the total loss on a societal level originating from non-conformance to requirements. Many generic descriptions have been proposed to describe the form of the Taguchi QLF. Best known is the quadratic model originally proposed by Taguchi for describing minor variation. Since, many different models have been proposed focusing on different quality loss (QL) situations [12, 13].

As an alternative to generic QLFs, a QLF can be derived from any relevant data set. Such models will be referred to as customized QLF models. Looking beyond the Taguchi definition any function describing the relationship between one or more input variables and a measure of quality as the response could be named a QLF. Thus, any data describing such a relationship could be used. However, qualitative data does present some difficulties, especially concerning the continuity of the QLF. For instance, a quantified scale going from 0-100 % satisfaction will have a well understood progression, whereas the significance of each step on a qualitative scale going from very dissatisfied to very satisfied, with the intermediate steps satisfied, dissatisfied, and neutral, would be harder to interpret. That being said, using a qualitative scale can still be a viable way of presenting data. Obtaining data for customized QLF models can be challenging as it requires well defined input variables and a well understood evaluation scale to measure the level of quality. Here Design of Experiment theory presents a suitable way of extracting data while controlling input variables and their potential interactions.

1.3. Design of experiment

Design of experiment (DoE) is an obvious way of acquiring data for customized QLF modelling as it allows for an investigation into specific product functions, features, and attributes [14]. Typically an experiment would test a number of different combinations of input variable levels against a response, in this case a measure of quality. The purpose of such investigations can be many, but the method is usually used for identifying key drivers for a given response, optimizing for a certain variable, or exploring interactions between variables. Selecting the combinations to test can be done in several different ways. First, there is a full factorial experiment where data is collected for each combination of parameters levels. Depending on the case this can be very resource demanding. Thus, alternatives exploring only a subset of the possible combinations have been developed based on statistical analysis. Such alternatives include fractional factorial or orthogonal experimental designs. Typically these alternatives would focus less on the interactions between parameters. A thorough knowledge of the mechanisms and dynamics in play of the system to be tested can therefore be crucial for choosing the right approach.

The use of DoE for exploring how a response variable depends on one or more input variables is well described in the literature within many different fields [15, 16, 17]. However, in most instances both input variables and response variable will be a physically measurable entity. When using DoE for the purpose of customized QLF modelling, the response variable will for some definitions of quality be a subjective matter requiring appropriate studies of the stakeholders determined by the quality definition. Often this would be the user or customer of the product, but other stakeholders could also be relevant, such as technicians or regulatory personnel. This adds another dimension to the experiment as subjective evaluations can be hard to quantify.

1.4. Product evaluation

When evaluating the design of a product, different drivers will influence the result. For some product evaluations the evaluation criteria can be tied to one or more measurable physical characteristics, for instance, the throughput of a pump or the stiffness of a rod. Here the quality of a product is objectively evaluation on basis of a product function, feature, or attribute. This would typically be the case for products that are sold business to business (B2B) or are very practical by nature. On the other hand, some product evaluations will be based on a more subjective basis. Here the drivers will differ from person to person and often be a combination of many different product function, features, or attributes.

One of the most known and used evaluation scales is the Likert scale, which is typically used with qualitative levels, but also exists in a quantitative form. Other scales can be used as long as distinctions are made between qualitative and quantitative measures and the number of, and progression between, steps are carefully considered. Especially for studies that require a high level of validation for data and model, it can be advantageous to use more sophisticated methods such as generalizability theory [18] or item response theory [19], none of which will be described any further in this article.

Depending on the intended use of the QLF the number of steps and whether to use a qualitative or quantitative scale can be adjusted. If the QLF is intended for identifying trends or drivers for product quality a qualitative scale will often be sufficient. However, in situations where the QLF will be used for quantitative optimization a quantitative scale is required. The number of steps to use will determine how accurate differences in quality can be registered. Thus, a higher number of steps will provide more accuracy, but also increase the complexity of the experiment. Especially, for subjective evaluation scales where it is desirable to limit the cognitive processing required for each evaluation.

2. Approaches

With basis in the above consideration an approach for deriving QLFs, given one of the five previously introduced quality definitions, will be presented in the following.

2.1. The transcendent approach

Using the transcendent quality definition quality is perceived as an abstract characteristic of a product that is unmeasurable and only recognized through experience. In later works, such as described by Kelemen in Managing Quality: Managerial and Critical Perspectives [2] additional definitions of quality are introduced differentiating between managerial and critical perspectives. Here the transcendent approach is represented in the critical perspectives group along with the social constructivist approach, the discursive approach, and the slogan approach (not included in this article as they tend to move away from the product quality focus). All these approaches differentiate from the four remaining approaches described by Kelemen, referred to as the managerial perspective, and describes quality as “a political, cultural and social process rather than a technical, operational issue”. Thus, the transcendent approach for deriving QLFs rely on a subjective evaluation of the product and the product’s level of quality. This approach is especially meaningful for a product where quality is considered a part of its “DNA” or where an emotional experience is connected to the product, as often seen in advertisement.

While one might be able to find data on quality perception on other similar products it is very hard to determine what product characteristics that drive the quality perception and therefore it can be hard to determine whether non-specific data for the product and the customer group will be applicable. Consequently, a customized QLF modelling approach should be used.

Using DoE for acquiring data for modelling the QLF requires the use of an evaluation scale and one or more input variables. Input variables could be any variable of interest. For the transcendent approach the evaluation scale will refer directly to the perceived quality of the product as defined by the transcendent approach. Using a five step Likert scale such steps could be “Very low quality”, “Low quality”, “Neutral”, “High quality”, and “Very high quality”, where quality is defined as an innate product excellence.

2.2. The product-based approach

According to the product-based approach quality is determined by a specific quality attribute (variable) and can be measured simply by measuring the variable. Thus, the evaluation of product quality can be performed on an objective level based on physical measurements. The product-based approach would typically be relevant when few performance characteristics determine the users or customers perception of the product. For instance, this could be motor parts sold to car manufacturers where the product solely contributes to the functionality of another system. It could also be products fulfilling a simple purpose for the user, such as light bulbs, where relatively few quantifiable product characteristics determine the attractiveness of the product compared to its competitors. For this example it would be life time and energy efficiency, assuming lumen and color temperature is the same. The goal here is simply to maximize

the “strength” of the product function, feature, or attribute that control the quality. Other products where a good user experience rely on multiple factors that are hard to determine the product-based approach can be misleading if used for predicting the saleability of the product. Using the light bulb example a producer might assume that all users want as many lumen as possible, which almost certainly will not be a correct assumption for all users. Therefore, the approach should be limited to products where an acceptable majority of the users can agree on the traits controlling the product quality.
Using the product-based approach a QLF would typically describe the relation between a product function, feature or attribute and one of the variables controlling it.
As product quality equals the “strength” of an input variable the input variable in focus will determine the scale on which the quality of the product is evaluated. If more input variables control the product quality they can be summarized in a single scale with weightings for each input variable, resulting in an abstract product-based quality scale. In some instances this relationship, described by the QLF, can be derived analytically using established physics. In other instances a customized DoE will be required to accurately estimate the QLF.

2.3. The user-based approach

Here the user is the final judge when it comes to product quality. Inherently the approach relies on a subjective evaluation and generalizations will rarely be applicable. In many ways the approach is similar to that of the transcendent approach only the evaluation scale will differ in that the user-based approach investigates user satisfaction rather than perceived quality. This approach is closely related to the saleability of the product and is therefore appropriate for predicting saleability, which is often the purpose of measuring quality. Compared to the product-based approach it is often a bit more demanding as user testing is required. This typically introduces some expenses and uncertainty to the result. Again, using a five step Likert scale such steps could be “Very dissatisfied”, “Dissatisfied”, “Neutral”, “Satisfied”, and “Very satisfied”. Depending on the intended use of the QLF the number of steps and whether to use a qualitative or quantitative scale can be adjusted. In Loss Functions Used in Quality Theory by Tarcolea and Paris 2011 [12] a number of different models are proposed for describing quality loss data.

2.4. The manufacturing-based approach

According to the manufacturing-based approach a quality product is a product with conformance to product requirements. Consequently, nonconformance to requirements leads to quality loss. The reasons for nonconformance can be many but will not be further addressed in this article. This approach is known from the Taguchi theory where the input variable typically would be the performance of a product function and the response variable will be a measure of quality loss in monetary terms. Many generalized models exist for describing the relationship between varying functional performance and quality loss, for instance described by Joseph 2004 [13] or for multiple input variables described by Szonyi and Hawkins 1997 [20].

2.5. The value-based approach

The value-based approach adds another dimension to the product evaluation as price is introduced. The definition of quality to use can vary. As the approach has a strong focus on product saleability it goes very well with the user-based product quality definition. Consequently, quality is here a compromise between price and user satisfaction. Both the user-based quality definition and the price-compromise are subjective evaluations and the resulting scale will be an abstract quality scale representing the compromise between user satisfaction and price. If asked to judge whether a product is a quality (user-based definition) product for the price it will most likely not be a simple matter of dividing the user satisfaction score with the price as the weighting of each parameter might be different and change throughout their respective scale.

2.6. Comparison of the approaches

The five approaches described in the above each represent a certain view on quality and value. What constitutes a meaningful definition of quality heavily depends on the context and the stakeholder. For a production engineer it might be meaningful to define quality from the manufacturing-based approach, whereas a usability expert might prefer the user-based approach. Differences in quality definitions can often cause misunderstandings why it is important to recognize these differences and clarify one’s point of reference. In Table 1 some of the main differences between the approaches when deriving QLFs are shown.

Table 1: Table 1: Overview of differences between approaches. Top row states the quality approach, second row the objectivity of the evaluation scale, the third row the specific scale to be used, and the fourth if customized or generic models are typically used

Quality Approach	**Transcendent**	**Product**	**User**	**Manufacturing**	**Value**
Eval. Scale perspective	Subjective	Objective	Subjective	Objective	Subjective
Eval. Scale type	Innate excellence	Quality driver	Customer satisfaction	Monetary	Performance for price
Type of QLF	Customized	Customized	Customized	General	Customized

As seen in Table 1 the transcendent-, user-based, and value-based approach relies on a subjective evaluation scale, whereas the product-based and manufacturing-based approach relies on an objective scale. The specific evaluation scales used differ for each of the approaches, but some are closely related. The approaches relying on subjective evaluation scales all refer back to users or other stakeholders. Descriptions of the evaluation scales can be found in sections 2.1 to 2.5. Lastly, whether to use customized or generic models for deriving the QLF are shown, which is also slightly elaborated on in sections 2.1 to 2.5.

Another important aspect of the differences between approaches is the availability of information. In Figure 1 an overview of the sources of information for each approach is shown.

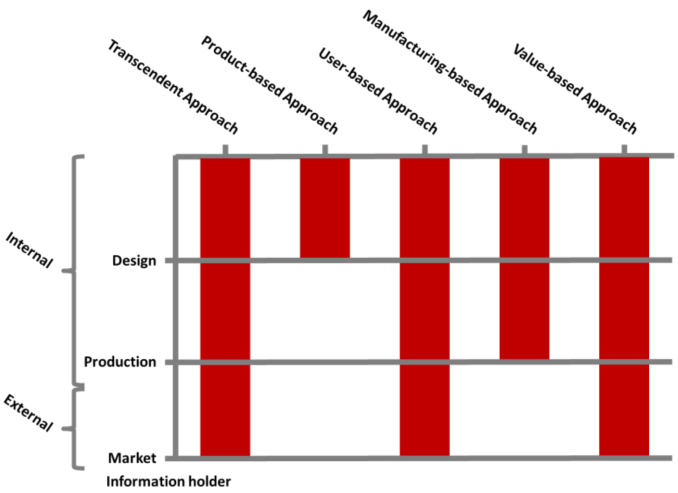

Figure 1: Source of information for the evaluation scale for each of the five approaches.

The second column of Figure 1 shows that the product-based approach requires design information. That is, information that can be measured from the product. Sometimes this can be done analytically or by computer simulations, other times it will require an experimental approach. In all cases the information is objective and will therefore require less data to produce statistical significant QLFs than had it been subjective. Column four shows that the manufacturing-based approach requires information from the production. That is, information that can relate actual performance with specifications. Again the information is objective making measurements easier. The remaining approaches, the transcendent-, the user-based, and the value-based approach all rely on information coming from stakeholders externally of the company. Furthermore, the information is subjective and will thus require the design of human studies, which is typically more resource demanding than physical measurements.

3. Discussion

The five quality approaches presented by David A Garvin has formed the basis for this overview. Many other quality definitions exist and could have been used. However, as the focus of this article is on product quality rather than quality in general it has been the impression of the authors that the chosen approaches were an appropriate fit.

Often a company's interest in measuring the quality, or quality loss, associated with changes in the design is directly related to the profitability of the product or the company as a whole. On short term the focus would typically be on the saleability of a specific product and on a longer term it could be about the brand and overall perception of the company and its products. With basis in the assumption that this is the motive for companies to measure product quality it is obvious that the satisfaction of the customers is a good indicator of the saleability of the product. Thus, the user-based and value-based approach would be the most effective approaches. If the company is more interested in improving its brand moving towards a luxury or high-end product the transcendent approach is the more appropriate. However, as mentioned earlier, user evaluations can be very resource- and time demanding. Therefore, objective and internal quality approaches can be beneficial. Here, the product-based and the manufacturing-based approach are two alternatives that do not require any user evaluations. Being able to measure directly on the nominal design or the produced parts or products, are in many ways more practical, which is why such approaches usually are used in quality control. However, under the assumption that quality somehow relates to the profitability or saleability of the product another assumption applies for these objective approaches. Namely, that whatever product functions, features, or attributes that have been identified as quality drivers are in fact the real drivers of quality. Often the situation is more complex as interactions between functions, features, and attributes apply and little changes in the design can have a big impact on the accuracy of such assumptions. Therefore, the applicability of the objective approaches heavily depends on the product in question, but in cases where they are applicable they can be an easy way of reducing the resources going into predicting quality loss.

For the acquisition of data for customized QLFs, the use of DoE has been proposed. DoE allows for an exploration into the impact of each included input variable on the response variable, which in this case is the defined quality. As the purpose of a QLF is exactly to determine the relationship between quality loss and one or more input variables, the use of DoE fits well.

4. Conclusion

Quality is a concept that is hard to accurately define. This is evident not only from the many definitions that exist, but also from the everyday use of the term where it is used interchangeably to describe many different things, some of which have been captured by the literature. As companies have come to learn that quality is central for a successful business, being able to produce quality products has become a major priority. Thus, a demand for means of measuring and monitoring quality of products has emerged.

QLFs are a great tool for describing the relationship and translation between product quality and underlying variables. With basis in the five different product quality definitions introduced by David A. Garvin an overall approach for deriving QLFs has been provided in this article. The work only describes a top level approach based on logical and practical considerations, with little detail on the technical aspects.

Future work will address the technical aspects and include a step-by-step guide for designing DoE studies, fitting QLF models, and putting these models to use. Preferably supported by case studies to help identify appropriate approaches for given products and companies.

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