An Application of Fuzzy-AHP Approach to a Product Variety Management Problem

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***Abstract*—Due to the proliferation of mass customization, firms are struggling to explore the balance between the number of product variants and operation performance. In this article, a soft approach of the decision making on product variety management is proposed. A fuzzy-analytic hierarchy process (Fuzzy-AHP) is a main tool; however, we also introduce an applicable procedure in which consists of other decision tools, such as, group technology, activity-based costing analysis, and brainstorming in order to make this research project practical. A sample automotive part manufacturer is the case experiment. It faced with more than 1,200 SKUs and deteriorated the performance of manufacturing system. However, there were arguments from different perspectives from different managers about discontinuing products. The proposed method compromised all crisp information from relative departments and all numerical information from factory's activities. The results show that the sample factory could reduce the product variety by 311 SKUs, about 26%. This makes the company more efficiency by reducing setup cost, material handling cost, warehouse space, and all other relevant operations.**

***Index Terms*—analytic hierarchy process, product variety, fuzzy, soft approach, decision making**

I. Introduction

The proliferation of product variety has been increasing as the changing of manufacturing paradigm from mass production to mass customization [1]. It is a trend of many industry sectors worldwide [2] and also be an effective strategy for increasing sale volume because it allows a firm to serve a number of different market segmentations [3]. Due to the negative impacts of product variety on operation performance, many studies have focused on the trade-off between the product variety and operation performance. [4].

In literature, there are a number of studies which devote to optimize between product variety and other key factors; such as production performance, logistics performance, and inventory management efficiency [5]. Fisher and Ittner [6] made used of simulation technique in order to testify the impacts of product variety on the manufacturing performance. They reported that the product variety had a significant impact to productivity of assembly lines.

Wang et al. [7] balanced between product variety and manufacturing complexity. The best set of product variants could be found by deploying a multi-objective mathematical model, then, solved by genetic algorithm. The numerical experiments were demonstrated in the article. Fujita and Yoshida [8] studied how to design the module combination and module attributes simultaneously in order to optimized product variety by considering manufacturing process constraints. A combinatorial mathematical programming was proposed and solved by a number of optimization techniques: a branch-and-bound, quadratic programming, and genetic algorithm. The design of a commercial airplane was used as an example. The result showed that the procedure of simultaneous design between module combination and module attributes was valid and effective.

In our study, nevertheless, the problem is attacked differently. As the requirements of the sample factory, it needs to consider all relevant factors, especially, the perspectives of all departments in the factory. It is not just only quantitative analysis, but also qualitative analysis. As a result, the Fuzzy-AHP technique [9] was presented as a main solving tool. Additionally, we also present a framework of tool set in which making this study project practical in a real industrial situation.

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This paper is organized as follows. Section 2 presents the problem statement and research method of this study. We then describe, in Section 3, the case simulation and its results. The discussion of the results are drawn in the section as well. Section 4 concludes the findings of the study, and also projects the direction of future research for interested researchers.

II. Research Methology

A. The Sample Factory

The sample factory produces vehicle brake pads for the aftermarket segmentation. The products are used for replacing when the original parts were worn and then end of used. The factory serves the market worldwide in both domestic market and international market. The number of product variety explodes to 1,200 stock keeping units (SKUs). This makes the factory struggling to satisfy customers' needs while maintaining low manufacturing cost.

The problem at hand is how many SKUs should the factory keep? And which one must be discontinued. The more complicated issue is, it is not just an economical optimization problems, but also the problem of subjective decision making; since, the different managers have different points of view on keeping or terminating the SKUs. In the perspective of production department manager, for example, she wants to produce only large batches because it makes production system more productive. In the perspective of marketing manager, however, she needs to keep loyalty of customers by offering rare SKUs in which other companies could not do. This is one example of arguments between departments. The problem at hand is how to compromise these arguments in our approach?

B. Fuzzy-AHP Approach

Analytic Hierarchy Process (AHP) was first proposed by Saaty [10] in order to cope with a scarce resource allocation problem of military in the early 1970s. It, then, was modified to deal with the linguistic nature of human judgements. As a result, the Fuzzy-AHP approach was introduced in which comprises the following steps [11-13]:

Step 1: Pairwise comparisons between criteria and sub-criteria by using 5-point fuzzy scale in order to express uncertain and imprecise preferences for core attributes.

Step 2: Aggregate the different managers' decision. Letting S evaluators assess m core attributes and expert k conducts pairwise comparisons by using a fuzzy scale. The relative importance of C_i over C_j is shown by the following fuzzy matrix:

$$S_k = \begin{bmatrix} b_{11k} & b_{12k} & \cdots & b_{1mk} \\ b_{21k} & b_{22k} & \cdots & b_{2mk} \\ \vdots & \vdots & \vdots & \vdots \\ b_{m1k} & b_{m2k} & \cdots & b_{mmk} \end{bmatrix} \quad (1)$$

where b_{ijk} represent the fuzzy preference of C_i over C_j assessed by evaluator k for $i = 1,2,..,m$, $j = 1,2,...,m$, and $k = 1,2,..,S$. The experts' decisions, then, are aggregated through Eq. (2) – (4).

$$b_{ij} = \left(L_{ij}, M_{ij}, U_{ij}\right) b_{ji} = b_{ij}^{-1} = \left(\frac{1}{U_{ij}}, \frac{1}{M_{ij}}, \frac{1}{L_{ij}}\right) \quad (2)$$

$$L_{ij} = \min_k\left(b_{ijk}\right), M = \text{median}_k(b_{ijk}), U = \max_k(b_{ijk}) \quad (3)$$

$$\acute{b}_{ij} = \left(\frac{L_{ij}+M_{ij}+U_{ij}}{3}\right) \quad (4)$$

where b_{ij} represents an aggregated fuzzy member and $\acute{b}_{ij}$ represents its defuzzified crisp value using the scheme of *centroid of area* method [13].

Stem 3: Computing the maximum eigenvalue and its corresponding eigenvector. As shown in Eq. (5) and (6).

$$A = \begin{bmatrix} \acute{b}_{11} & \acute{b}_{12} & \cdots & \acute{b}_{1m} \\ \acute{b}_{21} & \acute{b}_{22} & \cdots & \acute{b}_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ \acute{b}_{m1} & \acute{b}_{m2} & \cdots & \acute{b}_{mm} \end{bmatrix} \quad (5)$$

$$AW = \lambda_{\max} W \quad (6)$$

where A is an $m \times m$ crisp matrix among m attributes, $\lambda_{\max}$ is the largest eigenvalue of matrix A, and W denotes its corresponding eigenvector. The eigenvector is treated as managers' preferences, in this study.

Step 4: Consistency verification of the decision matrix by using consistency index (CI) and consistency ratio (CR). The following equations are used in this study.

$$CI = \frac{\lambda_{\max} - m}{m-1} \quad (7)$$

$$CR = \frac{CI}{RI} \quad (8)$$

where CI denotes the inconsistency index, and RI is a random index, as shown in Table I. If the value of $CR \leq 0.1$, the decision is consistency; otherwise, the decision needs to be revised.

C. The Proposed Method

We are not only propose a solving method in technical aspect, but we are also present the procedure in term of application by using the sample factory as a case simulation. In this manuscript, nevertheless, we could not describe every step in detail. Fig. 1 depicts the approaching procedure of this research project.

As shown in Fig. 1, the first step is categorizing the products into groups; because, this helps us reduce number of considering sub-attribute needed to consider.

TABLE I. Random Index

m	2	3	4	5	6	7	8	9	10
RI	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

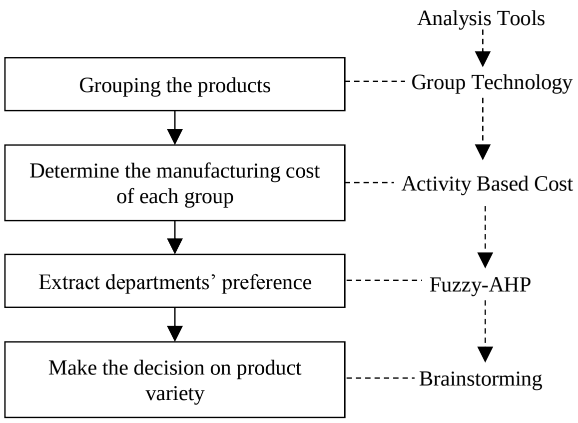

Figure 1. The proposed method of applying Fuzzy-AHP.

Next, the activity-based costing analysis is deployed to determine manufacturing cost of each group. This affects to the consideration of batch sizing, discontinuing, or products' margin.

The Fuzzy-AHP, then, is used to collect the information from all perspectives in the company, marketing, finance, purchasing, quality assurance, production, maintenance departments, etc.

The final step, all well-organized information is presented in a management meeting in order to conduct a brainstorming. The judgement is not only based on measurable and traceable information, but also acceptable by the peer managers.

III. Case Applicaiton and Results

A. Grouping the SKUs

As mentioned before, the factory produces more than 1,200 SKUs in which deteriorated the performance of its manufacturing system. The grouping technology is applied to figure out the similarity of products; however, we focus on the similarity of required process to complete the finish products since the pad brakes are not different in term of parts.

The product grouping starts with studying each product precisely about the processes that products need to be manufactured. Then, we group the similar products in the perspective of required process and process ordering. Typically, the manufacturing of brake pads consists of 12 processes; powder mixing, housing preparation, cold brake pad forming, hot brake pad forming, baking, trimming, surface finishing, first coloring, stamping, shim mounting, second coloring, and packing.

From the study, we could group the production into 478 groups in which each group has the similar processes and its process ordering. This makes us easier to analyze by using AHP because less attributes means less pairwise comparisons and then smaller size of matrices. Table II shows some of product groups and their required processes.

B. Activity-Based Cost Analysis

The activity based costing technique is applied to each process in the manufacturing system. Typically, the analysis accounts for the cost of labors, the cost of energy, the cost of machine and tools, and the cost of consumption materials. We do not consider the direct material cost since we need to compare only on different processes on different product groups.

The data are collected for 12 months from the last fiscal year. The data do not only detailed on processes, but also drills down to the sub-activities of each process. Table III presents the detail cost allocation on labor workforce for producing one unit of the brake pad.

The code means the department in the production department. It can be seen that some processes are fall into the same department; accordingly, it uses the same department's labor. It can be seen from the column of percentage working. It means how much of workforce is allocated to an activity. This information is received from a bilateral meeting between production department and accounting department. The cost allocation is also allocated corresponding to the percentage working. Finally, the cost is divided by the production volume of the last 12 months. As a result, the activity based cost of each unit produced by that activity is presented.

For example, one unit produced by department B in which manufactured by all activities in the department has labor cost of 630.16 units of money. However, if that product manufactured by trimming and surface finishing processes but not by first coloring process, the cost of labor is 471.68 - 353.61 – 0.07 = 118.00 units of money.

TABLE II. Sample of Product Groups

Process	Product Group							
	1-DPM	2-DNP	3-KJY	4-DNX	5-ONL	6-MCH	7-MCJ	8-DCN
Powder mixing	✓	✓	✓	✓	✓	✓	✓	✓
Housing preparation	✓	✓	✓	✓	✓	✓	✓	✓
Cold brake pad forming	✓	✓	✓	✓	✓	✓	✓	✓
Hot brake pad forming	✓	✓	✓	✓	✓	✓	✓	✓
Baking	✓	✓	✓	✓	✓	✓	✓	✓
Trimming	✓	✓	✓	✓	✓	✓	✓	✓
Surface finishing	✓	✓		✓	✓			
First coloring	✓		✓	✓	✓	✓		✓
Stamping	✓	✓	✓	✓	✓	✓	✓	✓
Shim mounting	✓	✓		✓				
Second coloring				✓				✓
Packing	✓	✓	✓	✓	✓	✓	✓	✓

TABLE III. LABOR COST ALLOCATION

Code	Process	Sub-Code	Activity	% of working	Cost (units of money)	Activity Based Cost (units of money/a unit of producing)
A	Powder mixing	A11	Powder preparation	20.00	32,600.00	0.29
		A12	Powder weighing	46.65	76,039.50	9.50
		A13	Mixing and Testing	33.35	54,360.50	67.95
	Total			100.00	163,000.00	77.74
B	Housing preparation	B11	Housing cleaning	4.65	50,685.00	0.09
		B12	Housing gluing	2.35	25,615.00	0.05
		B13	Sorting	2.30	25,070.00	0.04
	Cold brake pad forming	B21	Machine setup	3.70	40,330.00	32.32
		B22	Processing	23.30	253,970.00	0.94
	Hot brake pad forming	B31	Machine setup	14.00	152,600.00	122.28
		B32	Processing	46.60	507,940.00	5.13
	Baking	B41	Counting and sorting	1.25	13,625.00	189.24
		B42	Baking	1.85	20,165.00	280.07
	Total			100.00	1,090,000.00	630.16
C	Trimming	C11	Counting and sorting	5.80	28,127.10	9.38
		C12	Machine setup	8.30	40,250.85	67.08
		C13	Trimming	66.30	321,513.81	0.61
	Surface finishing	C21	Machine setup	0.40	1,939.80	40.41
		C22	Finishing	4.00	19,398.00	0.24
	First coloring	C31	Machine setup	7.00	33,946.50	353.61
		C32	Spraying and baked	8.20	39,765.90	0.07
	Total			100.00	484,941.96	471.68
D	Stamping	D11	Stamping product code	19.00	58,909.50	0.11
		D12	Stamping brand	5.00	15,502.50	0.58
	Shim mounting	D21	Shim mounting	8.50	26,354.25	0.59
	Second coloring	D31	Machine setup	0.50	1,550.25	16.15
		D32	Spraying and baked	5.00	15,502.50	0.22
	Packing	D41	Bag putting	31.00	96,115.50	0.76
		D42	Box putting	31.00	192,231.00	0.76
	Total			100.00	406,165.50	19.17

For more practical example, we would like to show the labor cost of product group 7-MCJ of Table II. The product group needs to be manufactured by all departments but except some processes which are surface finishing, first coloring, shim, and second coloring. Accordingly, the products of 7-MCJ group have labor cost 77.74 + 630.16 + (471.68 – 40.41 – 0.24 – 353.61 – 0.07) + (19.17 – 0.59 – 16.15 – 0.22) = 787.46 units of money. The negative number means the activities in which the product group 7-MCJ does not need to be manufactured. Please noted that we also determine the cost of energy, the cost of machine and tools, and the cost of consumption materials.

C. Fuzzy-AHP Application

There are 3 attributes need to be weighted; marketing, manufacturing, and costing. Each attribute is divided into sub-attributes as shown in Table IV. The weights are determined from the questionnaire on pairwise comparisons; then, the managers and assistant managers of five departments in the company; marketing, production, accounting, purchasing, maintenance fill the questionnaire. The data are analyzed by using the procedure of Fuzzy-AHP as shown in section 2.

From Table IV, the marketing attribute is the most important compared to the manufacturing and the costing. It accounts for 68.0% while costing is the second important attribute with weight 20.6%. And the manufacturing attribute is the last among three attributes; it accounts for 11.4%

Sub-attributes are weighted, as shown in Table IV, according to the survey. The weights of sub-attributes are compared among sub-attributes in each attribute. We need, then, to analyze the weight among universal sub-attributes.

Thus, Table V shows the weights of sub-attributes among 10 sub-attributes. By multiplying the weight of attributes and the weight of sub-attributes, the universal weight of sub-attributes are shown in Table V and their rank are shown in the last column.

As mentioned before, we need to calculate the consistency ratio for evaluating the decision consistency. In this application, the consistency ratio (CR) equals 0.057 in which is less than 0.1. This means the decision is consistency and not need to be revised. Even we have pretty much evidence on both numerical form (cost analysis) and subjective opinion (using Fuzzy-AHP). Practically, we need to do a peer judgement in the final step.

TABLE IV. ATTRIBUTES AND SUB-ATTRIBUTES

Attribute (Weight: B)	Sub-attribute	Weight (A)	Rank
Marketing (Weight 0.680)	Demand volume	0.736	1
	Niche market	0.154	2
	Age of model	0.110	3
Manufacturing (Weight 0.114)	Complexity	0.137	3
	Capability	0.718	1
	Defective rate	0.145	2
Costing (Weight 0.206)	Raw materials	0.587	1
	Production cost	0.256	2
	Inventory	0.086	3
	Designing	0.072	4

TABLE V. WEIGHT ANALYSIS

Attribute	Sub-attribute	A × B	Rank
Marketing	Demand volume	0.500	1
	Niche market	0.105	3
	Age of model	0.074	5
Manufacturing	Complexity	0.016	8
	Capability	0.082	4
	Defective rate	0.016	7
Costing	Raw materials	0.121	2
	Production cost	0.053	6
	Inventory	0.018	9
	Designing	0.015	10

D. Brainstorming

All department managers are gathered in a meeting to consider the relevant information; activity based costing and Fuzzy-AHP weight results. They are asked to evaluate each product group based on the sub-attributes, one at a time. Then, the product groups are ranked based on their total weight. Theoretically, this step is also conducted based on the Fuzzy-AHP; however, it is simpler than the last step.

Nevertheless, the management asked to show more computational analysis by multiplying the gross profit rate of the product group with its weight score. The gross profit rate can be calculated as follows.

$$GR = \frac{(Sale\ Price - Cost)}{Sale\ Price} \times 100 \tag{9}$$

And the determination of gross profit rate and the weight is calculated as follows.

$$GR \times Weight\ Score \tag{10}$$

For example, the product group 7-MCJ has profit of 385.25 units of money; thus, the gross profit rate = (385.25/787.46) × 100 = 48.923. The scores of sub-attribute and the results as calculated by Eq. (10) are shown as table 6. From Table VI, the 7-MCJ group has weight score 3.172. The score is assigned by the management in the brainstorming meeting. Then, the gross profit rate × weight score of product 7-MCJ group = 155.183.

All 478 product groups are determined as an example above. Then, the product groups are ordered descendingly. The more important product groups are listed on the top. Finally, the management discusses cutting the low rank off. They deploy the concept of pareto rule (80/20 rule) on this matter.

E. Results and Discussion

The results are the company cut 132 product groups in which accounts for 311 SKUs off and discontinue production. As a result, there are 896 SKUs left for continue serving customers need. Honestly, we could not measure the customer satisfaction for the discontinue products; nonetheless, we do guarantee that the complexity of the manufacturing system of the sample company is much better than before.

TABLE VI. WEIGHT SCORE OF 7-MCJ

Sub-attribute	Weight	Score (1-5)	Weight × Score
Demand volume	0.500	5	2.500
Niche market	0.105	2	0.210
Age of model	0.074	2	0.148
Complexity	0.016	3	0.048
Capability	0.082	4	0.328
Defective rate	0.016	1	0.016
Raw materials	0.121	2	0.242
Production cost	0.053	2	0.106
Inventory	0.018	3	0.054
Designing	0.015	4	0.060
		Total	3.172

Moreover, the efficiency of the support system is increased. Logically, less SKUs of raw materials, less material handling, less warehouse space needed, and less machine setup time are the evidences of this study. Additionally, cutting by 311 SKUs come from the consent of all relevant departments. It is measurable and traceable. This is one of the top management desire.

IV. CONCLUSIONS AND OUTLOOK

The decision of discontinuing products of a company and implement of mass customization is not simple. Since it concerns many relevant departments and also has issues on different perspectives, number of product varieties became a situation of manufacturing system and other relative operations. In this study, we proposed a framework of applying the Fuzzy-AHP for managing the product variety. The study started with grouping the products of the sample company by using grouping technology. We, then, applied the activity-based cost analysis in order to acquire information about the manufacturing cost of each product group. Next, the Fuzzy-AHP was deployed to quantify the decision of 6 relevant department's management with 3 attributes and 10 sub-attributes. Finally, a group meeting was conducted to make the final decision. By the consent of all department, 311 SKUs were discontinued. This made manufacturing system more efficiency.

However, we need to monitor the impact of this study on both manufacturing system and supply chain management since reducing product variety is also reduce the burden of supply chain management. We also need to quantify the impact in term of economical measurement, evidently.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Thanathorn Karot collected the data; Choosak Pornsing conducted the research; Tongtang Tonglim wrote the final report; Peerapop Jomtong wrote the paper.

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