

Creating a Vehicle Proportion, Form, and Color Matching Model

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Abstract: Product design in the manufacturing industry is one of the most critical elements influencing consumer purchase behavior. As consumer values become increasingly diverse, design is becoming an important element for automakers as well. To address this issue, the authors took a Customer Science approach, creating supporting ideas for product development that capture the customers' sense. One original idea was creating a Vehicle Proportion, Form, and Color Matching approach method, and the effectiveness of this tool was then verified. The first step in the research process was to conduct a survey of sensory words and then perform a principal component analysis and cluster analysis to identify the elements that influence vehicle preference. Next, an eye camera and electroencephalograph (EEG) was used to analyze line of sight and discover the areas that caught customers' attention. The insights gained from these investigations were then used to create 3D-CAD model cars with different proportions and forms, which were in turn analyzed using experimental design (DE) and analytic hierarchy process (AHP) methods to identify ideal relationships among proportion, form, and color. The effectiveness of the proposed model in supporting idea generation during actual vehicle design and development was then verified.

Keywords: vehicle, Proportion, Form, Color, Matching Approach Model

I. Introduction

Product design in the manufacturing industry is one of the most critical elements influencing consumer purchase behavior. As consumer values become increasingly diverse, design is becoming an important element for automakers as well. Unfortunately, as people's values and subjective preferences become more varied and complex, it becomes increasingly difficult to accurately define their wants and needs. To address this issue, the authors took a Customer Science approach, creating supporting ideas for product development that capture the customers' sense. One original idea was creating a Vehicle Proportion, Form, and Color Matching approach method, and the effectiveness of this tool was then verified. The first step in the research process was to conduct a survey of sensory words and then perform a principal component analysis and cluster analysis to identify the elements that influence vehicle preference. Next, an eye camera and electroencephalograph (EEG) was used to analyze line of sight and discover the areas that caught customers' attention. The insights gained from these investigations were then used to create 3D-CAD model cars with different proportions and forms, which were in turn analyzed using experimental design (DE) and analytic hierarchy process (AHP) methods to identify ideal relationships among proportion, form, and color. The effectiveness of the proposed model in supporting idea generation during actual vehicle design and development was then verified.

II. Background

The development of a Customer Science approach able to identify customer wants for the purpose of market creation has become increasingly critical in recent years. The core challenge is using better overall vehicle quality—in other words, employing statistics—as a means of scientifically (numerically) representing the customers' unspoken senses (customer preferences) in design work. Reforming this business process is absolutely essential to successfully creating attractive vehicles.

Figure 1 shows the sensory elements of design work. It starts with the three elements (1) proportion (profile design), (2) form, and (3) color. Recent design work strategies make it a point to optimize business processes so that they are in line with the vehicle design concept from the product planning stage. Next, each element must be matched: (4) proportion and form, (5) form and color, and (6) proportion and color. Finally, all three elements—(7) proportion, form, and color—must be integrated harmoniously to address modern market demands.

As an example of a business process innovation that addresses profile design (1), the authors (Amasaka, 2005) applied the Customer Science approach to Lexus design work and used it to spur the development of design. The authors have simultaneously reported examples of other innovations in form (2) and color (3), while additional research examples have focused on proportion and form matching (4) and form and color matching (5).

Based on the insights gained from the above research, the authors (Toyoda, Nishio, 2014) now attempt to develop a Matching Approach Method to integrate proportion and color (6) as well as the three elements (proportion, form, and color) together (7). Details are given in the following sections .

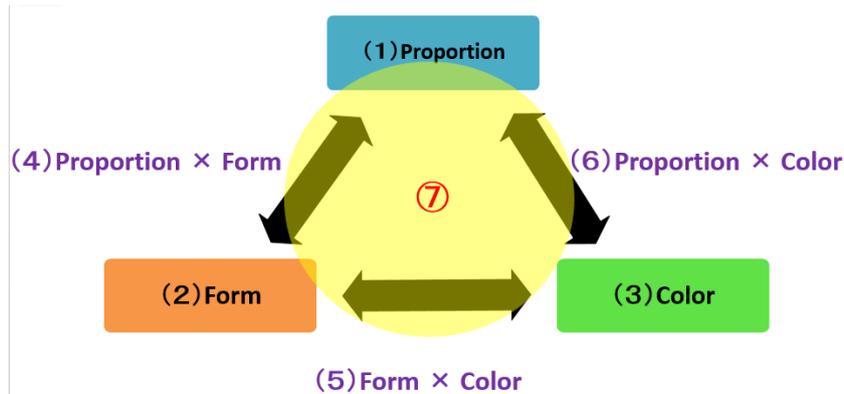


Fig 1. The sensory elements of design work

III. Developing A Vehicle Proportion, Form, And Color Matching Approach Model.

This study quantitatively determines the customers’ senses in order to clearly and rationally identify the unspoken characteristics of vehicle design with the purpose of developing optimum proportion, form, and color matching. The approach is shown in figure 2.

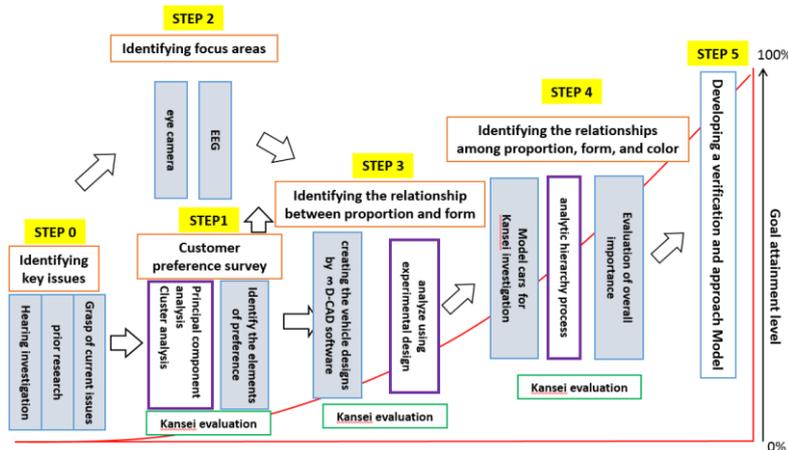


Fig 2. A vehicle proportion, form, and color matching model

3.1 Identifying Key Issues (STEP 0)

To better understand today’s auto industry, the authors began by conducting interviews with key automakers and dealers as well as with customers. They also consulted prior research to see which issues had already been addressed and which have yet to be clearly identified.

3.2 Customer Preference Survey (STEP 1)

The authors conducted a customer preference survey based on the key issues identified above. In this step, customers were given a questionnaire to find out which vehicles they were interested in and to pinpoint the main factors they considered when purchasing a vehicle. Once the data was collected, the authors subjected it to a principal component analysis and a cluster analysis in order to quantitatively determine the relationships among different customer senses.

3.3 Identifying Focus Areas (STEP 2)

In this step, the authors used the insights gained from the customer preference survey in STEP 1 to recruit test subjects that resembled target customers. Once the test subjects were selected, they were each fitted with an eye camera to analyze line-of-sight information. This told the authors where the subjects placed their attention when looking at vehicles. At the same time, an electroencephalograph (EEG) was used to measure brain waves. This device ascertained how the subjects were feeling when they looked at certain parts of the car.

3.4 Identifying the Relationship between Proportion and Form (STEP 3)

The authors continued to build upon the information gained in the previous steps in order to identify the relationship between proportion and form, two of the critical elements in exterior automotive design. To do this, they used 3D-CAD software to actually convert vehicle characteristics into numerical specifications, thus actually creating the vehicle designs that customers want.

3.5 Identifying the Relationships among Proportion, Form, and Color (STEP 4)

The models designed in STEP 3 were then analyzed using statistics (Design of Experiments (DOE) and AHP) to select the model that had the optimum combination of design elements.

3.6 Developing a Verification and Approach Model (STEP 5)

Finally, the authors evaluated the success of the model selected in STEP 4. Test subjects were again fitted with EEG equipment as the authors compared their reactions to the selected model and other vehicle designs. The effectiveness of the model developed using their approach method was thus confirmed.

IV. Application: Development And Effectiveness Of The Vehicle Proportion, Form, And Color Matching Approach Model.

The development of the Vehicle Proportion, Form, and Color Matching Approach Model outlined in the previous section was applied to young men in their 20s to see whether the model selected by the method would match their preferences. The effectiveness of the research was thus confirmed.

4.1 Customer Preference Survey (STEP 1)

In order to identify the current state of vehicle sales and design, the authors conducted interviews between June and August with automotive companies (Nissan, Toyota, Honda), design firms (Kansai pain, Toyota design institute), dealers (Netz Toyota Fuchinobe), and customers (51 men in their 20s) to find out what they prioritized when building cars and/or the kinds of cars they hoped to drive. The interviews revealed a gap between the vehicle concepts held by automotive companies and design firms on the one hand, and the look of the vehicles that customers wanted.

Interviews with dealers also revealed that customer demands were not being sufficiently addressed. One of the reasons for the key issues identified in the interviews was that customer demands were often unexpressed and therefore difficult to identify. The authors thus sought to develop the Vehicle Proportion, Form, and Color Matching Approach Method based on customers' senses with the idea of clearly, rationally, and numerically identifying previously unspoken customer desires. The model was then used to help resolve the key issues listed above.

Table 1. The factor loading

Variable Name	Principle Component Scores 1	Principle Component Scores 2
1	0.572	-0.208
2	0.094	0.252
3	0.521	-0.562
4	0.709	0.303
5	0.825	-0.002
6	0.343	0.055
7	0.277	-0.592
8	0.263	0.304
9	0.700	0.202
10	0.409	-0.446
11	0.533	-0.420
12	0.359	0.644
13	0.615	0.052
14	0.448	-0.142
15	0.531	0.295
16	0.361	-0.253
17	0.748	-0.017
18	0.295	-0.028
19	0.780	0.113

Table 2. Principle component scores

Sample Name	Principle Component Scores 1	Principle Component Scores 2
Refined	1.141	0.266
Traditional	-1.469	0.820
Eye-catching	-1.265	-1.717
Smart	-0.025	0.804
Modern	-0.268	-1.956
Calm	0.138	1.342
Orthodox	-0.946	1.529
Individual	-*0.143	-1.635
Roundish	-1.136	0.028
Advanced	0.862	-0.650
Sporty	0.443	-0.179
Luxurious	1.291	0.140
Sophisticated	1.203	0.460
Stylish	1.226	-0.034
Compact	-0.843	0.939
Square	-1.373	0.352
Practical	0.389	0.874
Feeling of oppression	-0.841	0.238
Cool	1.841	-0.194
Youthful	0.218	0.139
Showy	-0.433	-1.567

The first step was to survey young men in their 20s and subject the collected data to a principal component analysis and a cluster analysis. Tables 1 and 2 show the factor loading and principle component scores from the principal component analysis; these were used to identify 21 sensory words (refined, eye-catching, traditional, etc.) and the correlations among them as well as to assign meaning to the principle components.

Figure 3 shows the subjects categorized into five purchase behavior groups based on the cluster analysis: (1) disinterested, (2) functionality-oriented, (3) self-expression-oriented, (4) outward appearance-oriented, and (5) practicality-oriented. The self-expression and outward appearance group were combined into an “exterior design-oriented” group and selected as targets for further research. To identify more specifically the core preferences of these customers, the cluster analysis data was transposed and sensory words for the exterior design group were summarized into five clusters (see figure 4).

In line with the results of the principal component analysis, it was found that four sensory words from the clusters (luxurious, sophisticated, stylish, and cool) represent the demands of the members of the exterior design group.

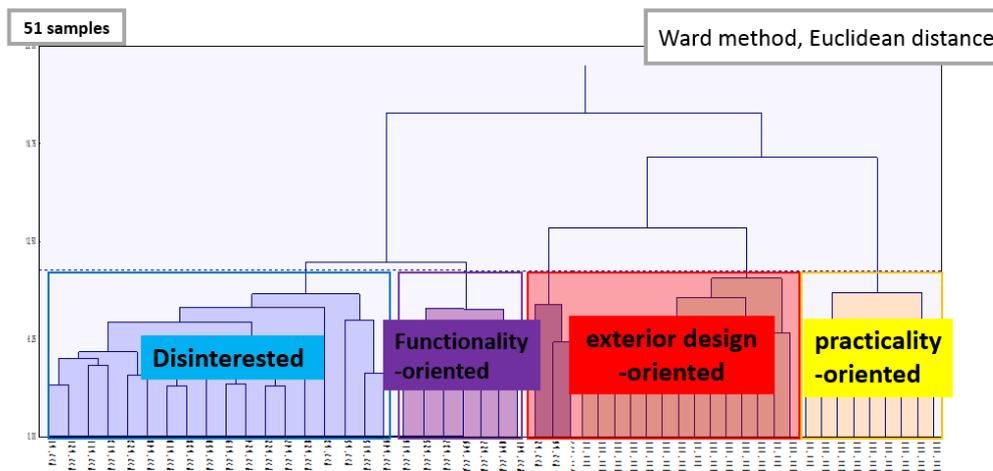


Fig 3. Five purchase behavior groups based on the cluster analysis

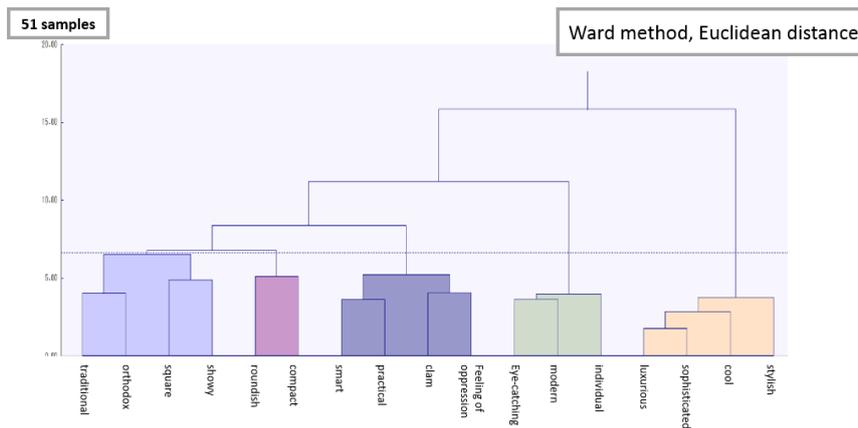


Fig 4. Identify more specifically the core preferences of these customers

In line with the results of the principal component analysis, it was found that four sensory words from the clusters (luxurious, sophisticated, stylish, and cool) represent the demands of the members of the exterior design group.

4.2 Identifying Focus Areas (STEP 2)

During this step, male subjects in their 20s were fitted with optical cameras and EEG equipment for testing. The optical cameras measured line-of-sight information using a camera mounted on a headpiece as well as a camera that detects pupil movement. The areas viewed by the subjects are shown in red marker in figure 5, providing quantitative information on where they were looking. The EEG is a device that measures electrical signals emitted from each part of the cerebrum, and allows researchers to predict correlations between human behavior and brain activity. Figure 6 shows the alpha waves measured with the EEG equipment. The solid red line represents high alpha waves, while the blue line represents low alpha waves. The size of these values makes it possible to quantitatively determine the parts of the vehicle subjects were giving the most attention.



Fig 5. Providing quantitative information on where they were looking

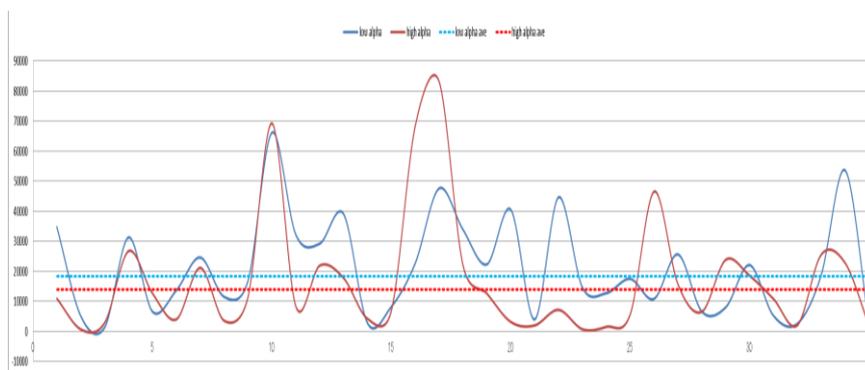


Fig 6. The alpha waves measured with the EEG equipment

4.3 Identifying the Relationship between Proportion and Form (STEP 3)

The authors next used 3D-CAD software to actually design a vehicle exterior that reflected the critical proportion and form element as indicated in the results obtained above (see figure 7). The study used a mid-size sedan and selected standard proportion and form dimensions based on collections of dimensional body drawings from Jidosha Koronsha (see table 3) and then numerically represented them at three levels. The authors then created models that combined different front (length of the front windshield, edge and groove lines), side (hood bulge, strength of character lines), and rear (C pillar angle, rear bumper width) form elements.

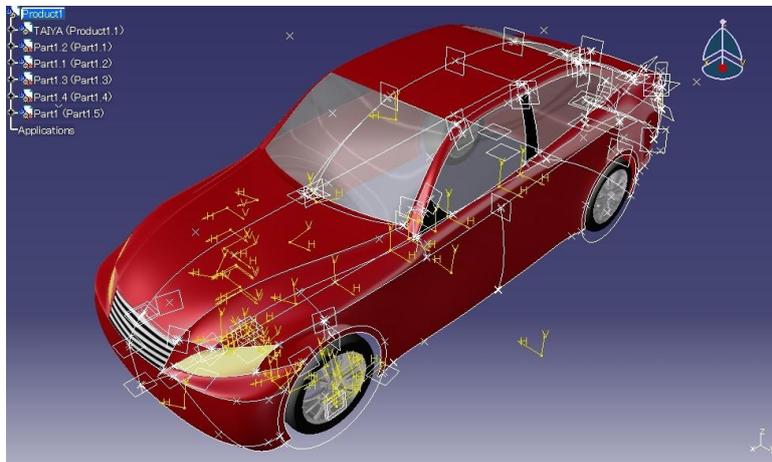


Fig 7. Designing a vehicle exterior that reflected the critical proportion and form element

Table 3. Selected standard proportion and form dimensions

Model	length of the front windshield	hood bulge	edge and groove lines
A	730	40	40
B	655	25	15
C	805	25	15
D	655	50	15
E	805	50	15
F	655	25	45
G	805	25	45
H	655	50	45
I	805	50	45

4.4 Identifying the Relationships among Proportion, Form, and Color (STEP 4)

The nine models designed in STEP 3 were analyzed using Design of Experiments (DOE) to determine the optimum combination of design elements. As shown in table 4, the analysis revealed that factor A (length of the front windshield), factor B (hood bulge), factor C (edge and groove lines), and the interplay between factors B and C had a 5% significance—indicating that shallow edge and groove lines were more significant than differences in hood bulge. Similarly, table 5 shows that when it came to the side areas, the interplay between the strength of the character lines and the angle of the A pillar also had a 5% significance. These results allowed the authors to identify two front patterns, one side pattern, and one rear pattern.

Table 4. Analysis result (Front part)

Factor	Sum of Squares	Flexibility	Variance	Variance Ratio	Test
A	20.816	1	20.816	21.575	**
B	11.391	1	11.391	11.806	**
C	5.348	1	5.348	5.543	*
AB	0.660	1	0.660	0.684	
AC	1.266	1	1.266	1.312	
BC	7.223	1	7.223	7.486	*
ABC	2.250	1	2.250	2.332	
Error	7.719	8	0.965	0.558	

Table 5. Analysis result (Side part)

Factor	Sum of Squares	Flexibility	Variance	Variance Ratio	Test
A	3.754	1	3.754	2.099	
B	10.160	1	10.160	5.682	*
C	14.063	1	14.063	7.864	*
AB	1.129	1	1.129	0.631	
AC	1.266	1	1.266	0.708	
BC	16.000	1	16.000	8.948	*
Error	16.094	9	1.788	1.042	

Three colors (black, white, red) were added to the model to create six alternatives (Type A, Type B, Type C, Type D, Type E, Type F). They were then subjected to an analytic hierarchy process (AHP) in order to identify the model that optimally matched the sensory words that represent the demands of the exterior design group. Models created using 3D-CAD software were given to subjects to visually compare using a paired comparison method in order to assign priority levels to the different standards and alternatives. The test subjects' subjective responses were gathered using a questionnaire. Table 6 shows the relative priority of each standard (sensory word) and alternative (CAD model). This information was then comprehensively evaluated to identify the model with the best proportion, form, and color combination.

Table 6. The relative priority (Standard)

Subject	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative 6
1	0.13	0.17	0.12	0.10	0.16	0.32
2	0.13	0.15	0.10	0.13	0.18	0.30
3	0.09	0.10	0.26	0.39	0.06	0.11
4	0.25	0.29	0.03	0.04	0.15	0.24
5	0.33	0.31	0.19	0.09	0.02	0.06
6	0.31	0.34	0.16	0.10	0.06	0.03
7	0.31	0.34	0.16	0.10	0.06	0.03
8	0.06	0.11	0.08	0.07	0.21	0.48
9	0.17	0.16	0.06	0.08	0.31	0.21
10	0.19	0.23	0.09	0.25	0.11	0.13

The analysis indicated that among young men in their 20s within the exterior design group (the target of the study), two models created using this method (Type B, Type F) received the highest evaluation score of 0.21 (see figure 8). The results indicate that the Type B model, with a front windshield length of 805 mm, a hood bulge of 50°, edge and groove lines of 45°, emphasized strong character lines, an A pillar angle of 30°, and black paint, has the “cool” sensory word as its main focus. The Type F model had the same proportions and form as Type B in red, and has the “luxurious” sensory word as its main focus.



Fig 8. Two models created using this method (Type B, Type F)

4.5 Verification, Creating a Vehicle Matching Approach Model (STEP 5)

The models identified in STEP 4 were verified, and the authors were then able to develop the Vehicle Proportion, Form, and Color Matching Approach Model. Here, EEG equipment was used to measure the subjects' alpha waves as they looked in random order at the models they were asked about in the STEP 4 questionnaire. Figure 9 shows the results of this test; namely, that the models triggering the highest alpha wave

values were the same models that the study predicted through the Matching Approach Model. The effectiveness of the model was thus confirmed.

V. Conclusion

This study focused on three vehicle design elements that were handled separately in the past (proportion, form, and color) and attempted to match them all while pinpointing their correlations to customer senses. In order to get this information, the authors made full use of statistical tools (multivariate analysis, DOE, AHP), optical cameras, EEG equipment, and 3D-CAD software to develop a Matching Approach Model. Their research demonstrated that this model can be used to clearly and rationally identify previously unspoken customer senses. In future studies, the effectiveness of the model will be tested with other age groups as well.

References

Journal Papers:

- [1]. Amasaka, K., (2002) , New JIT, A New Management Technology Principle at Toyota, International Journal of Production Economics, Vol. 80, pp.135-144.
- [2]. Amasaka, K., (2005), Constructing a Customer Science Application System “CS-CIANS”- Development of a Global Strategic Vehicle “Lexus” Utilizing New JIT -, WSEAS (World Scientific and Transactions on Business and Economics, Issue3, Vol.2, pp.135-142.
- [3]. Asami, H., Owada, H., Murata, Y., Takebuchi, S. and Amasaka, K. (2008), The A-VEDAM Model for Approaching Vehicle Exterior Design, Journal of Business Case Studies, Vol. 7, No. 5, pp.1 –8.
- [4]. Asami, H., Ando, T., Yamaji, M. and Amasaka, K. (2010), A Study on Automobile Form Design Support Method “AFD-SM”, The Journal of Business & Economics Research, Vol.8, No.11, pp. 13-19.
- [5]. Muto, M., Miyake, R. and Amasaka, K. (2011), Constructing an Automobile Body Color Development Approach Model, Journal of Management Science, Vol.2, pp. 175-183.
- [6]. Takebuchi, S., Asami, H. and Amasaka, K. (2012), An Automobile Exterior Design Approach Model Linking Form and Color, China-USA Business Review, Vol.11, No.8, pp. 1113-1123.
- [7]. Muto, M., Takebuchi, S. and Amasaka, K. (2013), Creating A New Automotive Exterior Design Approach Model -The Relationship Between Form and Body Color Qualities-, Journal of Business Case Studies, Vol.9 No.5, pp. 367-374

Books:

- [8]. Amasaka, K., (2004), Science SQC, New Quality Control Principle: The Quality Strategy of Toyota], Springer.
- [9]. Amasaka, K. ed., (2012), Science TQM, New Quality Management Principle: The Quality Management Strategy of Toyota] Bentham e-Books: Bentham Science Publisher.
- [10]. Amasaka, K., (2014), New JIT, New Management Technology Principle, Tayler and Francis Group (Forthcoming).