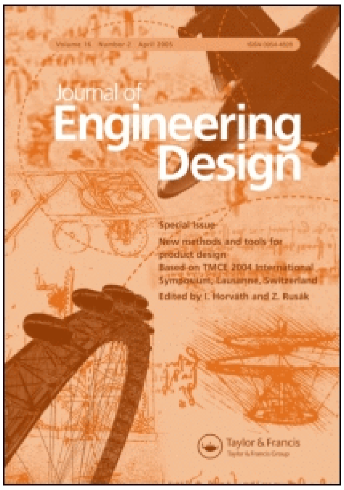


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# Modelling perceptions of craftsmanship in vehicle interior design

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In the automobile industry, one approach for assessing craftsmanship is to have experienced designers evaluate the craftsmanship of a vehicle interior on a set of vehicle craftsmanship characteristics. This article extends one industry approach by evaluating vehicle interior craftsmanship in a quantitative manner. Study 1 presents data suggesting that an existing craftsmanship scale does not lead to acceptable levels of consensus across evaluators nor to interpretable clusters or dimensional spaces after data reduction. A new list of interior characteristics and perceived attributes of craftsmanship is developed and analysed using a functional dependence table (FDT). Study 2 uses the new list of perceived attributes and shows there is an improved degree of consensus across evaluators, meaningful clusters and spatial arrangements emerge using cluster analysis and multidimensional scaling, and the clusters from the evaluators' data are consistent with the subproblems that emerged from the FDT of product attributes and characteristics. The paper demonstrates that engineering designers can use this approach to guide their work about perceived craftsmanship. One benefit of the proposed method is that engineering designers can work at the level of perceived product attributes (the same attributes potentially observed by the consumer) and map those attributes to engineering characteristics.

**Keywords:** craftsmanship; customer perceptions; agreement measures; multidimensional scaling; cluster analysis; vehicle interior design

## 1. Introduction

Craftsmanship is the perception of quality experienced by a customer; it is based on sensory interaction and emotional impact (Turley *et al*. 2007). Craftsmanship is a property that gives the product the appeal of being well made and well functioning at its very early interaction with the customer. In the automotive industry, craftsmanship is often associated with high scores on the Automotive Performance Execution and Layout (APEAL) Study conducted by JD Power and Associates (APEAL 2008). APEAL complements the JD Power and Associates Initial Quality Study[SM], which focuses on problems experienced by owners during the first 90 days of ownership. It examines how gratifying a new vehicle is to own and drive, based on owner evaluations

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on 10 measures, encompassing more than 90 vehicle attributes. However, it is not obvious how design engineers can make design decisions based on these ratings and predict increases in subsequent ratings as a function of design changes. To the extent possible, craftsmanship should be linked to discernible design attributes in the form of a quantitative functional model, and attribute interactions should be included in the model.

Craftsmanship evaluation is based on impressions. Complex human feelings and thoughts play a major role in forming impressions, and thus much will remain outside our ability to formalise and quantify craftsmanship. Nevertheless, analysing and organising user preferences employing methods from quantitative psychology in a manner that design engineers can use is worthwhile and is the main focus of this article.

The concept of craftsmanship is broad and includes attention to detail, material selection, careful workmanship and innovative product design (Wang and Holden 2000). Several studies have shown that craftsmanship plays an important role in consumer perception of quality (Sherman 1989, Winter 1997, Ganguli *et al*. 2003). The literature on customer preferences and perceptions includes studies that employ quality function deployment (Vairaktarakis 1999, Askin and Dawson 2000, Yang *et al*. 2003), kansei engineering (Ishihara *et al.* 1997, Jindo and Hirasago 1997, Tanoue *et al*. 1997, Nagamachi 1999, Tsuchiya *et al*. 1999, Hsu *et al*. 2000, Kobayashi and Ota 2000), multidimensional scaling (MDS) (Hooley 1984, Kamoshita and Yano 1984, Rao and Lohse 1993, Lin *et al*. 1996, Zhang *et al*. 1996, Hsiao and Wang 1998, Kleiss and Enke 1999, Mojsilovic *et al*. 2000, Chuang and Ma 2001, Yannou and Petiot 2002), cluster analysis (Toms *et al*. 2001) and conjoint analysis of consumer data (for reviews see Green and Srinivasan 1978, 1990).

Liu (2000a, 2000b) considered the need to add aesthetics to the field of human factors, and recognised the lack of systematic, scientific and engineering methods to help designers study aesthetic concepts and incorporate them in design decisions. MacDonald (2001) discussed the concept of 'aesthetic intelligence': people's innate, often subconscious, ability to perceive a wide range of qualities in products that shape our responses to them. He linked sensorial qualities to cultural values and proposed designing for the senses so that customers can feel a greater degree of empathy with the product.

Wang and Holden (2000) studied craftsmanship in automotive products and proposed a methodology for craftsmanship assessment. They examined the influence of consumers' demographic backgrounds on their craftsmanship assessment and found that gender, age and education were not significant factors of the craftsmanship assessment. Their approach is similar to the starting point of the present study, which used a proprietary vehicle assessment process developed at Johnson Controls Inc. (JCI). In this vehicle assessment process various vehicle attributes are assigned scores through human inspection, like a showroom experience, rather than derived from physical measurement instruments. However, the evaluators are trained designers. Unlike a typical vehicle buyer, a team with calibrated observational skills systematically combs the complete interior to assess the attributes they believe are related to craftsmanship. Similarly, Turley *et al*. (2007) discussed the final vehicle product audit methodology, which includes craftsmanship evaluation by many original equipment manufacturers.

In this paper, we describe the evolution of a craftsmanship attributes checklist tuned to engineering design. Our goal is to create an attribute checklist that has acceptable consistency of attribute scores across users. Study 1 demonstrates that an existing craftsmanship attribute checklist used in the automotive industry does not reach acceptable levels of consensus across raters and does not lead to interpretable clusters or an interpretable spatial arrangement following data reduction techniques (cluster analysis and MDS). We discuss the creation of a new attribute list along with a corresponding list of product characteristics and use a (FDT) to partition the list into subproblems. Study 2 uses the new attribute list with a procedure similar to that used in Study 1 and demonstrates higher levels of consensus, interpretable clusters, interpretable spatial arrangement and a consistency between the clusters emerging from subjects' data and the subproblems that emerged from the FDT analysis on the list of attributes. Our goal is to demonstrate a methodology that engineering designers can use to guide their work in a way that relates perceived craftsmanship to measurable product characteristics.

## 2. Behavioural Study 1

Previous research has shown that perception differences exist between designers, engineers and customers (Hsu *et al*. 2000). Therefore, we first investigate the perceptions of customers when they use an industry-developed attribute list. A good attribute checklist should have acceptable consistency of attribute scores across consumers, which could be considered the target population (other targets include expert designers). This study addresses the following research questions: (1) Are the interpretations of the attributes consistent among users? (2) If yes, what are the underlying dimensions of the craftsmanship concept?

### 2.1. *Procedure*

Five male, graduate student mechanical engineers participated in the study. The main reason for this selection was to reduce noise in the data resulting from gender, background and age differences. This limits the generality of the results but it is sufficient for the study because we are mostly interested in showing the feasibility of establishing consensus across evaluators. Two reasons for having a relatively large sample size are to produce narrow confidence intervals around parameter estimates and to establish representativeness of the results across a population. The sample size in the present study provides sufficiently narrow confidence intervals for our purposes. The purpose of this study is an exploratory evaluation of an existing technique. Future studies can provide data from nationally and internationally representative samples. Research with collaborators in our own lab demonstrates that there can be cross-national differences in customer preferences and perceptions (Petiot *et al*. 2009).

Participants were asked to complete two types of tasks. In the first task the subjects were presented six vehicle interiors where model and year details were omitted intentionally (see Table 1 for the list of vehicles). Subjects were asked to evaluate these interiors using the attributes of the existing industry checklist (e.g., gaps and colour harmony) on a seven-point Likert scale (Foley 1998). A sheet with attribute definitions was provided. We tested the consistency of people's perceptions, i.e., whether or not people who were presented with the same vehicles rated them in the same way. In the second task, the subjects were asked to sort the attributes written on cards into piles according to criteria that make sense to them. For example, one subject could group 'gaps' into the same pile as 'colour harmony', because he thinks they both relate to visual impressions. Another subject, however, might group them into different piles, because he thinks that 'gaps' refers to an assembly problem, whereas he views 'colour harmony' as a subjective

Table 1. Average gamma values for each vehicle.

| Vehicle | Average gamma |
|---|---|
| Toyota | −0.09 |
| Saab | 0.01 |
| VW | −0.05 |
| Nissan | −0.09 |
| Chevy | −0.09 |
| Honda | 0.11 |

matter of aesthetics. Subjects were allowed to create as many piles as they wanted (but more than one and less than the total number of attributes). Information about whether a subject placed two attributes in the same pile or in different piles was coded into an attribute-by-attribute binary dissimilarity matrix. Three different analyses were used: correlation, multi-dimensional scaling and cluster analysis.

### 2.2. *Gamma measure of agreement*

A measure of agreement called gamma (Kruskal 1958, Goodman and Kruskal 1963) is an index of monotonic agreement between a pair of ratings in the following sense. Suppose that Rater A assigned a vehicle a lower rating on colour harmony than on gaps (e.g., 5 on colour harmony and 6 on gaps), and Rater B also gave the same vehicle a lower rating on colour harmony than on gaps (e.g., 3 on colour harmony and 5 on gaps). These two pairs of ratings are called concordant because the two raters assigned consistent order ratings on these two attributes. Ratings are discordant when they do not have this property. The gamma measure is a normalised difference of the total number of concordant pairs and the total number of discordant pairs over all possible pair-wise comparisons of attributes between two raters. The gamma index ranges from $-1$ (perfect ordinal inconsistency) to 1 (perfect ordinal consistency).

There exist other measures of agreement, such as absolute agreement, which counts the proportion of times two raters assign exactly the same rating on an attribute, but the other measures are too conservative given the ordinal nature of the seven-point response scale (ranging from failure to excellent). Many domains in social sciences yield high consistency measures between pairs of raters, so we know that it is possible for people to agree at an ordinal level about ‘fuzzy’ or vague concepts. The question we explore here is whether the particular assessment of craftsmanship leads to consistency across raters.

Results are shown in Table 1 and Figure 1. For each vehicle, we computed gamma between all possible pairs of raters. Table 1 presents the average gamma (over the 10 observed gammas for each pair of raters) for each vehicle. All gammas are close to zero, which suggests no concordance

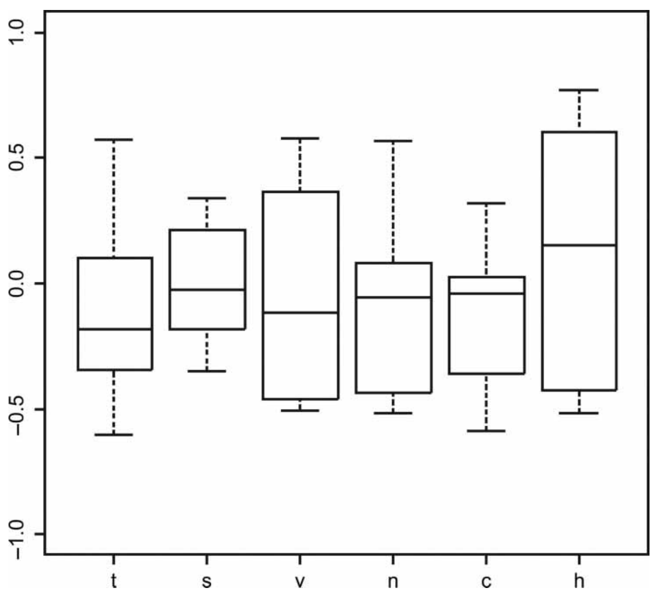


Figure 1. Boxplot of the gamma distribution for Toyota, Saab, VW, Nissan, Chevy and Honda.

between pairs of raters. No pair of raters consistently agreed over the 40 ratings for the six vehicles in the study. For example, a pair of raters that showed moderate agreement on the VW ($\gamma = 0.57$) showed moderate disagreement on the Honda ($\gamma = -0.52$) and virtually no agreement on the Saab ($\gamma = -0.02$).

In Figure 1, gammas are summarised in the standard boxplot developed by John Tukey (Wu and Hamada 2000). A boxplot displays the first and third quartile (ends of the rectangle), the median (horizontal line inside the rectangle) and outliers ('whiskers' that emerge from the rectangle). All medians are near zero with relatively wide ranges, suggesting a relatively high degree of variability for gamma.

### 2.3. *MDS and cluster analysis*

Possible design dimensions of craftsmanship are explored next. A non-metric MDS analysis was applied to the categorisation data (Schiffman *et al.* 1981, Borg and Groenen 1997). MDS represents measurements of perceived dissimilarity among pairs of stimuli as distances between points of a low-dimensional space. It uses proximity values as input, i.e., how similar or dissimilar two objects are perceived to be, and produces a spatial representation consisting of a geometric configuration of points as an output. Each point in the output configuration corresponds to a given object. The greater the dissimilarity between two objects, the further apart they are in the spatial configuration (Chen *et al*. 2001). Useful insights result from examining the arrangement of points to find dimensions that underlie judgments of dissimilarity. In the present context, the emerging dimensions can be interpreted as perceptual dimensions that characterise craftsmanship.

A binary dissimilarity matrix was created for each subject, i.e., an attribute-by-attribute matrix such that a 0 was assigned to a cell when corresponding row and column attributes were grouped into the same pile and a 1 was assigned to a cell when the corresponding attributes were grouped into separate piles. The data collected from five subjects provided five binary dissimilarity matrices. The matrices of each subject were then added to create the total dissimilarity matrix for the sample. The MDS analysis was computed from two to six dimensions with no meaningful results, suggesting high attribute ambiguity across the subjects.

Cluster analysis was also applied to the dissimilarity data (Corter 1996). Cluster analysis joins stimuli together into successively larger clusters, using a dissimilarity matrix. Cluster members share particular properties and the resultant classification may provide insight by reducing the dimensionality of the data set. The agglomerative technique was used (Kaufman and Rousseeuw 1990). The method starts with all objects apart, i.e., at Step 0 there are $n$ clusters, where $n$ is the number of stimuli. At Step 1, the two objects with smallest dissimilarity are joined, leaving $n - 1$ clusters, one with two objects and the rest with one. In subsequent steps, two clusters are merged again, until a fit function is minimised.

Cluster analysis of the dissimilarity data did not result in meaningful clusters, i.e., attributes clustered together did not share implicit or explicit properties, again signalling high ambiguity in the attribute interpretations across the participants in the study.

## 3. Craftsmanship checklist

Lack of agreement in Study 1 among relatively knowledgeable subjects, who were engineers but responded as customers, confirmed our concern that there would be little consensus on craftsmanship judgments using the existing assessment tool. Three prominent analytic techniques (an ordinal measure of association, a dimensional scaling analysis and a clustering analysis) suggested poor consensus. These findings suggest that a more refined list of attributes with clearer

Table 2. Example: proposed quantities to replace the attribute 'gaps'.

| |
|---|
| Gaps |
| Number of gaps |
| Gap size |
| Variation between gaps within grouping |
| Variation within each gap |
| Number of gaps not covered in swing positions |
| Number of interference fits for soft-trim surfaces |
| Number of self-centring stops to align 'at-rest' position |



definitions is needed to improve consistency across raters. Moreover, the list used in Study 1 was intended for designer and engineer training. To refine the list of attributes, we expressed the attributes in terms of measurable quantities. The manufacturer's attribute list was expanded to include attributes from the JD Power ratings. We also focused on ergonomic attributes as well as aesthetic attributes; we believe both types of attributes contribute to the perception of craftsmanship because they demonstrate the attention to detail in design. Presenting evaluators clearly defined attributes is a necessary condition for consistency and agreement across raters. An example is given in Table 2.

We introduce a distinction between product characteristics and perceived attributes. Product characteristics are quantities directly measurable and manipulated (e.g., number of buttons on the dashboard), whereas perceived attributes are more general properties resulting from assigning values to two or more product characteristics (e.g., stitching quality). This distinction expresses craftsmanship in terms of attributes, which in turn are expressed in terms of engineering characteristics. Establishing such a mapping would enable designers and engineers to design for craftsmanship by directly changing product characteristics. Following this idea, craftsmanship can be represented as a function of perceived attributes $f_i$ that are functions of product characteristics $\mathbf{x}$. Craftsmanship can then be defined by an index that is the weighted sum of the attributes.

$$\begin{aligned} C &= \sum_{i=1}^{k} \omega_i f_i \\ f_i &= f_i(\mathbf{x}) \\ \mathbf{x} &= (x_1 x_2 \ldots x_n)^{\mathrm{T}}, \end{aligned} \tag{1}$$

where $C$ is the craftsmanship index (level of craftsmanship value), $\omega_i$ is a weight that determines how much attribute $f_i$ contributes to craftsmanship, with a total $k$ and $n$ product attributes and characteristics, respectively. The simple weighted sum of the $f_i$s is an assumption that merits further investigation. In addition, attributes are functions of customer as well as product characteristics. For example, the difficulty of reaching a control knob or the perception of stitching quality in a seat will depend on the individual user as well as the objective characteristics. Future research can extend this model by allowing heterogeneity to account for individual differences in a relevant target population or to account for variability within and between different market segments. A larger sample from a heterogeneous population would be needed to estimate latent classes or treat parameters as random effects (or variance components) to model individual differences.

### 3.1. *Quantification scale*

Characteristics can be placed on a 'quantification scale', according to how well they can be quantified (Figure 2). Physically measurable characteristics (e.g., volume of the glovebox) are called 'quantifiable' and denoted with a Q; characteristics measured using behavioural sciences

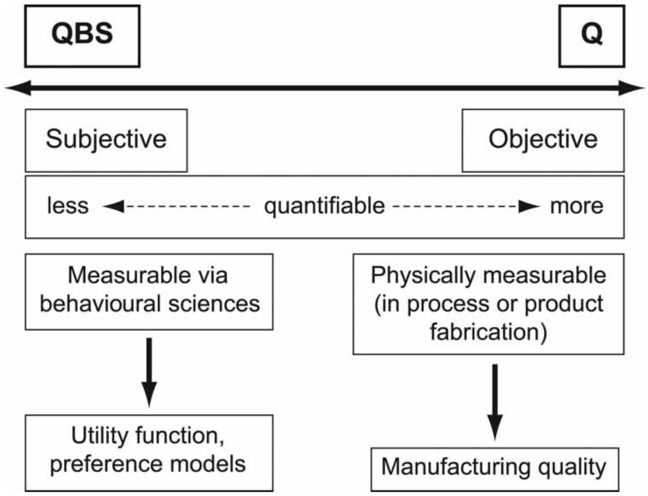


Figure 2. Quantification scale.



methods (e.g., similarity of tactile feel) are called 'quantifiable in behavioural sciences' and denoted with QBS.

'Statistical' characteristics denoted with an S are statistically quantifiable, meaning that their mean values and standard deviations are taken as measures (e.g., deviation within multi-seam alignments). The objective here is to classify as many characteristics as possible into the 'quantifiable' category, because they are easier to address in a repeatable and consistent manner. Also, because the eventual goal is to quantify perceived craftsmanship and relate it to engineering decisions, the units used to measure each characteristic and the direction of desired improvement (maximise, minimise, or optimise) for each attribute and characteristic have been added to the list. For the QBS product characteristics the column for the measurement unit is left blank. The complete list of perceived attributes is given in Table 3 and a partial list of product characteristics in Table 4. There were 22 attributes and 84 characteristics considered in this study.

### 3.2. *Functional dependence table*

A functional dependence table (FDT) was created to examine the interactions between the list of 84 product characteristics and the list of 22 perceived attributes (Wagner 1993), see Figure 3. The FDT provides a visual representation of the functional dependences: a dark cell indicates dependence of $f_i$ on $x_j$, and an empty cell indicates independence. When the FDT is large and sparse, an abridged FDT is visually helpful, as in Table 5. In this table, each line $f_i$ (representing the $i$th attribute in the checklist) is a function of the $x_j$s (representing the $j$th characteristics in the checklist). For example, perceived attribute $f_{20}$ is a function of product characteristics $x_{54}$ and $x_{55}$.

### 3.3. *Partitioning of the FDT*

A large complex problem is often easier to analyse if it can be decomposed into smaller sub-problems. In the present case, we examine whether attributes and characteristics can be grouped together based on their interrelations, and create a craftsmanship decomposition through partitioning of the FDT (Wagner 1993). The partitioning process groups the functions (the perceived attributes) together based on their shared variables (the product characteristics). Each block defines

Table 3. Complete list of perceived attributes.

| No. | Name | Direction |
|---|---|---|
| $f_1$ | Ability to easily discern where all controls are located | Maximise |
| $f_2$ | Material sound response | Minimise |
| $f_3$ | Component feel/sound of activation/engagement (seatbelts, doors, buttons) | Maximise |
| $f_4$ | Buzz, squeak and rattle | Minimise |
| $f_5$ | Stitching quality | Maximise |
| $f_6$ | Adjustability of components | Optimise |
| $f_7$ | Shape harmony | Maximise |
| $f_8$ | Colour harmony | Maximise |
| $f_9$ | Storage space in front console | Optimise |
| $f_{10}$ | Visibility of mechanical elements and manufacturing distortions | Minimise |
| $f_{11}$ | Component/passenger interference | Minimise |
| $f_{12}$ | Material quality | Maximise |
| $f_{13}$ | Seated comfort | Maximise |
| $f_{14}$ | Difficulty reaching controls, lights, seatbelts | Minimise |
| $f_{15}$ | Consistency of tactile feel | Maximise |
| $f_{16}$ | Usability of vents | Maximise |
| $f_{17}$ | Usability of glovebox | Maximise |
| $f_{18}$ | Usability of door pockets | Maximise |
| $f_{19}$ | Usability of sun visors | Maximise |
| $f_{20}$ | Usability of cup holders | Maximise |
| $f_{21}$ | Usability of trunk | Maximise |
| $f_{22}$ | Quality of finishing | Maximise |

Table 4. Partial list of product characteristics.

| No. | Type | Name | Direction | Unit |
|---|---|---|---|---|
| $x_1$ | QBS | Consistency of button/knob activation feel within grouping | Maximise | |
| $x_3$ | Q | Number of different geometries for buttons and knobs | Optimise | # |
| $x_4$ | Q | Number of buttons and knobs | Optimise | # |
| $x_{10}$ | Q | Number of gaps | Minimise | # |
| $x_{11}$ | Q | Gap size | Minimise | mm |
| $x_{12}$ | S | Variation between gaps within grouping | Minimise | mm |
| $x_{13}$ | S | Variation within each gap | Minimise | mm |
| $x_{17}$ | S | Deviation within multi-seam alignments | Minimise | mm |
| $x_{18}$ | Q | Number of radius sews on A-surfaces causing cover tension and wrinkles | Minimise | # |
| $x_{31}$ | Q | Number of insecure component fastenings | Minimise | # |
| $x_{32}$ | Q | Number of places where tautness in materials shows stitch holes | Minimise | # |
| $x_{47}$ | Q | Drop angle of glovebox lid | Optimise | rad |
| $x_{48}$ | Q | Drop speed of glovebox lid | Optimise | rad/s |
| $x_{49}$ | QBS | Accessibility of glovebox from driver's side | Maximise | |
| $x_{57}$ | Q | Number of places where different materials have to mimic the same grains | Minimise | # |
| $x_{59}$ | QBS | Similarity of tactile feel between similar components | Maximise | |
| $x_{64}$ | Q | Number of similar components (having the same texture and form) that do not match in colour | Minimise | # |
| $x_{66}$ | Q | Number of visible internal components that could have been masked with matt black colouring | Minimise | # |
| $x_{67}$ | Q | Number of visible mechanical elements and exposed fasteners | Minimise | # |
| $x_{69}$ | Q | Number of places where carpets and other finished surfaces do not extend far enough into visible areas | Minimise | # |
| $x_{72}$ | Q | Number of visible parting lines | Minimise | # |
| $x_{75}$ | Q | Number of places for potential wear paths from interactions between components | Minimise | # |
| $x_{80}$ | Q | Compression uniformity among similar components | Maximise | N/m |
| $x_{81}$ | Q | Compressibility of components where body contacts regularly and for prolonged time | Optimise | N/m |

Note: # Stands for number of.

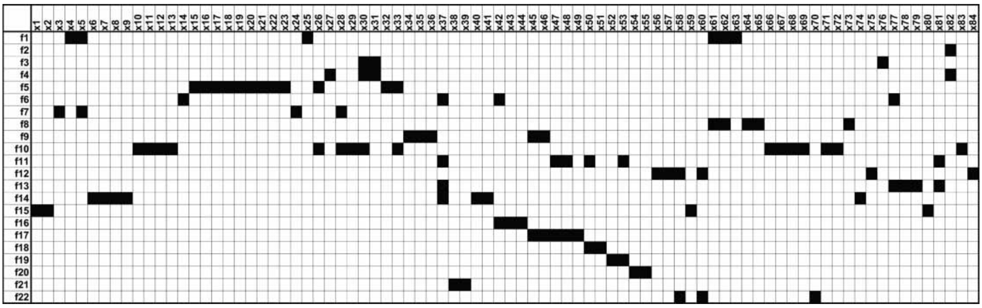

Figure 3. Functional dependence table.

Table 5. Abridged functional dependence table.

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $f_1$ | $x_4$ | $x_5$ | $x_{25}$ | $x_{61}$ | $x_{62}$ | $x_{63}$ | | | | | | | | | | |
| $f_2$ | $x_{82}$ | | | | | | | | | | | | | | | |
| $f_3$ | $x_{30}$ | $x_{31}$ | $x_{76}$ | | | | | | | | | | | | | |
| $f_4$ | $x_{27}$ | $x_{30}$ | $x_{31}$ | $x_{82}$ | | | | | | | | | | | | |
| $f_5$ | $x_{15}$ | $x_{16}$ | $x_{17}$ | $x_{18}$ | $x_{19}$ | $x_{20}$ | $x_{21}$ | $x_{22}$ | $x_{23}$ | $x_{26}$ | $x_{32}$ | $x_{33}$ | | | | |
| $f_6$ | $x_{14}$ | $x_{37}$ | $x_{42}$ | $x_{77}$ | | | | | | | | | | | | |
| $f_7$ | $x_3$ | $x_5$ | $x_{24}$ | $x_{28}$ | | | | | | | | | | | | |
| $f_8$ | $x_{61}$ | $x_{62}$ | $x_{64}$ | $x_{65}$ | $x_{73}$ | | | | | | | | | | | |
| $f_9$ | $x_{34}$ | $x_{35}$ | $x_{36}$ | $x_{45}$ | $x_{46}$ | | | | | | | | | | | |
| $f_{10}$ | $x_{10}$ | $x_{11}$ | $x_{12}$ | $x_{13}$ | $x_{26}$ | $x_{28}$ | $x_{29}$ | $x_{30}$ | $x_{33}$ | $x_{66}$ | $x_{67}$ | $x_{68}$ | $x_{69}$ | $x_{71}$ | $x_{72}$ | $x_{83}$ |
| $f_{11}$ | $x_{37}$ | $x_{47}$ | $x_{48}$ | $x_{50}$ | $x_{53}$ | $x_{81}$ | | | | | | | | | | |
| $f_{12}$ | $x_{56}$ | $x_{57}$ | $x_{58}$ | $x_{60}$ | $x_{75}$ | $x_{84}$ | | | | | | | | | | |
| $f_{13}$ | $x_{37}$ | $x_{77}$ | $x_{78}$ | $x_{79}$ | $x_{81}$ | | | | | | | | | | | |
| $f_{14}$ | $x_6$ | $x_7$ | $x_8$ | $x_9$ | $x_{37}$ | $x_{40}$ | $x_{41}$ | $x_{74}$ | | | | | | | | |
| $f_{15}$ | $x_1$ | $x_2$ | $x_{59}$ | $x_{80}$ | | | | | | | | | | | | |
| $f_{16}$ | $x_{42}$ | $x_{43}$ | $x_{44}$ | | | | | | | | | | | | | |
| $f_{17}$ | $x_{45}$ | $x_{46}$ | $x_{47}$ | $x_{48}$ | $x_{49}$ | | | | | | | | | | | |
| $f_{18}$ | $x_{50}$ | $x_{51}$ | | | | | | | | | | | | | | |
| $f_{19}$ | $x_{52}$ | $x_{53}$ | | | | | | | | | | | | | | |
| $f_{20}$ | $x_{54}$ | $x_{55}$ | | | | | | | | | | | | | | |
| $f_{21}$ | $x_{38}$ | $x_{39}$ | | | | | | | | | | | | | | |
| $f_{22}$ | $x_{58}$ | $x_{60}$ | $x_{70}$ | | | | | | | | | | | | | |

a subproblem. Variables belonging to more than one subproblem are the linking variables. The partitioning process aims to minimise the number of linking variables, i.e., to separate the subproblems as much as possible. If a large problem is divided into smaller subproblems and the linking variables are fixed *a priori* (through some agreed upon process), the subproblems become independent and can be handled separately and in parallel, see Figure 4.

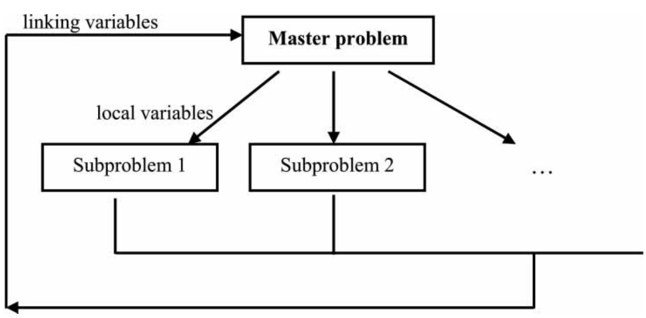


Figure 4. Partitioning of a master problem into subproblems.

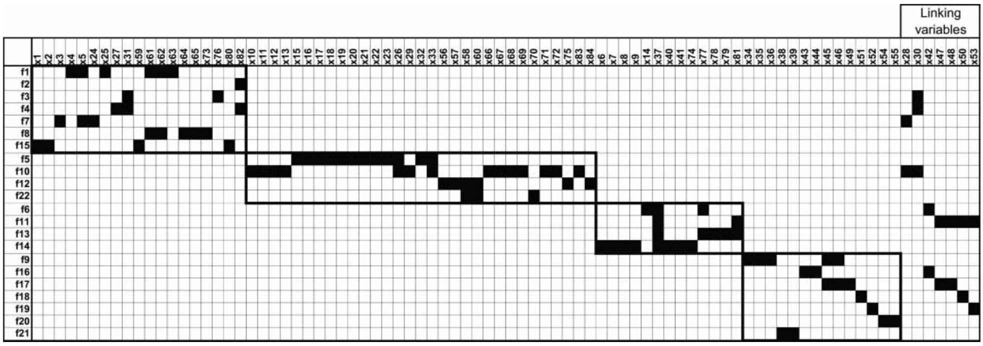


Figure 5. Partitioned FDT.

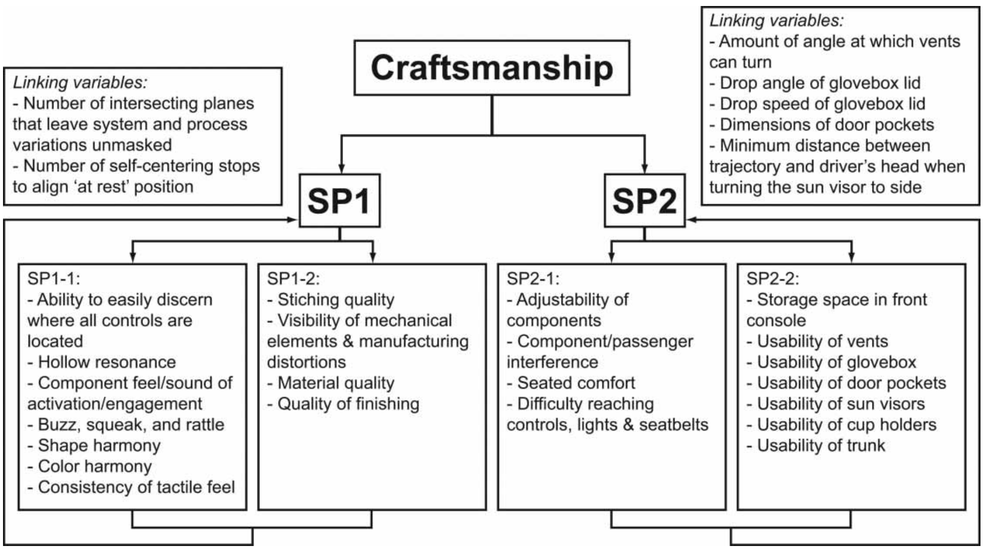


Figure 6. Structure of the craftsmanship problem (SP: subproblem).



An initial partitioning of the craftsmanship FDT was performed, specifying the number of subproblems from 2 to 10. Using higher numbers of subproblems resulted in at least three linking variables. After some experimentation, we decided to use the result from a two-subproblem partition and re-partition each subproblem into two new subproblems. This led to the partitioned FDT in Figure 5, which is a rearranged version of Figure 3.

Figure 6 represents the final structure of the craftsmanship problem with four subproblems: SP1-1 contains visual, auditory and tactile perceptions; SP1-2 contains visual elements as well, but they are mostly 'pure quality' issues; SP2-1 includes overall comfort, whereas the usability items are in SP2-2. This FDT partition sets up a logical connection between characteristics and attributes. We now turn to a second behavioural study that builds on these vehicle characteristics.

## 4. Behavioural Study 2

Research in consumer decision theory shows that consumers compare products on the basis of attributes and not characteristics (Kaul and Rao 1995). Therefore, a second behavioural study

Table 6. Average gamma values for each vehicle.

| No. | Vehicle | Average gamma |
|---|---|---|
| 1 | Hyundai | 0.34 |
| 2 | Mercury | 0.08 |
| 3 | Ford vehicle 1 | 0.28 |
| 4 | Ford vehicle 2 | 0.03 |
| 5 | Mazda | 0.20 |
| 6 | Nissan | 0.26 |
| 7 | Buick | 0.11 |
| 8 | Chevrolet | 0.04 |



identically structured as the first one was conducted using the new list of 22 perceived attributes, with nine subjects (male graduate engineering students) and eight vehicles, see Table 6. The subjects were not provided with attribute explanations. The same set of analyses as in Study 1 was conducted (gamma, MDS and cluster).

### 4.1. *Gamma results*

With nine raters there were 36 estimates of gamma for each vehicle; Table 6 presents the average vehicle gammas. Although the average gamma values do not seem large, they are greater than in Study 1. All gamma values are positive suggesting concordance, whereas in the first study most of the gamma values were negative suggesting discordance. The boxplot in Figure 7 shows that all the medians are above zero with relatively smaller ranges as compared with the first study. Thus, the improved product attribute list served to increase consensus across the participants.

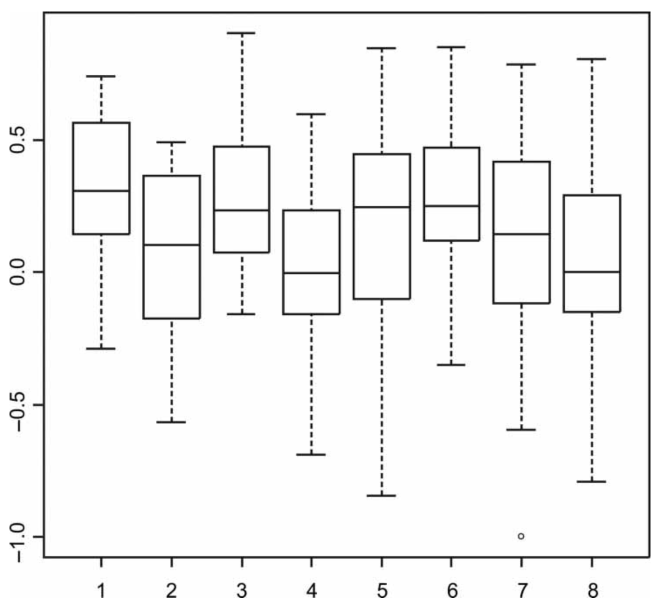


Figure 7. Boxplot of the gamma distribution for the eight vehicles.

### 4.2. *Cluster analysis and MDS*

Dissimilarity data for the cluster analysis were collected and analysed as in Study 1. Four meaningful clusters emerged. The first cluster contains all the auditory attributes, the second cluster involves quality and aesthetic attributes and the third cluster is about driving comfort. The usability items fell into the fourth cluster. Table 7 lists the 22 attributes as arranged into the four clusters.

Interestingly, these four clusters correspond closely to the decomposition structure in the partitioned FDT: Cluster 4 completely overlaps with SP2-2, Cluster 3 includes all attributes of SP2-1 plus one additional attribute and Cluster 2 includes all attributes of SP1-2 plus three additional attributes. Those additional attributes together with the attributes of Cluster 1 correspond to the SP1-1. This is interesting because the FDT partitioning was a purely mathematical process based on graph theory on a table of researcher-defined relations between characteristics and attributes, whereas the cluster analysis employed user perception data where the subjects only had access to the product attribute list (not the 84 product characteristics). The practical implication of this finding for engineers and designers is the following: in order to improve a particular aspect of craftsmanship perception (a cluster), an engineer can refer to the FDT to determine the product characteristics that relate to the perceived attributes of that cluster. Modifying these characteristics along the specified directions will improve the corresponding aspect of craftsmanship without interfering with the rest of the craftsmanship perception, as long as the linking variable values remain unchanged.

MDS analysis was conducted from two to six dimensions. To interpret the dimensions of the perceptual space (i.e., interpret and label the axes) the clusters from the cluster analysis were superimposed on the spatial configuration. The goal was to see whether the attributes in each cluster conform to spatial configurations, spanning a meaningful space. After analysing the multidimensional spaces, the 2D space showed the most meaningful characteristics in terms of ability to identify the dimensions.

Figure 8 shows the cluster position in the 2D perceptual space. The layout of the clusters is meaningful in terms of the relative positions of the clusters. The first axis spans one dimension from ‘sensory requirements’ to ‘functional requirements’, whereas the second axis spans another dimension from ‘overall comfort’ (physical and psychological) to ‘overall quality’ (design and manufacturing).

There are two attributes that are semantically misplaced in the 2D space, namely, Attributes #4 and #20, circled in Figure 8. This misplacement may be due to the loss of dimensionality that occurs in MDS. On the other hand, Attribute #4 (‘Buzz, squeak and rattle’ or BSR) could indeed appear in the cluster of driving comfort, because continuous BSR noise would affect driver

Table 7. Clusters of craftsmanship attributes.

| Cluster 1: auditory attributes | Cluster 2: quality issues | Cluster 3: driving comfort | Cluster 4: usability |
|---|---|---|---|
| Material sound response | Stitching quality | Ability to easily discern where all controls are located | Storage space in front console |
| Component feel/sound of activation/engagement | Shape harmony | Adjustability of components | Usability of vents |
| Buzz, squeak and rattle | Colour harmony | Component/passenger interference | Usability of glovebox |
| | Visibility of mechanical elements/manufacturing distortions | Seated comfort | Usability of door pockets |
| | Material quality | Difficulty of reaching controls/lights/seatbelts | Usability of sun visors |
| | Consistency of tactile feel | | Usability of cup holders |
| | Quality of finishing | | Usability of trunk |

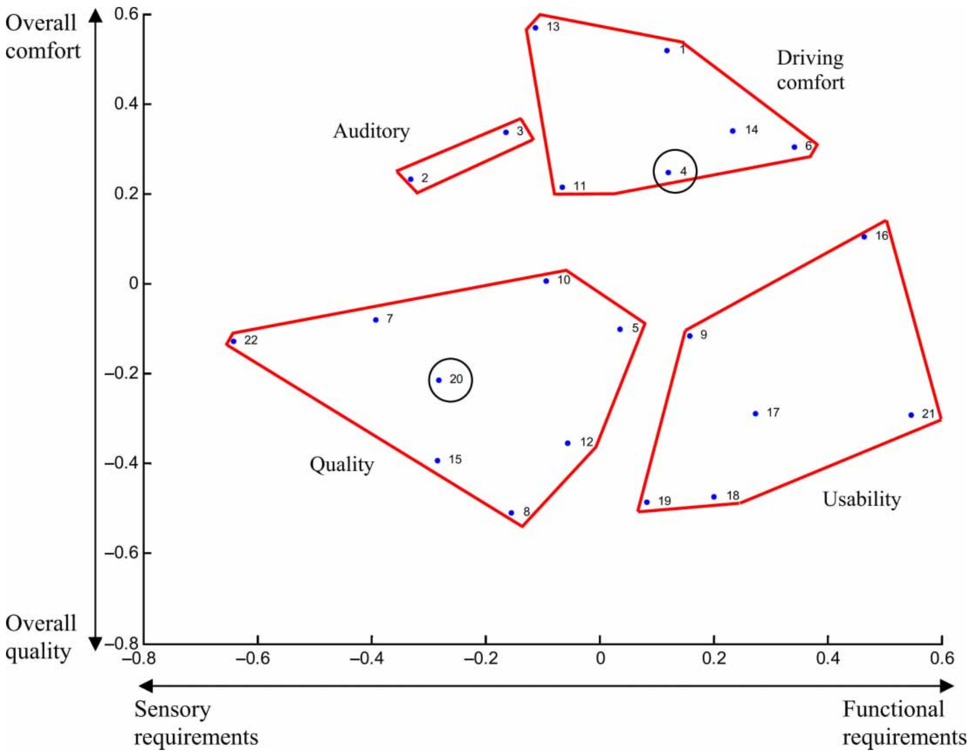


Figure 8. Position of the clusters in the 2D-perceptual space and interpretation of the axes.

comfort. These MDS results are clearer than in Study 1, and show that it is indeed possible to represent user perception of craftsmanship in a space of reduced dimensionality, as long as the attribute list is clear and reaches consensus across the raters.

## 5. Conclusion

An analytical approach to the craftsmanship problem in vehicle interior design is promising, in terms of developing design tools that are less subjective but still capture the inevitable subjectivity of the perceiver. We demonstrated that an existing craftsmanship checklist used in industry does not achieve acceptable levels of consensus across participants nor does it achieve acceptable consistency of clusters and dimensions. We developed a new craftsmanship checklist that consists of product attributes that are directly linked to engineering product characteristics. In this manner, engineers can make design decisions on product characteristics that yield predictable changes on the perceived product attributes of craftsmanship. Further, the generated craftsmanship checklist allows industrial designers and engineers to communicate more comfortably about a 'soft' concept like craftsmanship. We view this process, a connection between FDT and methods from the behavioural sciences, as a general tool, even though the specific checklist used in the present paper applies narrowly to vehicle interiors. Different products will, of course, require tailored checklists, but the point is that new checklists can be based on FDTs of product characteristics and perceived attributes, where necessary measurement properties such as high consensus among raters can be assessed and tested.

While the proposed method is general, the results presented are obviously limited. Our goal in this paper was to propose a workable analytical-functional representation of the constitutive elements of craftsmanship, and the practical design decisions that engineers can make. In a small follow up study, the craftsmanship structure for vehicle interiors was successfully extended to derive a craftsmanship assessment tool for a different product – MP3 players. However, relating design decisions to user perceptions is a complex problem, so a generalisation of the present findings to craftsmanship judgment for diverse products remains a challenge.

An important aspect of the problem that remains is the selection of values for the attribute weights in calculating the craftsmanship index, and the form of the aggregation equation for the index. This selection would then determine the relative importance of each attribute and identify any dominating attributes. Future research can explore more complicated index functions, for example, indices based on lexicographic ordering that take into account dominating attributes (Keeney and Raiffa 1976, Jia *et al.* 1998). Also, the specific empirical results presented in this paper should be viewed providing a demonstration of the technique. The relatively small sample sizes used in the two behavioural studies were adequate for producing the necessary statistical power. That is, we have sufficient statistical power to demonstrate that the new checklist improved consensus relative to the original checklist. But obviously a larger and more representative sample would be needed to use the data in an industry setting. Our choice of using male engineering students led to a homogenous sample that contributed to adequate statistical power (that is, by having a reduced error term relative to a more heterogeneous sample), but obviously limits the generalisability of the empirical results presented in this paper to male engineering students. Different subgroups could lead to more or less variability relative to male engineering students. It is plausible given some behavioural research that participants not familiar with the details of a vehicle interior may show more consensus than more knowledgeable participants because novices apply a common, but possibly suboptimal, prototype when making judgments (Wilson and Schooler 1991).

At a much broader level, craftsmanship relates not only to the design itself, but also to the quality of design execution, i.e., the manufacturing quality. Some aspects of craftsmanship identified above are directly related to manufacturing (or design for manufacturing), and so reducing manufacturing defects in turn will improve the craftsmanship aspect of a product. The link between design for manufacturing and craftsmanship would therefore be a promising area for further research.



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