INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN
ICED 05 MELBOURNE, AUGUST 15-18, 2005

EVALUATING THE IMPACT OF PRODUCT VARIETY IN EARLY DESIGN PHASES THROUGH THE ANALYSIS OF INDUSTRIAL SCENARIOS

Abdelhakim Yahiaoui, Jean-François Boujut

Abstract

The integration of product design and its manufacturing process in the early stage of the product development project enhance the ability of manufacturers to offer a large variety of product at a low cost. This research has been carried out in an international company which designs and manufactures a wide range of mass customized electrical equipments. Our work was to provide a methodology based on a graphic representation named the "*differentiation tree";* which is a graphic representation displaying the progressive appearance of the products variants during the manufacturing process of a products family. Inspired from works done in Design for Variety, we propose in this paper a Differentiation Tree Index (DTI) regarding the specific context of the study: i.e. the early design phases. This new index enables the discrimination between different scenarios of manufacturing sequences for a given family of products, using the differentiation tree representation. This work has been integrated in a wider corporate methodology and is available in the CAD-CAM environment.

Keywords: Early design phases, Mass customization, Commonality index, Delayed Differentiation.

1 introduction

As companies look for ways to stay competitive in the global marketplace, the concept of mass customization has appeared as a potential advantage. However, the strategy of mass customization is associated with product variety often leading to high production costs. Two types of variety can be observed, namely external and internal variety. While the former can provide a competitive advantage, the latter entails costs inside the supply chain and is often experienced as negative by the companies [1]. A mass customizer should manage efficiently this variety in order to provide external variety when minimizing internal variety.

In order to benefit from the advantages of mass customization, we introduce the concept of differentiation point; the point at which generic products take on different physical features. Many researches have intended to model the benefits from delaying differentiation via standardization (commonality), modular design or process restructuring via postponement or reversal of operations.

Frequently the consequences of design choices on product variety are experienced during industrialization phase, which is far too late for any effective modification of the design.

Actually there is a lack in effective tools for evaluating solutions during early design phases from the industrial point of view. The objective of this paper is to contribute to develop a method based on quantitative indices, which helps the designers to handle variety from an industrial point of view.

2 Industrial context

2.1 Industrial needs

Our work has been motivated by the industrial policy of the company which can be summarized through the following axes:

- Simultaneously design the product and its manufacturing processes at the early stages of the product development project

- Promote the delayed differentiation of products and the maximum standardization of the components, the subsets and the materials.

- Integrate the performance of exploitation in the products design and the manufacturing processes by taking into account the socio-technical aspects of the different countries.

This policy is strongly inspired by the concept of concurrent engineering. Indeed, this well known approach aims to integrate the whole product life cycle as early as possible in the development phase of the product. A good practice within the company is to locate the teams in a same geographical space - the project platform– allowing then the integration of the different downstream activities in the design phase, which helps to early detect the possible errors in the development process and to integrate the manufacturing dimension. The product quality is thus improved, the additional costs due to the modifications are eliminated and the time to market is reduced. Consequently, the company succeeds to satisfy the customer needs and reduce its global costs.

The main issue in our research work is the integration of the manufacturing dimension of the product. In our case we particularly focus on the product assembly process which is a key point because it is at that step that the product variety is actually created.

The key notion in our work is the concept of *scenario*. Indeed, the process engineer defines the product architecture taking into account the manufacturing process consequences. This is why he explores several alternatives or "scenarios" for the product architecture and the related manufacturing process.

The term scenario is associated to the pair "product / process". The process engineer will select the optimal product architecture / manufacturing process, at least the one which best fulfills the requirements (product, manufacturing process and costs) on the basis of the information of the moment. This selection will be done by estimating various scenarios mainly relying on the personal know-how of the engineers, and can be decomposed as follows:

- Technical criteria: for example feasibility (according to the product architecture), performance, etc.

- Economic criteria: like costs (direct variable cost - purchase, labour -), stocks and investments, etc.
- Complexity: for example bill of materials, number of product component, complexity of assembly and weight and volumes of the component, etc.

The disadvantage of this evaluation method which is mainly based on analogy with other projects, is that the process engineer must test all the hypothesis in these scenarios, and analyse the specific details before evaluating the relevance of the scenarios (given that some information are incomplete or inalienable). Exploring uninteresting scenarios generates a waste of time, this is why we are looking for criteria or indices which allow discriminating between the various scenarios at the level of the product development project, given that at this stage of the project few technico-economic information about product is available. Such indices should give the process engineer a tool to remove non-promising scenarios, and allow testing a greater number of hypotheses at the same time.

We will detail in the following the tools and related representations involved and developed for the purpose of our research.

2.2 Differentiation tree

The Differentiation Tree (*DT*) is the major tool used in our work. It allows the process engineer to evaluate the level of manufacturing similarity between several product variants. Based on a Generic Chronology, the process engineer creates a tree graph that shows the manufacturing assembly sequence. In this representation a new branch illustrates a difference in the manufacturing process. This graph is used by the company as a basic tool for evaluating the product variety and designing the manufacturing process. The process engineer's goal is to postpone branches creation as much as possible by concentrating the common manufacturing steps at the beginning of the sequence, and by delaying the dissimilar steps as much as possible; this way the manufacturing process is optimized. The DT is also used to compare different Generic Chronologies for the same tasks and to find the best one. This graphic representation is therefore the basis for the evaluation of various industrial scenarios inline with a given product architecture. We propose here an index for evaluating the given scenarios and comparing them.

The Differentiation Tree is crated by the process engineer. It allows the users to evaluate the level of similarity between any alternatives of product variants. The Differentiation Tree is based on one Generic Chronology, and on a list of product variants to be evaluated.

The result takes into account all the relevant Chronologies. The difference in specific step (different part or no part used) creates a new branch in the tree, while similar steps (use the same part type) represent the same branch. New branches are permanent, even if similarity exists later in the sequence, the branches can never be merged afterward.

The result of this Differentiation Tree generation is a graphic representation, firstly represented in the form of a curve (of variant) that shows the number of braches for each Step.

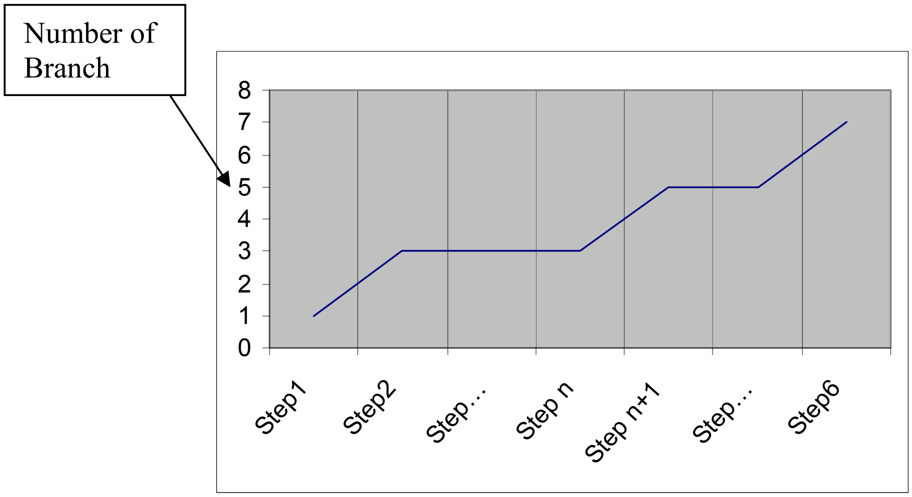


Figure 1. Differentiation tree representation in the curve like form

The horizontal axis shows the steps, and the vertical axis shows the number of branches.

But the Differentiation Tree itself is more complex. It shows not only the tree branches, but also the parts which are assembled in each branch, the different steps, and the product variants. A black point on a branch indicates that the part (or subset) is assembled at this step of the process, while the vertical line leads to the part name, which is mentioned above as shown in figure 2.

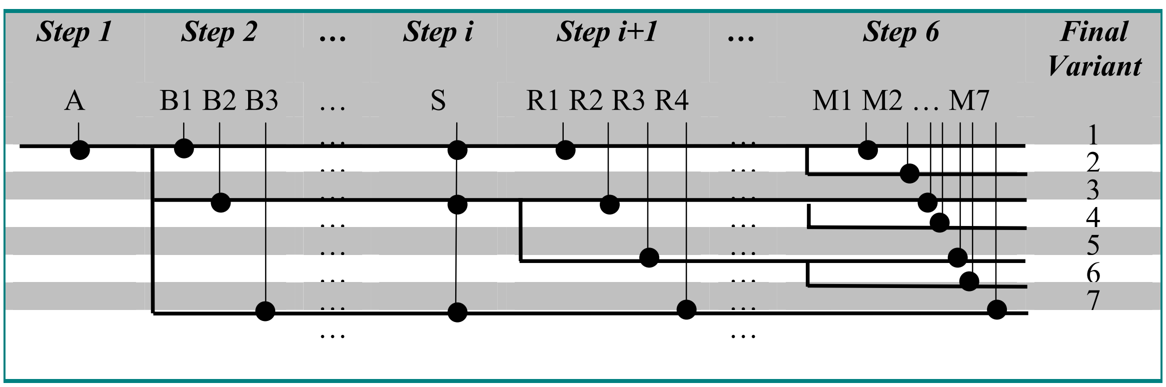


Figure 2. Differentiation tree representation in the treelike form

A, B1, B2 … that are the Part Instance names. Step 1, Step 2, etc. are the assembly steps. And 1, 2, 3… are the Product Variants names.

The *Generic Chronology*: is a logical ordered sequence of generic operations that describes the generic process required in order to manufacture a specific sub-assembly. The generic chronologies are used later as a template sequence for the different product variant chronologies.

We assume here that the project is at the definition phase of the architecture of the product family. The engineering department then determines the organic response to the functional needs expressed by the marketing specifications. It is expressed by the determination of a product architecture based on some organic and functional subsets, each one being decomposed into different variants.

The extent of the product range being considerable (hundreds, even thousands of commercial variants) the technical definition made by engineering department is obviously progressive. The construction of the differentiation tree which is going to express the manufacturing complexity of the family will then be also progressive, in parallel with the development process, in order to retroact continuously with the product architecture. Therefore, during the construction of the trees in the project phase, several hypotheses must be explored for purpose of comparison.

3 Theoretical framework

3.1 Related works

Pine [10] introduced the concept of mass customization which goal is to produce goods and services for a relatively great sales market and to simultaneously meet the needs of nearly every customer demand. The question is how the product development team can increase the number of products proposed to the customer without increasing the related production costs. Various answers are given in the literature, but companies often choose to manage the product variety by grouping product into families. The product family is a set of products dedicated to a market which share a set of features, components or functions.

This problem inspired several research themes among which we can cite: Product Variety Management, Design for Variety, etc. Many concepts and notions emerged from these researches like delayed differentiation, standardization, modular design, operations reversal, etc.

Mac Duffie et al. [6] looked at the effects of product variety in the automotive industry. The authors took a descriptive approach and studied empirical data in order to determine how variety affected manufacturing.

Lee and Tang [4] modeled the benefits from delaying differentiation via standardization, modular design or process restructuring via postponement or reversal of operations. Lee and Tang [5] focus on operations reversal, and examine how it impacts variability in production volumes in a multistage process for two products. These methods only impact intermediate variety and not end-product variety. They also impact competitive differentiation via reduction of response time and product cost.

In another implementation, Swaminathan and Tayur [13] consider delayed differentiation for an assembled product manufacturer that produces multiple end products by adding specific components to generic semi-finished inventories that they called vanilla-boxes. For a given product line, the firm must decide how many and what vanilla box configurations to use, and how to allocate them in order to minimize production and market mismatch costs, subject to capacity constraints. Swaminathan and Tayur [14] extend this model for including the one-time costs of designing alternative assembly sequences for the vanilla box manufacturing process. In related work, Gupta & Krishnan [3] proposed an algorithmic approach for determining the best assembly sequence for a given set of products. Their work prescribes an algorithm to develop subassemblies which will increase component commonality.

In Stadzisz and Henrioud [12] a general approach for the integrated design of families of products and multi-product assembly systems has been proposed. They address the problem of reducing process differentiation in the assembly of families of products. From the analysis of an industrial case study (a family of car horns), they developed a method for product and process modelling, and for the evaluation of the required assembly flexibility. The aim of the proposed method is to allow designers to evaluate the effects of product design decisions on the assembly process and to consider constraints and decisions made in the process domain.

Nidamarthi et al. [9] showed that by using a systematic process of analyzing an existing product family's variety and re-designing it, one can indeed meet both objectives of customers' choices and profit margin. They also discussed how to manage and sustain profitable product families.

Fujita et al. [2] proposed an assessment method for value distribution for a product family by extending the cost planning framework with QFD from a single product to a series of products. The method aims to facilitate the establishment of product definitions over a product family. First the variety of the customer requirements is translated into a chained definition of required worth of respective modules and parts across products through value engineering techniques and quality function deployment. Second the manufacturing cost is estimated on respective modules and parts across products through systematic utilization of design-for-X methodologies. Then the absolute levels of both worth and cost of all modules over different products are contrasted over the cost-worth graph.

3.2 Basic indices

We should not forget that the criteria that we will present in this section aim to provide tools for discriminating between various differentiation trees, and as exposed before, the objective is to offer personalized products while benefiting from the advantages of mass production (i.e. implement delayed differentiation).

We assume here that a good differentiation will be a compromise (considered to be optimum) between direct costs of the product line and the induced indirect costs. The literature initially proposed indices which allow the evaluation of the indirect costs of providing variety. Before proposing our own index it is important to present and discuss the indices drawn from the literature.

3.2.1 Commonality Index CI

During the design process, the main goal is to use each part in as many products as possible because "products that use many common parts inherently have less variety cost than products with unique parts" [1]. The development of new products on the basis of standardized and common parts leads to the reduction of complexity at the design stage.

Martin and Ishii [8] defined the commonality index (*CI*) as follows:

$$CI = 1 - \frac{u - \max p_j}{\sum_{j=1}^{Vn} p_j - \max p_j} \quad (1)$$

$0 < CI \leq 1$
u = number of unique part numbers.
p_j = number parts in model j.
v_n = final number of varieties offered. Source: Martin & Ishii [8]

This index indicates to what extent the different product variants within a product family include non standard parts.

A high index value indicates a high degree of standardization. The key metric *CI* may be suitable when products have an integral architecture but not when they have modular or building bloc architecture. Moreover, Martin & Ishii [8] do not explain, how to determine the unique parts in the product family.

However, in our case the *CI* is not useful because it does not allow the comparison between the differentiation trees since it is exceptionally related to the BOM, while the differentiation tree takes into account the BOM as well as the assembly sequence.

3.2.2 Differentiation Indices *DI*

Still in this context of high variety, the goal of this index is to displace the variant determination point towards the end of the value chain in order to avoid variety proliferation at the beginning of the process. Then it is possible to optimize inventory costs while offering a high delivery service.

Martin and Ishii [7] define the Differentiation point Index (*DI*) capturing the position where the product differentiation occurs within the process flow:

$$DI\,1 = \frac{\sum_{i=1}^{n} v_i}{n v_n} \qquad (2)$$

$0 < DI1 \leq 1$
v_i = number of different products exiting process i
n = number of processes
v_n = final number of varieties offered — Source: Martin & Ishii [7]

However, this index does not consider the time taken by the products to flow through the system. For example, if the product is differentiated at an early stage of the process, and if the throughput time between this stage and the end of the process is large compared to the overall throughput time, then the effect on costs will not appear if measured by *DI1*. To account for this a proposed measure is to weight the *DI1* factor by the throughput time (TPT) from process *i* up to end of process. This is shown below in *DI2*:

$$DI2 = \frac{\sum_{i=1}^{n} d_i v_i}{n d_1 v_n} \qquad (3)$$

$0 < DI2 \leq 1$
d_i = average throughput time from process i to sale
d_1 = average throughput time from beginning of production to sale

Source: Martin & Ishii [7]

There is one last factor that must be incorporated into the measure, and that involves the value-added amount that is being "carried". This is incorporated in the following index (*DI3*):

$$DI3 = \frac{\sum_{i=1}^{n} d_i v_i a_i}{n d_1 v_n \sum_{i=1}^{n} a_i} \qquad (4)$$

$0 < DI3 \leq 1$

a_i= value added at process *I* — Source: Martin & Ishii [7]

The denominator of this index shows the worst case where all variants are determined at the beginning of the production process and the numerator reflects to what extent the actual process flow moved away from the worst-case situation. A lower value of the index indicates that the differentiation is occurring later.

However, this notion of value-added remains rather ambiguous; in fact everyone can interpret the information in a personal way, because the authors of the article omitted to mention the definition of the term. In our case, it is the constituents (items) cost (in valuable term) which we add at every step of the process, this choice is motivated by the availability of this information, at this stage of development of the product.

Analysis and discussion

We are going to analyze each one of the *DIs* through the following examples. Let's consider 4 differentiation trees represented in the form of curves of variant:

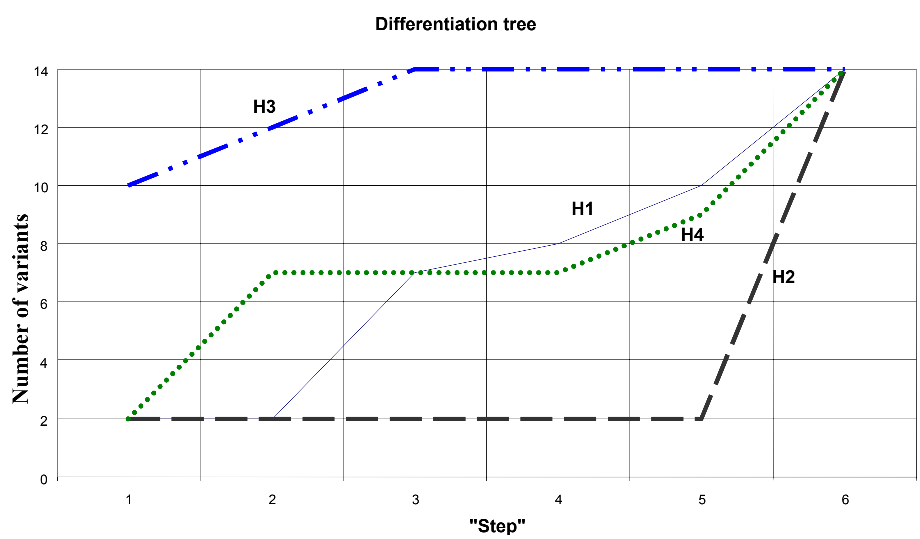


Figure 3: Example of 4 differentiation trees

Applying the *DI1* formula gives:

Table 1. Example of application of *DI1*

Number of step *'n'*	6
final number of varieties offered *'Vn'*	14

	Dif.tree H1	***Dif.tree H2***	***Dif.tree H3***	***Dif.tree H4***
v1	2	2	10	2
v2	2	2	12	7
v3	7	2	14	7
v4	8	2	14	7
v5	10	2	14	9
v6	14	14	14	14
Σ (vi)	43	24	78	46
DI1	**0,5119**	**0,2857**	**0,9286**	**0,5476**

If we look at the results of table 1 it seems that the index allows discriminating (classify) the 4 hypothesis of differentiation trees. However, we will see afterward that this is not always true.

Industrial application for the DIs:

We consider now the example of a real developed product in the company of our case study, we studied a differentiation tree of 21 variants, assembled in 18 steps. We have two chronologies (sequences) of assembly. In the first one all the variants appear in the 10th step, while in the second sequence they all appear in the 12th step. We obtained this result after the process engineer checked that the postponement of the steps which create the differentiation was possible.

A) 1st chronology:

From the available data relative to the product line, we found the operating time which allows having an evaluation of the throughput time (*di*), and as we have already mentioned, we consider the cost of components as the value-added. The results are summarized in the tables below:

Table 2. Example of application for *DIs* 1st chronology

Vn	21
n	18
∑vi	198
n Vn	378
DI1	**0,5238**

Vn	21
N	18
d1	4,05
∑ vi di	283,26
n Vn d1	1530,9
DI2	**0,1850**

Vn	21
N	18
D1	4,05
∑ai	17,4552
∑vi di ai	71,608
N d1Vn ∑ai	26722,167
DI3	**0,0027**

B) 2nd chronology:

This chronology is obtained from the first one by delaying the operations that originate all the variants. The results are summarized in the following table:

Table 3. Example of application for *DIs* 2nd chronology

Vn	21
n	18
$\sum vi$	160
n Vn	378
DI1	**0,4233**

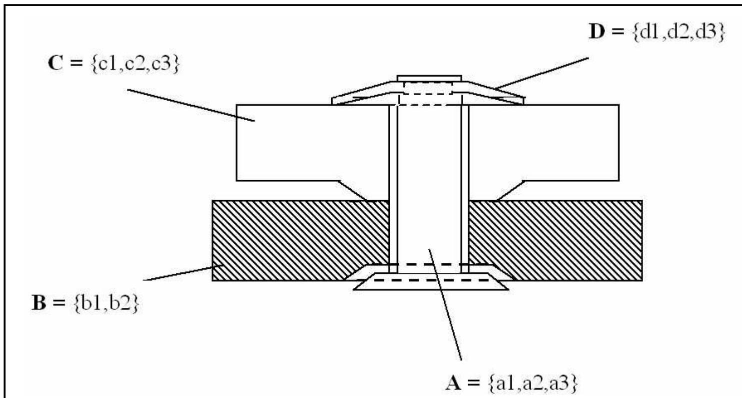
Vn	21
n	18
d1	4,05
$\sum vi\ di$	191,26
n Vn d1	1530,9
DI2	**0,1249**

Vn	21
n	18
d1	4,05
$\sum ai$	17,46 €
$\sum vi\ di\ ai$	67,630
$n\ d1 Vn \sum ai$	26725,227
DI3	**0,0025**

The results of calculation highlight the fact that the 2nd chronology (improved from the first one) was better in terms of delayed differentiation.

However, it should be noted that every time we integrate a new parameter (*di, ai*), the value of the indices decreases significantly, which reduces the accuracy of the index and therefore the ability to discriminate correctly the scenarios.

Finally we will take another example given by Stadzisz [11] (see figure 4) as a basis for comparison:



Product families

P1={a1, b1, c1, d1}
P2={a1, b1, c2, d1}
P3={a2, b1, c2, d2}
P4={a2, b2, c3, d3}
P5={a3, b2, c3, d1}
P6={a3, b1, c2, d2}

Figure 4. Example of an assembly.

For the 6 product families, we have two chronologies given by the following trees (fig. 5 and 6):

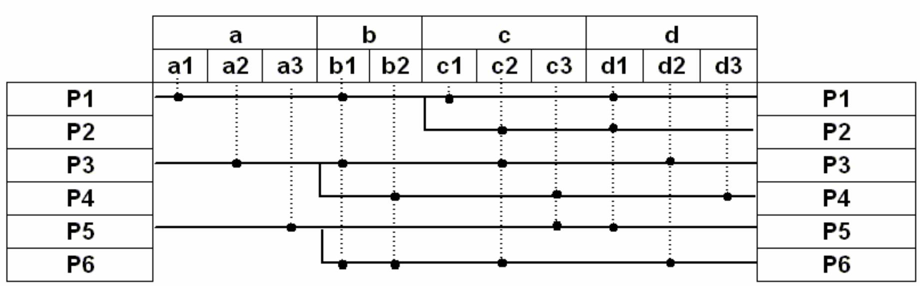


Figure 5. Chronology: a-d-c-d

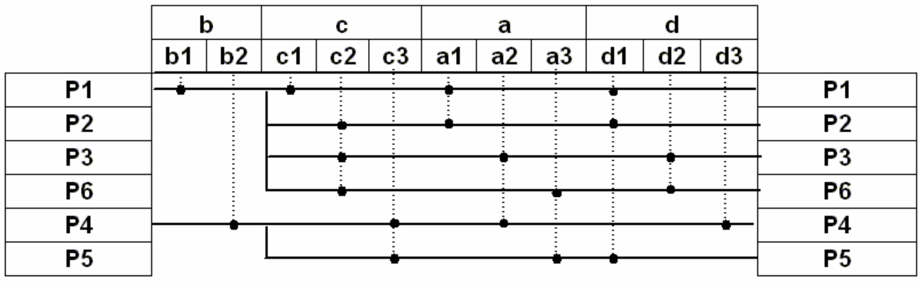


Figure 6. Chronology: b-c-a-d

Application of DI1:

Table 4. Application for *DI1*

Chronology "a-b-c-d"	
Number of steps *n*	4
Final number of varieties offered *Vn*	6
Number of variants at the step1 *v1*	3
Number of variants at the step 2 *v2*	5
v3	6
v4	6
∑(vi)	20
DI1	***0,8333***

Chronology "b-c-a-d"	
n	4
Vn	6
v1	2
v2	6
v3	6
v4	6
∑(vi)	20
DI1	***0,8333***

Through this application (we also tested all the possible combinations of appearance of variants for this example) we find that this index (*DI1*) is not relevant in certain cases, because we have the same value of the index for two trees while they are actually different. We suppose that this is due to the fact that we consider only the sum of the variants that appear in the different steps of the process without taking into account their position in the whole process.

4 Proposition

4.1 Differentiation tree index

The application of the index *DI1* on the above examples shows that it does not allow distinguishing between the scenarios shown in figure 5 and 6. This is due to the fact that the index does not take into account the weight of the step's order as we said before. We introduce the index *DTI1* based on an existing approach used in the company (but not formulated mathematically) and on the indices proposed by Martin and Ishii [7]:

$$DTI1 = \frac{\sum_{i=1}^{n} ((n+1)-i)\ vi}{\frac{1}{2} n(n+1)Vn} \qquad (5)$$

v_i = number of variants in step i
n = number of steps
v_n = final number of varieties offered

The numerator allows to capture the differentiation point, because it weights the number of variants that appear at a given step by a coefficient *((n+1)-i))*, which in the first step is equal to the total number of the chronology steps, and which is decrement by "1" as we move into our process until the value 1 is reached, at the last step.

The interest of this coefficient is to favour the delayed differentiation, because an important weight in the first steps penalises the appearance of variants at this level, while it favours their appearance at the end of process (a weak weight being associated to these steps).

This index allows to distinguish between all the differentiation trees, which was not the case with the *DTI1*.

We can also enrich this index by integrating the notions of throughput time and value-added, from the works of Martin and Ishii [7], we propose these indices:

$$DTI2 = \frac{\sum_{i=1}^{n} ((n+1)-i)\ vi\ di}{\frac{1}{2} n(n+1)Vn\ d1} \qquad (6)$$

And

$$DTI3 = \frac{\sum_{i=1}^{n} ((n+1)-i)\ vi\ di\ ai}{\frac{1}{2} n(n+1)Vn\ d1 \sum_{i=1}^{n} ai} \qquad (7)$$

We note that the above indices present the same problem as *DI2* and *DI3*, therefore they are not really useful in our case. We just present them here for comparison.

Example of application

Coming back to our industrial example, with both assembly chronologies, we obtain the following results:

1st chronology:

Vn	21
N	18
Σ((n+1)-i) vi	748
½ (n (n+1) Vn)	3591
DTI1	***0,2083***

Vn	21
N	18
d1	4,05
Σ((n+1)-i) vi di	1192,51
½ (n (n+1) Vn)	14543,55
DTI2	***0,0820***

Vn	21
n	18
d1	4,05
Σai	17,46 €
Σ((n+1)-i) vi di ai	763,51
½ (n (n+1) Vn) d1	253889,66
DTI3	***0,0030***

2nd chronology:

Vn	21
N	18
Σ((n+1)-i) vi	1071
½ (n (n+1)	3591
DTI1	***0,2982***

Vn	21
N	18
d1	4,05
Σ((n+1)-i) vi di	1942,7
½ (n (n+1) Vn)	14543,55
DTI2	***0,1336***

Vn	21
n	18
d1	4,05
Σai	17,46
Σ((n+1)-i) vi di ai	786,66
½ (n (n+1) Vn) d1	253860,57
DTI3	***0,0031***

4.2 Coming back to the context and the use of the indices:

Our objective was to give a means to evaluate differentiation trees at early steps in the design process, i.e. when the product architecture is not yet stabilized and numerous points remain fuzzy or unknown. Our indices formalize some basic rules that are listed bellow:

1. Minimize the number of constituents: we can use *CI* as criterion for that, because it measures the degree of commonality. Indeed this index allows evaluating in a certain way the degree of standardization or rationalization of the used constituents (components).

2. Delay differentiation: it is obvious that the various indices which we proposed can be used. However, it would be interesting to study more deeply the relevance of adding new parameters, especially when they are not known at this step of the design process.

Moreover, the process engineer could propose on the basis of *DTI1* new variants to the Engineering or to the Marketing department, these variants do not engender additional costs and may be good commercial opportunities (in this case by adding these variants, the value of the index remains unchanged or there is only a small variation). The index could then be used as a simulation tool. Reversely the process engineer could also propose to stop developing a variant if there is a too important impact on the *DTI* index. If it is clear that the actual impact of the manufacturing department on the product architecture is low, such tools can help the process engineers to anticipate the design choices and be more proactive in the design process.

5 Discussion and conclusion

The objective of this work was to propose criteria or indicators which allow discriminating between the various scenarios in early phases of the product development project, knowing that at this stage the technical-economic information concerning the product is subject to evolution and is partially incomplete. To achieve this we considered tools and representations, especially the differentiation tree which is a key representation at the development stage.

We were inspired by works realized in the field of mass customization, delayed differentiation, and particularly from these of the Design for variety, by adapting their results to our problem. We made an analysis and a critical study of the various indices that led us to propose a new differentiation index, relying on our industrial context.

The various indices proposed here, even if they are rather global, give the means to the process engineer to already reject the scenarios considered not promising, and to test a larger number of hypotheses at the same time, on the basis of the form of the differentiation trees (using curve representation).

Despite the global aspect of the indices, the lack of information on the product at this stage of the development process makes it difficult to implement the evaluations brought by the proposed indices. Furthermore, even if the indices integrate well the notions of appearance of variants, of the throughput time of process and of value-added, they allow only a partial estimation of the impact of the scenarios. Even if we were able to compare between two trees in terms of delayed differentiation, we can only partially measure the impact (in terms of cost) of the two scenarios on the manufacturing process, on management, on the investments, on the staff, etc.

References:

[1] Anderson, David M. “Agile Product Development for Mass Customization”, Chicago: Irwin Professional Pub.,1997.

[2] Fujita,K, Takagi,H and Nakayama,T. “ Assessment method of value distribution for product family deployment”, Proceedings of international conference on engineering design ICED 03, Design Society, Stockholm, 2003, file n° 1484.

[3] Gupta, S. and Krishnan, V. ”Product family-based assembly sequence design methodology” IIE Transactions, Volume 30 (10), 1998, p. 933-945

[4] Lee, H.L. and Tang, C.S. “Modelling the costs and benefits of delayed product differentiation”. Management Science, Volume 43(1), 1997, p. 40-53

[5] Lee, H.L. and Tang, C.S. “Variability reduction through operations reversal” Management Science, Volume 44(2), 1998, p. 162-172.

[6] MacDuffie, J.P. ,Sethuraman, K. and Fisher,M.L. “Product variety and manufacturing performance : Evidence from the international automotive assembly plant study” Management Science. Volume 42(3), 1996, p. 350-369.

[7] Martin, MV. and Ishii, K, "Design For Variety: A Methodology For Understanding the Costs of Product Proliferation", Proceedings of The 1996 ASME Design Engineering Technical Conferences and Computers in Engineering Conference, California 1996, 96-DETC / DTM-1610

[8] Martin, MV. and Ishii, K, "Design For Variety: Development of Complexity Indices and Design Charts", Proceedings of DETC'97, Sacramento1997, DETC97 / DFM-4359

[9] Nidamarthi,S ,Mechler,G and Karandikar,H. "product family development and management: architecting for maximum profitability", Proceedings of international conference on engineering design ICED 03, Design Society, Stockholm, 2003, file n° 1296.

[10] Pine, B. J., II, "Mass Customization: The New Frontier in Business Competition" Harvard Business School Press, Boston, MA, 1993

[11] Stadzisz, P.C. "Contribution à une méthodologie de conception intégrée des familles de produit pour l'assemblage".N° 594, Thèse à l'Université de Franche-Comté, Besançon France, 1997.

[12] Stadzisz, P.C. and Henrioud, J.M. "An integrated approach for the design of multi-product assembly systems". Computers in Industry, Volume 36, 1998, p. 21-29,

[13] Swaminathan, J.M. and Tayur, S. "Managing Broader Product Lines through Delayed Differentiation Using Vanilla Boxes". Management Science, Volume 44(12), p. 161-172.

[14] Swaminathan, J.M. and Tayur, S. "Managing design of assembly sequences for product lines that delay product differentiation". IIE Transactions, Volume 31, 1999, p. 1015-1026.

Abdelhakim YAHIAOUI, Jean-François BOUJUT
GILCO - INP Grenoble technical University
46 av Félix-Viallet, 38031 Grenoble
FRANCE
Phone: (+33) 04 76 57 47 06
Fax: (+33) 04 76 57 46 95
E-mails: Jean-francois.boujut@gilco.inpg.fr
Abdelhakim.Yahiaoui@gilco.inpg.fr