CHAPTER 1. INTRODUCTION

1.1 Motivation

Craftsmanship is what makes a product have the immediate appeal of being well made and well functioning at its very early interactions with the customer. Although several approaches exist that focus on customer preferences and aesthetic issues, e.g. Quality Function Deployment (QFD) and Kansei Engineering, which became very popular in Japan, none of these methods is able to integrate customer preferences and engineering decisions in an analytical way. The objective of this thesis is to extend the understanding of the craftsmanship concept, so that it can be quantified and included in the product development and decision making stages from the design, engineering and manufacturing points of view. The analyses that were performed are intended to result in tools that assist both engineers and designers in the design process.

At the business level one can ask the question of how a vehicle will get high scores on the JD Power ratings. But simply relying on these ratings is not necessarily a good strategy. A better long-term strategy is to understand the causality of attributes and their interactions that result in high ratings. Therefore, the strategy in this research was to look at preference data and try to uncover the underlying dimensions of people's craftsmanship perception.

There is both empirical and theoretical evidence suggesting that a certain number of contributing elements can create a positive or negative attitude, which sets in and "tips the balance" even if other attributes point to the opposite direction. Along this observation the approach of this thesis was to develop a methodology that allows incorporating relative importance weights of attributes in the design decisions.

The starting point of this work was a checklist of craftsmanship attributes (along with their explanations) for vehicle interiors created by Thomas J. Aitken of JCI in 1999. JCI has been using this list to evaluate vehicle interior designs and to develop a craftsmanship index. The craftsmanship index is a scoring system that allows comparison between different interior designs.

Two possible issues with JCI's existing craftsmanship checklist and index include the importance assigned to each craftsmanship attribute, and the variety of implications the list may have to users from different disciplines. Concerning the first issue, equal weights is likely not a good way to evaluate interiors as a result of the fact that attributes may have different magnitudes of importance for different customers. As far as the second issue is concerned, since engineers and designers are working together as a team to satisfy customer needs and preferences, any ambiguity about the checklist may cause serious communication problems and result in inferior or delayed design decisions. It is important to note here that the JCI craftsmanship checklist was intended for use by designers and engineers only. However, the goal of the present study is to look at customer perceptions and preferences at large.

The following subsections summarize the problem definition, the objectives and the work performed for the thesis as well as the literature about craftsmanship and customer preferences in engineering design. Since the JCI craftsmanship approach is proprietary, the exposition is made so as to respect this requirement.

1.2 Problem definition

The goal of this section is to provide a deeper understanding of the craftsmanship concept. A selection of craftsmanship considerations will be discussed on examples.

As defined in the previous section, craftsmanship is what makes a product have the immediate appeal of being well made and well functioning at its early interactions with the customer. Here, the keyword is “at its early interactions with the customer”, which is the major difference between quality and craftsmanship perception. In other words, craftsmanship can be described as the “perceived quality” early in the interaction.

EXAMPLE 1

Figure 1 shows two samples of 2nd row seats. In the sample on the left, misaligned sew lines and poor fitting components can be seen in the opening of the arm rest, whereas the components of the sample on the right are aligned in all aspects. Also, on the sample on the left, vinyl and leather have very different heat reflections and gloss, whereas on the sample on the right it is difficult to tell vinyl and leather apart.

Figure 1: Craftsmanship considerations – example 1

EXAMPLE 2

Figure 2 shows two samples of the back of the 1st row seats. In the sample on the left, the wires can easily interfere with the rear passenger’s feet, whereas the sample on the right demonstrates clean interface. Also, it is not desirable that wires and mechanical elements can be seen as it is the case in the first sample.

Figure 2: Craftsmanship considerations - example 2

<u>EXAMPLE 3</u>

Figure 3 provides a good example of shape harmony consideration. The design on the left carries out the trapezoid theme successfully on the airbag cover, vents, the wood door bezel and the radio, whereas the design on the right shows no sign of shape or color harmony.

Figure 3: Craftsmanship considerations - example 3

<u>EXAMPLE 4</u>

The steering wheel in Figure 4 demonstrates poor control of gaps, parting lines and grain harmony.

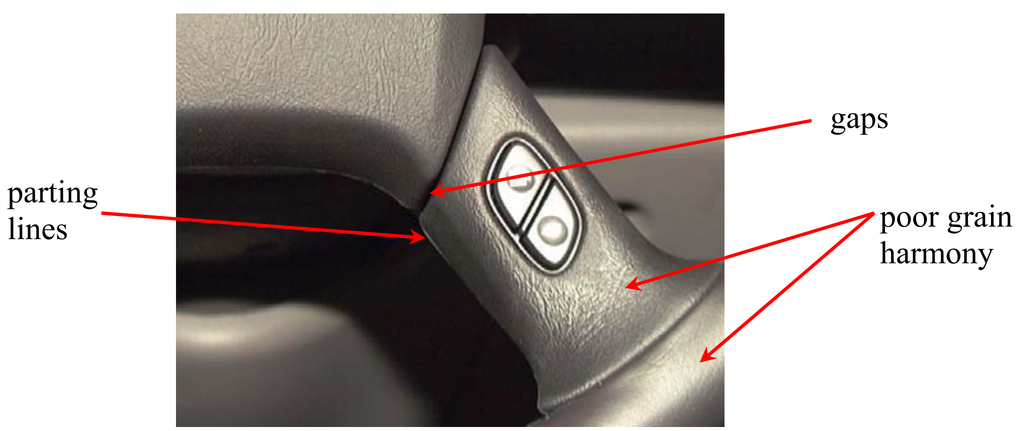

Figure 4: Craftsmanship considerations - example 4

EXAMPLE 5

The first sample in Figure 5 is an example of a poor sew control. The second sample has several screws holes randomly placed on the surface.

Figure 5: Craftsmanship considerations - example 5

Other examples for desirable features of a vehicle interior design include smooth and quiet mechanisms, solid sounding panels, low effort switches, pleasing feel of textures, easy-to-reach components and readable labels.

1.3 Objectives

The objectives of this thesis can be summarized as follows:

1. To define a set of criteria that reflects the craftsmanship issues of a vehicle interior design in a way that is as "quantifiable" as possible for engineering and design purposes, but also suitable for data collection purposes.
2. To model customer perceptions of craftsmanship in terms of variables that can be manipulated by engineers and designers.
3. To develop a mathematical tool that helps to uncover relative contributions of craftsmanship attributes to the overall craftsmanship perception of a product.

1.4 Thesis outline

THE QUANTIFICATION OF CRAFTSMANHIP

The process of quantifying craftsmanship began with modifying the existing checklist. This involved extensive reference to the attribute explanations provided by Thomas J. Aitken, as well as the JD Power vehicle quality survey. The initial step was to express as many of the craftsmanship attributes as possible in terms of measurable quantities. In order to do this, some attributes from the original list produced by JCI were divided into smaller, more specific ones to make them more quantifiable. With these changes a new terminology has been proposed, making a distinction between "product characteristics" and "perceived attributes". Everything that can be directly measured and manipulated is called a product characteristic, whereas a perceived attribute is a more general concept resulting from two or more product characteristics.

The second part of the quantification included the development of a craftsmanship index that allows for a numeric comparison of different interior designs. The original index is a scoring system where interiors are measured by assessing the scores of the attributes from the checklist, then adding them up and taking the average. In this way the relative importance weights of all attributes is assumed to be equal. The modified approach allows for the specification of different magnitudes of importance to be given to the perceived attributes. In this way it can be taken into account that some of the attributes may be more important than others for customers. The given scores can then be multiplied by the corresponding weights to give an overall score for craftsmanship.

THE NEW MATRIX FORM OF THE CRAFTSMANSHIP CHECKLIST

The next step was to examine the interactions between the product characteristics and the perceived attributes, and create a functional dependence table (FDT). Having an FDT allows for easy visualization of the implications of changing product characteristics in a decision making process. Another use of the FDT is to partition the craftsmanship problem into smaller subproblems. Once engineering decisions are made concerning the variables that link the subproblems, each problem becomes independent and can be handled separately.

From the FDT created using the craftsmanship checklist, partitioning produced two primary subproblems, each with two secondary subproblems. The first part of the first problem contains all the visual, auditory and tactile perceptions of craftsmanship. Although the secondary part contains visual elements as well, they are mostly pure quality issues. The first part of the second subproblem concerns overall comfort, and the usability items belong to the second part.

STUDYING THE ATTRIBUTES OF CRAFTSMANSHIP

In the earlier stages of the research the existing checklist was studied in depth. In order to investigate the completeness and efficiency of the list, a pilot survey was designed and run with five subjects. The goal was to answer the following questions:

- Are the interpretations of the attributes consistent among people?
- Does the checklist cover everything that contributes to people’s perception of craftsmanship?
- What are the underlying dimensions of the craftsmanship concept?

Three different analyses were used to test the reliability of the original craftsmanship index. These three were correlation, multidimensional scaling and cluster analysis.

The first analysis, correlation (in this case, gamma), assessed the agreement between individuals using the checklist. A reliable rating index is one that yields near perfect ordinal consistency across two raters. The initial results were not promising; they suggested that there was little agreement between two raters judging the same vehicle. In fact, the gammas were all near 0, suggesting no concordance between raters. Though disappointing, this indicated the need to develop a modified index of craftsmanship.

Next, a multidimensional scaling analysis (MDS) was applied to the data to provide a multidimensional representation of the attributes in the space of craftsmanship. Instead of using commercial software, a Matlab program was written in order to have full control over the algorithm. In addition, this allows for the flexibility to link the software with several optimization algorithms if needed. The MDS analysis was conducted for cases of two to six dimensions. The goal was to be able to label the axes of the MDS representation so that the craftsmanship problem could be reduced from a long list of attributes to a few more general ones. None of these dimensionalities, however, was able to return a meaningful MDS-space. For 2 and 3 dimensions the algorithm did not converge. For 4, 5 and 6 dimensions the data was extremely noisy, such that it was impossible to interpret the results. The conclusions suggest that the attributes are too ambiguous to span a multidimensional space.

Another attempt at simplifying the problem was done by applying cluster analysis to the dissimilarity data. The purpose of the cluster analysis was to join characteristics into successively larger clusters, using some measure of distance. Cluster members share certain properties, and it was hoped that the resultant classification would provide some insight into the whole problem by reducing the dimensionality of the data set. Unfortunately, applying cluster analysis to the data set did not result in meaningful clusters; attributes grouped together did not always share implicit or explicit properties. Although some of the lower level clusters were meaningful, higher level clusters were essentially impossible to interpret. Again, this indicated too much noise in the data.

TESTING THE NEW LIST OF CRAFTSMANSHIP ATTRIBUTES

The next step was to assess the new craftsmanship checklist in terms of consistency among people. Therefore, a second survey was conducted using the new list of perceived attributes. Same set of analyses (Correlation, MDS and Cluster analysis) were carried out with the collected data. The results showed that the new version of the craftsmanship checklist performs much better compared to the old one in terms of agreement among people. The cluster analysis produced four meaningful clusters including the auditory attributes, quality issues, driving comfort attributes and usability items. These clusters were also identifiable in the 2-dimensional MDS space spanning a dimension from "sensory requirements" to "functional requirements", and another dimension from "overall comfort" (physical and psychological) to "overall quality" (design and manufacturing).

DEVELOPING A CRAFTSMANSHIP INDEX

Having completed the craftsmanship checklist, now the following question arose: Given a number of attributes, how do we determine their relative importance, or their contribution to the perception of craftsmanship? Namely, how do we choose weights of each attribute to establish the overall craftsmanship score? A method that employs product ratings along attributes and overall preference rankings is proposed to compute the weights. To test the method, an algorithm was written in Matlab, and simulations were run that show that the method produces acceptable ranges of attribute importance weights. Also, effects of increasing the number of attributes and products on the efficiency of the results were shown.

Choosing attribute weights requires a multistage study of real profile data. Once weights are assigned to the attributes, it will be possible to make engineering decisions on the relevant product characteristics that will increase the craftsmanship index of an interior. Keeping this in mind, the developed algorithm was run with the available data sets. Since the number of attributes was too large to return meaningful results, an attempt was made to compute relative importance weights for the four clusters that resulted from the cluster analysis. Since no data was available about the cluster ratings and rankings, it was not possible to get more accurate results. For future studies a two-staged approach is proposed to overcome this problem.

OUTLINE OF CHAPTERS

Chapter 2 is about studying the attributes of craftsmanship. It describes the pilot survey and the analysis results. Chapter 3 discusses the attempts to quantify the craftsmanship problem. In Chapter 4, the new matrix form of the craftsmanship checklist is described. Chapter 5 discusses the second survey results. In Chapter 6, an attempt to compute relative importance weights of attributes in order to develop a craftsmanship index is described.

1.5 Literature review

Craftsmanship is defined as the technique, style, and quality of working (Roget's II). The idea of craftsmanship is creating products that are skillfully created, lasting in nature and possessing a timeless elegance. Attention to detail, material selection, careful workmanship and innovative product design are all key components of craftsmanship (Wang and Holden, 2000).

Several studies show that craftsmanship plays an important role in today's consumer perception on product quality (Sherman, 1989; Winter, 1997, Ganguli et al., 2003). Today's consumer, having become more sophisticated during the technical age, is changing manufacturers' attitudes towards the satisfaction of customer preferences. Customer preferences also became a trend in the engineering literature. The literature about customer preferences includes techniques like Quality Function Deployment (QFD), Kansei engineering, multidimensional and conjoint analyses of consumer data. This section reviews highlights from the customer satisfaction literature.

AESTHETICS

Liu (2000) states that human factors researchers and practitioners have been focusing research attention on the ease-of-use, productivity, safety, comfort and effectiveness aspects of product and system design. He points out the need of adding aesthetics as another important dimension to the field of human factors research and practice. He also recognizes the lack of systematic, scientific and engineering methods to help designers make aesthetic design decisions and conduct aesthetic evaluations. He proposes the establishment of a new scientific and engineering discipline called "engineering aesthetics" that addresses the issue of using mathematical, engineering and scientific methods to study aesthetic concepts and incorporate them in design decisions.

MacDonald (2001) discusses the concept of "aesthetic intelligence", which acknowledges that we possess an innate, sometimes subconscious, ability to perceive a wide range of qualities in products that shape our responses to them. He argues that these qualities can be purposefully discussed and attempts to provide, for engineering designers, a way of structuring the complex field of aesthetic response. He links sensorial qualities to cultural values and proposes a process of designing for the senses as a means to providing products with which customers can feel a greater degree of empathy.

Yoshimura and Horie (2001) proposed the use of evaluation maps to include aesthetic factors in the design of machine systems. As a case study they used the design of a service robot. They also focus on the tradeoff between aesthetics and cost.

A similar study (Yoshimura and Yanagi, 2001) discusses the relationships between aesthetic and objective product attributes and product cost.

These ideas about aesthetics' perception are very close to those where the craftsmanship concept derives from. As previously stated in the definition of craftsmanship, "elegance" is deeply involved in craftsmanship along with other quality measures.

QUALITY FUNCTION DEPLOYMENT

QFD is a four-stage process to design products that optimally meet customer needs. In the first stage the House of Quality converts each customer need into one or more design-independent and measurable engineering characteristics. After determining the relationship between engineering characteristics and customer needs, a target value is set for each engineering characteristic that maximizes the extent to which that product would satisfy all important customer needs. In the second stage of QFD, Parts Deployment, engineering characteristics target values from the House of Quality are translated into components, part characteristics or design features. Here, parts are designed or features are specified that will meet engineering characteristic targets. Similar to the first phase, design features are related to engineering characteristics and design feature target values are chosen. The third stage, Process Planning, designs a production process that can manufacture the design features, parts, or components from the second phase. The final phase, Production Planning, translates the key manufacturing processes into work instructions, control and reaction plans, and training necessary to ensure the quality of key parts and processes (Pullman et al., 2002).

Vairaktarakis (1999) used the House of Quality to develop and solve optimization models for the identification of consensus rankings and ratings that take into account the priorities and perceptions of all the customers in a target market. Then, based on the consensus rankings, a parts mix for the new/improved product was identified that satisfies a budget constraint and matches or exceeds the performance expectations of all customers surveyed in the target market.

A similar approach was proposed by Askin and Dawson (2000). They employed the HOQ and developed a mathematical programming model for determining the optimal settings for engineering characteristics based on value functions constructed to capture customer preferences while accounting for the impact of costs and technological constraints when designing products.

Yang et al. (2003) proposed a QFD-based optimization method to reflect customer's preferences in making a trade-off between multiple objectives. The optimization problem they pose is to maximize the overall customer satisfaction level that is a weighted sum of individual customer satisfaction levels of each customer need. This method is limited, however, since all customers' needs are reflected into a design by only optimizing geometrical dimensions.

MULTIDIMENSIONAL SCALING

In psychology, MDS is used to discover psychological dimensions that would meaningfully explain the data that is based on direct (dis)similarity judgments of stimuli by the respondents (Borg and Groenen, 1997). For design purposes, MDS is used as a tool to construct the perceptual space of products, the dimensions of which characterize people's perception of the products.

Kleiss and Enke (1999) conducted an MDS study to identify the visual appearance attributes of automotive audio systems that impact qualitative response to products. They found that 3-D shape, visual complexity and cost/quality are visual appearance attributes that contribute separately to the perception of stylish appearance.

Chuang and Ma (2001) found that the five most expected images perceived in micro-electronic products are high-technology, efficiency, lightness/handiness, nobility and delicacy. Then they revealed subjects' perception of these images for the evaluated products and derived a perceptual map for these products.

Yannou and Petiot (2002) proposed to use four design spaces ("stakeholders' needs space", "perceptual space", "functional space" and "physical space") that allow consideration of four design process types ("unstructured design", "perceptual design", "functional design" and "complete conceptual design"). To define the perceptual space of a given set of similar existing products, they suggest using the MDS technique.

Other applications of MDS in the design and engineering literature include the conceptual modeling of sitting comfort (Zhang et al., 1996), quantifying the degree of fitting of plastic parts judged by touch (Kamoshita and Yano, 1984), identifying features of texture perception (Rao and Lohse, 1993) and color patterns (Mojsilovic et al., 2000), defining relationships between product shapes and abstract image words (Hsiao and Wang, 1998), studying product semantics (Lin et al., 1996) and modeling perceptions of products in the market (Hooley, 1984).

Multidimensional scaling is used in this study as a tool to model customers' perception of craftsmanship attributes.

CONJOINT ANALYSIS

Marketers use conjoint analysis to determine the most desired level of each feature included in the study. Choice simulators allow designers to explore the impact of different design decisions on sales, profits, and cannibalization. Conjoint analysis decomposes overall measures of preference for hypothetical objects into the utility associated with different features or attribute levels making up that object. Conjoint choice simulators use these individual level utilities along with descriptions of potential competitive products to estimate market shares for possible new product designs (Pullman et al., 2002).

A review article, Green and Srinivasan (1990) state that the purpose of conjoint analysis is to predict customer reactions to new products and services. They also point that full-profile method conjoint analysis works better for six or fewer attributes. They provide a summary of recent developments in conjoint analysis including approaches to handle large numbers of attributes.

KANSEI ENGINEERING

Kansei Engineering was founded by M. Nagamachi at Hiroshima University about 30 years ago. Kansei is the Japanese word for feeling. Nagamachi (1999) defines Kansei Engineering as a powerful ergonomic consumer-oriented technology that translates customers' feelings (kansei) about a product into design elements. Kansei Engineering has been applied to the design of automobiles, construction machines, home electric appliances, housing and costumes in studies conducted in Japan, Korea, England, Sweden and Netherlands.

The standard procedure of Kansei engineering involves: (1) Selection of adjective words for expressing Kansei on the products, (2) Evaluation of the product samples using a semantic differential (SD) method scale questionnaire, (3) Multivariate analysis of evaluation data, (4) Development of Kansei engineering expert systems. Obtained relations among components' design, features and semantic structure are built into inference rules (Ishihara et al., 1997).

Kobayashi and Ota (2000) developed a Kansei dictionary system of more than 800 Kansei words applicable to the semantic network by making use of the similarity of each word. This dictionary system can construct the numerical values of Kansei words that are quite ambiguous.

Hsu et al. (2000) conducted a study to investigate the differences in the product form perception of designers and users. Using the semantic differential (SD) method they determined the relationship between the subjects' evaluation of different telephone designs and form characteristics of these designs. They performed multivariate analyses to analyze subjects' perception and to build conceptual models for telephone design. They found that many differences exist between designers and users in their perceptions of the same objects and their interpretations of the same image-words.

Tsuchiya et al. (1999) proposed a method for learning Kansei reasoning rules with application to canned coffee design. They obtained Kansei evaluation data through experiments with canned coffee and analyzed the data using genetic algorithms (GA). This method extracts Kansei rules to represent the relationship between design elements of canned coffee and its Kansei.

Jindo and Hirasago (1997) studied the styling and design specifications of passenger car interiors as a Kansei engineering application. They focused on the styling of the speedometer and the steering wheel of a passenger car. They collected subjective evaluations using semantic differential methods and analyzed those using multivariate analyses. The results showed the relationship between the impressions and characteristics of styling that help to understand the conditions which create a desired impression. Their study is relevant to this work as far as shapes and styling goes, but other aspects of craftsmanship is out of their focus.

Tanoue et al. (1997) explored roominess and oppressiveness of a vehicle interior using Kansei engineering. They revealed that color and shape play an important role on those perceptions. They also analyzed the interior dimensions and proposed optimum dimensional ranges for roominess and oppressiveness.

OTHER

Ludvigsen (1995) provides a very nice review of the development in car comfort and convenience over 100 years.

Toms et al. (2001) used the cluster analysis technique to support menu interface design for in-vehicle multimedia applications. They suggest this as a tool to construct an intuitive menu interface that supports the driver's expectation as to where to find a particular function without roaming the interface.

Wang and Holden (2000) studied the craftsmanship issue in automotive products and proposed a methodology for craftsmanship assessment. They followed a very similar approach to the issue of craftsmanship as in this work, however, they didn't use any perceptual modeling techniques that this study employs. They developed a computer-based system where the user enters the product information, selects the system (exterior or interior) and the subsystem (instrument panel, steering wheel/column, etc.) and fills out the evaluation form which includes selecting the metric (attribute), its priority (importance), its rating (excellent, average, etc.) and remarks (if any) about each item (component) of the subsystem. When the assessment is finished, the software processes the data and obtains the overall craftsmanship rating for the product. They examined the influence of consumers' demographic background on their craftsmanship assessment and found that gender, age and education were not significant factors impacting the craftsmanship assessment.

The next chapter describes the pilot survey followed by the data analyses and results.