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Design of product families: methodology and application.

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Abstract

This work proposes a methodology for the design of product families. The proposed methodology distinguishes stable and variable aspects so as to design and produce modular elements independently. The various phases are presented and implemented on a case study.

This work is illustrated with an application on electrical wire harnesses in a context of synchronous delivery. In this case, it is possible to delocalize a part of the production to minimize the production costs and to complete the final assembly in a shortened time.

The contribution of this research is to integrate the manufacturing process in the selection of the Industrial Modules to manufacture. The costs related to the diversity caused by the modules are compared with the time saved in the final process assembly.

Keywords: Design method, product diversity, product family, modularity, wire harness.

1. Introduction

In nowadays markets where the production capacities are higher than the market requests, manufacturers can, either focus their activity on a strategic function in order to reduce their costs and become more competitive, or diversify their production to embrace a broader set of needs and be closer to the customers' requirements.

Let us assume that the second strategic option is selected. From this point of view, a set of different needs is to be satisfied. The context consists of a mass production of highly diversified products. More precisely, the focus is on a product that is carried out starting from the assembly of a great number of components. Among the components to assemble a certain quantity can be optional (options), another mandatory but with various variable characteristics (alternatives).

To satisfy diversified needs, various solutions are available. On one hand standardization [17, 15] makes it possible the satisfaction of a whole set of needs with a single product and/or process. On the other hand manufacturing specific products aims to the strict satisfaction of each need. Compromising between those two, most industrial products are at an intermediate stage between these solutions and have at the same time standard elements and personalized elements, assembled in a more or less personalized way. The intermediate solutions can use the modular concept [16, 20] and/or delayed differentiation [17, 13 , 23]. It becomes possible to rationalize the production and to optimize either the products, or the processes, sometimes both, in order to benefit from a better productivity [18, 6]. This compromise aims to combine the cost benefice of mass customization with the larger range of market allowed by personalized products.

In the literature, some design methodologies suggest to enrich the design of product families by defining a stable product architecture. These methodologies separate fixed and variable elements when designing the product. Some are based on negotiation [10], others distinguish stable and variable aspects from the coupling between the functional and technical models [8, 14], others are based on the analysis of the customers' requirements [25, 19, 7, 24], others finally take into account the process [11, 2, 12].

The contribution of this paper is a proposition of a model that supports a global methodology for the design of products with high diversity. It has been applied to electrical wire harnesses for automotive industry.

This paper is organized as follows. Section 2 presents an industrial case study in which a supplier has to provide high diversified products in a short delay, section 3 proposes a methodology for the design of product families and applies it on the industrial case study presented before.

2. Case study

In the automotive industry, electrical wire harnesses are amongst the most expensive equipments [3]. Electrical wire harnesses are sets of cables used to connect various elements in an electromechanical or electronic system. The function is to provide electric power and electronic signals to various peripherals. Essential component, a delay in the realization of the electrical wire harnesses causes a delay on the end product. A bad quality of the electrical wire harnesses is not tolerated by the customer, it can cause large nuisance which can go until the immobilization of the vehicle (or sets fire to it!).

In spite of the strategic importance of this equipment, few works were interested in their design. Ng et al. [21] carried out a state of the art of the field. They present the problems and difficulties met for their design and planning. According to them, the design of electrical wire harnesses is regarded as a second importance activity which takes place at the end of the development cycle of the products where they are embedded.

Let us point out however the work of Thoteman and Brandeau [22] which shows that an optimal design (from a financial point of view) can be obtained by seeking the optimal commonality of the components in the sub-products. Hamou [12] proposes an approach starting from the use of product configurators to contribute to the design of products with strong diversity with a case study dedicated to electrical wire harnesses. Agard [1] proposes a product/process design for electrical wire harnesses that enables a synchronous delivery.

Let's consider the following industrial context (represented Figure 1).

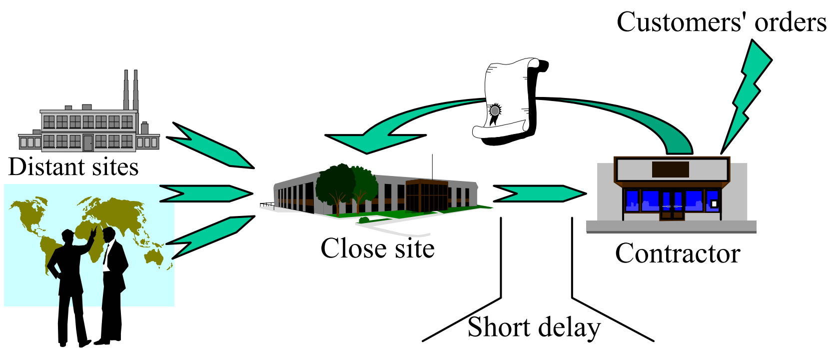

Figure 1: Industrial context for the industrial case study

A supplier manufactures electrical wire harnesses for a contractor. The supplier disposes of a production site located at a short distance from the contractor and some distant sites with lower production costs. The supplier can easily supply the close site. The contractor receives orders from its customers, and transmits them to its supplier. The supplier must then deliver the exact component in a short delay because the contractor works in synchronous production and requires to be delivered in the order where the products are on its assembly line.

To satisfy a maximum of customers, the contractor proposes many options and alternatives on the final product. Each customer combines the options and alternatives which he wishes so as to select a personalized product. The consumers' needs are different, that means that each final product will not have to fulfill the same functions, each final product is then different. The contractor awaits from its supplier the exact component (which does not contain any element not strictly necessary), because each element (used or not) causes a cost (material, installation) for him. This cost is considered unjustified, and shows a proof of bad quality.

Electrical wire harnesses intervene in the operation of a great number of functions in the end product, in particular among the functions for which there are options and alternatives. Thus, the composition of each electrical wire harnesses is completely linked to the configuration of each final product for the customer. Taking into account the great number of final products that it is possible to obtain by the selection of options and alternatives, the electrical wire harnesses are almost all different although obtained by combinations of standardized components.

To carry out all these electrical wire harnesses, the supplier must take into account at the same time the great diversity and the short delivery period. Two industrial approaches are possible to solve this problem, namely the standardization and the modular concept.

Presently, the supplier carries out standard electrical wire harnesses. It is then necessary to find a balance between the overcosts related to the elements not used and the benefit coming from the reduction of diversity. An approach of this type is used by the supplier [5]. However this standardization causes additional costs due to the unused functions present in the electrical wire harnesses. Thus the purpose of the application of the following methodology is to produce them with total diversity and in the time available for the synchronous delivery.

3. Methodology

A proposition of a methodology with 8 steps is carried out in [2]. The methodology focuses in particular on the analysis of the functional requirements (with a distinction between stable and variable functions), the creation of a functional structure, the creation of a technical structure and an analysis of the set of relevant available processes. The methodology is described and applied on the case study in the following sections all along its lifecycle.

Step 1. Creation of a team to manage the product diversity

The first step of the methodology focuses on the creation of a team to manage the product diversity. The members of the team should belong to different departments within the company in order to have a global representation of the product.

The supplier considers prohibitory the additional costs due to the standardization and wishes to provide electrical wire harnesses with total diversity. The goal is to redesign the product and/or the process. The adopted strategy (Figure 2) is:

1. To break down the electrical wire harnesses into Industrial Modules (IMs) which will be manufactured in the distant sites;
2. To carry out a final specific assembly in the close site;
3. To deliver the electrical wire harnesses in a synchronous mode.

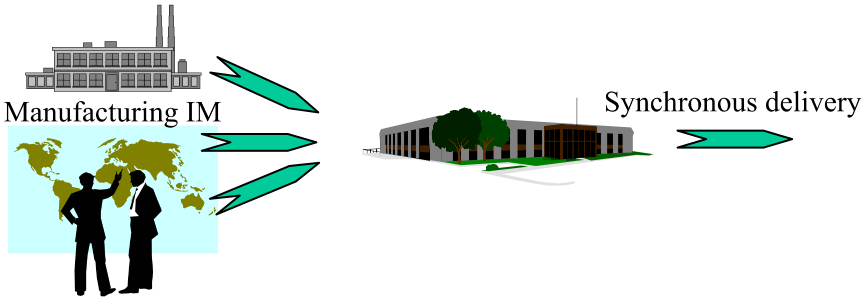

Figure 2: Adopted strategy for the industrial case study

Step 2. Selection of indicators

To have relevant views about of the situation and about its evolution, it is necessary to have some indicators. In our case study, according to the adopted strategy, the first indicator will be the maximum time of final assembly. This time of final assembly will have to be under the time available for the synchronous delivery for each different harness.

Besides, the time of final assembly will not be sufficient to qualify a solution; it will be necessary to take into account the number of IMs to realize. These IMs represent a cost for the supplier. These two indicators are aggregate in a criterion using the following conversion [1]:

$$y = DTFA.\Delta MOD.VA\text{-}x.CGR \qquad (1)$$

With:

– *DTFA* = Decreasing Time of Final Assembly, it denotes the time to manufacture the IMs in the distant sites;

– *ΔMOD* = difference between the production cost in close and distant sites per unit of time;

– *VA* = number of vehicles manufactured per year;

– *x* = number of new modules to create;

– *CGR* = management cost for a module for one year;

Then:

– *DTFA.ΔMOD.VA* corresponds to the profit in the production costs;

– *x.CGR* characterizes the management costs for the additional references;

– *y* stands for the financial profit (or the loss) to carry out a module, it represents the cost to manufacture an IM.

Step 3. Functional requirements analysis

This aspect has not been managed in our case study, as functional requirements are mandatory. Nevertheless, in other applications, this step seems to be very critical in the management of diversity.

This step gives information about the customer's expectations. The Engineering Design Research Laboratory (K. Otto et al. [10, 24]) proposes to make a distinction between the origin of the diversity; they ask customers (or a group of targeted customers) about their functional expectations at different time. Two measures identify the dispersions:

- σ_a represents the dispersion at a given time,
- σ_t represents the evolution of the dispersion in the time.

Diversity comes first of all from the heterogeneous needs for the customers, but also from internal parameters to the company. For example the company's strategy can seek to manufacture products with strong diversity while following a commercial logic seeking against competitors. A study of the request will allow:

- to build an average customer, who will become the target to satisfy;
- to define several groups of customers. It could be judicious to propose several groups of products targeted by group of customers;
- to select a whole or subset of customers to be satisfied in priority (ex: to make a top-of-the-range product for a certain category of customers);
- to quantify the correlation in customers' requests (link analysis).

The analysis of the functional requirements can provide: a description of the functions to realize, an estimate of the correlations in functions, estimated quantitative assessments of sales, a whole of functional constraints and/or commercial constraints.

Step 4. Creation of a functional structure

Following the functional requirements analysis a functional structure must be setup that separates stable and variable functions. Three questions are necessary to distinguish relevant cases according to Figure 3.

Q1: Is the function stable?

Q2: Can the variation of the function be supported by a robust and inexpensive design?

Q3: Is the variation time-dependant?

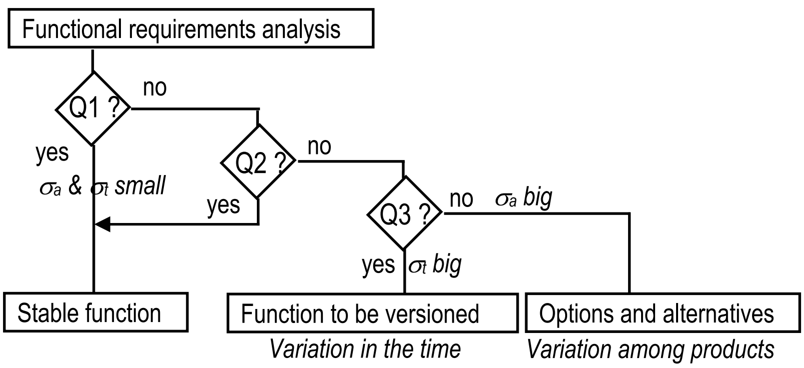

Figure 3 : Creation of a functional structure.

The previous figure splits stable functions, functions to be versioned, options and alternatives.

The study of the literature shows that it is preferable to dissociate the stable and variable features. Stable features are developed to increase the performance/cost ratio while integrating a maximum of functions. That also makes it possible to rationalize the means of production. Variable features are conceived while following an optimal variety/cost ratio. Features without variation are a stable factor in the design.

Step 5. Creation of a technical structure

For this step, the *functional* diversity is given; one wonders about *technical* diversity, it is necessary to answer the question: how to manufacture a great (functional) diversity of products at a lower cost?

Various strategies are available which depend on the context in which the company evolves. The design can be:

– specific: in the case of a non reproducible single product;

– standardized with a single product, in particular on emerging markets or with weak competition;

– customized: mainly on mature markets subjected to hard competition. It is then possible to create a common platform for all the products, and propose options and alternatives, or to propose various platforms standardized by range of product.

A strategic choice is necessary to answer such question. This choice is argued by an evaluation as complete as possible about all various possible solutions by answering the following questions:

– how much costs/pays to make such option/alternative?

– how much costs/pays not to make such option/alternative?

The standardized option being equivalent to the specific option with widened functions, it is treated like a single product, that is not developed here.

Let us consider that it is selected to manufacture a diversified offer based on a common platform with options and alternatives. Alternatives are always in the final products but with variations, options are not always in the final products. As for the functional structure, the technical structure separates stable and variable features. The creation of the technical structure follows an algorithm shown in Figure 4.

Q1: Is there a high demand and are standardization costs small?

Q2: Is there a high association in the requirements and are standardization costs small?

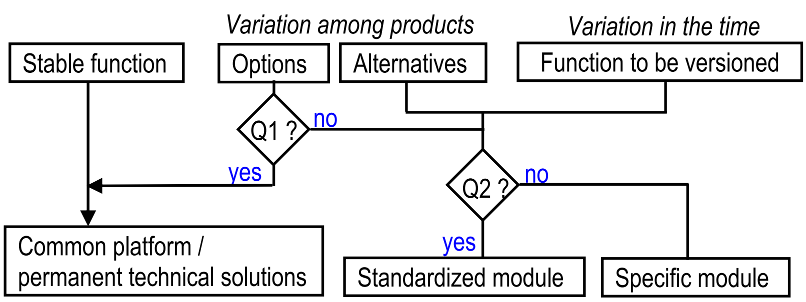

Figure 4 : Creation of a technical structure

Stable aspects are integrated in the common platform as much as possible. A negotiation on the variable elements makes it possible to include some of these elements in the common platform [10]. Variable elements are designed around modules with standards interfaces to facilitate exchange of modules and it makes it possible to take advantage from product delayed differentiation using the same module for several uses.

The integration of various functions in the same module is all the more interesting as the association between the functions is significant. The measurement of these associations can be determined using Data Mining tools [4, 9].

Step 6. Process selection

All relevant available processes to realize the products must be considered. In our case study, the degrees of freedom remaining to manufacture the electrical wire harnesses concern the selection of the modules. Our proposal is on two types of modular approach (cf Figure 5) based on a selection of components (structural modules) or based on a selection of functions (functional modules) [1].

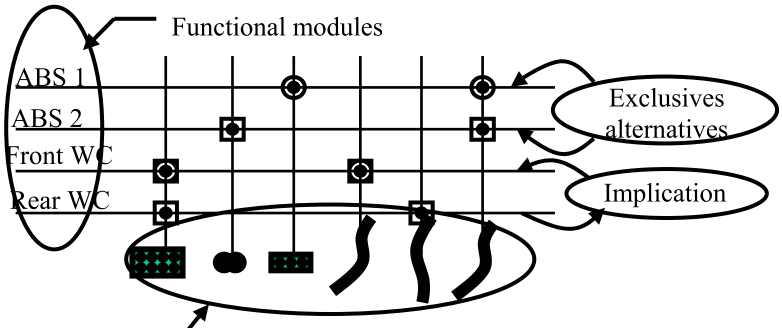

Figure 5 : Modular approaches: structural modules of functional modules

Step 7. Search for valid solutions

All propositions are evaluated with the indicators defined in step 2. If a proposition is valid (Q1: Is the solution valid?) then it becomes a valid solution, otherwise it is necessary to redesign the product and/or the process.

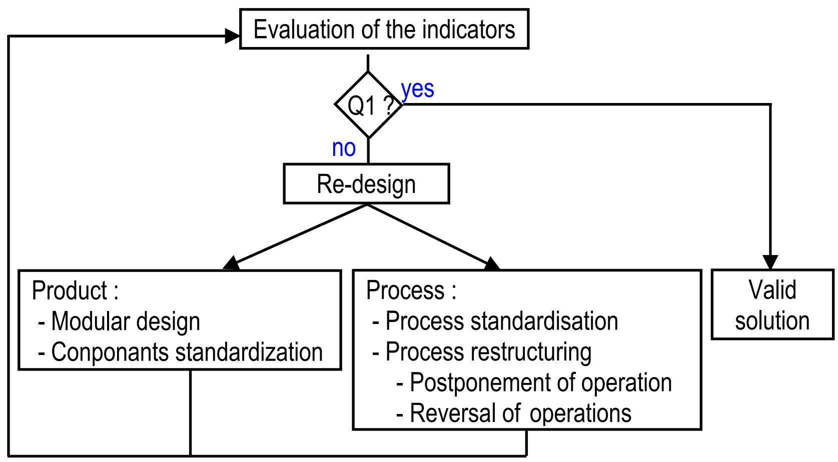

Figure 6: Search for valid solutions

The algorithm to search for valid solution (Figure 6) is adapted for the present case study. For that, the question *"is the solution valid?"* becomes *"is the DTFA lower than the available delay?",* the modular algorithm presented in Table 1 was developed.

Table 1: Modular algorithm

Modular algorithm	
1	The starting point is such that the electrical wire harnesses are entirely manufactured in the close site. Thus the time of final assembly is maximum, because all the work of assembly remains to be made, on the other hand the cost for IMs is null, because there are no IM.
2	Determine the whole set of possible pre-assemblies according one of the two strategies (structural or functional).
3	For each pre-assembly, calculate: – the time saved in final assembly: DTFA – the number of additional IM references: x
4	Select the industrial module which offers the best y using conversion (1).
5	Start again in 2) until one of the following criteria is up: – time of final assembly ≤ target time – cost of management for the new references ≤ maximum cost of investment – no more possible cutting.

Step 8. Selection of a final solution

The algorithm presented in Table 1 was implemented with the two types of modular approaches (*structural* and *functional*). Figure 7 [2] represents the delocalization cost for the additional references in function of the time of final assembly with both strategies for the same electrical wire harness. This figure shows how much it costs for the supplier to manufacture the electrical wire harnesses family below a certain limit of time with each strategy.

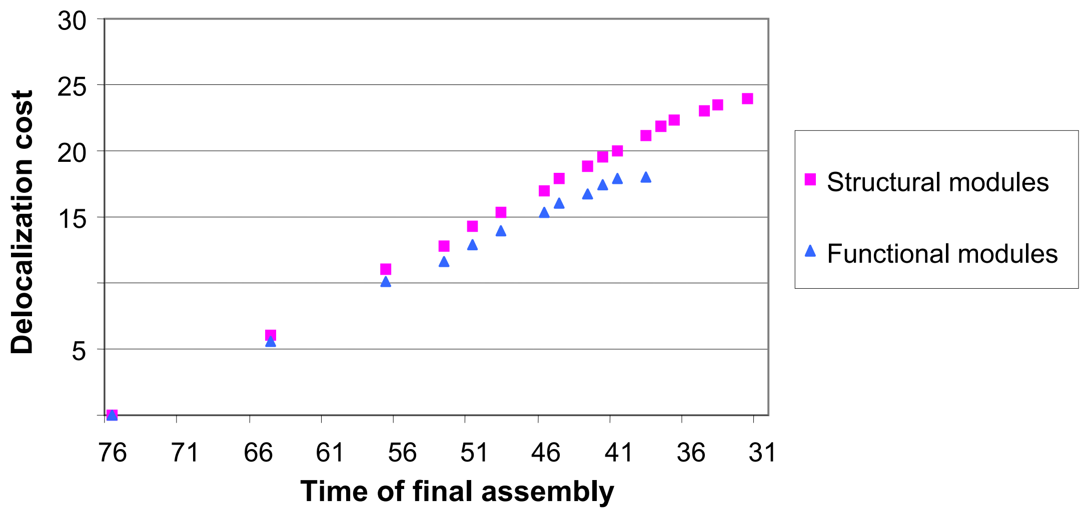

Figure 7 : Delocalization cost with both algorithms

One can notice that for high limits of time, the functional strategy is always cheaper than the structural strategy. However if the contractor wishes to decrease the time of final assembly below the minimal limit of the functional strategy, the supplier will have to adopt a structural strategy to decrease the time of final assembly.

Thanks to this type of representation, the supplier is able to negotiate with the contractor on the tariff and the time which they project. The supplier can propose to his contractor to modify his process to increase the synchronous delivery period, and thus to decrease the tariffs of purchases of the electrical wire harnesses.

4. Conclusion

This paper proposes and applies on an industrial case study a methodology for the design of product families. The 8 steps methodology is based on a distinction between stable and variable features that are developed independently. The methodology allows controlling defined parameters linked with product diversity by influencing the design of the product family and/or by influencing its manufacturing process.

On the case study presented, it was possible to delocalize a part of the production in order to decrease the time of final assembly for a family of electrical wire harness, with minimum production costs. The contribution here was to integrate the manufacturing process in the selection of the Industrial Modules comparing the costs related to the diversity with the time saved in the final assembly process.

Nevertheless the application of such a type of methodology must be validated on various industrial cases so either to make evolve the methodology to take into account additional parameters, or in order to classify different types of problems and to develop specific tools for them.

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