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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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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

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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