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ASPECTS RELATING TO DEVELOPMENT OF MODULAR DESIGN IN MASS CUSTOMIZATION PRODUCTION

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Abstract. The paper proposes a novel integrated method for modeling a family of products, compatible with mass customization paradigm, that facilitate interchangeability between the product component modules. The proposed method is used in the design process of new families of products which are characterized by different levels of reconfigurability and it facilitate the reduction of the number of modules needed to be developed. In the article the mathematical algorithm used to calculate the number of variants for a given family of products is presented. The proposed method is used to model a system from automotive industry.

Key words: mass customization, modular design approach.

1. INTRODUCTION

The last decades showed a continuously shift in manufacturing industry from mass production to mass customization [1]. The market faced a saturation of mass production goods, the customers started looking more and more for new products that allow a certain degree of customization, in this way satisfying more their needs [2]. As result, companies from different economic sectors like automotive, clothing or computers manufacturing realized the important competitive advantage that mass customization could bring and implemented the paradigm in the development of their new products [3]. This trend is encouraged also by the academic community, in the recent scientific literature multiple successful implementation of mass customization in different economic sectors could be found: clothing industry [4,5], food industry [6,7], automotive industry [8] or electronics [9].

The mass customization concept could be defined as a serial production where the developed products have distinct features specified by the customer [3,10]. In this way, the customer became an important element in the manufacturing chain. The implementation of mass customization raised multiple challenges to companies, from the design phase where new products that are customizable had to be develop to the manufacturing process where the already existing manufacturing chains had to be adapted to facilitate high product variety and cost efficiency [11]. The challenges don't stop here, as the implementation of the concept implies also the development of complex manufacturing networks that can properly coordinate, collaborate and communicate in a globalized environment [1] and in the same time be compatible with a sustainable production that allows implementation of non-polluting processes and systems [12].

The development in researches related to this domain in the last years, allowed implementation of new ways for interacting with/integrating the costumer in this process. The use of web-based configurators and the implementation of more organized customer interaction methods allows the companies to adapt more easily to the fluctuation on the market demands (quantity or product types) but also to be able to fulfill customer options concerning the characteristic of a certain product [3].

In spite of the greater attention it places in practice and research, mass customization is still not fully explored. The customizability of a product is the key for successfully implementation of mass customization [13]. Academic research has not properly investigated this aspect and researches related to the modeling of the variety in relationship with the customers' demands and practical implementation of new families of goods are still in the beginning in this field [3]. In this paper, the authors propose an integrated method for modeling a set of products to facilitate interchangeability between the modules of these systems. The scope of the method is to obtain a model that facilitate the reduction of the number of modules needed to develop a set of products with different level of reconfigurability compatible with mass customization paradigm.

2. PROPOSED MODELING METHOD FOR MASS CUSTOMIZATION PRODUCTS

In this chapter the proposed method is presented. The challenge in implementing customizability of a product is to create a framework that allows to integrate different needs of diverse customers into generic families of products architectures. From these families, a large number of products variants could be implemented. Modularity is a solution to this challenge [14]. In this case the creation of product variety can be obtained by mixing and matching the system modules into different preset configurations. In the proposed method – **MO**dules **F**unctional **I**ntegration (MOFI), we extend horizontally the mixing and matching process to more than one product. Several products can share one or more modules. In this way it is intend to reduce the costs of their maintenance and, implicitly, the reduction of stocks for a product family. At the same time, this approach allows to reduce production costs and facilitates the creation of production lines that facilitate development of a large number of products.

The challenge in developing these systems comes from the design stage, the stage where the product categories developed and the modules that make up such a product are defined. At this stage the product configurations/variants it's an important parameter that can offer to the designers a measurement scale which is direct related to the external perception of variety induced complexity [15]. This is an important element that influence on one side the acceptance of the costumer of a certain developed product and on the other side the complexity of the production lines.

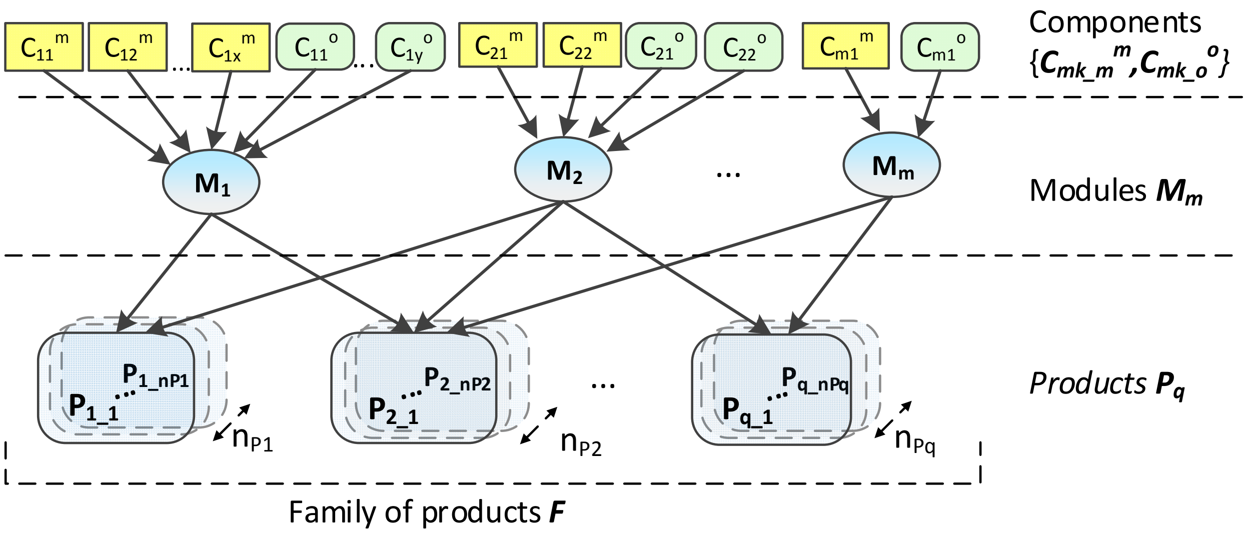

Fig. 1 – Proposed modular concept.

In Fig. 1 the schematic representation of the MOFI method is presented. It can be noticed that in the development of a family F of products P_i, $i = 1,2,...,q$ a set of m modules M_j, $j = 1,2,...,m$ is used. These modules are shared by several products and do not necessarily each of them need to be used by all developed products. Each of the modules are composed by mandatory C_{mk}^m and optional C_{mk}^0 components.

The number of mandatory components for the j module M_j is given by k_j^m parameter and the number of optional components for the j module M_j is defined by k_j^0 parameter. As result, each of the modules can have several variants, depending on the way the components combine.

For example, the module M_2 is formed from two mandatory components $\{C_{21}^m, C_{22}^m\}$ and two optional components $\{C_{21}^0, C_{22}^0\}$. This will result in four variants for the M_2 module (Fig. 2).

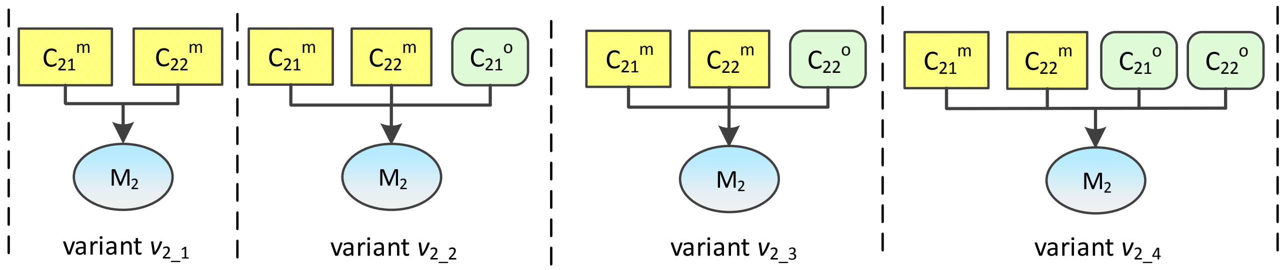

Fig. 2 – Variants of module M_2.

The equations presented next allows calculations of the product family variety. In obtaining the equations for family variety the authors adapted the equations presented in [16] to suits the MOFI method. The numbers of variants v_2 obtained for the module M_2 can be calculated using the following equation:

$$v_m = \frac{\frac{2!}{(2-0)!}}{0!} + \frac{\frac{2!}{(2-1)!}}{1!} + \frac{\frac{2!}{(2-2)!}}{2!} = 1 + 2 + 1 = 4. \quad (1)$$

The general form of the equation (1) for a module M_j, $j = 1,2,\ldots,m$, can be written as follow:

$$v_j = \sum_{x=0}^{k_j^0} \left(\frac{\frac{k_j^0!}{(k_j^0 - x)!}}{x!} \right), \quad (2)$$

where k_j^0, $j = 1,2,\ldots,m$, represent the number of optional components for the j module M_j and v_j is the number of variants for the j module M_j, $j = 1,2,\ldots,m$.

In order to obtain the number of variants for a product P_i, $i = 1,2,\ldots,q$, the individual variants v_j, $j = 1,2,\ldots,m$ of all modules that form P_i part must be multiplied. For example, the product P_q is obtained from 2 modules $\{M_2, M_m\}$. In order to calculate the product variants, first the modules variants v_1 and v_m are computed:

$$v_m = \sum_{x=0}^{1} \left(\frac{\frac{k_m^0!}{(k_m^0 - x)!}}{x!} \right) = \frac{\frac{1!}{(1-0)!}}{0!} + \frac{\frac{1!}{(1-1)!}}{1!} = 1 + 1 = 2. \quad (3)$$

The number of variants n_{P_q} for the product P_m is obtain as follows

$$n_{P_q} = v_2 v_m = 2 \times 4 = 8. \quad (4)$$

The general form of (4) is

$$n_{P_i} = \prod_{y=1}^{q_{P_i}} (v_y), \quad (5)$$

where q_{Pi} represents the number of modules that compose the P_i product.

All the variants that could be obtained for the product P_q are presented in Fig. 3.

To obtain the total variants f for the products family F, all products variants n_{P_i} are summed. The equation used to obtain f is:

$$f = \prod_{i=1}^{q} (n_{P_i}). \tag{6}$$

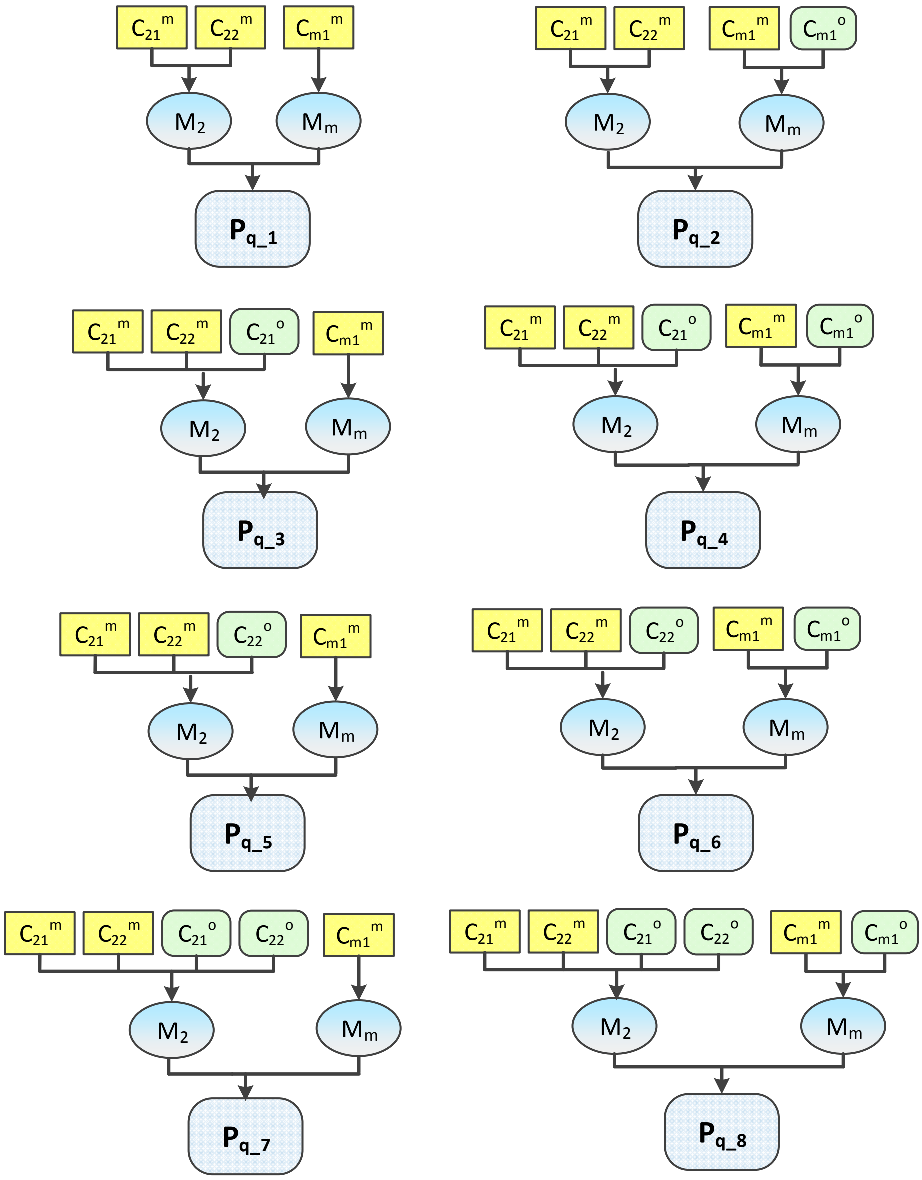

Fig. 3 – Variants of product P_q.

The n_{P_i} variants and the total family variants f are used to evaluate the customer acceptance of the P_i products from F family. As shown in [17] these parameters could then be reduced to a value that is acceptable for customer, reducing in this way the complexity of the developed products in the family. Sharing multiple modules M_j by products P_i from the same family F contribute in reducing the complexity. From the manufacturing and maintenance services perspective the reduction in complexity offers multiple advantages in simplifying the production lines by producing smaller numbers of different modules and at the same time, optimize the stocks used in maintenance services by shearing modules by different products from the same family.

3. APPLICATION OF THE CONCEPT IN AUTOMOTIVE-EXAMPLE

The automotive industry had faced in the last decade a tough period as result of the global financial crisis [18]. These events have led to rethinking of how the cars are designed, developed, recycled and maintained during their use and in the same time integrating the customer in this process. The materialization of these new ideas leads to new products which cost less to produce and with a more simplified maintenance chains by reducing the types of automobile spare parts and in the same time offering a high variety of customization options for the customer [19].

In automotive industry the integration of the customer can occur during the design, manufacturing or distribution phase. The most common situation at the moment, allows customer to select from a high variety of options and in this way favoring personalization of the final product. The implementation of this approach is possible only by integrating the customer in the manufacturing process, but in the same time the goal is to maintain the high-volume production in order to be competitive on the marked and ensure profit for the car manufacturer [20].

The proposed method supports the implementation of the above premises by allowing to develop a wide range of cars from a certain family (ex. of families: small city cars, medium cars, sports cars or large cars platforms/SUVs). The propose model favorized development of new cars at a greater and more precise pace using as few unique pieces as possible and in the same time allowing to include in the same family cars from different automakers from the same group.

To exemplify the MOFI method two modules of the system are defined, these modules are then integrated in three different products. The chosen family F is SUV, and the first module M_1 refers to the power transmission. This module can integrate two components, one mandatory $C_{11}{}^{m}$ – front wheel drive and the second optional $C_{12}{}^{o}$ – all wheel drive.

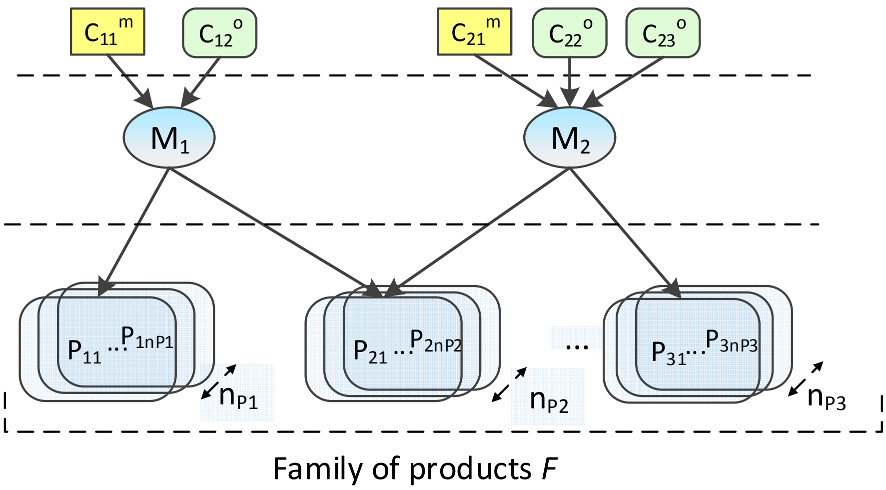

Fig. 4 – Family of products F in automotive.

The second module M_2 is materialized by the fog lamps system. This model can integrate three components, one mandatory C_{21}^{m} – fog lamps and two optional: C_{22}^{0} – coming home function and C_{23} – corner function. The second module is used only in the second and third product.

The variants for each module are calculated using equation (3), the obtained values are $v_1 = 2$ and $v_2 = 4$. Using these values, the number of variants for each product can be obtain $n_{P_1} = 2$, $n_{P_2} = 8$ and $n_{P_3} = 4$, respectively. The total variants on the family is $f = 14$.

4. CONCLUSIONS

The paper presents a method for modeling a family of products that facilitate interchangeability between the product component modules. A mathematical method that allows to determine the product variants was developed. The proposed method was used to model a system from automotive industry.

Several advantages of the approach were mentioned in the paper: the proposed method offers multiple advantages in simplifying the production lines by producing smaller numbers of different modules; optimize the stocks used in maintenance services for products from the same family; development of large number of variants of product at lower costs. The research presented in the article offers new potentials in modeling new systems with more complex relations between components.

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