Adaptation of European product to emerging markets: Modular product development

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***Abstract*— Adopting existing European product development facilities to develop new products tailored to emerging markets is a challenge as product requirements for emerging markets are different in terms of geographic, economic, context of use, local and international governing, utilization of resources, and standards. The modular product development approach for the adaptation of European product and production facilities to emerging markets is presented in the paper. This includes (i) Definition of basic features in order to propose the possibility of elaborating a module structuration of the product and product-service, and also for identification of modules, (ii) Product modules and their selection strategies, (iii) Product configuration strategies. Using modular approach, the product definition evolved iteratively along the development stages starting from the early stage of design to the final production.**

***Keywords*—Adaptation of European production, Emerging market, Modular product development.**

I. INTRODUCTION

A product is goods, consisting of a bundle of tangible and intangible attributes that satisfies consumers and is received in exchange of money or some other unit of value [1]. Factors that influence consumer behavior are cultural, social, personal, psychological and the buyer. Goods are tangible that one can see them, feel them, and touch them whereas services are intangible which are the results of human or mechanical efforts to people or objects. Sales of goods and services are frequently connected, i.e. a product-service will usually incorporate a tangible component and an intangible component. Each product includes a bundle of attributes capable of exchange and use. Product planning refers to the systematic decision making related to all aspects of the development and management of a firms products including design, production, packaging and transportation [2].

An emerging market is a country that is characterized as a market under development without meeting standards as of a mature market in the developed countries [3]. It includes countries that may become developed in near future. Countries with large economies such as China, India, Brazil, Russia, Mexico and many others are considered emerging markets because of their continuous evaluation. To respond to the competition from emerging countries, frugal innovation is considered as a solution to produce customized products in a shorter time for improving the attractiveness of western companies [4, 5]. Frugal innovation or frugal engineering is the process of reducing the complexity and cost of goods and their production. A frugal product is defined in terms of the attributes: Functional, Robust, User-friendly, Growing, Affordable and Local and can be found in most industries [6,7]. As per the study [8], these frugal attributes are not sufficient for adopting existing product development facilities in European countries to emerging markets as product development for emerging markets does not have same requirements in terms of geographic, economic, context of use, local and international governing, standards, and utilization of resources. And also different components, parts and services attached to a product have varied requirements.

A product is considered as a single entity against a set of requirements and the product is developed as a whole. This view of product development hinders the adaptation of an existing European products and development facilities to address the emerging market requirements. So we proposed a modular product development as **divide** the existing product development facilities into modules and **conquer** to address the emerging market requirements. After introducing the concepts of product module and modular architecture in the next section, the proposed modular development approach for the adaptation of European products to emerging markets is detailed with examples in the following sections.

II. PRODUCT MODULE AND MODULAR ARCHITECTURE

Product architecture is the way by which the functional elements (or functions) of a product are arranged into physical units (components) and the way in which these units interact [9]. The choice of product architecture has broad implications for product performance, product change, product variety, and manufacturability [10]. Product architecture is also strongly coupled to the firm's development capability, manufacturing specialties, and product strategy [11]. Generally, product architecture is thought of in terms of its modules [9].

A product module is a physical or conceptual grouping of product components to form a consistent unit that can be easily identified and replaced in the product architecture. Modularity is the concept of decomposing a system into independent parts or modules that can be treated as logical units [11,12]. Modular product architecture, sets of common modules that are shared among a product family, can bring cost savings and enable introduction of multiple product variants quicker than without architecture. Several companies have adopted modular thinking or modularity in various industries such as Boeing, Chrysler, Ford, Motorola, Swatch, Microsoft, Conti Tires, etc. [13]. Hubka and Eder [14] define a modular design as “connecting the constructional elements into suitable groups from which many variants of technical systems can be assembled”. Salhieh and Kamrani [15] define module as “building block that can be grouped with other building blocks to form a variety of products”. They also add that modules perform discrete functions, and modular design emphasizes minimization of interactions between components. Ulrich and Eppinger [9] define a module as a chunk of a product with an identifiable function. Alternative modules of a module are group of modules of the same type and satisfy several reasoning criteria/features for a product module.

Generic Product Architecture (GPA) is a graph where nodes represent product modules and links represent connections among product modules according to specific interfaces (functional, physical, information and material flow) to represent a product or a set of similar products forming a product family. A GPA represents the structure of the functional elements and their mapping into different modules, and specifies their interfaces. It embodies the configuration mechanism to define the rules of product variant derivation [16, 17]. Products can be configured to satisfy individual customer requirements. As a prerequisite, a clear definition of what the company is potentially ready to offer is necessary and feasibility of product characteristics should be established and verified a priori [18]. The similar concepts mentioned in the literature are ‘building product architecture’, ‘design dependencies and interfaces’ and ‘architecture of product families’, which can be used for the development of GPA. The GPA can be constructed by using different methods presented in literature [19, 20]. Examples of product modules and GPA in a product (Galley-system) are presented in Figure 1. The modular product development composed of GPA, modules, and alternative modules is presented in the next section.

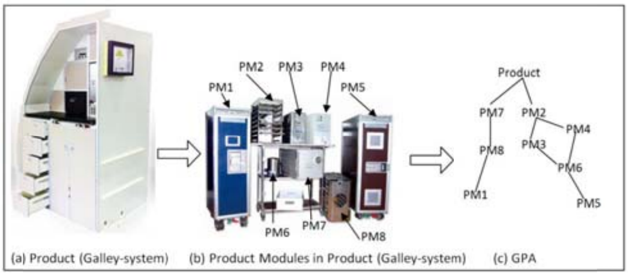


Figure 1. EXAMPLE OF GENERIC PRODUCT ARCHITECTURE OF A GALLEY SYSTEM (PM: PRODUCT MODULE).

III. MODULAR PRODUCT DEVELOPMENT FOR ADAPTATION TO EMERGING MARKET

Customer’s requirements fluctuate across geographical regions, standards, and type of use context of a product. Whereas global production facilities to address such requirements are constrains by local governing policies, standards, and local resources available. In order to address emerging market’s requirements and adopt existing product development facilities, it is important to analyse and evaluate different modules in a product against specific requirements of the market. The product developed can be specified and/or evaluated using frugal criteria [6, 7, 21] namely Functional, Robust, User-friendly, Growing, Affordable, Local with specific values as per the emerging markets. Additional features are identified based on requirements of the proposed modular product development for decision making and selections. The initial list of these features with their definition is presented in Section III.A.

Product features, design and production processes as well as quality and cost should all be tailored to the requirements of targeted emerging market. A modular product development methodology is developed for modular organization of a product, product-service, and production facilities used and then to configure the feasible product addressing the market requirements and also utilizing existing development facilities. Figure 2 depicts the methodology using three views namely Requirements, Product and Production. The figure also represents the logical flows and reasoning steps required for the product development.

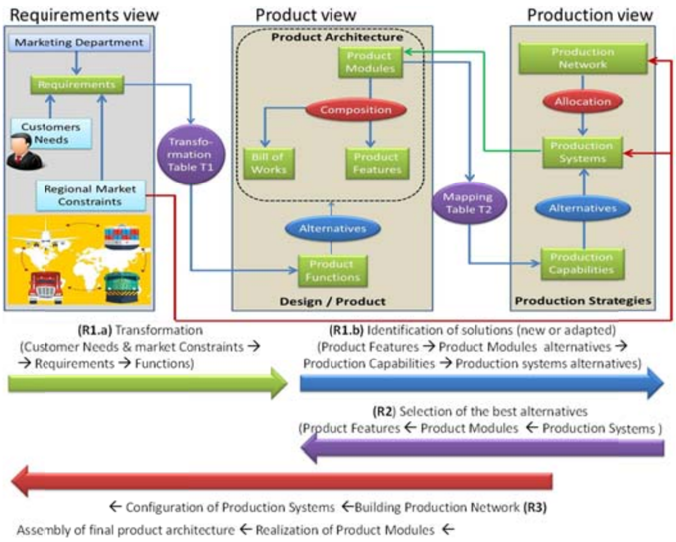


Figure 2. MODULAR PRODUCT DEVELOPMENT METHODOLOGY

Requirements view: It is to collect and identify customer requirements, emerging market constraints, and requirements for the targeted emerging market. These requirements collected in this view from the earlier stages of the project will be exploited on the following views at three levels: (i) Identification of product function; (ii) selection of a product structure and modules, (iii) identification of the best production systems and network configuration [7].

Product view: It is to identify possible product structures and modules to fulfil the requirements identified in requirements view and also to connect (link) product structure and product modules to production view and required services.

Production view: It is to identify production capabilities and then identify best combination of production system against frugal attributes, emerging market constraints and company policies. The combination of production systems in production view is also used to build production network.

The navigation between the views' items of the modular approach is fulfilled through three sequential routes as shown in the bottom of the Figure 2. The main logic is that after the elicitation of market requirements to a set of product functions in (R1.a), the route (R1.b) consists on the identification of feasible alternatives of product and production solutions, the second route (R2) aims then to identify the best combination of production systems (fixing the optimal production network) and product modules to answer to targeted requirements with respect to additional local constraints (logistics, standards, etc.). The last route (R3) focuses on the implementation of the selected options at the production and product levels.

The connection between the three views following the previous routes is ensured by two tables: the first one (T1) contains the rules to transform requirements collected by the marketing department from customer requirements and emerging market constraints to a set of product functions with related features representing the functional solution. Example: to answer the need of using the car in very high temperature conditions, the cooling function should be defined with a high performance level. The second table (T2) aims to define mapping between known product modules solutions and all related possible production capabilities, which inform about the possible standard manufacturing processes and technologies able to provide the module with the desired characteristics.

The identification of all feasible alternatives of modules responding to the selected list of functions and all alternatives of production capabilities and systems dealing with the realization of these modules are identified in route 1.b through an exact reuse or an adaptation of existing product structures or families. It can be obtained by selecting some existing modules solutions without consideration of the whole product structures.

The selection of the best alternatives of solutions is fulfilled in R2 as a decision-making taking in consideration the different requirements from emerging market, interfaces' capabilities and all other supplying facilities, etc. For instance, for two similar production systems or suppliers (in terms of manufacturing functionalities and performance), it can be useful to choose this proposing low price or implying low transport and logistics cost for one specific production network and targeted market. Then the selection of the best modules solutions can be obtained as a consequence of selecting the related production systems.

Based on these decisions, the last route (R3) concerns the definition of all necessary inputs to obtain the final product: Production network building as a combination of selected production systems and the definition of cooperation and coordination mechanisms between different components of the production network; Production systems configuration to integrate collaboration and planning constraints; Realization of different product modules and their assembly in the final optimal product structure. By fixing the different production systems (and suppliers), the structure of the production network is defined as a combination of the selected items, the final definition of the expected behavior of the network is achieved by the definition of the global production planning and all collaborative processes supporting information and material exchange between these production systems. Then, the configuration of each production system consists on the definition of local planning and adaptation of working processes to integrate requirements of cooperation and coordination mechanisms. In the same manner, by fixing a production system, the related production capabilities and then the bill of work to obtain the related product module are automatically fixed. The assembly process of the whole product structure is obtained in coherence with the global production planning defined at the production network level.

The product modules and their production facilities are evaluated against emerging market requirements to configure a requested product for the emerging market. The definition of module and generic product architecture as basic elements in the methodology has been presented with example in Section II. The identified set of modules is configured into a feasible product. The configuration methods with examples are presented in Section IV.

A. Features for elaborating a module structuration of a product and product-service

A feature (also refereed as product module feature or product feature) is application dependent, describing some characteristics, and to help in decision making processes in the modular product development. A feature is not limited to common geometric features but has a wider conception. It is usually defined according to specific requirements in specific application context with the help of users or experts from different domains. Product module features are defined to translate the regional customer requirements to product design and also connect the product and requirements view to production planning and supplier network design. The product module features are used to connect the product view to downstream activities such as maintenance, recycle and disposal. The product module features are considered as bridge among customer requirements, product design and production facilities of product and product-service development in the customer-driven context. The product module features are defined to address following three categories as inputs for decision making problems regarding the objectives of the modular product development (Figure 2).

i. Responding to customer/market requirements: Category of module. This category of features is related to product modules, and link product modules to requested functions. Examples of product module features lie in this category are presented in Table 1 along with their definition and their importance in the modular product development.

ii. Responding to module parameters and its interfaces: Performance, Interfacing flexibility, Interchangeability, Customization. This category of features is used to identify product module category and to define or identify compatibility with other modules. Preliminary list of proposed features in this category are presented also in Table 1.

iii. Responding to production strategy: Process positions, Freedom Pre-condition, Sustainability Constraints, Supplying tolerance, Supplying flexibility. This category of features is used to identify requirements for supplying properties, identify requirements for production processes and refine selection of product module. This category of features are further grouped as (a) features requested to link modules to the production strategy of the final product, and (b) features requested to create suppliers requirements from modules characteristics and are presented in Table 2 and Table 3 respectively.

Feature name		Feature definition	Importance
Category of module		Name of product module + Main Function + Principle of solution	Identify module(s) using function
Performance (Perf.)		Regarding the final product performance and the market requirements	Relate module to final product performance and requirement
Perf.	1. Standardization level	The module respects high or low levels of standards (quality requirements)	Required for production, selection of PM and compatibility with other modules
	2. Precision	Acceptable tolerance on the performance parameters	
Interfacing Flexibility (Int. Flex.)		The flexibility of one module to be connected with other modules in the same architecture	Interaction/Connectivity of a module to other modules and identify product structure
Int. Flex.	1. Functional Interface	Describes the category of link between two product modules	
	2. Physical Interface	Type of compatible assembly/fixture methods acceptable by the module	
	3. Technology Interface	Type of compatible technologies according to the principle of solution	
	4. Information / Energy Flow	Type of information or energy the module is able to exchange (input or output)	
Interchangeability		The capacity of one module to be replaced by one or more other modules from the same category to provide the same function. List (or number) of replaceable modules.	Provide alternative production / supplier. Replace by other modules.
Customization		Possibility to change some properties of the module (ex. paint, material, etc.). Modify or replace module (or sub-module) according to changes in customer specifications or preferences. Possible modifications and list of product modules.	Just-In-Time-Specification / Customization

Table 1. FEATURES RELATED TO CUSTOMER/MARKET REQUIREMENTS, MODULE PARAMETERS AND ITS INTERFACES

Feature name		Feature definition	Importance
Process Position (Proc. Pos.)		The connection of the module to different steps of the final production process of the main product, including assembly, painting, additional transformations and transportation (if relevant).	For identification of CDF of a module. For customer inspections during production.
Proc. Pos.	1. First concerned step	First time the module is involved in the final production process.	Visibility of production status to specify stakeholders (customer, shop-floor personnel, others (if relevant)) and link to customer.
	2. Intermediate steps	Different steps the module is concerned by.	
	3. Final step	Last time the module is involved in the final production process.	
Freedom pre-condition		Evaluate the dependence of assembly operations of the concerned module.	For identification of CDF of a module.
Sustainability Constraints (Sust. Const.)		Additional properties to be considered for the production, transportation, or manipulation of a module.	To identify preferred location/ type of production/ assembly etc...
Sust. Const.	1. Sensibility	Fragility, risk to be considered for the connection with other modules	
	2. Security	Is there some security standard required for the production of the product/ module?	
	3. Proximity	Is there some request to assemble two modules in the same site or proximity (ex. Critical Weight, size, assembly methods,...)?	

Table 2. FEATURES REQUESTED TO LINK MODULES TO PRODUCTION

IV. PRODUCT CONFIGURATION STRATEGIES

The use of the modular approach should propose the facility to work in different configurations. The concept of GPA can give interesting advantages for these issues. Indeed, by using existing GPA to extract reusable modules, a first assessment of interfaces' compatibilities and performance of the selected modules can be performed regarding various whole product structures. Thus, module features are defined to support these assessments and used to link process specifications, production capabilities, and all other important criteria involved in the product development process. As the developed GPA are a materialization of the existing products, the adaptation of these products to the new market requirements will be easily obtained through some swapping, replacing, combining or modification actions on the product structure, including configurations of the selected modules.

Feature name		Feature definition	Importance
Criticality of module (Crt. Mod.)		The importance of a module in the final product structure	To identify suppliers/ subcontractors/ manufacturing sites.
Crt. Mod	1. Added value	According to relevance of a function	
	2. Core product	According to core product strategy (in-home manufacturing or to be supplied)	
Supplying Tolerance (Sup. Tol.)		Level of request on the supplier regarding the module criticality, technology, sustainability, ...	
Sup. Tol.	1. Cost tolerance	Acceptable cost allocated to the module regarding its importance	
	2. Delivery time tolerance	Acceptable delivery date according to the request of the module in the manufacturing process.	
	3. Confidence level	Acceptable level of standardization and competence from the supplier.	
Supplying flexibility		How many suppliers (or internal production sites) can provide this module?	

Table 3. FEATURES REQUESTED TO CREATE SUPPLIERS REQUIREMENTS

In fact, the application of customer-driven product-service design can follow one of two ways processes, either collectively through generic product architecture by mapping all the requested functions, or by mapping functions individually through features and then configuring product modules (Figure 3). In this last case, more flexibility is allowed for the selection of products modules and consequently more innovative possibilities for the final product alternatives. However, more attention is required for the global consistency of the whole structure. The concept of feature is considered as a generic term that includes technical characteristics used for engineering perspective as well as inputs for decision making criteria useful for the deployment of customer-driven design process in context of adaptation to emerging market.

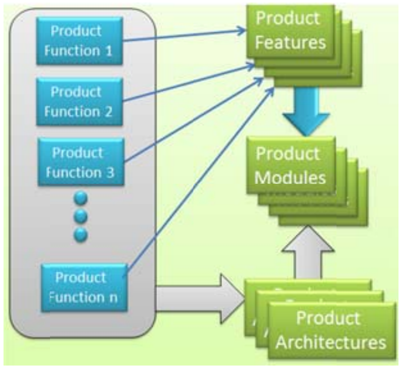


Figure 3. TWO WAYS PRODUCT CONFIGURATION STRATEGIES FOR IDENTIFICATION OF MODULES FOR A PRODUCT

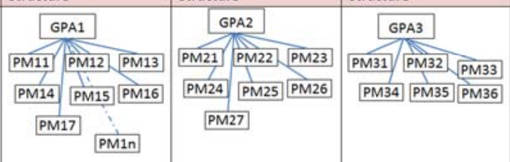
In the first case, based on existing solution implies high level of knowledge about the whole development process and will reduce considerably the cost of adaptation to new market. Based on individual mapping of modules, the second way will give more possibilities to imagine new solutions (even the design process doesn't go from scratch) including the possibility to reuse modules that are not originally created for similar need context. The implementation scenarios detailing these two ways are presented in the following sub-sections.

A. *Configuration 1: Mapping of Requested Functions to GPA*

The main idea in this configuration is that the adaptation of existing solutions is performed based on the analysis of existing final products really produced and sold to customers in previous market. According to the level of correspondence between new requirements and existing solutions, the importance of each customer option and the possible compatibilities between local production capabilities and those used for the realization of original product will define the final product structure and production strategy (at system and network levels) for the targeted context.

The starting point in this configuration is the existing product families that contain existing functions and then adapt the definition of modules regarding the requirements. The modular approach is used to satisfy set of functions collectively through GPA by mapping all the functions required. Some of the product modules need only to be focused in the identified alternative products to satisfy the requirements and to adapt GPA of an existing product or set of similar products. Mapping of Requested Functions to GPA, as adaptation of existing products (solutions) a company has, is presented in Figure 4.

Requested Function	GPA1	GPA2	GPA3	...
F1	PM11—F1	PM21—F1	PM31—F1	...
F2	PM12—F2	PM22—F2	PM32—F2	...
F3	PM13—F3	PM23—F3	PM33—F3	...
F4	PM14—F4	PM24—F4	PM34—F4	...
F5	PM15—F5	PM25—F5	PM35—F5	...
F6	PM16—F6	PM26—F6	PM36—F6	...
	PM17	PM27		...
	: PM1n			...
	Structure	Structure	Structure	...



Note: PM12 means Product Module for GPA1

Figure 4. EXAMPLE FOR MAPPING OF REQUESTED FUNCTIONS TO GPA

An example for the first two mapping possibilities of functions to product modules in a GPA is presented in Figure 4. Set of functions (F1 to F6) are mapped to identify alternative GPAs to satisfy the requested functions. This identifies all GPAs that contain the list of requested functions. There are two possible types of matching GPAs, first GPAs that the product modules mapped exactly to the requested functions (GPA3 in the figure) and second GPAs that contain mapped product modules and additional product modules (GPA1 and GPA2 in the figure). These alternative GPAs are adapted as possible products based on the interfacing compatibilities of the mapped product modules in the GPA.

This configuration links three views (Figure 2) through identified product modules from existing GPA. The product includes the connection of product functions (that represent the requirements) to product modules (that represent the solutions). The combination of product module and production is described by additional characteristics (features) on the product module for identification of optimal combinations that represents the integration of market constraints in the product module itself. The identified product modules are further refined based on product-production combinations to fit the best possible product and production configuration.

B. *Configuration 2: Mapping set of functions to modules through features*

In the second configuration, more attention is given to product modules separately regardless of the final products structures using these modules. This is also the case when all previous product structures contain partial correspondence with new requirements. This configuration offer more innovation freedom for the design of new product but include a very strong analysis stage of performance and interfaces' compatibilities. In this configuration, we go from the interpretation of the functions to identify all modules' features and then, search if there are some adequate modules and then configure these modules to possible products. The modular approach is used to satisfy functions individually through features and then configuring products based on interfacing compatibilities among mapped product modules. GPA can be used as a repository containing possible modules for specific functions. Mapping set of functions to modules through features, as identification of new product using existing modules a company has, is presented in Figure 5.

Requested Function	Feature	Product Modules
F1 →	Fr1 →	PM11, PM12, PM23, PM22, PM48
F2	Fr2	PM13, PM21, PM24, PM31
F3	Fr3	PM14, PM25, PM39, PM49
F4, F5	Fr4	PM15, PM38, PM49, PM53, PM58

Note: PM12 means Product Module from GPA1; → Represents mapping

Requested Function	Feature	Product Modules
F1 →	Fr1 →	PM11, PM12, PM23, PM22 PM48
F2	Fr2	PM13, PM21, PM24, PM31
F3	Fr3	PM14, PM25, PM39, PM49
F4, F5	Fr4	PM15, PM38, PM49, PM53 PM58

Product 1 Product 2 Product 3 Product 4

Figure 5. EXAMPLE FOR MAPPING SET OF FUNCTIONS TO MODULES THROUGH FEATURES AND CONFIGURATION OF A PRODUCT

An example for the mappings to identify product modules and then configure alternative products is presented in Figure 5. The requested functions are individually mapped to find alternative product modules as shown in upper panel of the figure. Each combination of the identified product modules for the functions is used to evaluate as possible product based on interfacing compatibilities. Thus identified possible alternative products as Product 1 (PM22, PM24, PM25, PM15), Product 2 (PM23, PM24, PM39, PM49), Product 3 (PM11, PM21, PM39, PM53) and Product 4 (PM48, PM31, PM49, PM58) are presented in lower panel of the figure.

This configuration links three views (Figure 2) through creation of new product which is configured using identified product modules for the requested functions. The product includes the connection of product functions (that represent the requirements) to product modules (that represent the solutions) through features. The identified alternative products and product modules are further refined based on product-production combinations to fit the best possible product and production configuration.

In the proposed modular product development approach, a product is considered as composed of a set of modules and these set of modules are configured to generate a product structure. Product structure with their defined module features are used as a key media tool to support information flows among the product development activities. A module is defined as a smallest independent entity to address a requirement or a set of requirements. Company has alternative modules for this module based on certain feature(s) specific to a market, design or production strategies. Thus identified set of modules are configured to generate feasible product structures and then to identify optimal product for addressing emerging market requirements, which leads to adapting the existing product structures and development facilities according to emerging market characteristics. The potential of the proposed modular approach has been demonstrated by involving the customer(s) requirements in the product development and enhancements.

V. Conclusion

Product module concept has been introduced and analyzed so as to respond to the requirements of adapting product-service design and production in a customer-driven context, adaptation to customer's needs in emerging market. Module features have been defined to help translate the regional customer requirements to product and product-service structure design and also connect the product-service design to production planning as well as other downstream activities. The modular design approach for the adaptation of European product to emerging markets has been presented. The approach is under implementation for structuring the PLM repository that supports the ProRegio platform.

The proposed modular product design approach will be further investigated as an implementation applied to industrial use case requirements and also to connect with a knowledge base system for information exchanges for reasoning and usages in the development.

VI. Acknowledgement

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