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A COMPARATIVE STUDY OF QUALITATIVE AND QUANTITATIVE MODULE IDENTIFICATION METHOD: A CASE STUDY

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ABSTRACT

Modularity can be defined as a special form of design that creates high degree of independence between components. Modular design emphasizes the identification of independent, standardized, flexible and interchangeable modules, which can be used to produce variants. Efficient utilization of these modules lead to higher quality, faster production time and lower cost. This paper compares two module identification methods namely the quantitative and qualitative approach. For the quantitative approach, an extended triangularization algorithm developed by Kusiak et al. is used and the module heuristic method developed by Stone is used as typical representative of the qualitative approach. The definition, advantages and methodologies of each method are elaborated and to illustrate the application of both approaches, a case study on module identifications of an electric blender is presented. By using the quantitative method, three modules are identified based on assembly interaction while using the qualitative method four modules are identified. As the assembly interaction is the only criterion used in the quantitative method, the modules generated are less logical and less natural in terms of its grouping. The qualitative approach produces modules, which are smaller in parts number but better since it took into account the physical constraints of electrical flow, force and operational parameters.

1.0 INTRODUCTION

Modularity can be applied in product design and management problem, which can make product development faster and reduce cost in future product design [1]. Product variants based on mixing and matching modules are now appearing in the market such as aircraft, automobiles, consumer appliances, personal computer, software, power tools, educational curricular and furniture. For example watch manufacturer, Swatch produces hundreds of watch models at low cost [2] and Nippondenso panel meter which produces 40 products from 288 different models developed from six modules combinations [3]. Modular product design can be described as a special form of design that creates high degree of independence between components within the module and low dependence on components outside the module [4].

2.0 LITERATURE REVIEW

There are six module identification methods as available in the literature [5-10]. Generally most of the methods use similar steps with some additional tools to increase the efficiency as summarized in Table 1. One of the major breakthroughs in the formal method for module identification was reported by Huang and Kusiak [5], which proposed the extended triangularization algorithm to identify clusters. With similar approach of components interaction Lapp and Golay [6] generated cluster using Bond Energy Algorithm. This approach accepts cost as an added criterion in the clustering method. Salhieh and Kamrani [7] developed a module identification method by focusing on customer requirements and product functions. Modules are then identified based on degree of association between components. The terminology is similar to interactions as used by other methods. Finally the module is optimized using p-median model. Similarly Tsai and Wang [8] proposed module identification method by using fuzzy logic. The component decomposition is presented in the form of dynamic clustering graph and rating is given for each decomposition level. The optimal module is selected due to lowest assembly and manufacturing complexity.

Table 1 Generalize steps of various module identification methods. Shaded block represent the processes involve in each approach

Approach / Task	**Ext. Tri. Algorithm**	**Bond Energy Algorithm**	**p-median**	**Heuristic**	**Modular Function Deployment**	**Fuzzy Logic**
Customer requirement	■	■	■	■	■	■
Product Decomposition	■	■	■	■	■	■
Function Structure	■			■		■
Components Interaction	■	■	■	■	■	■
Matrix From Clustering	■	■	■		■	■
Module Efficiency	■	■	■	■		■

In this paper two qualitative module identification methods are presented which include the heuristic approach by Stone [9] and Modular Function Deployment (MFD) by Erixon [10]. In heuristic approach, three modularity rules are introduced in order to identify module, while MFD listed twelve module drivers to accelerate module identifications. Both approaches have also taken customer needs and components interactions into consideration during module identification process.

The most challenging task in modularization is to identify independent, standardized and interchangeable module. Miller et al. [11] has listed the definitions of module based on their applications and this case module can be defined as a physical structure that has one-to-one correspondence with functional structure [12]. From the identified modules, a wide variety of products can be produced from the different combinations of modules. Initially there are several methodologies developed to identify the module qualitatively and quantitatively. These methods have been successfully applied to the product design. For example Bond Energy Algorithm (BEA) [6] was applied to the design and fabrication of nuclear power plant, fuzzy logic [8] in developing Autonomous Guided Vehicle and p-median [7] in the redesign of a gearbox. Modular Function Deployment (MFD) developed by Erixon [10] has fulfilled the requirements for new or existing modular product design while Stone [9] used heuristic approach. They have proven their methods in developing modular consumer product by demonstrating design applications in coffee maker and power hand drill.

To date, there has been no publication comparing the various approaches particularly in comparing the strength of each approach and the suitability of the approach. This paper intent to shed some light on the relative strength of the two major approaches which represents the major paradigm in cluster identification

In this paper, the extended triangularization algorithm and the heuristic method are chosen to represent quantitative and qualitative method respectively. Qualitative method is defined as method(s) which does not require the user to rank or quantify the attributes in terms of numbers, while quantitative method is the method which requires the user designer to quantify or rank the design attributes. The contribution of this work is to analyze and evaluate the quantitative and qualitative module identification method and compare them based on several criteria such as number of modules and commonality of the identified module. The paper begins with introduction and then followed by the methodology of each approach with aid of illustrated case study. The analysis of the resulting module is discussed and the paper ends with a conclusion.

3.0 METHODOLOGY

In this paper two methods were used to identify modules, i.e. the extended triangularization algorithm to represent quantitative approach and the heuristic approach to represent qualitative approach. A consumer item (electric blender) was chosen as a test case where both methods are applied to the same product. The resulting modules will be compared in terms of number of modules and the module itself will be compared.

3.1 Quantitative Approach

This approach was developed by Kusiak et al. [13], and in this approach the product is described schematically by a listed requirements in terms of graph of function structure named assembly digraph, after that the decomposition process is done [5]. In the decomposition process function of a product is broken to the lowest level of the functional elements that consist exclusively functions that cannot be sub-divided further while remaining generally applicable [14]. After the components are recognized, interaction matrix is mapped to represent the inter-relationship between the components numerically based on features similarity such as geometric, temporal, force, electrical, thermal and photometric [1]. The module is then identified in the modularity matrix after applying clustering method using extended triangularization algorithm. The basic process is shown in the process flow chart as in Figure 1. The efficacy of this approach can be determined from the number of components, number of modules and times required. Due to its length, the extended triangularization algorithm is not included here. Modules are then optimized based on module density as shown in Figure 2.

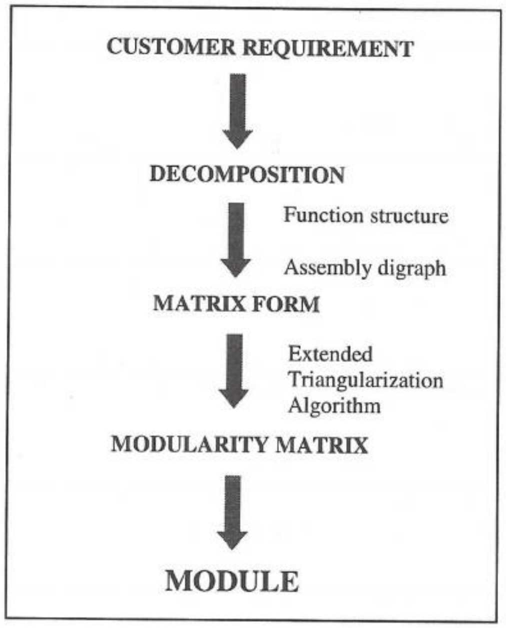


Figure 1 Quantitative module identification method process flow charts

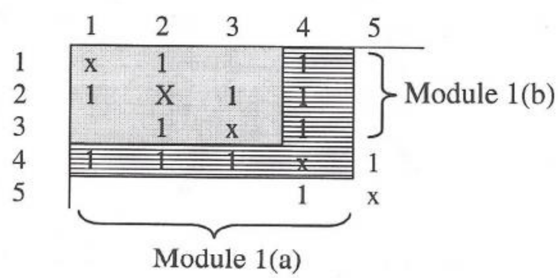


Figure 2 Module 1(a) has density 5/6 and module 1(b) has 4/6 density, so that module 1(a) is selected as the density is higher than module 1(b).

3.2 Qualitative Approach

One of the representative approach was developed by Stone [9] and then extended with some improvement and modification by Zamirowski et al. [15] and Dahmus et al. [16]. Stone defined module heuristic as a method of examination in which the designer uses a set of steps, empirical in nature, yet proven significantly valid to identify modules in design problems. Three modularity rules of dominant, branching flow and conversion-transmission modules are introduced from a formal functional decomposition.

By using this approach the module can be simply identified by examining and analyzing the arrangement of the functions and flow in form of function structure. The three modularity rules can be defined as follows [17];

1. Dominant flow heuristic is the set of sub-functions, which a flow passes through from entry or initiation of the flow in the system to exit from the system or conversion of the flow within the system as shown in Figure 3.

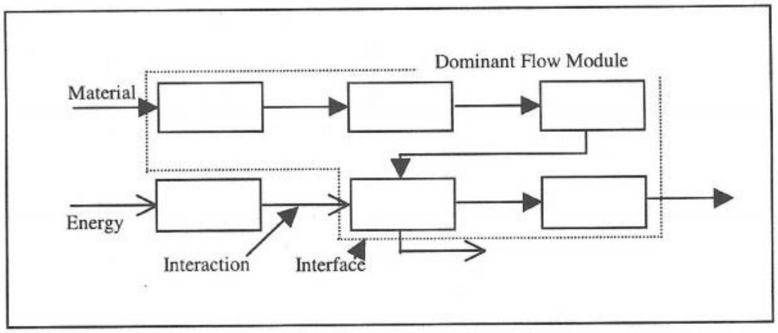


Figure 3 Representation of dominant flow heuristic

2. Branching flow as illustrated in Figure 4 is the limbs of a parallel function constitute modules. Each of the modules interfaces with the remainder of the product through the flow at the branch point.

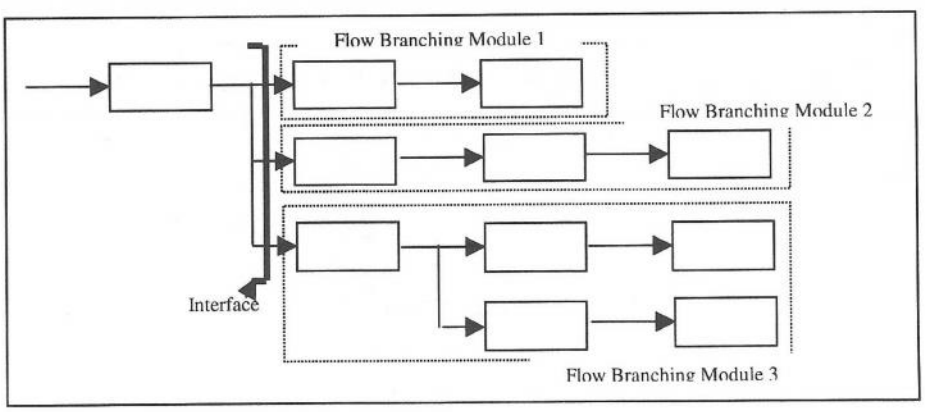


Figure 4 Representation of branching flow heuristic

3. Conversion/transmission heuristic is a conversion sub-function or a conversion-transmission pair or proper chain of sub-functions constitutes modules as shown in Figure 5.

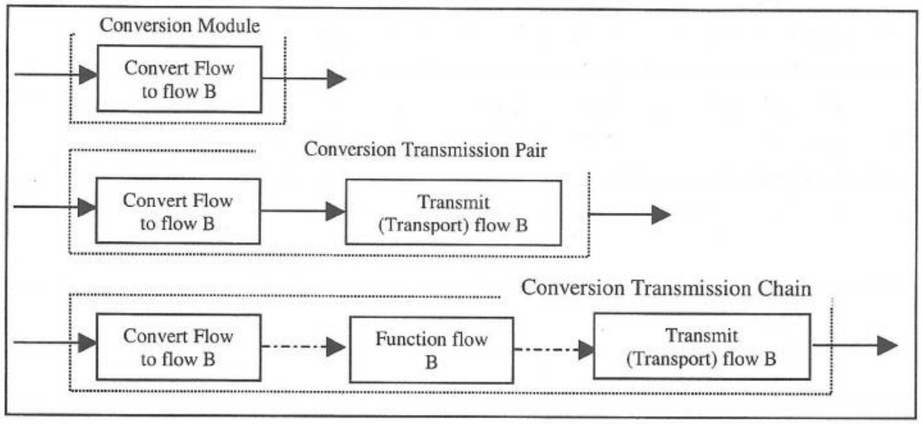


Figure 5 Representation of conversion/transmission flow heuristic

In this approach, the construction of function structures is the main task. Function structure can be defined as a set of sub-functions intercorrelated by flows. Flow in this case refers to the energy, materials or signals in the system or product. The function structure is one of the effective tool to visualize the interactions of flows and candidate modular partitions. The successful product portfolio architecture is critically determined from the feed back on how an individual product fits into a family of product [16]. The process of qualitative module identification is shown in Figure 6. This approach has been applied and proven successful on seventy consumer products as claimed by Stone [9].

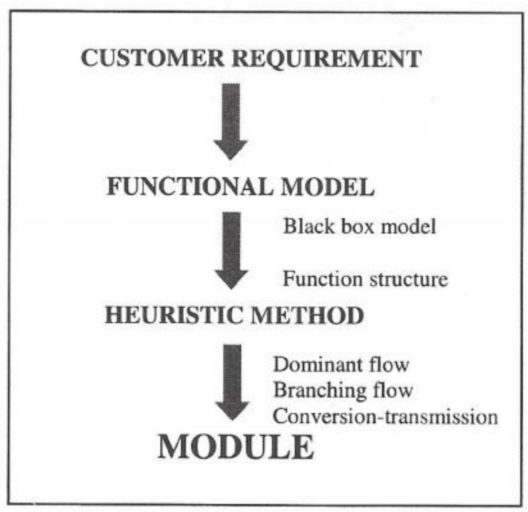
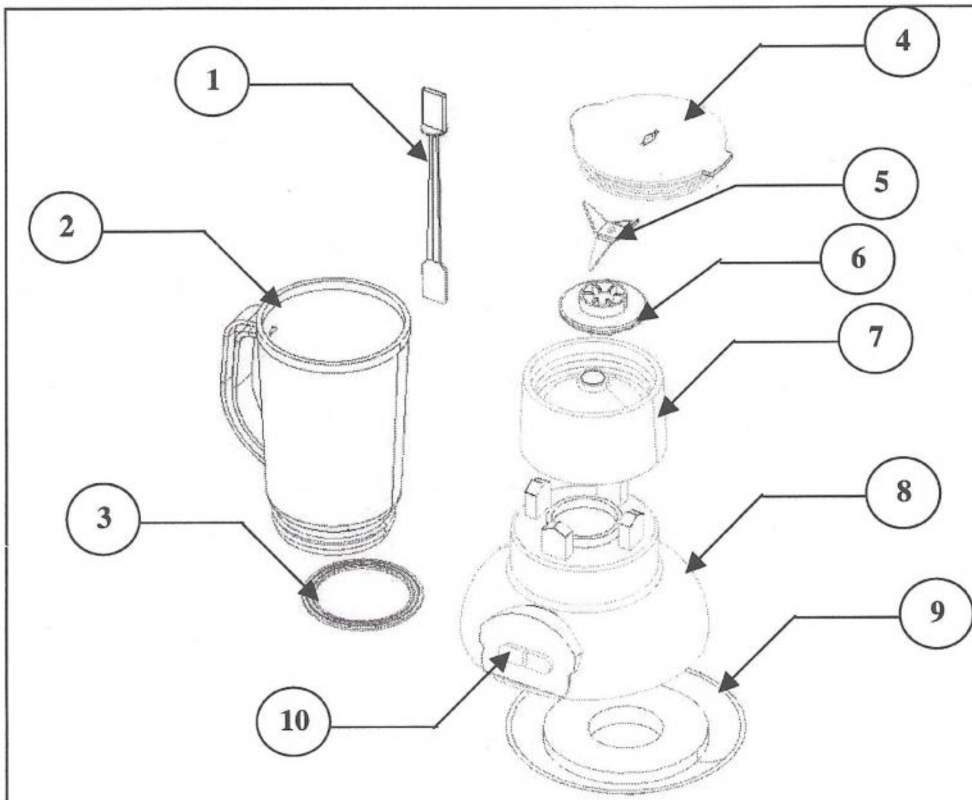


Figure 6 Quantitative module identification method process flow charts

4.0 IMPLEMENTATION

An electric blender generally used in kitchen is selected in this case study due to reader familiarity with such appliances and also to better describe the implementation of the two methodologies on consumer products.

Generally, electric blender can be divided into two types: the wet type which chops and blends in fluid suspension and the dry type which only chopping of dry items such as peanuts and dried chilies. Here only the wet type is analysed and it has ten components in the product as shown and labeled in Figure 7. Two approaches was used to compare the resulting modules.



Part List

1	Scrapper	**4**	Lid	**7**	Jar holder
2	Jar	**5**	Blade	**8**	Motor housing
3	Seal ring	**6**	Rotor	**9**	Base
				10	Switch panel

Figure 7 Exploded view of an electric blender and part list

4.1 Quantitative Approach

After analyzing the product and understanding the functional and physical elements of the components, the assembly digraphs are constructed. The construction of the assembly digraph shows how these components are assembled (Figure 8). This allows for evaluation of the interaction of the components in terms of numbers of assembly, assembly direction and type of assembly as indicated by the arrows.

These information are necessary as they form the input values for the interaction matrix. This functional decomposition demonstrates flow interaction in the systems and clearly shows the component level interaction and the location of the interface. Then interaction matrix is constructed to map the listed components and their interaction based on their assembly connectivity in terms of direction. The interaction matrix M_A is constructed using the information interpreted from the assembly digraph as shown in Figure 9(a).

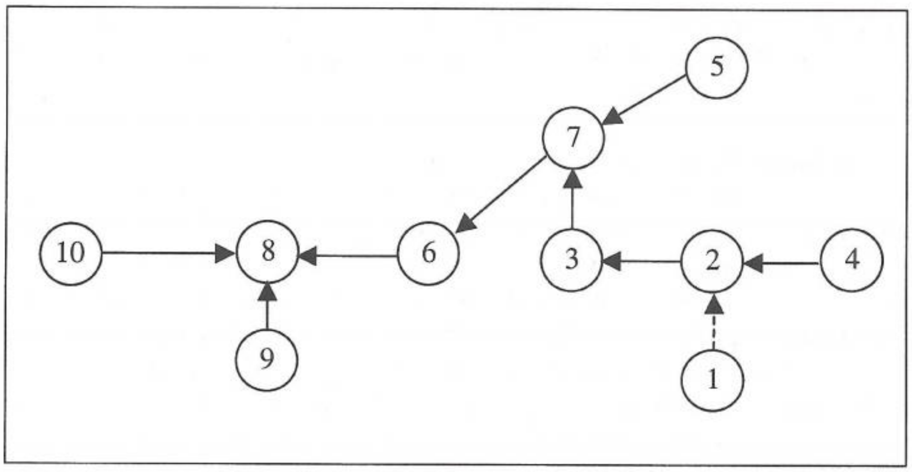


Figure 8 Assembly digraph represents the interactions among the components, dash line depicts indirect interaction.

	1	2	3	4	5	6	7	8	9	10
1	x									
2		x	1	1			1			
3		1	x				1			
4		1		x						
5					x		1			
6						x	1	1		
7		1	1		1	1	x			
8						1		x	1	1
9								1	x	
10								1		x

(a)

	2	3	4	5	6	7	8	9	10	1
2	x	1	1			1				
3	1	x				1				
4	1		x							
5				x		1				
6					x	1	1			
7	1	1		1	1	x	1			
8					1	1	x	1	1	
9							1	x		
10							1		x	
1										x

(b)

Figure 9(a) Interactions matrix and (b) modularity matrix after rearrangement

The overall matrix is then subjected to clustering method by reordering the matrix using the extended triangularization algorithm. The final overall modularity matrix, M_A after rearrangement is shown in Figure 9(b). As a result, there are three sets of modules identified, which can be a candidate for module development, which are:

Module 1: {2, 3 and 4}
Module 2: {5, 6, 7, 8 and 9}
Module 3: {10}

The modules are selected based on interaction density of the components in the module, for example module 1 which consists of components 2, 3 and 4 form 4/6 matrix density but by clustering components 1, 2, 3 and 4 it only has density 4/12. For example, in the case of module 2, there are two possibilities, module 2(a) clustering components 5, 6, 7 and 8 which form 6/12 or ½ module density and module 2(b) contains of components 5, 6, 7, 8 and 9, which also have similar module density 10/20 or 1/2. But based on the component structure, module 2(b) is selected.

4.2 Qualitative Approach

In this approach, the main and important task is the establishment of function structure establishment. Customer requirement recognition is another important task in the development of function structure. Figure 10 shows the possible function structure of the same electric blender discussed earlier. It describes the process of handling the food to be processed, the actions required to activate the blender, the flow of electrical power and cleaning action. After applying the modularity rules of dominant, branching and transmission-conversion heuristics (Figure 11) as described earlier, four modules are identified as follows.

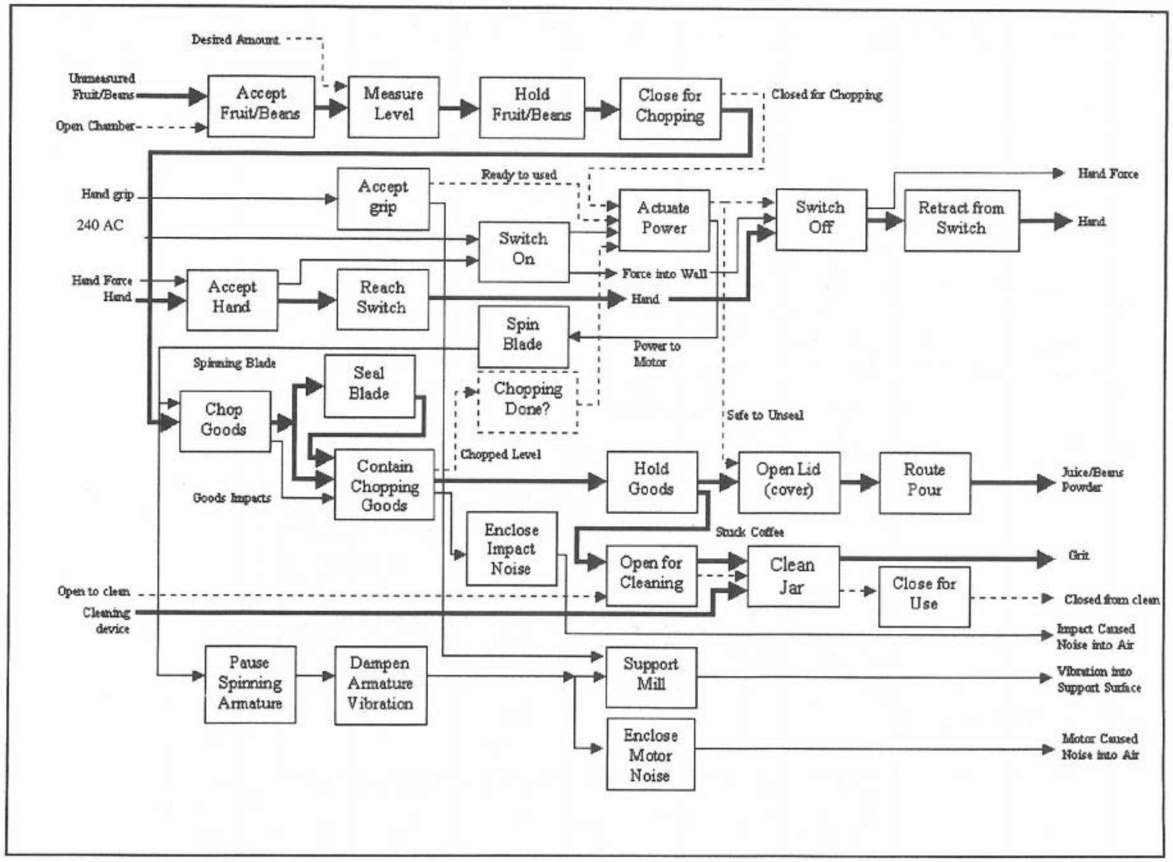


Figure 10 Function structure represents the overall process and function by flow, dash arrows represent material flow, line arrows represent electrical flow and bold arrows represent funcion flow

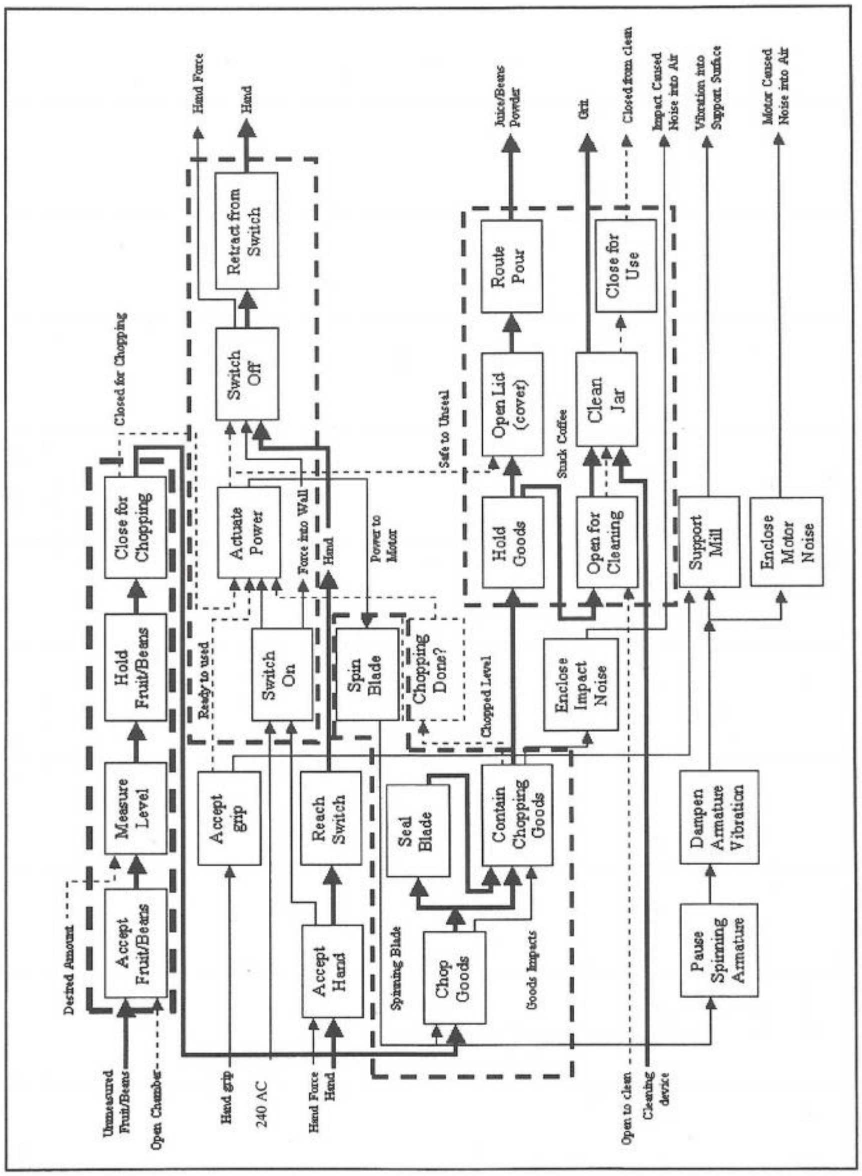


Figure 11 Function structure with dashed lines indicating the module clustered

5.0 DISCUSSION

Two module identification methods have been successfully applied to a product resulting in four modules identified by the qualitative method and three modules by the quantitative method. The components in the modules identified from each approach are almost similar as shown in Table 2. First module for both methods recognized the same component to create modules from components 2, 3 and 4. This is a logical choice since the lid, jar and ring seal forms an independent structure itself. In particular the single assembly direction in these three components and its coordinates forms a module.

Table 2: Result summary from the case study

Module	Assembly Interaction	Heuristics	No. of part difference
I	2, 3, 4	2, 3, 4	
II	5, 6, 7, 8, 9	5, 6, 7	2
III	10	10	
IV	-	8, 9	2

For the second module, the quantitative method recognizes components 5, 6, 7, 8 and 9 as a module while the qualitative method recognizes only components 5, 6 and 7 as a module. Thus the module from the heuristic approach forms a subset of the module identified using the quantitative approach. Clearly quantitative approach relies heavily on the assembly interaction as apparent in this case. All the components in the second module can be assembled in a single direction. However, the second module identified by using the qualitative approach recognizes components 5, 6 and 7 as a cluster. In this case, the heuristic methods can better recognize the external constraints. The bearing supporting the drive shaft and the rotating chopper blade is housed in component 7. It would be unwise to install the bearings deep inside the module as assembly in such case is very difficult. Clearly, the second module identified using the heuristics approach is the better module.

The third module identified is a single component module consisting of component no. 10, which is the switch. It is an electrical connection and can be quite freely located anywhere on the machine and can be adjusted in terms of coordinates to have maximum aesthetics impact. The heuristic method seem to isolate electrical component but the quantitative method selection is due to the different assembly direction of the switch components (radial direction) to the motor housing.

Module 4 identified only by the heuristics method consists of components 8 and 9 which is the motor housing and the base. Again this clustering is also logical since the motor housing and the base form a good partner based on assembly and also function interaction.

From the modules identified, it is obvious that the quantitative approach heavily on the assembly direction and presently cannot consider other form of interaction resulting in a very assembly driven modules. The heuristics approach has identified more modules, which are more logical and natural. In this sense the heuristic approach is quite good in recognizing the various constraints and interactions apart from the assembly direction.

Compared to qualitative approach, the quantitative approach required more steps. By the quantitative approach, the establishment of the assembly digraph, components listing, interaction matrix and end by modularity matrix are needed before module can be identified in the modularity matrix, whereas by the qualitative approach, only the function structure is required in achieving the objective. The advantages of the former method compared to the latter are in terms of mathematical representation, which directly can be measured and in determining the degree of modularity or the efficiency of the identified modules.

6.0 CONCLUSION

As a conclusion, the paper has presented the comparison of module identification method in quantitative and qualitative point of view. From the result there are several advantages and disadvantages of both approaches that can be listed as follows:

1. Two methods for determining modules have been discussed and the two different approaches require different thinking method.
2. Quantitative approach emphasises on the assembly parameter resulting in interaction matrix, from which modules are grouped together, this resulted in three modules.
3. Qualitative approach emphasises on the flow of various entities from which the flow direction, branching or function conversion, used for modules identification and this resulted in four modules.
4. The module identified using the qualitative approach is more logical and natural as the approach recognizes other constraints apart from assembly direction.

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