Development of Satisfaction Models for Passenger Car Interior Materials Considering Statistical and Engineering Aspects of Design Variables

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As the functionality of a passenger car has reached at a satisfactory level, customer needs for aesthetic aspects of a design such as shape and material become increased. The present study developed satisfaction models for passenger car interior materials by applying methods of variable screening and recoding. Six interior parts of a passenger car were selected including crash pad, steering wheel, transmission gearshift knob, audio panel, and wooden/metal grain. Eight to fifteen material design variables were defined for the six interior parts. A satisfaction survey was conducted to 30 vehicles with 30 participants (mean (SD) of 28.7 (6.6) in age) by using a modified magnitude estimation scale. Methods of variable screening/recoding were proposed to develop models that are stable and of statistical/practical significance. By applying the variable screening/recoding methods to the surveyed satisfaction data, satisfaction models were developed for the six interior parts. Using the satisfaction models, material designs to improve customer satisfaction were prepared and their potential effects were estimated.

Introduction

As the functional capabilities of passenger cars (such as speed and horsepower) reach at a satisfactory level, customers consider aesthetic aspects (such as color, shape, and material) more importantly than before (Jindo and Hirasago, 1997). Kansei engineering has been applied to develop models explaining the relationships between aesthetic aspects and customer satisfaction in product design. While most Kansei engineering studies on automobile designs (e.g., Tanoue et al. (1997), Jindo and Hirasago (1997), and Nakada (1997)) have focused on visual design variables, few Kansei studies exist focusing on material design variables (e.g., softness and slipperiness).

The objectives of the present study are twofold: (1) develop satisfaction models for materials used in the interior of a passenger car and (2) propose methods of variable screening/recoding for the development of models that are stable and significant from statistical and technical aspects. An experiment was conducted to survey the levels of satisfaction with various interior materials. Then, a procedure to develop a satisfaction model was established which includes the methods of variable screening and recoding. By applying the model development procedure to the satisfaction survey data, satisfaction models were constructed for the interior materials.

Survey of Material Satisfaction

Participants

A total of 30 men participated in the material satisfaction survey. Twenty-one participants were in their twenties and nine were thirty or above in age (average (S.D) = 28.7 (6.6)); fifteen were design engineers at a motor company and the others were students in college.

Interior Materials and Passenger Cars

As shown in Figure 1, six interior parts (crash pad, steering wheel, transmission gearshift knob, audio panel, and wooden/metal grain) of a passenger car were selected for evaluation of interior materials. These six parts are located in the front of the car and most frequently interfaced with the driver.

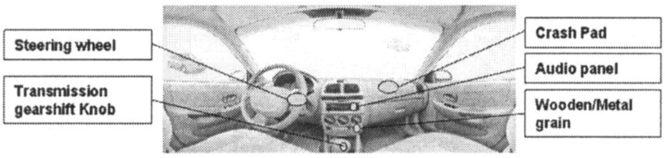

Figure 1. Interior parts of a passenger car selected for a material satisfaction survey

A total of 30 cars (23 compact cars and 7 sport-utility vehicles whose models are different from each other) were used in the material evaluation. These vehicles were at one place in a motor company and had various properties of interior materials. The number of vehicles evaluated for each interior part varies as shown in Table 1 because the vehicles had different properties of interior materials.

Table 1. Distribution of the number of evaluated vehicles by interior part

Interior part	Number of cars
Crash pad	30
Steering wheel	30
Transmission gearshift knob	30
Audio panel	28
Metal grain	14
Wooden grain	5

Design Variables and Measurements

Material design variables were defined for the six interior parts by surveying the web sites of customer reviews, opinions of interior design engineers, and a related study. From the customer review web sites, design variables that customers considered important were identified. From interior design engineers of a motor company, additional information of interior material characteristics was obtained. Lastly, two variables (softness and slipperiness) studied by Nishimatsu et al. (2001) were accommodated to the present study. Based on the design variable survey, 8 to 15 material design variables and corresponding levels were defined for the interior parts. As an example, Table 2 shows 13 material design variables of crash pad, their types (categorical and continuous), and definitions of corresponding levels.

Table 2. Material design variables of crash pad

Code	Design variable	Definition and level description of variable
x1	Type of material	Type of raw material from which the interior part was made: categorical type - 1~4 (1: plastic, 2: polyurethane, 3: leather, 4: miscellaneous)
x2	Color	Color of material: categorical type - 21 colors (by the standard color table)
x3	Brightness	Brightness of color: continuous type - 2~9 (by the standard color table)
x4	Saturation	Pureness of color: continuous type - 0~16 (by the standard color table)
x5	Shininess	Degree of material shininess: continuous type - 1~7 (1:very dull, 7:very shiny)
x6	Shape of embossing	Shape of embossing: categorical type - 1~7 (1: pinhole, 2: circular concave, 3: circular convex, 4: leathery, 5: stony, 6: flat, 7: miscellaneous)
x7	Size of embossing	Horizontal size of embossing: continuous type - 1~7 (1: < 0.1, 2: 0.1~0.3, 3: 0.3~0.5, 4: 0.5~0.7, 5: 0.7~0.9, 6: 0.9~1.1, 7: >1.1)
x8	Marginal size of embossing	Distance between embossing : continuous type - 1~7 (1: < 0.1, 2: 0.1~0.3, 3: 0.3~0.5, 4: 0.5~0.7, 5: 0.7~0.9, 6: 0.9~1.1, 7: >1.1)
x9	Arrangement of embossing	Regularity of embossing arrangement: categorical type - 0~1 (0: random, 1: regular)
x10	Clearness of embossing	Degree of embossing apparentness: continuous type - 1~7 (1: very indistinct, 7: very apparent)
x11	Roughness	Degree of surface roughness: continuous type - 1~7 (1: very smooth, 7: very rough)
x12	Softness	Degree of surface softness: continuous type - 1~7 (1: very soft, 7: very hard)
x13	Slipperiness	Degree of surface slipperiness: continuous type - 1~7 (1: very slippery, 7: very frictional)

The values of material design variables were determined by objective and subjective methods. As objective tools, a ruler or the standard of colors were used. For design variables where objective tools were unavailable, subjective evaluations of four experimenters based on the definitions of the variable levels in Table 2 were utilized to determine their values.

Satisfaction Scale

The degree of satisfaction with a material was evaluated by using a modified magnitude estimation scale as shown in Figure 2. Studies such as Han et al. (2000) and Yun et al. (2001) which surveys customer satisfaction with certain design characteristics have employed a magnitude estimation scale for sensitivity reasons. In the present study, participants were asked to evaluate satisfaction with a certain material by visual examination and/or touch.

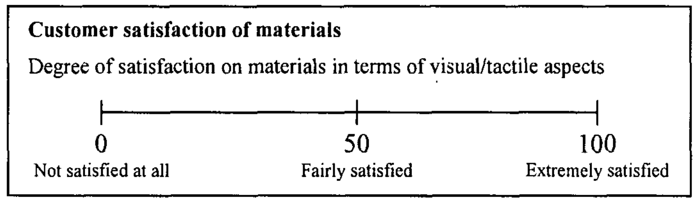

Figure 2. Modified magnitude estimation scale for material satisfaction evaluation

Procedure

The participants evaluated the materials of the 6 interior parts for 30 vehicles. The orders of the vehicles and interior parts to be evaluated were completely randomized to counterbalance learning and fatigue effects during the evaluation.

The satisfaction survey consisted of three sessions: introduction, main, and debriefing sessions. During the introduction session, the purpose and method of evaluation were explained by the administrator. Then, in the main session, each participant went to a particular vehicle by following a predetermined order and then evaluated the materials of the six interior parts at the vehicle based on the planned sequence. Lastly, a debriefing session was held. The total time to complete the evaluation for all the participants was about three hours.

Development of Satisfaction Models

Satisfaction models of the six interior parts were developed by following three stages (see Figure 3): (1) variable screening, (2) variable level recoding, and (3) regression analysis. Detailed explanation of each stage is presented as follows.

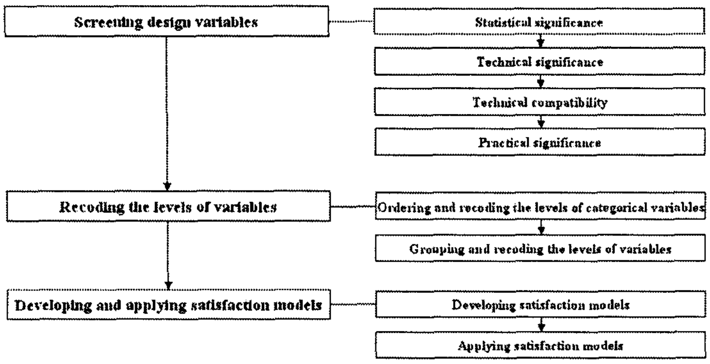

Figure 3. Procedure of satisfaction model development

Screening Design Variables

Statistical Significance

First, the statistical significance of each variable was evaluated to include design variables showing a satisfactory statistical power in the subsequent model development processes. For this statistical significance evaluation, ANOVA was conducted by defining satisfaction as the dependent variable and a particular design variable, age, and the interaction between age and the design variable as factors; age was included in ANOVA to separate the effect of the differences in age among the participants from the error sum of squares. Table 3 illustrates the results of ANOVA for the material design variables of crash pad, indicating all design variables except saturation and age are significant but none of the interactions are significant at $\alpha = .05$.

Table 3. Statistical significance analysis of material design variables (crash pad)*

Code	Design Variable (DV)		Age	Age × DV
x1	Type of material	O	O	✕
x2	Color	O	O	✕
x3	Brightness	O	O	✕
x4	Saturation	✕	O	✕
x5	Shininess	O	O	✕
x6	Shape of embossing	O	O	✕
x7	Size of embossing	O	O	✕
x8	Marginal size of embossing	O	O	✕
x9	Arrangement of embossing	O	O	✕
x10	Clearness of embossing	O	O	✕
x11	Roughness	O	O	✕
x12	Softness	O	O	✕
x13	Slipperiness	O	O	✕

* O: significant at α =0.05; ✕: not significant

Technical Significance

Next, the design variables with statistical significance were examined to identify if they affect satisfaction in a systematic manner (referred to as technical significance). The technical significance of a particular design variable was analyzed by plotting the averages of satisfaction scores along the levels of the design variable—if the pattern of change in satisfaction is systematic (random), the design variable is defined as one having technical significance (insignificance). As an example, Figure 4 shows that slipperiness lacks technical significance by affecting satisfaction at random while brightness has technical significance by influencing satisfaction in a second-order curvilinear pattern. The orders of the relationships between the material design variables of crash pad and satisfaction are summarized in Table 5.

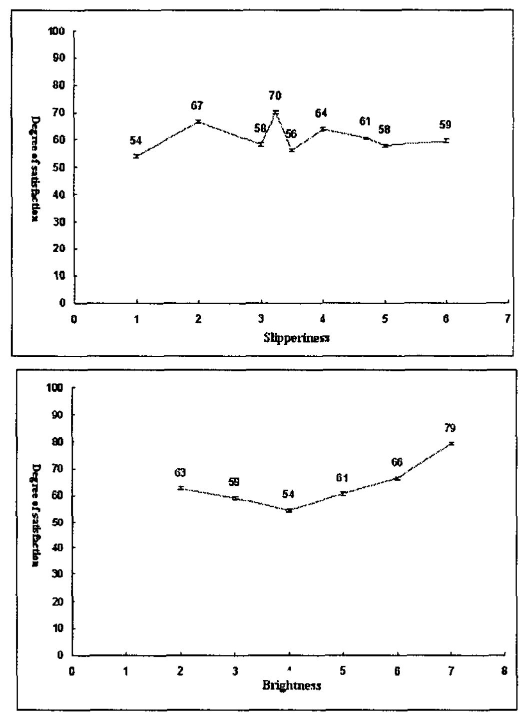

Figure 4. Technical significance analysis of material design variables (crash pad):
(a) slipperiness and (b) brightness

Technical Compatibility

Then, the design variables having both statistical and technical significance were checked to identify if the directions of their effects on satisfaction contradicts to previous findings and knowledge of experts (referred to as technical compatibility). Regression was conducted with a particular design variable as an independent variable and satisfaction as the dependent variable; then, the sign of each regression coefficient was examined for technical compatibility evaluation. As an example, no design variables of crash pad were found showing effects on satisfaction against existing knowledge (see Table 5).

Practical Significance

Last, the design variables having statistical/technical significance and technical compatibility were investigated to check if their effects on satisfaction are large enough from a practical aspect (defined as practical significance). A design variable which has a negligible effect on satisfaction should be better excluded from a satisfaction model for simplicity reasons.

The practical significance of a design variable was analyzed in three steps: (1) grouping levels of the variable by a multiple comparison test, (2) averaging satisfaction scores for each group, and (3) comparing the differences in average between the groups with a criterion designated. For example, as shown in Table 4, the levels of shininess were grouped into two (group 1: levels 1, 3, 2.5, 2; group 2: levels 4, 5, 6) by Duncan's multiple range test at $\alpha = .05$. Then, the averages of satisfaction scores for the two groups and their difference were calculated. Last, the difference of the two group averages was compared with a criterion (say, 5). Since the average difference (= 7) is higher than the criterion, shininess was considered practically significant. The results of practical significance evaluation for the material design variables of crash pad are displayed in Table 5.

Table 4. Practical significance analysis of shininess

Shininess*	N	Mean	Duncan Grouping	Group average	Difference of group averages
1	90	65	A		
3	269	63	A	63	
2.5	60	63	A		
2	210	61	A		7
4	90	57	B		
6	29	55	B	56	
5	148	55	B		

* 1~7(1: very dull, 3: dull, 5: shiny, 7: very shiny)

Recoding the Levels of Variables

Ordering and Recoding the Levels of Categorical Variables

The levels of a categorical design variable were ordered by satisfaction score average to develop a satisfaction model with simplicity. By ordering and then recoding the levels of a variable, a linear relationship could be constructed between satisfaction and the recoded variable. As an example, Figure 5 shows the levels of embossing shape were ordered by satisfaction score and then recoded.

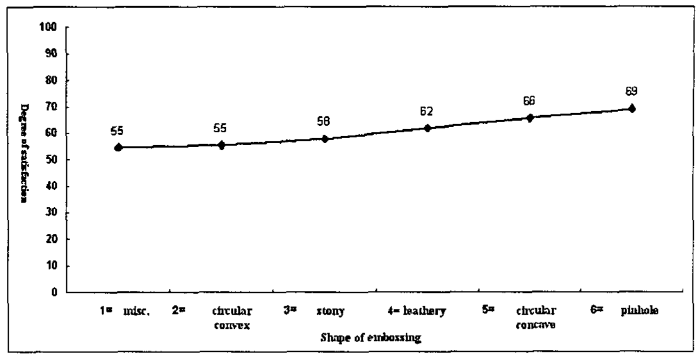

Figure 5. Ordering and recoding the levels of embossing shape

Grouping and Recoding the Levels of Variables

To develop a satisfaction model with simplicity, the levels of a variable that are insignificantly different in satisfaction were grouped and recoded. To group the levels of a particular variable, Duncan's multiple comparison test was applied. Figure 6 demonstrates that the levels of shininess can be grouped into two (group 1: levels 1 to 3; group 2: 4 to 6).

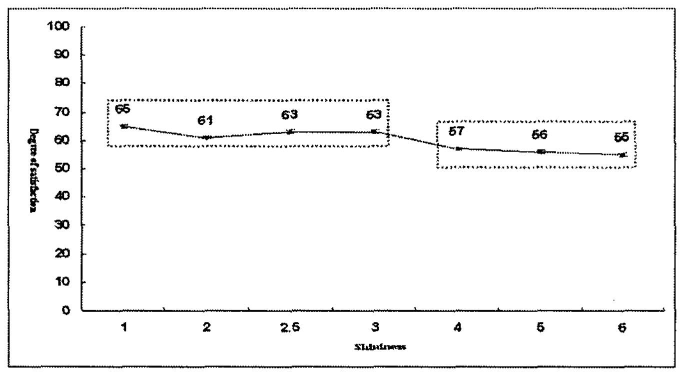

Figure 6. Grouping and recoding the levels of shininess

Developing and Applying Satisfaction Models

Developing Satisfaction Models

Satisfaction models were developed for the six interior parts by stepwise regression with design variables that were screened and recoded. As an example, Equation 1 is a satisfaction model ($r^2 = .148$) for crash pad materials, indicting four material variables (color, shininess, embossing shape, and softness) are important in predicting satisfaction for a certain crash pad material.

$$y = 56.54 + 1.45x_2' - 3.07x_5' + 1.45x_6' - 7.99x_{12} \quad \text{(Equation 1)}$$

where:

x_2'(color) = 1 (deep blue), 2 (dark blue), 3 (dark purple), 4 (achromatic), 5 (yellow), 6 (blue), 7 (orange), 8 (reddish yellow)

x_5'(shininess) = 1 (1 to 4 of shininess level; dull) ~ 2 (5 to 7 of shininess level; shiny)

x_6'(embossing shape) = 1 (miscellaneous), 2 (circular convex), 3 (stony), 4 (leathery), 5 (circular concave), 6(pinhole)

x_{12} (softness) = 1 (very soft) ~ 7 (very hard)

* x_2' and x_6': variables with levels ordered; x_5': variable with levels grouped

Applying Satisfaction Models

By using the satisfaction models developed, improved material designs were suggested for the six interior parts. As an example, Table 6 displays a material design of crash pad which was prepared by combining the levels of design variables that were identified as those maximizing satisfaction in the technical significance analysis.

In addition, by using the satisfaction models, the potential effects of the improved designs on satisfaction were examined and compared with other material designs. Table 7 illustrates the mean estimates and 95% confidence intervals of satisfaction for three different crash pad materials; the satisfaction level of the suggested design is 14 to 28 points higher than those of the materials in the two vehicles surveyed.

Table 6. An improved design of crash pad material

Code	Design var.	Alternative	Preference from technical tendency
x_2	Color	reddish yellow	reddish yellow ≻ orange, blue, yellow ≻ achromatic, dark purple, dark blue, deep blue
x_5	Shinines s	dull	dull ≻ shiny
x_6	Shape of embossi ng	pinhole	pinhole, circular concave ≻ leathery , stony ≻ circular convex, miscellaneous.
x_{12}	Softness	soft	soft ≻ hard

Table 7. Prediction of satisfaction scores (crash pad)

Model	Average	95% confidence interval
A	57	56~59
B	71	69~73
Proposed design	85	76~94

Discussion

The present study identified 15 design variables for the interior materials of a passenger car by using three types of sources (web sites of customer reviews, opinions of interior design engineers, and previous studies of interior materials). From these various sources, a comprehensive set of interior design variables could be defined effectively for the satisfaction survey. In addition, it was identified that the internet is a valuable resource to extract information of designs affecting customers' satisfaction.

Of the 15 design variables, the values of 5 variables (shininess, clearness of embossing, roughness, softness, and slipperiness) were determined by subjective judgment of 4 experimenters. The subjective judgment method was used for design variables where corresponding objective methods were unavailable. While the present study averaged evaluations of the experimenters to determine the value of a design variable, the measure mode can be employed as an alternative.

Methods of screening design variables and recoding the levels of variables were proposed to develop satisfaction models that are stable and significant from practical and technical aspects. Design variables were included in the models which showed satisfactory statistical powers, had practically significant effects on satisfaction, demonstrated systematic changes in satisfaction, and were in agreement with corresponding previous findings. Next, the present study has quite a few categorical variables (e.g., 4 out of 13 variables for crash pad, see Table 2) with 2 to 8 levels; thus, use of indicator variables for these categorical variables in regression analysis would produce a satisfaction model with undesirable complexity.

References

Han, S. H., Yun, M. H., Kim, K. J., Kwahk, J., Evaluation of product usability: Development and validation of usability dimensions and design elements based on empirical models, *International Journal of Industrial Ergonomics* 26, pp477-488, 2000.

Jindo, T., and Hirasago, K., Application studies to car interior of Kansei engineering, *International Journal of Industrial Ergonomics 19*, pp105-114, 1997.

Nakada, K., Kansei engineering research on the design of construction machinery, *International Journal of Industrial Ergonomics 19*, pp129-146, 1997.

Nishimatsu, T., Kamijoh, M., Toba, E., Ishizawa, H., Influence of covering fabric for hand feel of automotive seat, *JSAE Review*, Vol. 22, pp372-374, 2001.

Tanoue, C., Ishizaka, K. and Nagamachi, M., Kansei Engineering: A study on perception of vehicle interior image, *International Journal of Industrial Ergonomics 19*, pp115-128, 1997.

Yun, M. H., Han, S. H., Ryu, T., Yoo, K., Determination of critical design variable Based on the characteristic of products Image/Impression: Case study of office chair design, *45th Human Factors and Ergonomics Society Annual Conference*, Minneapolis, Minesota, USA, October 8-12, 2001.