Assessing Design Strategies in Modular Product Development

Bing-Hsuan Wu, Chung-Chuan Wang, Chung-Shing Wang, Ching-Hu Yang

***Abstract*—In the process of product development, it is essential to grasp customer preference and reduce development cost accurately. How to use product modularization to improve sharing of components in mass production, to meet the demand of consumers by the advantage of product diversity, is an important topic worth discussing. In this study, the modular architecture of product components was established by the domain mapping matrix. First, fuzzy Delphi method was introduced to evaluate the criteria of customer requirements. Secondly, design structure matrix method categorized the customer requirements to the goals of design and parts to the modular groups. Finally, analytic network process based on super matrix were used to find the weights for modular parts and assess the design strategies for a product development. Based on the research, three upright fitness bicycles were designed to realize the concept of product diversity.**

***Index Terms*—Fuzzy Delphi; Design Structure Matrix (DSM); Domain Mapping Matrix(DMM); Analytic Network Process (ANP).**

I. INTRODUCTION

The model for product development can divide into the re-design of existing product family, as well as the development of new products. The product development process is established in the existing product structure, and then through the improvement of parts, functions or new styles to meet consumer expectations. To face the market competition, the modularity for product parts has become one of the most effective ways to achieve the goal of product diversity and lowering development cost at the same time [1, 2].

Based on changing markets, fierce competition, as well as changing consumer preferences, product development is becoming more and more challenging. New product development (NPD) is an important issue for the enterprise, especially in the industry chain of fast-moving consumer goods belonging to a short product cycle or seasonal demand [3].

Applying the concept of customizing products to product development in mass production through the application of market segmentation and modular architecture, the design of the product family can meet the needs of consumers. Modular product architecture (MPA) provides solutions for the demand for product standardization and optimization of manufacturing processes. It provides significant help to increase supply chain management and inter-sector coordination [4, 5, 6].

Through the method of product development strategy analysis, this research will obtain the following aims:

1. To assist the designer to determine the user requirement in the designing stage.
2. To get the visualized results of the module of the design parts.
3. To evaluate the weights of the modular parts and finish the design strategy of the product development project.

II. METHODOLOGY

A. Fuzzy Delphi Method

Fuzzy Delphi method is a combination of the traditional Delphi method with fuzzy set theory in order to address some of the ambiguity of the Delphi panel consensus [7]. This study utilizes triangular fuzzy membership function to determine the relation between the levels of consensus within the expert panel. The cognitive fuzziness is found using the conservative and optimistic value from expert opinion to carry out fuzzy integration. Defuzzification is used to find the consensus for within expert opinions.

Fuzzy Delphi method can be expressed as following:

1. Collect opinions of experts: Find the evaluation score of conservative value, best value and optimistic value to form a fuzzy range.
2. For each evaluation item i, establish the triangular fuzzy set in conservative value $C^i = (C_L^i, C_M^i, C_U^i)$ and optimistic value $O^i = (O_L^i, O_M^i, O_U^i)$, see Figure 1.
3. The overlapping area is the fuzzy relation of opinion, which is the consensus value G^i and can be expressed as

$$G^i = \frac{O_M^i + C_M^i}{2} \tag{1}$$

4. If an overlapping region exists which means expert opinion is ambiguous. We need to check the value $M^i = (O_M^i - C_M^i)$ and $Z^i = (C_U^i - O_L^i)$. If $M^i > Z^i$, the consensus value G^i can be expressed in membership value $\mu(x)$. When $M^i < Z^i$ which means there is no consensus among the views of experts and extreme views differ greatly from those of other experts. In this case we need to reinvestigate the options.

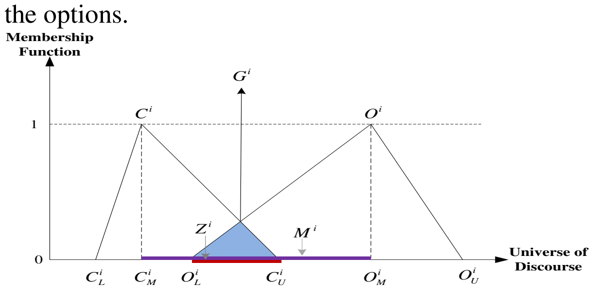

Figure 1. Double triangular fuzzy membership

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B. DSM and DMM

Design Structure Matrix (DSM) was proposed by D. Steward in 1980 [8]. DSM is both a system analysis tool and a project management tool that can illustrate the interdependencies among the elements. A DSM is a square matrix with identical row and column labels.

There are three dependency configurations for DSM elements, i.e., parallel relationship (independency), sequential relationship (dependency), and coupled relationship (interaction). See Figure 2 [9].

1. Parallel relationship: Two elements have no exchange of information and exist as independent functions. The characteristic of this relationship is that tasks A and B can be conducted act at the same time.
2. Sequential relationship: The relationship between the two elements is that they exchange information in a uni-directional manner. The characteristic of this type of relationship is that element B occurs after element A.
3. Coupled relationship: The two elements exchange information readily with each other. In other words, tasks A and B communicate in a bi-directional manner. Task A requires input from task B and vice versa. Tasks A and B often need to exchange information multiple times in order to accomplish their functions.

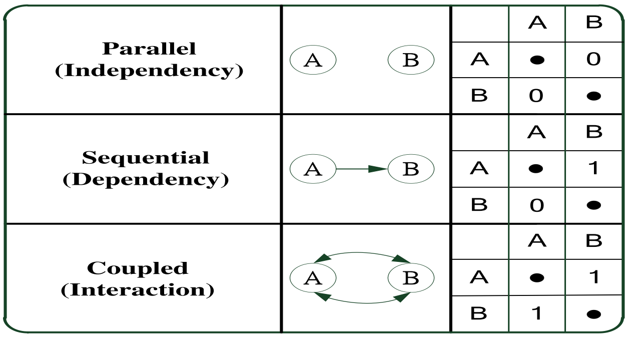

Figure 2. Relationship of elements in DSM

Domain mapping matrix (DMM) is a rectangular ($n \times m$) matrix that maps two DSM domains to present the relationship between these two. For example, in Figure 3, each individual domain can be modeled with a goals DSM ($g \times g$), components DSM ($c \times c$) and procedures DSM ($p \times p$). Three DMMs can be presented to construct the relationship among various domains goals-product DMM ($g \times c$), goals-process DMM ($g \times p$) and product –process DMM ($c \times p$) [10, 11].

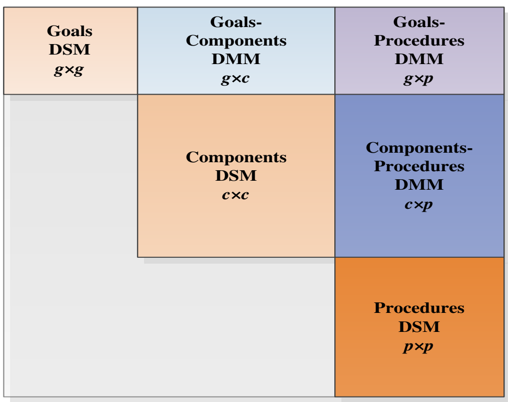

Figure 3. DSM and DMM in product development project

C. Analytic Network Process

Analytic Network Process (ANP) is a practical theory in multi-criteria decision making which derives the composite priority ratio scales from individual ratio scales. ANP consists of a network of criteria and sub-criteria that control the interactions. A super matrix computes for each control criterion. Finally, super matrix is weighted by the priority of its control criterion [12, 13, 14].

Steps of the ANP is outlined as follow:

1. Set a hierarchy structure including the goal, criterion, sub-criterion and program in Figure 4.

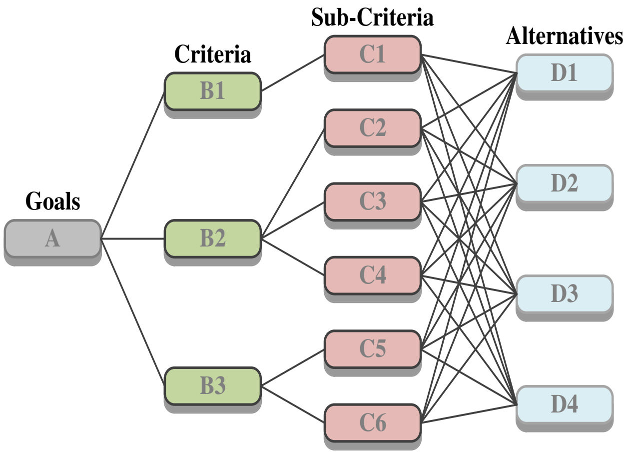

Figure 4. Fundamental structure of ANP

2. A super matrix of ANP was established according to the correlation between the feedback of pairwise comparison matrix. As shown in Figure 5, W_a is the relevance matrix of evaluation criterion for goals. W_b is the evaluated matrix between the interrelated criterion. W_c is the correlation matrix between criterion and sub-criterion. W_d is the feedback matrix between sub-criterion and criterion. W_f is the correlation matrix between sub-criterion and alternatives. W_{ANP} is the super matrix in ANP.
3. Using expert questionnaire to establish all pair-wise comparison matrix and calculate eigen vector for each matrix. Through consistency ratio calculation to confirm the expert investigation is at an acceptable consistency.

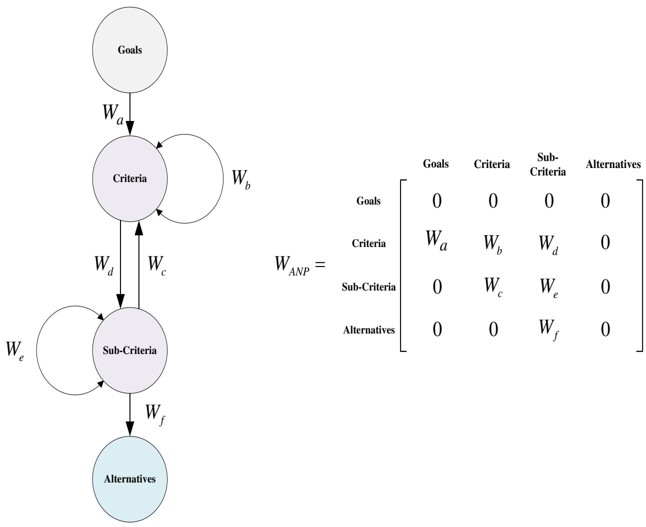

Figure 5. The structure for ANP

4. Construct a super matrix W_{ANP} in ANP process.

$$W_{ANP} = \begin{array}{c} \\ C_1 \\ \\ C_2 \\ \\ \vdots \\ C_m \end{array} \begin{array}{c} \\ e_{11}\\ e_{12} \\ \vdots \\ e_{1n_1} \\ e_{21} \\ e_{22} \\ \vdots \\ e_{2n_2} \\ \vdots \\ e_{m1} \\ e_{m2} \\ \vdots \\ e_{mn_m} \end{array} \overset{\begin{array}{cccc} C_1 & C_2 & \cdots & C_m \\ e_{11}e_{12}\cdots e_{1n_1} & e_{21}e_{22}\cdots e_{1n_2} & \cdots & e_{m1}e_{m2}\cdots e_{mn_m} \end{array}}{\begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1m} \\ W_{21} & W_{22} & \cdots & W_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ W_{m1} & W_{m2} & \cdots & W_{mm} \end{bmatrix}} \quad (2)$$

III. IMPLEMENTATION

A. Customer Requirements by Fuzzy Delphi Evaluation

In this study, 7 users who regularly use upright fitness bikes were interviewed to find out 26 customer requirements for their fitness equipment. Through fuzzy Delphi evaluation, we obtained the importance of each usage from expert advice. The statistical results are filtered by steep slope analysis (scree test) and presented in the form of scatter plot, as shown in Figure 6. Expert consensus threshold value α= 5.56. Based on the fuzzy Delphi evaluation, customer requirements can be rearranged according to rank as shown in Table 1 [15].

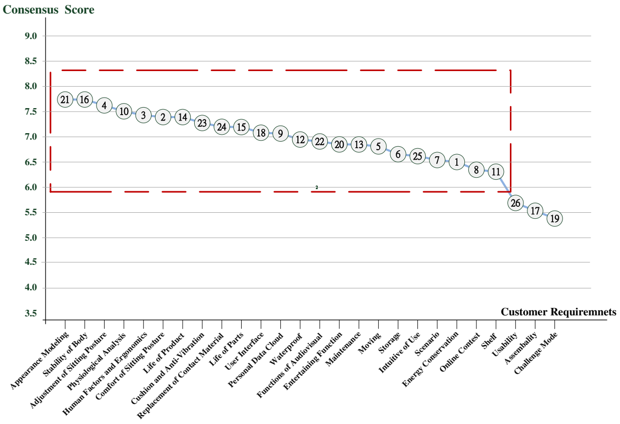

Figure 6. Scatter Plot using fuzzy Delphi evaluation

B. Parts of an Upright Fitness Bike

This research used upright fitness bike as case study. The main parts can separate into 29 items in Table 2, and the explosive diagram shown in Figure 7.

Table 1 Customer Requirements

No.	Items for customer requirements
CR 1	Appearance Modeling (Shape)
CR 2	Stability of Body
CR 3	Adjustment of Sitting Posture
CR 4	Physiological Analysis
CR 5	Human Factors (Ergonomics)
CR 6	Comfort of Sitting Posture
CR 7	Life of Product
CR 8	Cushion and Anti-Vibration
CR 9	Replacement of Contact Material
CR 10	Life of Parts
CR 11	User Interface
CR 12	Personal Data Cloud
CR 13	Waterproof
CR 14	Function of Audiovisual
CR 15	Entertaining Function
CR 16	Maintenance
CR 17	Moving
CR 18	Storage
CR 19	Intuitive of Use
CR 20	Scenario (Simulation)
CR 21	Energy Conservation
CR 22	Online Contest
CR 23	Shelf

Table 2 Parts of Product

P1	Monitor	P16	Right Pedal
P2	Front Frame	P17	Motor
P3	Left Case	P18	Brake
P4	Upside Case	P19	Right Case
P5	Front Case	P20	Transmission Belt
P6	Wheel	P21	Under Frame
P7	Support Frame	P22	Rear Case
P8	Main Frame	P23	Handle
P9	Relay	P24	Adjuster
P10	Battery	P25	Shelf
P11	PCB	P26	Chair Cushion
P12	Left Pedal	P27	Handrail
P13	Left Crank	P28	Right Shelf Groove
P14	Flywheel	P29	Left Shelf Groove
P15	Right Crank		

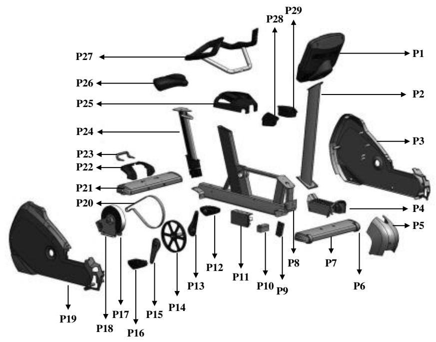

Figure 7. Parts of an upright fitness bike

C. DMM and DSM Partitioned

Figure 8 showed the structure for DSM and DMM for an upright fitness bike used in this research. 23 customer requirements and 29 upright fitness bike parts can be built into their own separate DSM. DMM across two domains can be constructed based on customer requirements and bike parts.

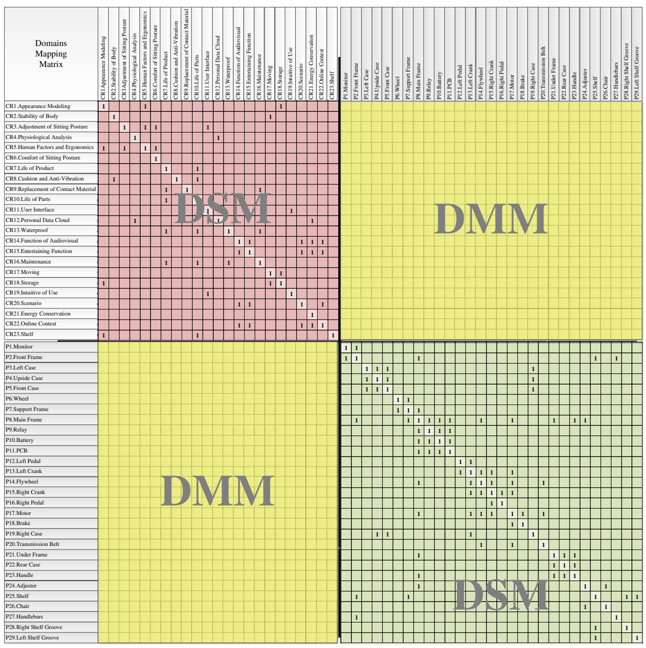

Figure 8. DSM and DMM for an upright fitness bike

Analyzing the coupled elements is of most importance when dealing with DSM. Interactions between these elements are established further by the use of DSM partitioning algorithms. Partitioning is the process of re-ordering the DSM rows and columns so that the new arrangement does not contain iterations. By using the Excel partitioned program from web site: dsmweb.org, we can categorize the customer requirements into 10 groups (G1~G10) (shown in Figure 9) and the parts of the fitness bike into 8 modules (M1~M8) (shown in Figure 10).

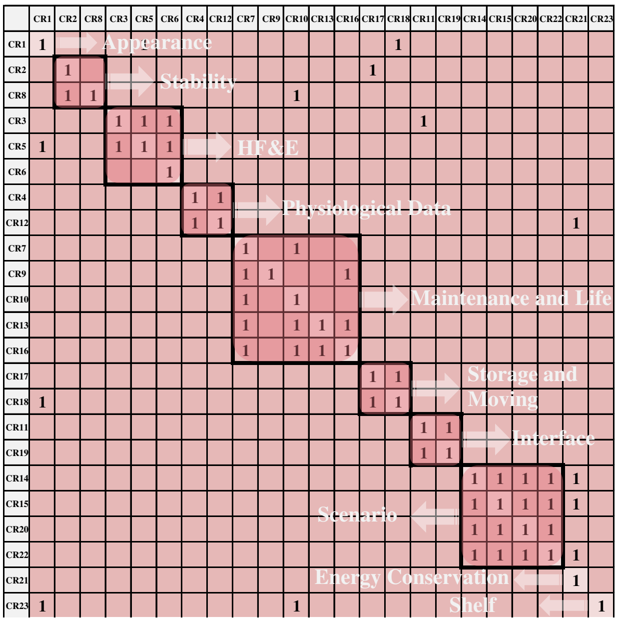

Figure 9. Partitioned DSM of Customer Requirements

D. ANP

Based on the DMM structure, the ANP method can be used to find the most suitable module for redesign. ANP hierarchical structure can be seen in Figure 11. The decision making process sets 10 customer requirements as the evaluation criteria and 8 modules as alternatives, as shown in Figure 12.

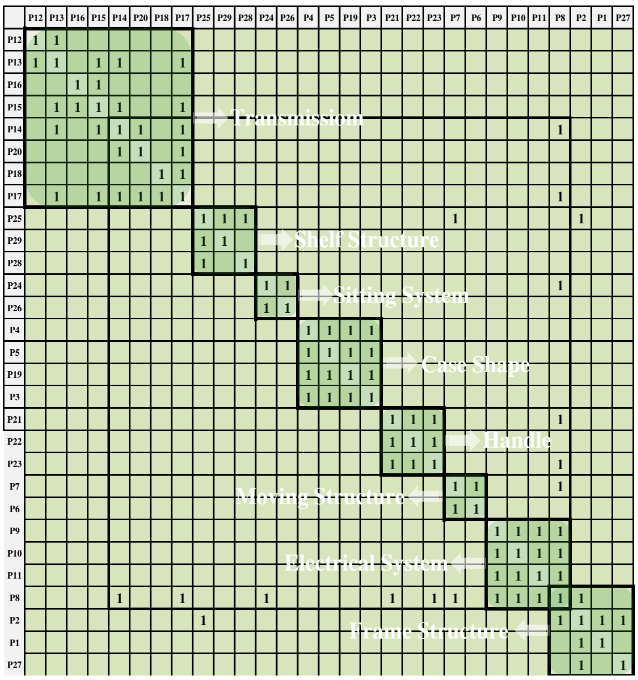

Figure 10. Partitioned DSM of parts module

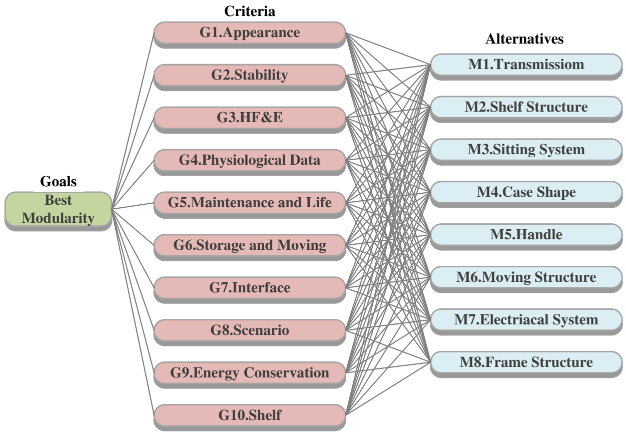

Figure 11. ANP Hierarchy

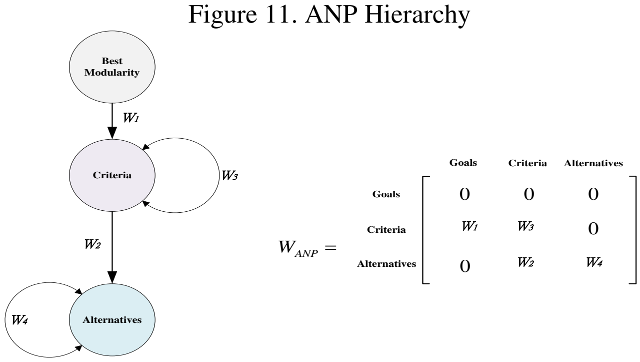

Figure 12. ANP super matrix for the upright fitness bike

The questionnaire design can calculated the super matrix in four parts. (1) W_1: evaluation criteria for goals in comparison matrix, the eigen vector shown in Table 3; (2) W_2: customer requirements to the part modules pairwise comparison; (3) W_3: dependency comparison of customer requirements; (4) W_4: dependencies of the parts modules pairwise comparison. Participants in the questionnaires include five experts users, as well as five R&D department engineers.

Table 3 W_1 eigen vectors

Goals	Description	Geometric average	Eigen value
G1	Shape	2.60	0.19
G2	Stability	2.63	0.19
G3	Adjustable	2.53	0.18
G4	Physiological data	0.67	0.05
G5	Life and maintenance	2.56	0.19
G6	Storage and removal	0.97	0.07
G7	Interface	0.44	0.03
G8	Environment	0.41	0.03
G9	Power saving	0.28	0.02
G10	Deposits	0.72	0.05

$$W_2 = \begin{array}{c} \\ M1 \\ M2 \\ M3 \\ M4 \\ M5 \\ M6 \\ M7 \\ M8 \end{array} \begin{array}{cccccccccc} W_{2G1} & W_{2G2} & W_{2G3} & W_{2G4} & W_{2G5} & W_{2G6} & W_{2G7} & W_{2G8} & W_{2G9} & W_{2G10} \end{array} \begin{bmatrix} 0.13 & 0.14 & 0.10 & 0.12 & 0.13 & 0.10 & 0.10 & 0.18 & 0.24 & 0.06 \\ 0.10 & 0.08 & 0.08 & 0.14 & 0.12 & 0.09 & 0.09 & 0.07 & 0.07 & 0.28 \\ 0.09 & 0.10 & 0.10 & 0.10 & 0.10 & 0.12 & 0.14 & 0.15 & 0.14 & 0.10 \\ 0.23 & 0.19 & 0.22 & 0.16 & 0.18 & 0.17 & 0.23 & 0.09 & 0.08 & 0.18 \\ 0.06 & 0.08 & 0.07 & 0.08 & 0.07 & 0.07 & 0.06 & 0.05 & 0.06 & 0.06 \\ 0.06 & 0.07 & 0.07 & 0.05 & 0.05 & 0.07 & 0.06 & 0.05 & 0.06 & 0.05 \\ 0.03 & 0.05 & 0.04 & 0.03 & 0.04 & 0.06 & 0.03 & 0.22 & 0.18 & 0.05 \\ 0.30 & 0.30 & 0.32 & 0.32 & 0.32 & 0.31 & 0.30 & 0.19 & 0.18 & 0.22 \end{bmatrix}$$

1. From a spaghetti diagram of customer requirements in Figure 13, we can see G1 (shape) has some relationship with G3, G7 and G10. By using pairwise comparison, the eigen vector for $W_3(10\text{x}10)$ can be calculated as follows:

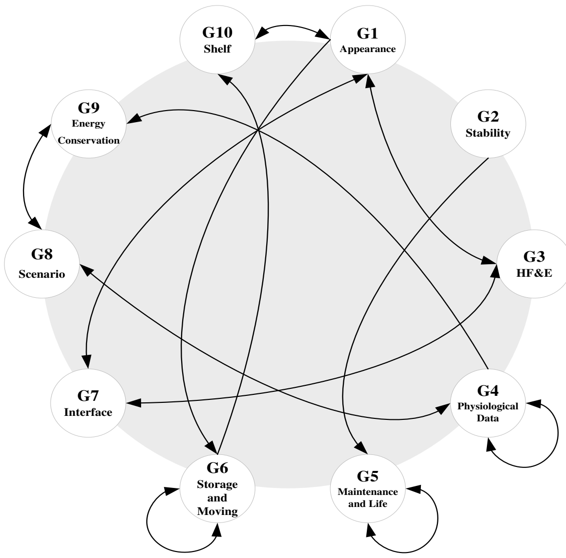

Figure 13. Customer requirements dependent relation (A spaghetti diagram for customer requirements)

2. From the spaghetti diagram for modular parts in Figure 14, we can see that M1 (transmission module) has some relationship with M3 (riding module) and M7 (electronic module). By using pairwise comparison, the eigen vector for $W_4(8\text{x}8)$ can be calculated as:

$$W_3 = \begin{array}{c|cccccccccc} & W_{3G1} & W_{3G2} & W_{3G3} & W_{3G4} & W_{3G5} & W_{3G6} & W_{3G7} & W_{3G8} & W_{3G9} & W_{3G10} \\ \hline G1 & 0 & 0 & 0.77 & 0 & 0 & 0.88 & 0.81 & 0 & 0 & 0.75 \\ G2 & 0 & 0 & 0 & 0 & 0.73 & 0 & 0 & 0 & 0 & 0 \\ G3 & 0.20 & 0 & 0 & 0 & 0 & 0 & 0.24 & 0 & 0 & 0 \\ G4 & 0 & 0 & 0 & 0.25 & 0 & 0 & 0 & 0.32 & 0.30 & 0 \\ G5 & 0 & 0 & 0 & 0 & 0.27 & 0 & 0 & 0 & 0 & 0 \\ G6 & 0 & 0 & 0 & 0 & 0 & 0.22 & 0 & 0 & 0 & 0.25 \\ G7 & 0.63 & 0 & 0.23 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ G8 & 0 & 0 & 0 & 0.75 & 0 & 0 & 0 & 0 & 0.70 & 0 \\ G9 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.68 & 0 & 0 \\ G10 & 0.17 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{array}$$

$$W_4 = \begin{array}{c|cccccccc} & W_{4M1} & W_{4M2} & W_{4M3} & W_{4M4} & W_{4M5} & W_{4M6} & W_{4M7} & W_{4M8} \\ \hline M1 & 0 & 0 & 0 & 0 & 0 & 0 & 0.58 & 0 \\ M2 & 0 & 0 & 0 & 0.17 & 0 & 0 & 0 & 0.18 \\ M3 & 0.68 & 0 & 0 & 0.17 & 0 & 0 & 0 & 0 \\ M4 & 0 & 0.28 & 0.28 & 0 & 0 & 0 & 0 & 0.82 \\ M5 & 0 & 0 & 0 & 0 & 0.55 & 0.42 & 0 & 0 \\ M6 & 0 & 0 & 0 & 0 & 0.45 & 0.58 & 0 & 0 \\ M7 & 0.32 & 0 & 0 & 0 & 0 & 0 & 0.42 & 0 \\ M8 & 0 & 0.72 & 0.72 & 0.66 & 0 & 0 & 0 & 0 \end{array}$$

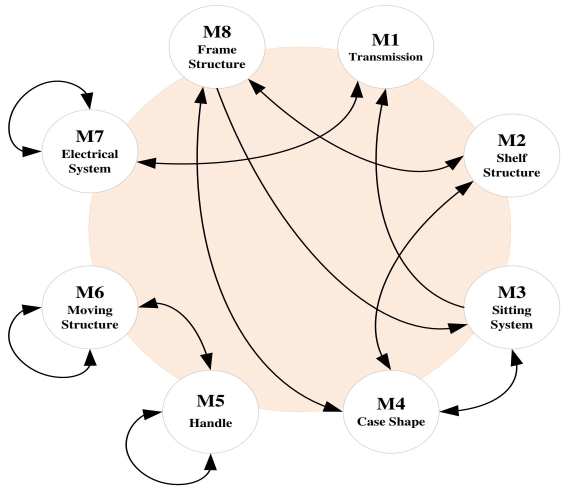

Figure 14. Modular parts dependent relationship (A spaghetti diagram for modular parts)

3. W_{ANP} calculation

The criterion matrix W_G was calculated by multiplying the matrix of the influence of the target W_1 and the influence of the internal dependencies of each criterion W_3, as shown in formula (3). The matrix of the influence of the part module scheme W_M was multiplied by the matrix of the dependent influence of each part module scheme W_4 and the scheme matrix of the criterion W_2, as shown in formula (4). Finally, we used the whole weights for the scheme W_{ANP}, in formula (5), to evaluate the overall architecture.

$$W_G = W_3 \times W_1 \tag{3}$$

$$W_M = W_4 \times W_2 \tag{4}$$

$$W_{ANP} = W_M \times W_G \tag{5}$$

This calculation used the "mmult ()" function of Microsoft Office Excel to solve matrix operations.

$$W_G = \begin{bmatrix} 0 & 0 & 0.77 & 0 & 0 & 0.88 & 0.81 & 0 & 0 & 0.75 \\ 0 & 0 & 0 & 0 & 0.73 & 0 & 0 & 0 & 0 & 0 \\ 0.20 & 0 & 0 & 0 & 0 & 0 & 0.24 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.25 & 0 & 0 & 0 & 0.32 & 0.30 & 0 \\ 0 & 0 & 0 & 0 & 0.27 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.22 & 0 & 0 & 0 & 0.25 \\ 0.63 & 0 & 0.23 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.75 & 0 & 0 & 0 & 0 & 0.70 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.68 & 0 & 0 \\ 0.17 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \times \begin{bmatrix} 0.19 \\ 0.19 \\ 0.18 \\ 0.05 \\ 0.19 \\ 0.07 \\ 0.03 \\ 0.03 \\ 0.02 \\ 0.05 \end{bmatrix} = \begin{bmatrix} 0.26 \\ 0.14 \\ 0.05 \\ 0.03 \\ 0.05 \\ 0.03 \\ 0.16 \\ 0.05 \\ 0.02 \\ 0.03 \end{bmatrix}$$

$$W_M = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0.58 & 0 \\ 0 & 0 & 0 & 0.17 & 0 & 0 & 0 & 0.18 \\ 0.68 & 0 & 0 & 0.17 & 0 & 0 & 0 & 0 \\ 0 & 0.28 & 0.28 & 0 & 0 & 0 & 0 & 0.82 \\ 0 & 0 & 0 & 0 & 0.55 & 0.42 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.45 & 0.58 & 0 & 0 \\ 0.32 & 0 & 0 & 0 & 0 & 0 & 0.42 & 0 \\ 0 & 0.72 & 0.72 & 0.66 & 0 & 0 & 0 & 0 \end{bmatrix} \times \begin{bmatrix} 0.13 & 0.14 & 0.10 & 0.12 & 0.13 & 0.10 & 0.10 & 0.18 & 0.24 & 0.06 \\ 0.10 & 0.08 & 0.08 & 0.14 & 0.12 & 0.09 & 0.09 & 0.07 & 0.07 & 0.28 \\ 0.09 & 0.10 & 0.10 & 0.10 & 0.10 & 0.12 & 0.14 & 0.15 & 0.14 & 0.10 \\ 0.23 & 0.19 & 0.22 & 0.16 & 0.18 & 0.17 & 0.23 & 0.09 & 0.08 & 0.18 \\ 0.06 & 0.08 & 0.07 & 0.08 & 0.07 & 0.07 & 0.06 & 0.05 & 0.06 & 0.06 \\ 0.06 & 0.07 & 0.07 & 0.05 & 0.05 & 0.07 & 0.06 & 0.05 & 0.06 & 0.05 \\ 0.03 & 0.05 & 0.04 & 0.03 & 0.04 & 0.06 & 0.03 & 0.22 & 0.18 & 0.05 \\ 0.30 & 0.30 & 0.32 & 0.32 & 0.32 & 0.31 & 0.30 & 0.19 & 0.18 & 0.22 \end{bmatrix} = \begin{bmatrix} 0.02 & 0.03 & 0.02 & 0.02 & 0.02 & 0.03 & 0.02 & 0.13 & 0.10 & 0.03 \\ 0.09 & 0.09 & 0.10 & 0.08 & 0.09 & 0.08 & 0.09 & 0.05 & 0.05 & 0.07 \\ 0.13 & 0.13 & 0.11 & 0.11 & 0.12 & 0.10 & 0.11 & 0.14 & 0.18 & 0.07 \\ 0.30 & 0.30 & 0.31 & 0.33 & 0.32 & 0.31 & 0.31 & 0.22 & 0.21 & 0.29 \\ 0.06 & 0.07 & 0.07 & 0.07 & 0.06 & 0.07 & 0.06 & 0.05 & 0.06 & 0.05 \\ 0.06 & 0.08 & 0.07 & 0.07 & 0.06 & 0.07 & 0.06 & 0.05 & 0.06 & 0.06 \\ 0.05 & 0.07 & 0.05 & 0.05 & 0.06 & 0.06 & 0.04 & 0.15 & 0.15 & 0.04 \\ 0.29 & 0.26 & 0.27 & 0.28 & 0.28 & 0.26 & 0.32 & 0.22 & 0.20 & 0.39 \end{bmatrix}$$

$$W_{ANP} = \begin{bmatrix} 0.02 & 0.03 & 0.02 & 0.02 & 0.02 & 0.03 & 0.02 & 0.13 & 0.10 & 0.03 \\ 0.09 & 0.09 & 0.10 & 0.08 & 0.09 & 0.08 & 0.09 & 0.05 & 0.05 & 0.07 \\ 0.13 & 0.13 & 0.11 & 0.11 & 0.12 & 0.10 & 0.11 & 0.14 & 0.18 & 0.07 \\ 0.30 & 0.30 & 0.31 & 0.33 & 0.32 & 0.31 & 0.31 & 0.22 & 0.21 & 0.29 \\ 0.06 & 0.07 & 0.07 & 0.07 & 0.06 & 0.07 & 0.06 & 0.05 & 0.06 & 0.05 \\ 0.06 & 0.08 & 0.07 & 0.07 & 0.06 & 0.07 & 0.06 & 0.05 & 0.06 & 0.06 \\ 0.05 & 0.07 & 0.05 & 0.05 & 0.06 & 0.06 & 0.04 & 0.15 & 0.15 & 0.04 \\ 0.29 & 0.26 & 0.27 & 0.28 & 0.28 & 0.26 & 0.32 & 0.22 & 0.20 & 0.39 \end{bmatrix} \times \begin{bmatrix} 0.26 \\ 0.14 \\ 0.05 \\ 0.03 \\ 0.05 \\ 0.03 \\ 0.16 \\ 0.05 \\ 0.02 \\ 0.03 \end{bmatrix} = \begin{bmatrix} 0.02 \\ 0.07 \\ 0.10 \\ 0.24 \\ 0.05 \\ 0.05 \\ 0.05 \\ 0.23 \end{bmatrix}$$

4. The eigen vector in W_{ANP} showed the weight of importance. Based on the value, the most worthy development parts module can be determined, as shown in Table 4.

Table 4 The weights for modular parts

Modular No.	Modular Items	Diagram for modules	W_{ANP}
M1	Transmission		**0.02**
M2	Shelf Structure		**0.07**
M3	Sitting System		**0.10**
M4	Case Shape		**0.24**
M5	Handle		**0.05**
M6	Moving Structure		**0.05**
M7	Electrical System		**0.05**
M8	Frame Structure		**0.23**

5. From the results of the study, the maximum weight came from the "exterior" module, followed by "skeleton Structure", followed by "Ride system", followed by "structure of material" and then three identical weight "portable", "mobile" and "Electronic System", the lowest weight value is "Drive system". The design strategy phase uses the previous two projects as the implementation target.
6. Three different design styles were proposed based on frame structure for concept design evaluation, as shown in Figure 15.

Style 1	Style 2	Style 3

Figure 15. Proposed 3 different styles in product

IV. Discussion

From the results of the study we aim to find out style and frame structures that are most important when developing a new upright fitness bike. The style module includes left cover, right cover, upper cover and front cover. Style is the first thing to be noticed by the customer. It creates a good first impression for the user. It has the highest weight value and is very consistent with the importance placed by designer and product manufacturers. Both parties value the appearance of the product for recognition, therefore it is the most frequently mentioned criteria during new product development projects.

The second most important part module in this study is "Skeleton structure module". This covers the main skeleton, the front skeleton, the screen and the handrail. The skeleton is extremely important to the hardware structure of the product. Under the most situations, the user does not have direct contact to the skeleton structure, which is covered by the outer type. In recent years, there have been many innovative design methods, through the exposure or extension of the skeleton to replace the shell-led visual presentation. Its benefits range from opportunity to reduce the number of shell components to reducing mold development costs.

V. Conclusion

The purpose of this study was to explore the strategies of product development by investigating part modules. Fuzzy Delphi theory introduced to obtain customer requirements as evaluation criteria. We imported a modular product development process structured by design structure matrix. Analytic network process with domain mapping matrix established the most worthy module scheme to finish the strategy evaluation for product development.

In this study, an upright fitness bicycle implemented as case study to evaluate the design strategy to reach the following conclusions:

1. Fuzzy theory used to extract the parameters of experts' opinions objectively. The study also used the weight value analysis to screen for important customer demands, such as an important reference criterion for designing strategy. These references were then evaluated and imported to following product development procedure to obtain quantitative results.
2. The partition rule of the DSM was designed and product parts were reordered with respect to relevance and dependency. This helped to achieve visualization result of the component grouping and allowed establishment of modularization of the product parts.
3. The domain mapping matrix was used to build the parameters of different fields to compare and appraise the importance of the project. In this paper, the analytic network process method was introduced to evaluate the importance of the part module scheme and the optimal weight was calculated as a reference for the designer to implement new strategies for product development.

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References

[1] M. Bonev, L. Hvam, J. Clarkson, A. Maier, "Formal Computer-aided Product Family Architecture Design for Mass Customization," *Computers in Industry*, 2015, 74, 58-70.

[2] M.V. Martin, K. Ishii, "Design for Variety: Developing Standardized and Modularized Product Platform Architectures," *Research in Engineering Design*, 2002, 13, 213-235.

[3] A. Kampker A., P. Burggräf, C. Deutskens, A. Maue, & R. Förstmann, "Integrated Product and Process Development: Modular Production Architectures based on Process Requirement." *Procedia CIRP*, 2014, 20, 109-114.

[4] S.W. Hsiao and J. R. Chou, "A Creativity-Based Design Process for Innovative Product Design," *International Journal of Industrial Ergonomics*, 2004, 34, 421-443.

[5] K.T. Ulrich & S.D. Eppinger, *Product Design and Development*. (5th Ed). NewYork : McGraw-Hill, 2012.

[6] A. Kusiak, C.C. Huang, (1996). "Development of Modular Products," *IEEE Transactions on Components, Packaging, and Manufacturing Technology*, 1996, Part A, 19(4), 523-538.

[7] Y.L. Hsu, C.H. Lee, V.B. Kreng, "The Application of Fuzzy Delphi Method and Fuzzy AHP in Lubricant Regenrative Technology Selection," *Expert Systems with Applications*, 2010, 37, 419-425.

[8] T.R. Browning, "Applying the Design Structure Matrix to System Decomposition and Integration Problems: A Review and New Directions," *IEEE Transactions on Engineering management*, 2001, 48(3), 292-306.

[9] S.D. Eppinger, & T.R. Browning, *Design Structure Matrix Methods and Applications*, MIT press, 2012.

[10] M. Danilovic, & T.R. Browning, "Managing Complex Product Development Projects with Design Structure Matrices and Domain Mapping Matrices," *International Journal of Project Management*, 2007, 25(3), 300-314.

[11] M. Maurer, U. Lindemann, (2007). "Structural Awareness in Complex Product Design - The Multiple Domain Matrix," *DSM2007: Proceedings of the 9th International DSM conference*, Munich, Germany, 16-18 October, 2007, 73-86.

[12] T.L. Saaty, "Fundamentals of the Analytic Network Process," *Proceedings of the Fifth International Symposium on the Analytic Hierarchy Process, ISAHP* 1999, Kobe, Japan, August 12-14, 1-14.

[13] C.L. Hwang, & M.J. Lin, *Group Decision Making under Multiple Criteria: Methods and Applications*. Springer-Verlag, 1987.

[14] S.W. Hsiao, & H.P. Wang, "Applying the Semantic Transformation Method to Product Form Design," *Design Studies*, 1998, 19(3), 309-330.

[15] D. Dubios, *Fuzzy Set and System: Theory and Applications.* (1st Ed), San Diego, Academic Press, 1980.

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