VARIANT DESIGN OF A PRODUCT FAMILY FOR SEGMENTED MARKET

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Abstrct

Variant design of a product family is an effective approach to simultaneously achieve competence of "time-to-market" and satisfy diverse requirements for different market segment during product development. In this study, a systematic approach of configuration design is proposed to develop a platform of products, which includes platform plans, chunk formation, and component modularity. A case study is, then, presented to illustrate the feasibility of this methodology and algorithm.

Keywords: modularity, platform of products, product family, variant design

1. Introduction

It is no longer possible to dominate market by delivering single product at a time. Increasingly, product development implies to provide a full line of product family and to produce them in a flexible process tailored to the needs of individual customers [1]. The strategy, based on product families sharing a common platform, has been proved to be a successful approach for many industries such as electronics, software, automobile, and domestic appliances [2]. Muffatto [3] described that platform of products can increase speed in product development, reduce development cost, enhance product reliability and variety, reduce managerial complexity, and improve business strategy flexibility.

Muffatto and Roveda [4], further, defined product platform as a set of subsystems and interfaces intentionally planned and developed to form a common structure from which a stream of derivative products can be efficiently developed. Accordingly, platform development can be organized in a strong relation to the other components of the complete product. A platform strategy needs specific problem-solving procedures and is related to other issues such as product

architecture and modularization [5]. Product architecture is to arrange functional elements of a product into physical blocks, which is used to define basic physical building blocks of the product in terms of both what they do and what their interfaces are with the rest of device [6]. Furthermore, modularity tends to support product architecture consisting of physically detachable units, which aims to identify independent, standardized, and/or interchangeable units to satisfy a variety of functions. Modularity has been viewed by Ulrich and Tung [7] as depending on the following characteristics: (1) similarity between physical and functional architecture of the design, and (2) minimization of incidental interactions between physical components.

As a concept, modular design has been explored by various approaches, in which the mapping relationship between design objectives (functional requirements) and physical solutions (design parameters) by clustering analysis of design matrix was proposed by Mitchell and Jianxian [8]. In addition, Salhieh and Kamrani [9] introduced a similarity index to measure functional and physical characteristics among basic components. A clustering technique is, further, used to integrate the basic components into design modules based on their similarity, in which Gu and Sosale [10] developed an integrated modular design methodology for life cycle engineering. Kusiak and Huang [11] proposed an approach to modularize a product by considering both cost and performance of a product. To summarize, the above studies are mostly dealing with single product development and the scope of modular formation is only limited in redesign.

To achieve the objective of simultaneously developing a product family through variant design, there is a need to have an innovative approach, which not only concerns modular design but also develops a platform product. Robertson and Ulrich [1] indicated that the crucial challenge of developing platform product is to concurrently meet the needs from diverse market segments while conserving development and product resources. Thus, the objective of this study is to develop a systematic methodology for configuration design which enables variant design for mass-customization without excessive resources.

2. The systematical configuration design of platform products

Product variety is mainly due to different market characteristics such as lifestyles, cognitions, habitual operational actions, and preferences, which also respond to different level of requirement in single market. The benefits to use existing technology in developing platform product were discussed by Ulrich and Eppinger [12]. The main task of variant design is to distinguish which components could be shared and whether modularity or integrity should be adapted in product architecture. In order to make judgments among platform product developing

requirements, platform product architecture design, product variety, and component-sharing specifications, the authors propose the following approach to develop platform product and product chunks categories and to evaluate product architectures (see figure 1). The following three phases demonstrate the detail of this systematic approach.

2.1 Phase 1: Platform Products Development

To simultaneously develop variant configurations for a product, it is necessary to consider the demands from various market segmentation (Figure 2), which is mainly constructed by lifestyles, ergonomics, and personal preferences, which can also be influenced by competitive products. The planning of derivative design includes form variety, parts replacement, and functional adjustment. Accordingly, the purpose of platform products development is to confirm the differentiation and similarity among a collection of products and build the basis to distinct chunks.
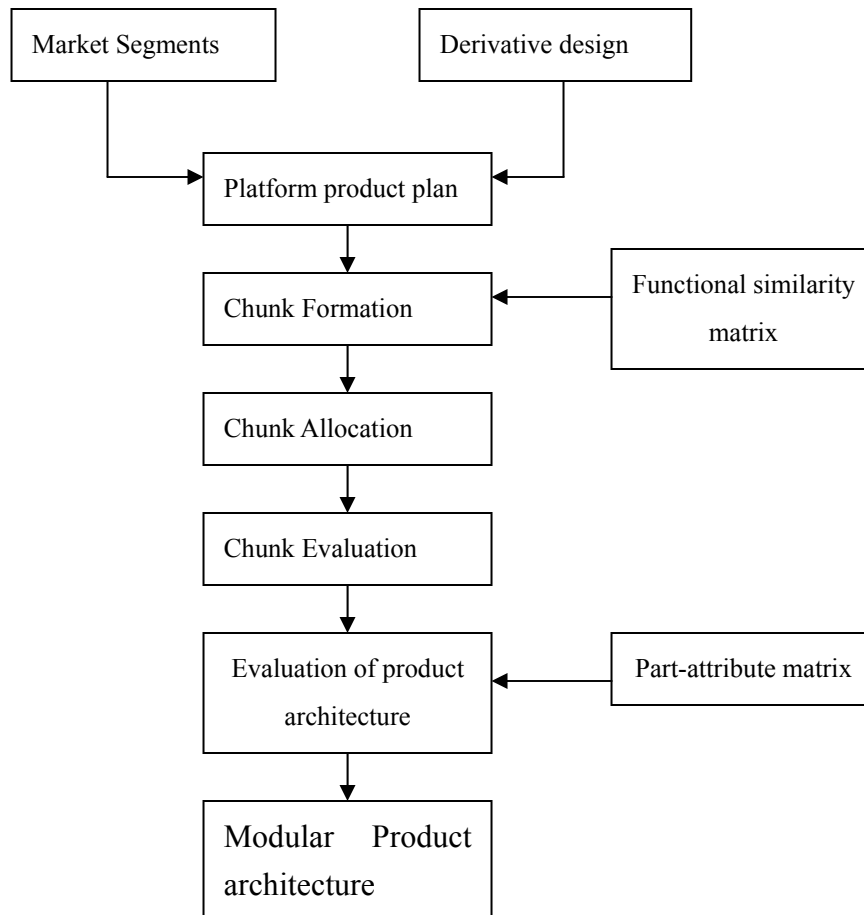
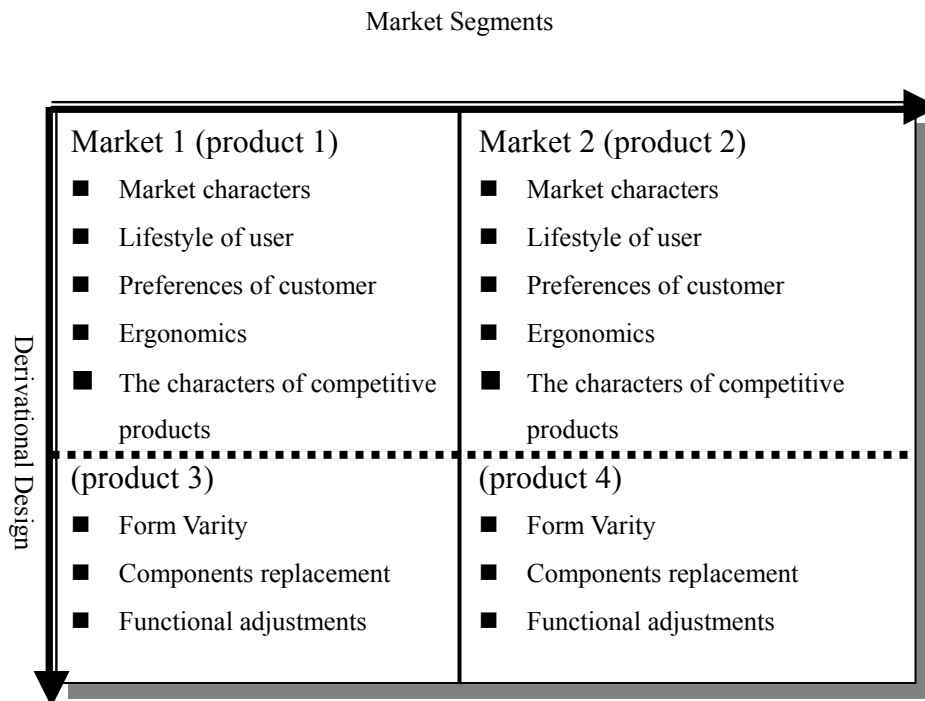Figure 1. The systematical configuration design process

Market Segments

Market 1 (product 1)	Market 2 (product 2)
■ Market characters	■ Market characters
■ Lifestyle of user	■ Lifestyle of user
■ Preferences of customer	■ Preferences of customer
■ Ergonomics	■ Ergonomics
■ The characters of competitive products	■ The characters of competitive products
(product 3)	(product 4)
■ Form Varity	■ Form Varity
■ Components replacement	■ Components replacement
■ Functional adjustments	■ Functional adjustments

Derivational Design (vertical axis label)

Figure 2. The dimensions to build platform product plan

2.2 Phase 2: Chunk Formation, Allocation, and Evaluation

Product design tends to correspond functional factors with physical factors, by means of decomposing parts and recomposing them according to different principles. Pahl and Beitz [13] classified functional requirement spaces into basic functions, auxiliary functions, adaptive functions, special functions, and customer specified functions. Based on the above principle, product architecture is rearranged to basic modules, auxiliary modules, adaptive modules, special modules, and customer-specified modules, which serve to increase the similarity and decrease the interaction among modules.

However, since only very few products can be modulized and then absolutely integrated, an alternative approach is, therefore, proposed to compose product physical factors into chunks and to satisfy single functional request by one set of components or a single part [12]. Accordingly, product architecture can rearrange functional factors by physical chunks and identify the interactions among chunks.

In this study, the authors simultaneously consider platform products development, market requirement for variety, differential components design, product appearance design, and requirement of brand images to develop chunks. Hence, functions and features allocation are integrated to evaluate the modular design in detail. The authors apply group technology (GT) to

distinguish chunks, which utilize a zero-one matrix to indicate the similarity between component i and j. As to the grouping algorithm, the authors apply block diagonalization of such matrix to help identify the chunks, where Rank Order Clustering (ROC) [14] approach used.

After the chunks are identified, further exploration of the possible allocations will lead to final design configurations. The physical relationships among chunks can be obtained by analyzing the interfaces and interactions. In order to demonstrate the possible chunk allocations, full-line rectangles are used to represent chunks, dot-line rectangles as components, and arrowed-straight lines to indicate physical relationships between chunks. These above concise representations are helpful for designers to discover new configurations during innovative designs. However, various chunk allocations need to be verified through perspectives of platform product plan, engineering specifications, product specifications, and customer requirements.

2.3 Phase 3: Product Architecture Evaluation

The architecture of a product is a scheme based on which the functional elements of the product can be arranged into physical chunk and their interactions. Based on the interactions within a product, three categories of modularity have been defined [7]: (1) Component-swapping modularity occurs when two or more different basic components are paired with a module, thus creating variant products belonging to the same product family. (2) Component-sharing modularity is complementary to component-swapping modularity, in which various modules sharing the same basic component create variant products to different product families. (3) Bus modularity occurs when a module match with any number of basic components in a product while component-swapping and component-sharing modularity allows only for the types of basic components to vary.

Parts within specific chunk are reviewed through variant design to identify the degree of similarity among parts and further group them to become appropriate modules. Since level of user requirement and engineering characteristics are the major considerations during variant design, the influential level between attributes and parts must be identified separately. Furthermore, part-attribute matrix is established and modules are constructed through similarity coefficient method by Offodile et al. [15]. In such matrix, value of 0-9 represents the influential level from low to high. The definition of similarity coefficient is shown as follows:

$$S_{ij} = \sum_{k=1}^{K} s_{ijk} \bigg/ \sum_{k=1}^{K} \delta_{ijk} \qquad (1)$$

$$s_{ijk} = 1 - \frac{\left| x_{ik} - x_{jk} \right|}{R_k} \qquad (2)$$

$$\delta_{ijk} = \begin{cases} 1, & \text{If comparison between component i and j is exist for attribute k} \\ 0, & \text{otherwise} \end{cases} \qquad (3)$$

where,

S_{ij} = similarity between component i and component j

s_{ijk} = score between component i and component j on attribute k

x_{ik} = weight assigned to component i for attribute k

x_{jk} = weight assigned to component j for attribute k

R_k = range of attribute k taken over the population space

K = number of attributes

Noted that $0 < S_{ij} < 1$ defining the similarity, in which there is no similarity between part i and part j while S_{ij}=0. After S_{ij} is obtained, parts are, then, assigned to the respective module according to the threshold level determined. At last, the modules are classified into component-swapping modularity, component-sharing modularity, or bus modularity based on their attributes characteristics.

3. Case Study

In this study, the authors select a coffee maker from a Taiwanese public company to illustrate the feasibility of the proposed approach. This company design and develop products in Taiwan for European and American market with production base in China. Since the technologies involved for coffee maker are mature, the main concerns of such design are appearance, operation process, aesthetics, lifestyles, and cognition. Hence, competitive advantages and demands for various market segments must be accomplished by differentiating product structure and operation methods.

3.1 Phase 1: Platform product development

A typical functional requirement of coffee maker includes filling water, boiling water, containing coffee, filtering coffee powder, transporting steam, and pouring coffee. Lifestyle requirements are, for example, whether the filter basket needs to be swing out or not. Besides, the carafe can be made of glass or thermal material determined by local temperature, and shape

Table 1. Development plan of coffee maker

	Market 1	Market 2
Primary design	■ 1.5L water tanker ■ Swing out filter basket ■ Glass carafe ■ V-shaped filter basket	■ 1.5L water tanker ■ Non-Swing out filter basket ■ Glass carafe ■ V-shaped filter basket
Derivation design	■ U-shaped filter basket ■ Thermal carafe	■ U-shaped filter basket ■ Thermal carafe

of filter basket. These features within coffee maker are mainly influenced by stereotypes from local market. Therefore, competitive strategies are proposed to assist product development planning for market 1 and market 2 concurrently.

To possess advantages of market competition, variant product planning and component replacement must be simultaneously considered during product development, such as carafe material changed form glass to thermal, or U-shape filter basket replaced by V-shape. The development plan of coffee maker is illustrated in Table 1. For market 1, the swing out V-shaped filter basket, glass carafe, and 1.5 L water tank are equipped. In addition, U-shaped filter basket and thermal carafe are available as derivative components. On the other hand, product planning of market 2 includes 1.5 L water tank, fixed V-shaped filter basket, and glass carafe.

For market 1, the swing-out filter basket is adopted according to the operational habit from users and the place where coffee maker is need to place. However the operational habit for market 2 is totally different from market 1. In addition, the carafe should be heightened and thickened due to the need for thermal effect, which eliminate the possibility of v-shape basket. The factors mentioned above are simultaneously taken into considerations during platform product development planning.

3.2 Phase 2: Chunks formation, allocation, and evaluation

Components of coffee maker are listed in table 2, the explosion view of product is illustrated in Figure 3, in which the components will be grouped into chunks according to functional correlation and interfaces related. Furthermore, the similarity matrix is established based on the perception from design department. The approach result shown in table 3 based on the R.O.C, four chunks are identified which are body, water tank, heating base, and carafe. In addition, components such as top cover, check valve, water or stream transport system, etc. are obtained as well.

The appearance of coffee maker is strongly bounded to chunks allocation; however, physical

relationship of chunks will affect the final allocation. In order to fulfill functional requirement as well as to satisfy basic constraints, three alternatives in Figure 4-6 are proposed. In alternative 1, four chunks are piled vertically which are C2(water tank chunk), C1(body chunk), C4(carafe chunk), and C3(heater base chunk) from top to bottom (figure 4). Components P3, is placed on two sides to transport water and steam separately. In alternative 2, C2 water tank is placed behind with C1 body chunk placed above C3 carafe chunk and C4 base chunk beneath both C1 and C4 (figure 5). In alternative 3, C1 base chunk is placed above C4 carafe chunk with two C2 water chunks placed on both sides and C4 base chunk located on the base (figure 6). Other allocations, such as the C4 carafe chunk placed above C1 body chunk, can not be adopted since basic design constraints cannot be fulfilled.
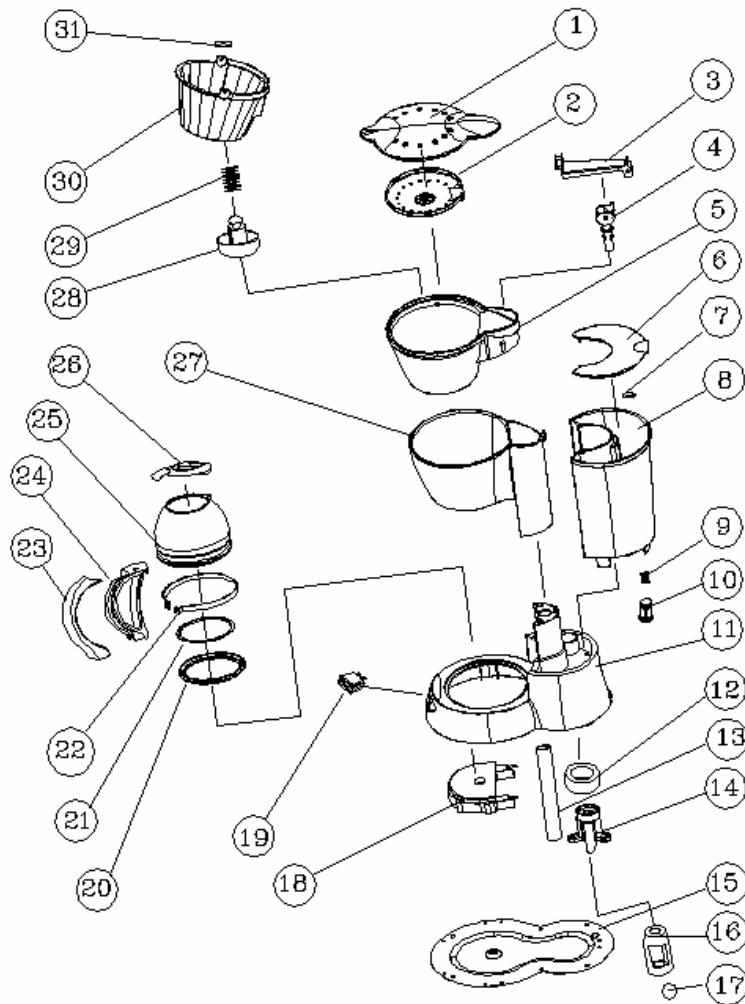

Figure 3. Explored view of coffee maker

Table 2. List of parts of coffee maker

No.	Part name	No.	Part name
1	top Cover	17	packing valve ball
2	top Cover base	18	heating element
3	spout	19	switch
4	spout seat	20	hot plate ring
5	top cover base	21	hot plate
6	water tank cover	22	cup bank
7	water tank packing silicone ring	23	carafe handle cover
8	water tank	24	carafe handle
9	packing spring	25	carafe
10	check valve	26	carafe cover
11	base	27	housing
12	silicone ring	28	filter holder packing valve
13	water outlet pipe	29	filter holder packing spring
14	pipe connection seat	30	filter holder
15	base cover	31	filter holder packing silicone
16	packing valve		

Table 3. Independent chunks and components

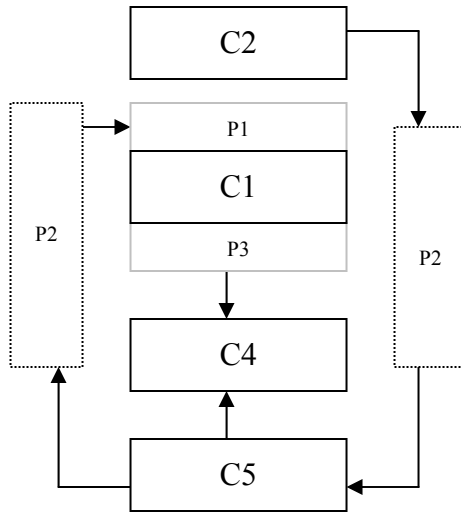|	No	1	2	3	4	30	5	27	8	6	10	7	9	11	15	19	21	20	14	12	13	16	17	18	22	23	24	25	26	28	29	31
P1	1	1	1																													
Top cover set	2	1	1																													
P2	3			1	1																											
Spout seat	4			1	1																											
C1	30					1	1	1																						1	1	1
Housing set	5					1	1	1																								
	27					1	1	1																								
C2	8								1	1	1	1	1																			
Water tank set	6								1	1																						
	10								1		1	1	1																			
	7								1		1	1																				
	9								1		1		1																			
C3	11													1	1	1	1	1														
Base set	15													1	1																	
	19													1		1								1								
	21													1		1	1							1								
	20													1			1	1														
	14																		1	1	1	1	1									
	12																		1	1												
	13																		1		1	1	1	1								
	16																		1		1	1	1									
	17																		1		1	1	1									
	18													1	1						1			1								
C4	22																								1	1	1	1	1			
Carafe set	23																								1	1	1	1	1			
	24																								1	1	1	1	1			
	25																								1	1	1	1	1			
	26																								1	1	1	1	1			
P3	28					1																								1	1	1
Filter holder	29					1																								1	1	1
Packing valve set	31					1																								1	1	1

Figure. 4. Chunks allocation 1
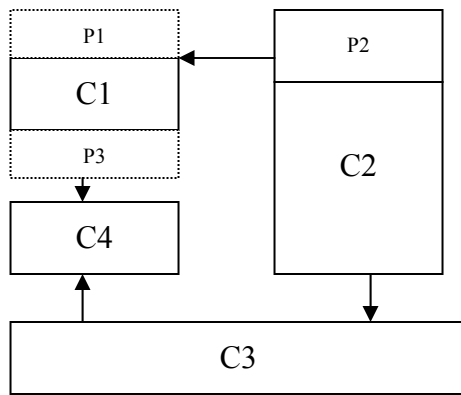
Figure 5. Chunks allocation 2
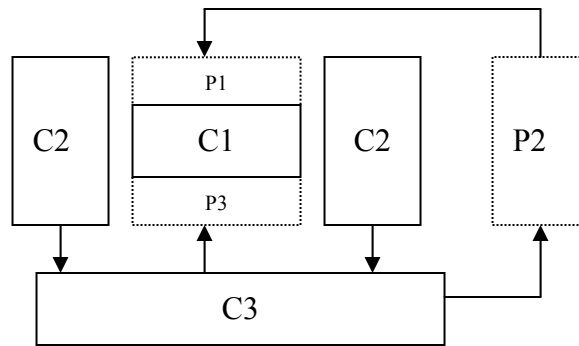
Figure 6. Chunks allocation 3

Table 4. Allocation evaluation

Dimensions	Weights	Allocation 1	Allocation 2	Allocation 3
1.Form originality	0.29	5	3	7
2.Derivation design requirement	0.21	1	7	3
3.Lifestyles requirement	0.13	1	5	3
4.Assembly easiness	0.08	3	7	3
5.Cleaning easiness	0.15	3	5	1
6.Operation easiness	0.14	5	5	3
	1	2.97	**3.53**	3.23

In order to select the appropriate chunk allocation, not only the experience of designers but also the methodology of platform products plan must be used. In addition, market requirements and engineering specifications are both under consideration. First, six characteristics are proposed to define proper chunk allocations which includes form originality, possibility for variant design, accordance with lifestyles, easy assembly, easy cleaning, and easy operation. Through Analytic Hierarchy Processing (AHP), product designers and engineers within such case company worked together to decide the weights of six parameters, which are 0.29,0.21,0.13,0.08,0.15 and 0.14. After this stage, seven points' differential scales are used to measure the different level. Finally, according to the opinion from product designers and engineers, the result is shown in Table 4 where allocation 2 is the ideallest choice due to the considerations below. Firstly, allocation 2 obtains higher value in variant design requirement, which is due to such design can replace the C1 housing set from V-shape to U-shape without affecting C2 water tanker set and C3 base set. Thus, allocation 2 allows to derivate new products in a comparatively low cost. On the contrary, alteration of C1 housing set will change the original design structure in both allocation 1 and 3. Secondly, allocation 2 possesses the leadership in easy of assembly since such design is less complicated in relationship chunk. However, swing-out basket filter will affect the C2 water tank set equipped in both sides of allocation 3. In allocation 1, C2 water tank set must be adjusted to match the design of fixed filter.

3.3 Phase 3: Product Architecture Evaluation

According to the above platform product plan, the difference between two primary designs has been identified as whether the filter basket should be swung out or not. Since the variant designs involve in the shape of filter basket and the material of carafe, the choice of product architectures are, therefore, depended on: the analysis of chunks interfaces and judgment of modular types. C1 filter basket can be designed as both swing-out and fixed types, however, both exist the issue of torque exchange with C2 water tank chunk. In order to save cost in exchanging relationship with P3 water or steam transport tube, components P3 is integrated into

Table 5. Modular Analysis

	Differential design		Derivation design	
	Form	Operation process	Parts replacement	Specification modification
base	8	4	4	1
base cover	4	0	4	1
switch	4	6	4	1
hot plate	2	0	2	1
hot plate ring	2	0	2	1
pipe connection seat	0	0	0	0
silicone ring	0	0	0	0
water outlet pipe	0	0	0	0
packing valve	0	0	0	0
packing valve ball	0	0	0	0
heating element	0	0	0	8

Table. 6. Similarity among parts

	base	base cover	switch	hot plate	hot plate ring	pipe connection seat	silicone ring	water outlet pipe	packing valve	packing valve ball	heating element
base	0.00	0.78	0.83	0.67	0.67	0.53	0.53	0.53	0.53	0.53	0.36
base cover		0.00	0.83	0.89	0.89	0.75	0.75	0.75	0.75	0.75	0.58
switch			0.00	0.72	0.72	0.58	0.58	0.58	0.58	0.58	0.42
hot plate				0.00	1.00	0.86	0.86	0.86	0.86	0.86	0.69
hot plate ring					0.00	0.86	0.86	0.86	0.86	0.86	0.69
pipe connection seat						0.00	1.00	1.00	1.00	1.00	0.78
silicone ring							0.00	1.00	1.00	1.00	0.78
water outlet pipe								0.00	1.00	1.00	0.78
packing valve									0.00	1.00	0.78
packing valve ball										0.00	0.78
heating element											0.00

body chunk. In addition, material of carafe is changed from glass to thermal with the choice of filter basket from U-shape or V-shaped. To achieve these goals, a sharing module is built, which is designed to serve both swing-out and non-swing out modules.

Finally, the loosely-constructed C3 base chunk is considered to carry out modular analysis for variant design. After considering appearance, operation, replacement of parts, and specification modification, the result of modular analysis is shown in Table 5 based on the value of 0-9, which represent the degree of influence from low to high. Accordingly, C3 base chunk is highly
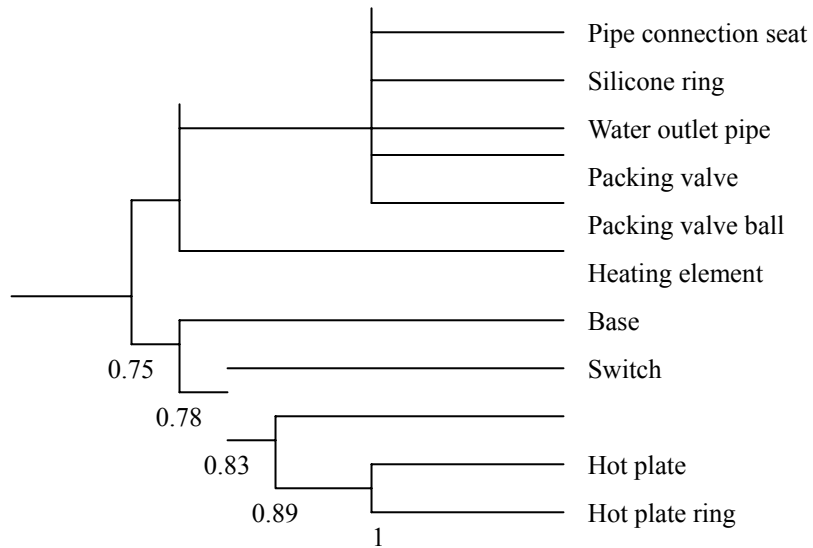
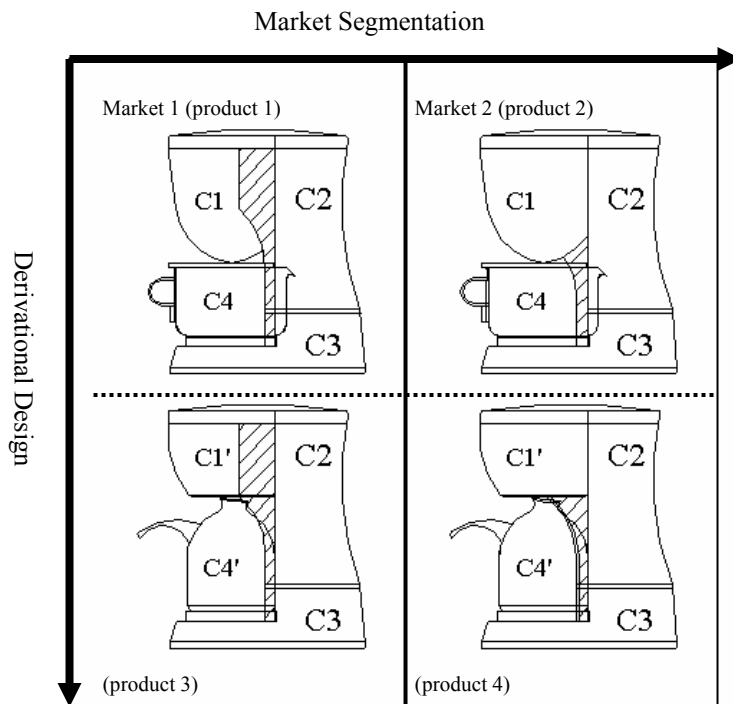Figure 7. Dendogram for the parts similarity matrix

Figure 8. Final design result

affected by form, operation, and replacement of parts. After constructing similarity matrix, Table

6 indicates that items 6,7,8,9,10 exist high similarity with 4 and 5 highly correlated. In addition, Figure 7 demonstrates that groups (6,7,8,9,10),(11),(1),(3),(2,4,5) can be obtained under 0.85 threshold level. Among these groups, the electric heating plate is confirmed as a swapping module. Figure 8 manifests the final design result, in which C1 (V-shape housing set) is shared by product 1 and 2 with C1' (U-shape housing set) shared by product 3 and 4. Hence, C1 and C1' both are component-swapping modular types. By the same token, C2(water tank set) and C3(base set), which can be used on four products, are component-sharing modular types.

5. Conclusions

The major objective of variant design for a platform product is to distinguish independent components and sharing modules. In this study, a systematic approach for configuration design is proposed to offer evaluation for chunk allocation and selection of product architecture based on platform product plan. The variant design is implemented with considerations of function, operation, and specification. Thus, designer can develop various configurations for product architecture and distinguish chunks through functional similarities. Since the chunks possess variant compositions, designers simultaneously consider features and operations of product, manufacturing possibility, and constraints of product designs to achieve the proper chunk allocations. At the final stage, while relationships among chunks are confirmed, the part-attribute matrix is, then, used to analyze the modular types.

From the case study of coffee maker, the proposed approach demonstrates its ability to simultaneously design a product family for different market segments, which can significantly improve design efficiency. In addition, this approach also identifies three different kinds of modularity, which can be used to develop product architecture consisting of physically detachable units.

Reference

1. Robertson, D. and K. Ulrich. 1998. "Planning for product platforms," *Sloan Management Review*, Summer, pp.19-31.
2. Meyer, M.H. 1997. "Revitalise your product lines through continuous platform renewal," Research Technology Management, March-April.
3. Muffatto, M. 1999. "Introducing a platform strategy in product development," *International Journal Production Economics,* Vol.60-61, pp.145-153.
4. Muffatto, M. and M. Roveda. 2000. "Developing product platforms: analysis of the

development process," *Technovation*, Vol. 20, pp. 617-630.

5. Baldwin, C. Y. and K. B. Clark. 1997. "Managing in the age of modularity," Harvard Business Review Sept-Oct, pp.84-93.

6. Ulrich, K. 1995. "The role of product architecture in the manufacturing firm," *Research Policy*, Vol.24, pp.419-440.

7. Ulrich, K. and K. Tung. 1991. Fundamentals of product modularity, Issues in Design/Manufacture Integration, pp.73-79. A. Sharon Ed. ASME, New York.

8. Mitchell, M. and J. Jianxin. 1997. "A module identification approach to the electrical design of electronic products by clustering analysis of the design matrix," *Computers & industrial Engineering*, Vol. 33, Nos 1-2, pp.229-233.

9. Salhieh, S. M. and A. K. Kamrani. 1999. "Macro level product development using design for modularity," *Robotics and Computer Integrated Manufacturing*, Vol. 15, pp.319-329.

10. Gu, P. and S. Sosale. 1999. "Product modularization for life cycle engineering," *Robotics and Computer Integrated Manufacturing,* Vol. 15, pp.387-401.

11. Huang, C. C. and A. Kusiak. 1998. "Modularity in design of products and systems," *IEEE Transactions on Systems, Man, and Cybernetics—Part A: Systems and Humans*, Vol. 28, No. 1, pp.66-77.

12. Ulrich, K. and S. Eppinger, 1995, Product Design and Development, McGraw-Hill, New York.

13. Pahl, G. and W. Beitz, 1988, Engineering Design, The Design Council, London, U.K.

14. King, J. R. 1980. "Machine component grouping in production flow analysis: an approach using rank order clustering," *International Journal of Production Research*, Vol.18, pp.213-232.

15. Offodile, O. F. 1990. "Application of similarity coefficient method to parts coding and classification analysis in group technology," *Journal of Manufacturing Systems*, Vol. 10, No. 6, pp.442-448.

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