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Agile Product and Process Development by Applying Modular Function Deployment Method

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Abstract- In this paper a modularization method is applied to a consumer product as a case example to develop modules in the product. The analysis of the modules drivers are used to establish the product and manufacturing relationships for agile development. In addition, the modules in the product are used to develop product platforms to gain flexibility in design and development as well as to address the market demands. Results show that nine modules are identified in this product along with the reasons to develop them. Interfaces between the modules are identified that make parallel development activities possible and reduce the product development lead times. Furthermore, the weight age of the module drivers are used to structure the manufacturing set up.

Keywords- Product Modularity, Product platforms, Module indication matrix, Mass customization, Design for manufacturing.

I. INTRODUCTION

In the era of globalization, short product life cycles and rising customer demands are some of the challenges. In this context, Mass customization has been recognized as a successful strategy in the design and development of products. In order to address these challenges and future uncertainty, mass customization concepts such as (modularity and platforms) are applied to products to gain flexibility in manufacturing, address market demands, reducing costs and increase profitability.

Mass customization is production of personalized products to address customer requirements. Mass customization (MC) has evolved into a flexible, fast delivery and cost effective production and marketing strategy in global market competition, as discussed by [1],[2]. Industries with high volume and a demand for customizable products have adopted the strategy over the last decade [3],[4]. Mass customization (MC) has been recognized as a successful approach in the design and development of products that fulfil the customer requirements. One of the concepts of MC is modularization. Modularization is a structuring concept, which enhances clarity, reduces complexity and increases flexibility for customization [5][20]. Some authors use the product architecture to enable mass customization. The product architectures using standardized interfaces mean that mass customization and related manufacturing strategies can be effectively realized [6],[7],[8][21][22].

Modularization is a way or method to develop modules. And module is a conceptual or physical grouping of parts in the product. Modularity is the approach of decomposing a product into independent components or modules that can be considered as separate units. Modularity can also be defined as the mapping of the product functions into its structure [9]. Agile product development is achieved by modular approaches [10]. Modular product design refers to the design of products, assembly and components that satisfy various functions by combination of its building blocks [11],[12],[13][19].

Different methods are being used and developed to identify modules in the product such as modular function deployment, (MFD), Suh axiomatic design, Design for manufacturing and assembly and Product architecture design [14], [15], [16]. Other agile and non agile methods such as design structure matrix (DSM) and modular product development (MPD) are used in academia and in industry; these methods have a range of applications to products and process domains.

All these methods use to develop modules in products and mainly use three steps such as product decomposition, module development and evaluation [14] [16] [17]. But the above methods except MFD do not considered the development of the manufacturing set up for product and process relationships. The purpose of this study is twofold: First, MFD is used for developing product platforms and families and secondly, this method is applied for structuring the manufacturing setup using a consumer product as case study. Thus this study support agile product and process development to gain flexibility and competitiveness in processes.

As industry is facing the issues and the requirement of personalized products and short time to market. To support the agile product development an electric tooth brush is used as a case study by applying the modular function deployment method to address the issues of short product life cycles and rising customer demands.

The rest of this paper is organized as follows: Section II describes the proposed method schematically and presents an overview of the overall approach and describes module drivers. Section III validates the proposed method by its application to the case study. This section illustrates all steps such as clarify customer requirements, identify possible modules using module indication matrix (MIM), and develop interfaces between modules. Section IV discusses the product platforms and families. Section V discusses the relationship between module drivers and manufacturing set up. Section VI discusses the significance of the modularization, product architectures, and how to incorporate recent technological developments. Finally, Section VII summarizes and concludes the paper.

II. Modular Function Deployment Method (MFD)

Modular Function Deployment (MFD), as proposed by [14] is a well established methodology for product modularization. MFD is a structured method applicable to an entire product range i.e. to design, manufacturing, and after sales etc while the other methods do not consider these aspects. This method gives any company the opportunity to select its own reasons and systematically choose a specific modular design. MFD consists of 5 steps (Fig.1):

Step1: Identify customer requirements
Step2: Analyze the various functions and select technical solutions that meet those functions.
Step 3: Generate concepts in the Module Indication Matrix (MIM) to identify modules.
Step4: Evaluate concepts by testing the interfaces between the modules.
Step5: Improve each module using visualization, design for manufacture (DFX) methodology and MIM as a guide

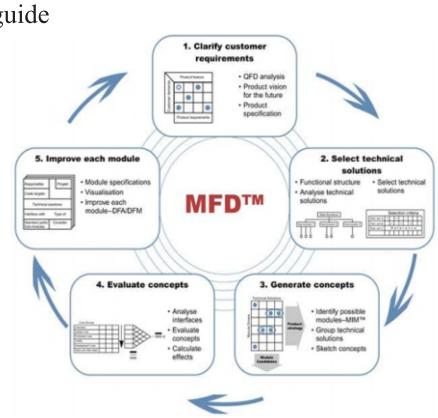


Fig 1 Modular function deployment method, adopted from [14]

Various companies such as Whirlpool, Alfa Laval, Bosch etc used it for design and assembly systems, but it is also useful to use this method for structuring the manufacturing system as a whole.

The Concept of Module drivers

The module drivers represent various reasons for modularization. The first module driver is *carryover* such as a part or subsystem that will carry over from one generation to another and no technology changes are expected. So future rework is avoided. The next is technology *push* that means a part will change due to technology change or customer needs. *Planned product changes*, are expected changes in parts or subsystems by the company. One is influenced by external factors such as technology evolution, while the other is internal and company related, such as decisions to develop and change the parts of the product. Technology push might enable an update of the module without upgrading the entire product. *Different specification* enables product variation, and *styling* considers the appearance of the product that must represent trend or fashion. *Common unit* involves parts that are identical in all product families and versions to create economies of scale. *Process and/or organization* refers to the fact that parts of the product that require the same production process can be combined into a module that might improve the efficiency of the production process. The possibility of *separate testing* of each module might improve the quality due to a reduction of feedback times and increase quality by allowing separate testing. *Supplier availability, service and maintenance* are related to the organizational effects of modularization. *Upgrading* allows redesign and future additions to the product that create after market opportunities for the companies. *Recycling*, the last modularity driver, considers issues related to the retirement of the product. This module driver considers the sustainability and environmental concerns.

III. Case Study: Electric Tooth Brush

A new type of electric toothbrush (Fig.2) different from the traditional brush, that is battery powered with oscillating brush head, has become more popular. It is an electric toothbrush and its main parts are rechargeable battery pack, electrical motor, removable brush head, on off switch, gear and circuit etc.

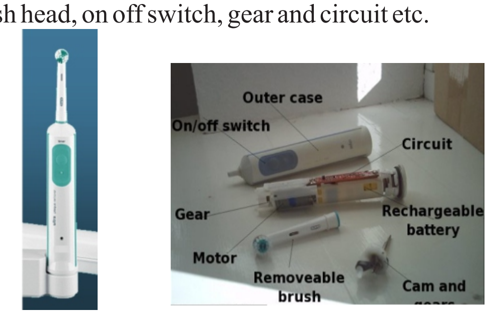


Fig. 2 Electric Tooth brush

Step 1. Clarify Customer Requirements and identify Functions

An international "small appliance" manufacturer has decided to launch a new global toothbrush platform, and has identified three important user segments such as Family, Young and Traveller. A market study has given the most important Customer Demands and the functionalities for each segment as shown in following Fig.3.

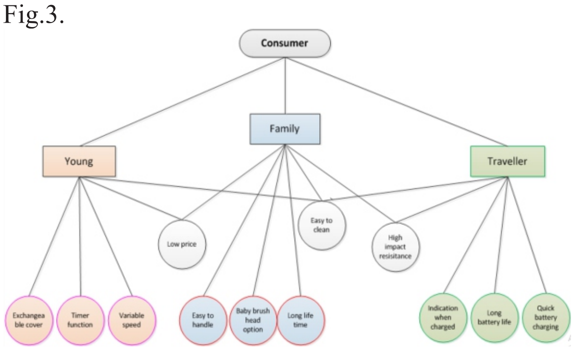


Fig 3. Customer demands for each segment

Step 2. Select technical solutions

Here, the Market study information is used to determine the design of the common platform and the features that shall be developed for each product family. The list in table I below contains the main Technical Solutions (TS) that form the three product families.

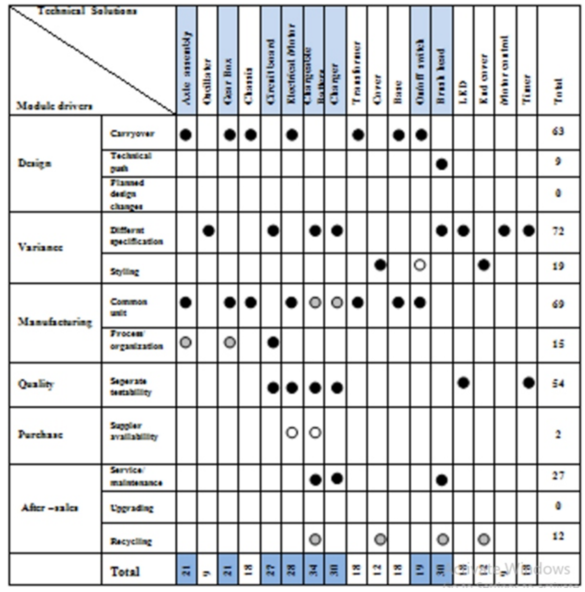
TABLE I: TECHNICAL SOLUTION IDENTIFIED IN THE ELECTRIC BRUSH

Technical Solutions	
Axle	Transformer
Oscillator	Cover
Gear Box	Base
Chassis	On/off switch
Circuit Board	Brush Head
Electric Motor	Baby brush
Chargeable battery	LED
High performance battery	End cover
Charger	Motor control
Quick Charger	Timer

Step 3. Generate concepts in Module indication matrix (MIM)

In the next step, each technical solution identified from product decomposition, is analysed against the module drivers to form potential modules. This analysis is performed in a module interaction matrix (MIM) as shown in Fig. 4. Technical solutions identified in system are essential in supporting the development of modules by using module drivers.

In the module interaction matrix, each technical solution is assessed with respective module drivers on a scale (9, 3 and 1) according to the importance of its reasons for becoming a module. According to this method, highly weighted, many and unique module drivers, points towards that the technical solution under consideration is likely to form a module.



Module drivers \ Technical Solutions		Axle assembly	Oscillator	Gear Box	Chassis	Circuit board	Electrical Motor	Chargeable Battery	Charger	Transformer	Cover	Base	On/off switch	Brush head	LED	End cover	Motor control	Timer	Total
Design	Carryover	●		●	●		●			●		●	●						63
	Technical push													●					9
	Planned design changes																		0
Variance	Different specification		●			●		●	●					●	●		●	●	72
	Styling										●		○			●			19
Manufacturing	Common unit	●		●	●		●	◍	◍	●		●	●						69
	Process/ organization	◍		◍		●													15
Quality	Separate testability					●	●	●	●						●			●	54
Purchase	Supplier availability						○	○											2
After –sales	Service/ maintenance							●	●					●					27
	Upgrading																		0
	Recycling							◍			◍			◍		◍			12
	Total	21	9	21	18	27	28	34	30	18	12	18	19	30	18	[illegible]	9	18	

Fig 4. In the module indication matrix each technical solution from the decomposition phase is assessed against the module drivers.

In Module indication matrix (MIM), there are large totals for the module drivers such as carryover, common unit, different specifications and separate testability. This points towards a mature product (or subassemblies) with availability of variants as well as good quality due to separate testability. High score for carryover points towards more technical solutions to carry in next generation products. Scores by Styling and different specification represents external factors as customer demands. Service/maintenance and recycling receive relatively small scores that show after sales service. Planed design changes and upgrading receive no scores as shown in the following Fig. 5.

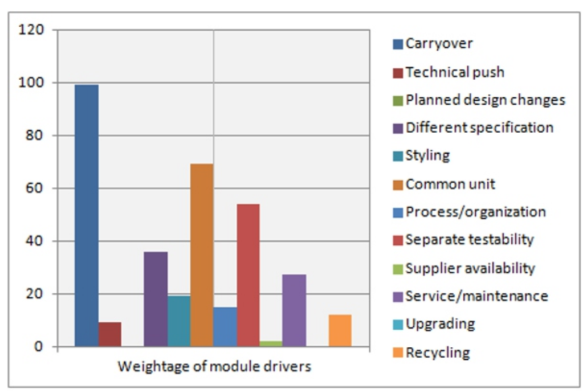


Fig 5. The module driver profile for the Electric Tooth Brush.

In the following table II modules and technical solutions are identified from the module indication matrix.

TABLE II
THE MODULES WITH THE STRONGEST DRIVERS, NUMBER OF VARIANTS AND TECHNICAL SOLUTIONS IDENTIFIED IN THE ELECTRIC TOOTHBRUSH

Module	Strongest drivers	Number of variants	Technical solutions
1.Electric motor module	Common unit Separate testing		Electrical motor
2.Battery module	Different specification Service/maintenance	2 variants	Chargeable battery High performance battery
3.Charger module	Different specification Service/maintenance	2 variants	Charger Quick charger
4.Brush head module	Different specification Service/maintenance	2 variants	Brush head Baby brush
5.PCB module	Separate testing Different specification	3 variants a. *CB with timer function and variable speed b. CB with battery indication when charged c. CB without both	Circuit board Motor Control Oscillator Timer LED
6.Switch module	Common unit		On/off switch
7.Transmission module	Common unit Carryover		Axle assembly Gear box
8.Styling module	Styling		Cover End cover
9.Chassis module	Common unit Carryover		Chassis Base Transformer

The weightage of each module along with the variants is given in Fig.6. In order to address the three market segments, four modules with the variants are identified in the MIM matrix. These variants are in battery, charger, brush head and PCB modules.

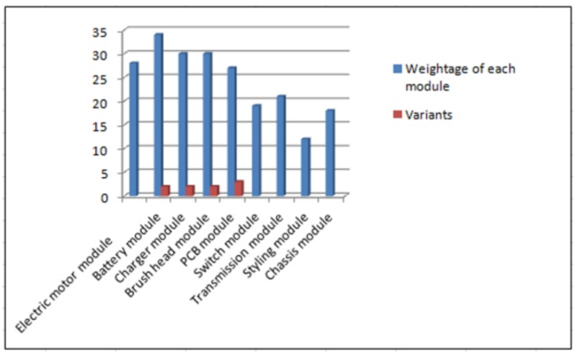


Fig 6. Wieghtage of each module and the variants identified in the module indication matrix.

A. Reasons for selected modules

Seven of the highest weighted technical solutions in the MIM are selected together with chassis and styling module to develop nine modules in the electric tooth brush. The reasons for selecting modules are explained in the following.

In *transmission module*, axle assembly and gear box seems a suitable module as having the same module driver's profile. They are combined in a same module having the same production process and to achieve economies of scale as a common unit in all product versions. *Brush head* as a separate module facilitate the different customer requirements i.e. baby brush and adults brush. Technological improvements such as the use of pressure sensors and LED could also be introduced in future generations.

Battery is considered as separate module that can be easily replaceable while doing service and maintenance. *Printed circuit board* (PCB) is placed as separate module, as it has different specifications and having three variants such as, a) Circuit board (CB) with timer function and variable speed, b) CB with battery indication when charged and c) circuit board without both timer function and indication. It is also placed in separate module with a provision of separate testing or provided by supplier to improve quality.

Electric motor is a separate module as it is common component in all three variants that is family, traveller and young. Similarly, styling as a separate module is introduced due to a) exchangeable cover required by young, and b) colours and special covers (i.e. cartoons) for babies.

Charger is considered as a separate module as it has two variants and service maintenance become easy. The reason for *brush head* as a separate module is it has two variants that can easily be replaced and service become easy.

Step 4. Evaluate Concepts- Interface between modules

After module identification, the next step is to identify interfaces between modules. These interfaces have the vital influence on the final product and their identification is essential part of the evaluation. The interface diagram represents the product structure along with modules and the connections between them. An interface can be a physical connection, energy flow, material flow and information flows. In the electric toothbrush case various interfaces are identified (Fig 7). For instance the interfaces between motor module and transmission module are physical connection (P) and energy transmission (E). Based on this evaluation the assembly order in this case is more close to base unit assembly.

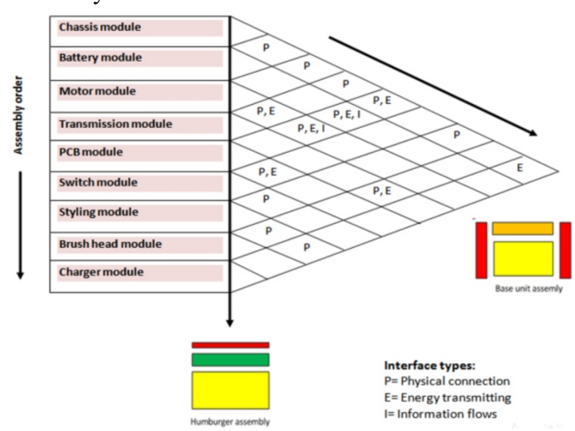


Fig.7 Evaluation of interfaces complexity. This product is close to base unit assembly.

Interface design reduces the dependence of one module with another one. Interface allows the reuse of modules in the same product that reduces costs. With the interfaces between the components product architecture can be developed that can be used for product families and platforms used in mass customization.

Step 5. Improve each module

In this step, the improvement that is performed in each module relates to specifications, visualizations, design for manufacture and assembly (DFX). The specifications of each module can be technical information, description of variants and cost targets etc. The module interaction matrix gives important information about what is important for each individual module. Further evaluation is mainly concerned with overall costs and design for manufacture & assembly. In this analysis cost analysis is not performed however the manufacturing set up is discussed in the next sections.

IV. PRODUCT PLATFORMS AND PRODUCT FAMILIES

By applying product platforms, companies can offer differentiated products by sharing modules in the product families. This will reduce the product cost, complexity and gain flexibility in production. In addition they can upgrade and redesign products for next generation. In the product platforms, the standard entities and the differentiated entities are balanced in the modular structure.

In the Electric brush example, nine modules are identified in the module identification matrix. One platform is developed that comprise common entities used in all the three variants of the Electric brush. This platform is further extended to product families such as *young, traveller and family*, where the derivative products can be developed from the platform (see Fig 8).

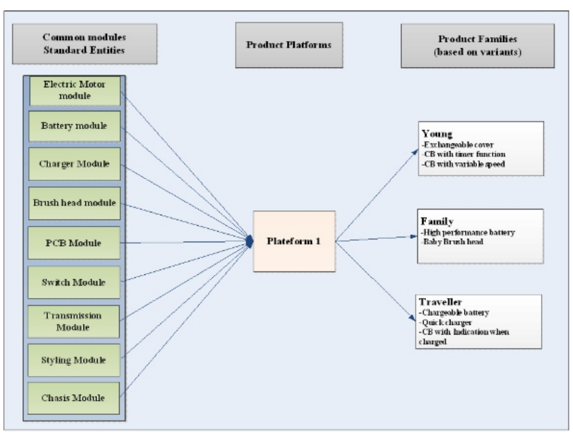


Fig.8 Product platforms based on the common modules identified in the electric brush to facilitate the different variants as required in the three market segments.

V. MANUFACTURING SET UP- PRODUCT TO PROCESS RELATIONSHIPS

The identified modules support the manufacturing setup. These modules establish a relationship between a product and manufacturing requirements thus enabling concurrent product and process development.

TABLE III
THE MODULE DRIVERS GIVE A DIRECT LINK BETWEEN THE REQUIREMENTS IN THE PRODUCT MODULE AND ITS MANUFACTURING SYSTEM.

S.Nr	Factors that determine manufacturing set up	Module driver	Property	Weight from Module indication matrix	Structure of manufacturing process
1	Internal	*carry over*	long life-cycle	63	heavy investments possible
2		*common unit*	More number of parts	69	automation possibility, create economies of scale
3	External	*Variance*	many different parts	72	Flexible manufacturing system and flexible material handling system
4		*Supplier availability*	Quality	54	Exploit supplier capability
5		*Service Maintenance*	After sales service	27	Ease of assmebly

The wightage of the module drivers can be used to structure the manufacturing set up. From the analysis of the case study (see Table III), the internal manufacturing set up is more relevant to carry over, common unit as they have more weightage in the module indication matrix. As carryover modules means long life cycles for components in the products, so the manufacturing process need more investments for those components. Similarly common unit is relevant to more number of parts so the manufacturing set up should be based on automation to achieve the economies of scale and produce more parts as fast as possible.

From the analysis of the case study (see Table III), the external factors that determine the manufacturing set up are variance, supplier availability and service maintenance as they have more weightage in the module indication matrix. As variance means many different parts so flexible manufacturing and material handling is more suitable to manufacture the variant parts. Similarly supplier availability ensures high quality products so the manufacturer must exploit the supplier capability for high quality parts. Service and maintenance modules also got more weightage in the MIM matrix so after sale service is made possible to the manufacturer due to ease of assembly of these parts.

So by modularization, companies can structure their manufacturing set ups and performs their development activities in a concurrent way.

VI. DISCUSSION

The product development has a major impact on the product success and its market penetration. A systematic approach is required throughout the entire development process from the identification of the customer needs to the delivery of a product fulfilling these needs for agile product and process development.

The design for manufacture and assembly (DFX) tools are very efficient in product design. However most DFX-tools only able to address the product structure at component level. While the MFD approach is applicable across the entire product range that address the design, manufacturing and after sale aspects. The module drivers in this method establish a direct link between the module requirements and its manufacturing system. For instance the module driver, common unit identified in four modules in the product MIM , that driver is related to more number of parts that enables automation and results in economies of scale in manufacturing set up , as shown in table III.

The selection of product architecture is vital to accommodate the varying requirements that could takes place during the product life cycle. Therefore the product development from the beginning must consider product life cycle including, design, manufacturing, supply chain and after sale issues. The modules identifies in this case study can be used to develop a product architecture to further structure the manufacturing process.

Based on the MFD analysis, product platforms can be developed to facilitate differentiated products. This can enables companies to reduce the product cost, system complexity and gain flexibility in production. In addition they can upgrade and redesign products for next generation. For example, the common entities identified in the electric brush is used (Fig. 8) to develop the three different variants such as young, family and traveller to address the market demands in the electric brush.

Modular product design has implications to supply chains in case of product variants. Delaying the differentiation of a product until late in the supply chain provides variety to the customers. In addition modular design facilitates to change some modules due to technological changes. The latest technologies, including the internet of things (IoT) and virtual inventories envisioned by industry 4.0 [18], will complement the use of modular innovation strategies. This will help to overcome the geographic distances and complexities involved in supply chain management, which could disrupt existing business models and the nature of global operations management.

VII. Conclusions

Modular Function Deployment (MFD) is applied to support the agile product and process development. This method is used in the analysis of electric tooth brush to address the market demands by developing modules and product families. Nine modules are identified in this product along with the reasons to develop them. Interfaces between the modules are identified that make parallel development activities possible and reduce the product development lead times. Interfaces facilities easier service and maintenance such as in battery and brush head modules. Three variants in circuit board module can be used to address different customer requirements. More functions such as use of LCD screens can also be introduced.

Furthermore, the weight age of the module drivers are used to structure the manufacturing set up. High scores for module drivers such as carry over and common unit indicates economies of scale and heavy investments in modules such as in transmission, chassis and electric motor etc. Similarly the analysis shows that high scores for variance, supplier availability and service maintenance can be used for flexible manufacturing and exploiting supplier availability are the possible solutions for this product. Overall effect is fast time to market, reduction in costs and high quality product according to customer demands to facilitate agile development.

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