DESIGN OF WIRE HARNESSES FOR MASS CUSTOMIZATION

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Abstract:

The paper focuses on the design of wire harness assemblies for mass customization by a delayed product differentiation. In order to manufacture wide diversified products, two algorithms are proposed both using a generic representation of wire harness with all options and variants in order to produce each wire harness in a short period of time. An industrial case study is presented in a contractor/supplier context, where the supplier must respond in a short time and provide a totally diversified product, which is to be delivered according to the specifications provided by the contractor. In the particular case described above, two different algorithms are applied and compared.

Keywords: Wire harness, Design of Product families, Product assembly.

1 Introduction

Wire harnesses are a set of electric cables that are used to connect different elements in electromechanical or electronic systems. The functions of a wire harness are to provide electric power and electronic signals to the different peripheral units. An example of a wire harness in an automobile context is provided in Figure 1.

A wire harness is composed of different kinds of elements:

- A set of cables that are used in order to transmit information and energy.
- Connectors are required to plug the wire harness with the other elements.
- Epissures are soldered joints between cables.
- Derivations are places on the wire harness where some cables change direction.
- Shafts are sometimes installed on zones of the wire harness when it is necessary to resist at certain constraints such as vibrations, shocks, friction, waterproofs, …
- Clips are in different places on the wire harness to fix the wire harness on to the final product.

All these elements are here to answer a lot of individual functions. In a medium wire harness in an automobile context, the family can be made of 400 references of cable, 120 Connectors, 50 Derivations and 30 Episures, in order to realize approximately 15 different functions with a maximum of 9 versions for several of these functions.

A wire harness is a component that is rather difficult to manufacture with economic constraints. Complexity comes from diversity; many components of the final product need to be connected to the wire harness in order to receipt energy and/or information. Nevertheless some components could be optional, many of them have different variants, and moreover these components can evolve in different versions. Usually different variants and different

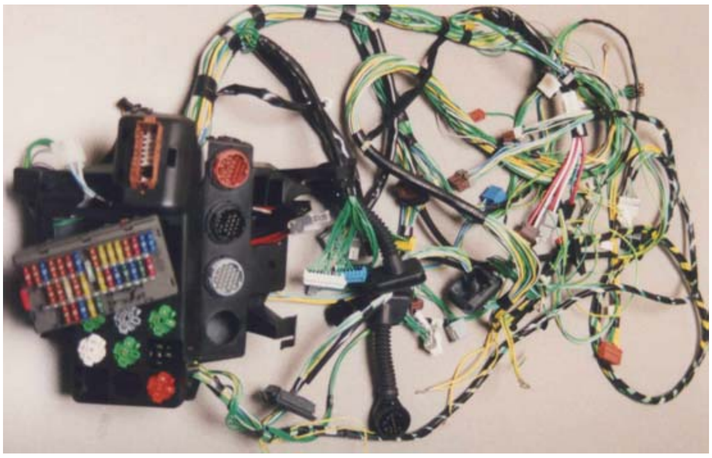

Figure 1: *An automobile wire harness.*

versions of a component do not have the same requirements with the wire harness. Each time these requirements change (intensity of current, type of connector, number of cable...) the wire harnesses have to be adapted.

Let's consider a vehicle for which there are 6 versions of transmission, 7 versions of engine cooler and 9 versions of engine, moreover there are 5 versions of ABS that could be installed or not and 2 versions of cruise control that could be installed or not. For that particular vehicle, one should be able to produce 6*7*9*6*3=972 different combinations of wire harnesses!

Actually the number of wire harnesses to produce is lower than that because some constraints between the different components do exist. For example one can install only one version of engine in each vehicle, there is no ABS on small vehicles … from where the existence of exclusive and inclusive constraints such as:

If *sunroof* then no *roof antenna.*

Difficulty also comes from manufacturing; the contractor wants the exact wire harness (without unnecessary components that he refuses to pay) and he wants it to be delivered in a specific order in a short period of time.

The assembly of a great number of sub-components is necessary to realize each wire harness to be delivered. The complexity of one wire harness is such that it is impossible to produce it from elementary components in less than the time that the provider disposes.

To realize all these wire harnesses, the provider has to take into account both the wide diversity and the short time of delivery. The supplier then decides to build a certain quantity of sub-assembled modules that he will assemble specifically for each final product during the time interval at his disposal.

These sub-assembled modules can be made anywhere, far from the final vehicle assembly line (where the handwork is cheaper), while the final assembly will be carried out in factories that are nearer. Then the most important lead time for the synchronization will be the final assembly in the nearer factories. The diversity will be supported by the good selection of the sub-assembled modules build in the distant factories; the manufacturing time of these modules then does not enter into the "time of final assembly" which is really of interest in this study. The contractor has an estimation of his average sales; the supplier then knows an estimation of his needs in each module per period; that will enable him to size each buffer for the same periods.

This results in an increasingly significant number of product alternatives in order to answer diversified functional requirements. For producers, this commercial diversity must be controlled; otherwise an expensive diversification process could result [11]. Necessary commercial diversity can be durably assumed only if it is supported by a low technical diversity, which guarantees acceptable management and development costs [2].

In a context of product design, this research focuses on the description of a product design problem for wide diversity with modular components and product-delayed differentiation for the realization of wire harnesses. This paper is broken up in the following way: section 2 describes the context of design for diversity. Section 3 provides a description of the problem that research addresses and how it could be solved. Finally Section 4 exposes the results provided from the algorithms described in section 3.

2 Design for diversity

According to the wide number of different wire harnesses to realize, the interest has been oriented in the design of products in a context of wide diversity.

To meet diversified needs, several solutions exist from standardized design that offer the possibility to satisfy a set of needs with a single product, to specific design aiming at the strict satisfaction of each need. Most industrial products are in an intermediate level between these two extremes. There are at the same time standard elements and specific elements that could be assembled in a specific way in the final product delivered to the consumer.

It is possible to distinguish two product design policies that make it possible to carry out different products starting from standardized elements. These policies are modular design and product delayed differentiation.

2.1 Modular Design

Product flexibility is related to modular design concept and to the use of common components within various finished products. The flexibility of a module (the number of its uses) depends on its functional surplus capacities and requires standard interfaces.

To increase use-case number appears to be a significant potential of economies. Fouque [3] did an analysis that demonstrates the effects of commonality on stock costs.

Huang and Kusiak [6] have worked on modular design with the intention of producing a large variety of products at lower cost. They use a matrix representation to model interactions between parts and functions, then they break down the matrix to extract elements which are interchangeable, standardized, and independent.

Following the numerous implications of modular design in all the activities of product manufacturing, a large amount of works brought consistency to the design of product and process. One can cite as an example the works of He and Kusiak [5], which proposed an algorithm of taboo search in the goal of designing an assembly system for modular products with balanced assembly lines. In the same way, Huang and Kusiak [7] worked on the development of modular products with an aim of minimizing the test costs of the final products. It is possible to find other examples of application of modular concepts in [9].

Modular design enables one to realize a great number of different products using a limited number of modular components. Search has also provided methods to design product families. In this connection, it is possible to refer to the work of Newcomb *et al.* [12] and Gonzalez *et al.* [4].

Jiao and Tseng [8] provided a methodology to develop an architecture of product families to rationalize the development of products for mass customization from 3 points of view (functional / technical / physical).

2.2 Delayed differentiation

For Lee and Tang [10] delayed differentiation consists in delaying the point of differentiation in the product or the process (from which each product acquires its single identity) in order to store semi-finished products instead of finished products.

The goal is to produce a maximum of standard elements and to push back to the latest moment the point when each product is different from the others and needs to be identified as such. They propose to redesign the product and/or the process so that the point of differentiation is delayed as far as possible.

Authors of various articles [10, 13, 14] employ the term postponement as a synonym of delayed differentiation. That is to say, postponement occurs when the assembly of a product is not finished before the order of the customer arrives. In that case the inventory control is less dependent on the variability of the request [14].

The main techniques to carry out postponement are the following:

Standardization consists in using components or processes that are common in a maximum of products. That enables a decrease in the number of references to be managed and an increase in the quantities of each component which results in a reduction of the complexity of the manufacturing system. However, it necessitates increasing the possibilities of each component while bringing additional functions that will not always be used. The profitability of such an exercise depends on the balance between the investments necessary to standardize the components and the profits resulting from economies of scale, reductions in variety, and buffers... Lee and Tang [10] developed a mathematical instrument that allows one to find the best compromise.

Modular Design consists in breaking up a product into more or less independent sub-elements called modules. It is then possible to produce each module independently. The differentiation of finished products is manufactured at the assembly operation by the choice of modules and their position in the final product (See paragraph 2.1).

Process restructuring concerns restructuring the operations of the manufacturing process of a product. Lee and Tang [10] present two examples, in the first one, the operation that causes the differentiation is delayed at the end of the process, it is at the distribution stage that the differentiation is realized by the assembly of the necessary elements. The second case deals with inversing the order of two operations.

3 Design of a wire harness family

Currently the provider produces standard wire harnesses. That means he designs a limited number of wire harnesses that can be assembled in the totality of the finished products. Then he has to produce a buffer for each family of wire harness, the delivery time is then no more a problem, and the synchronization is largely simplified for the provider. On the other hand, the standardization causes an envelope effect (some functions are unused) that will have a cost.

The interest of such kind of approach depends on the balance between the over costs related to the elements not used and the benefits coming from the reduction in diversity [1].

This approach could be used until now, but in order to decrease the costs, the contractor has asked the provider to make efforts. The contractor decided to pay only for the functions that are required for each end product. The provider will support the costs of the unused components himself.

The manufacturer is then concerned with in the following problem: which modules should be produced in pre-assembly? Knowing that there is a fixed time for the final assembly (a time lower than the total manufacturing time of the component), and that the contractor requires exact components for a minimum cost.

One of the key points in the modular approach is the total product division in modules. The efficiency of all the approach depends of the good compilation of the modules that enable the product to be assembled within the time that the provider disposes, that cover all the diversity, and that minimizes the number of expensive references.

The goal of this project consists in determining these modules.

Two strategies are presented. The first one will be called “structural strategy” and will consider the family of wire harness to produce according to its physical description; the second one is called “functional strategy” and considers the wire harnesses according to the functions it has to support.

3.1 Structural strategy

All the different wire harnesses that could be produced are modeled as a generic wire harness with options, variants and versions plus a set of rules to describe the constraints between the components.

The generic wire harness is described as a set of cables. From this point of view, a sub-assembled module, called industrial module (IM) is then a sub set of cables that will be produced in the distant fabrics. The generic wire harness is modeled as a tree. In each branch the cables that pass inside are depicted (see Figure 2).

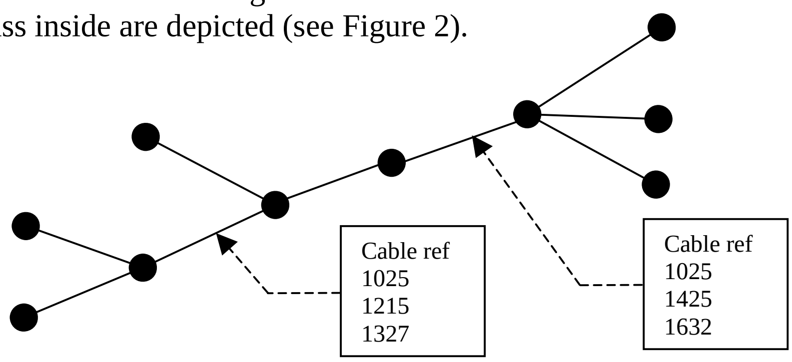

Figure 2: *Structural description of a wire harness.*

The idea is to split the generic wire harness in two independent sub generic wire harnesses, one of them will be the IM produced in the distant fabrics, the other one will be the specialization of the IMs in order to create a specific wire harness for the specific end product (See Figure 3).

One important criterion that one has to keep in focus is the time of specialization; this will be called "time of final assembly". That time has to be less than the time that the provider disposes to carry out each specific wire harness.

Once the specific wire harness has been split into different modules, if the time of final assembly is greater than the limit, the specialization module will then be split another time into two modules and so on until the time of final assembly is under the limit.

In practice the professional has to select the root of the tree by the choice of a node where the generic wire harness will not be split, in usual a node into a shape.

Each node is evaluated from the point of view of decreasing the time of final assembly and the cost of creation of IM.

The cost of creation of IM is directly proportional to the number of modules that support all the diversity. In fact one IM is in reality several sub modules. If an IM is created for the cables 1, 2 and 3, we will have to create 7 modules minus the constraints in order to produce each specific final product.

The Decreasing Time of Final Assembly (DTFA) is the time to produce the IM because they will be produced for buffers, and that time does not enter into the final assembly. These DTFA are calculated as following:

$$DTFA = \sum_{i=0}^{nb\_of\_branch} time\_to\_realize\_branch(i) + \sum_{j=0}^{nb\_of\_node} time\_to\_realize\_node(j) \quad (1)$$

$$time\_to\_realize\_branch(i) = type\_of\_assembly(i) \times length\_of\_branch(i) \quad (2)$$

$$time\_to\_realize\_node(j) = type\_of\_node(j) \quad (3)$$

Then a criterion is evaluated on each node; that criterion takes into account the DTFA, the cost of the references of modules and the work-hand cost; the best alternative is selected. The generic wire harness is then split in two parts (see Figure 3) and some branches on the specialization module are forbidden for a future split because some cables with an extremity in the IM have the other extremity in the other part.

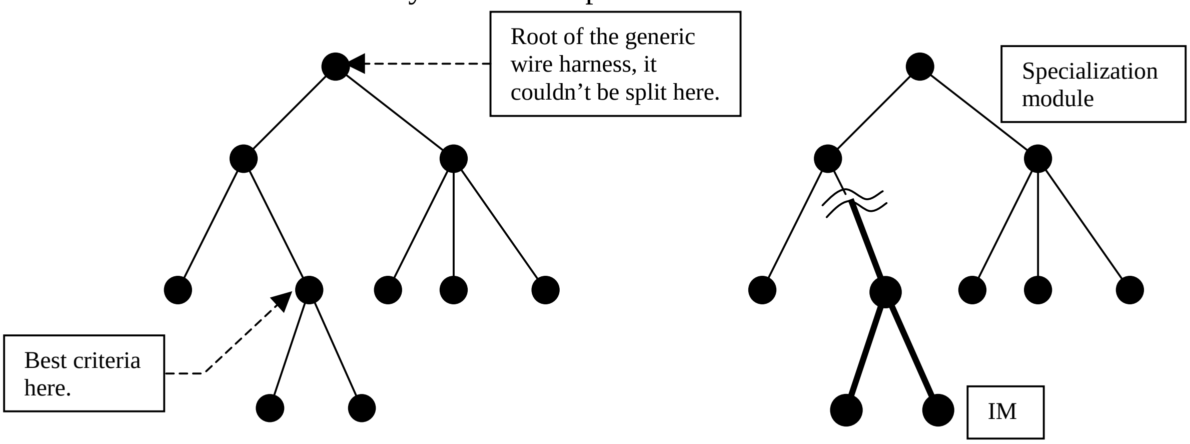

Figure 3: *Split of a generic wire harness.*

3.2 Functional strategy

As above, all the different wire harnesses that could be produced are modeled as a generic wire harness with options, variants and versions plus a set of rules to describe the constraints between the functions. The generic wire harness is described as a set of functions.

In that strategy an IM will be a set of functions that will be realized in the distant factories.

All functions are extracted from the generic wire harness; and for each set of functions that appears in one branch an evaluation of the time of final assembly that could be saved and the cost generated by the creation of IMs are calculated.

Then with the same criterion as above, the selection of the best alternative is made. The generic wire harness is then separated in two modules, and if the time of final assembly is greater than the limit, another separation is produced on the specialization module.

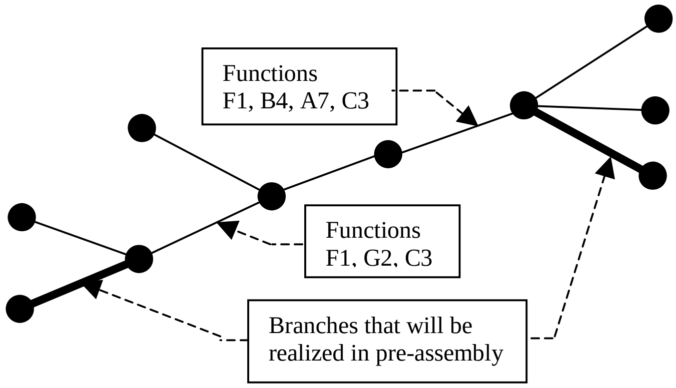

Figure 4: *Functional breakdown of a wire harness.*

In the functional strategy:

$$DTFA = \sum_{i=0}^{nb\_of\_branch} time\_to\_realize\_branch(i) + \sum_{j=0}^{nb\_of\_node} time\_to\_realize\_node(j) \tag{4}$$

$$time\_to\_realize\_branch(i) = \begin{cases} \bullet\, type\_of\_assembly(i) \times length\_of\_branch(i) & \text{if all functions into branch (i) belong to the module} \\ \bullet\, 0 & \text{otherwise} \end{cases} \tag{5}$$

$$time\_to\_realize\_node(j) = \begin{cases} \bullet\, type\_of\_node(j) & \text{if all branch from j belong to the module} \\ \bullet\, 0 & \text{otherwise} \end{cases} \tag{6}$$

3.3 First results

Both algorithms have been applied on a representative wire harness. For the structural strategy the results are presented on Figure 5. The results obtained with the same wire harness and with the functional strategy are presented in Figure 6.

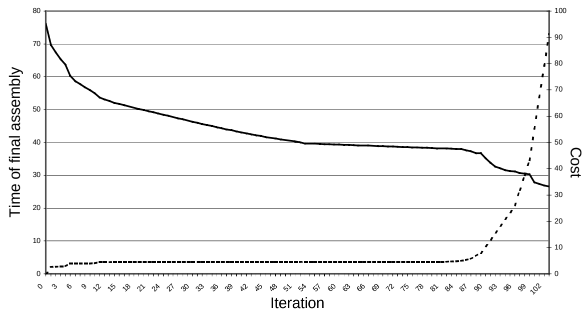

Figure 5: Evolution of the structural strategy.

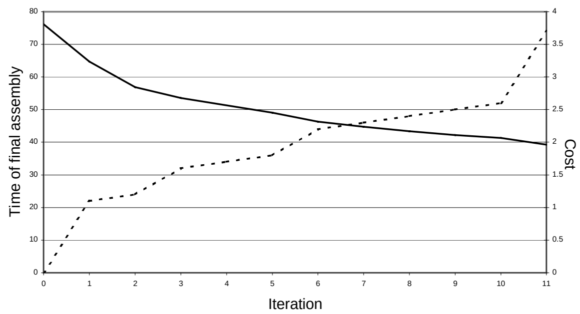

Figure 6: Evolution of the functional strategy.

The full line represents the time of final assembly, the dotted line represents the costs to produce the new modules and the X-axis is the number of iteration for each algorithm.

One can observe in both cases a significant decrease of the time of final assembly link to an increase of the cost of references to manage. Moreover the time of final assembly could be less for the structural strategy than for the functional strategy. Also in the structural strategy the cost explodes at the end to decrease the time.

The following curves (Figure 7 and Figure 8) show how much it costs for the provider to produce a wire harness under a certain limit time with both strategies. With that kind of representation, the provider can easily sign contracts with his contractor to sell the set of wire harnesses. They can discuss the cost and time they project. Moreover the contractor can modify his process to increase the time delay for his provider, and then decrease his contract costs.

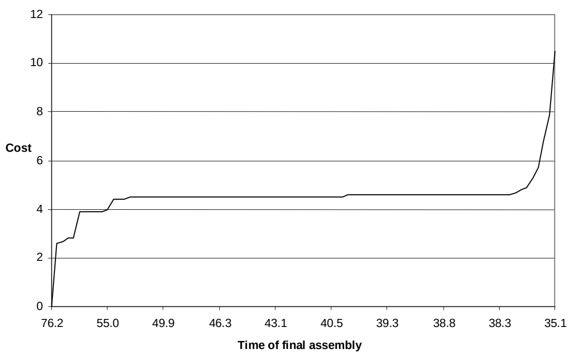

Figure 7: Average Cost and time for structural strategy.

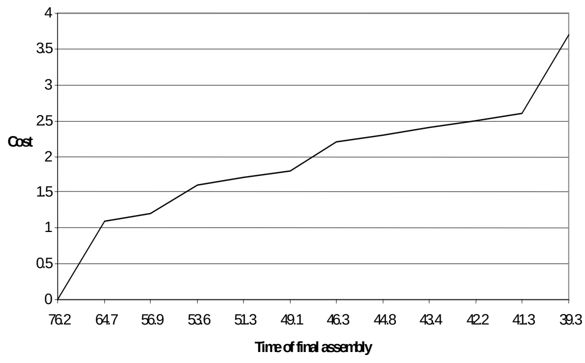

Figure 8: Average Cost and time for functional strategy.

In the following representation (Figure 9), both results have been set in the same range, the part that explode in the structural strategy have been deleted. The full line represents the structural strategy, the dotted line the functional strategy. We can note that for the high limit of time the functional strategy is always less expensive than the structural strategy. However in case the contractor wants to decrease the time of final assembly below the limit of the functional strategy, he must adopt a structural strategy.

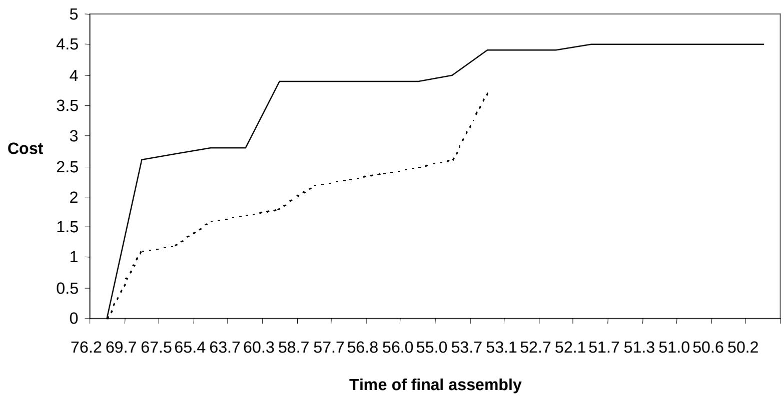

Figure 9: *Comparison of both algorithms before the cost explosion.*

4 Conclusions and prospects

For commercials purposes, it does not appear desirable to reduce the diversity of products perceived by customers with an aim toward marketing strategy. However we have to take into account that the explosion of products variety has a cost and that there exists for the company an optimal internal diversity, which minimizes costs. We provide a decision making tool that may help designers in their choices regarding harness subassemblies design in order to cover all the commercial diversity.

Two algorithms have been presented that permit the production of subassemblies for a wire harness family. The algorithms use a physical or a functional description of the wire harness family and provide a set of modules to produce in order to decrease the time of final assembly, knowing that it must provide all the diversity in a short time and for a minimum cost.

The results allow both the provider and contractor to discuss these relationships; they can adjust the time of synchronization and the number of versions to produce.

This research leaves open issues: the first development to be considered is an evaluation of the envelope effect. It could be cheaper to add standard elements to all wire harnesses, a tolerance of envelope effect will be integrated to try to decrease the very significant number of references due to the total differentiation. A development of the characteristics as a function of that tolerance will permit one to give the best price for the percentage that is permissible.

The actual representation of the wire harness is binary, which means that each option and variant is or is not in the final product. A development of the model can consider changing elements. Instead of regarding that one version of the air conditioning as incompatible with another one, it could be represented for the wire harness like a cable with a variant section that depends of the version.

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