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AN APPROACH TOWARDS IDENTIFICATION OF COMMON COMPONENTS IN PRODUCT FAMILY

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ABSTRACT
The overall goal of the research is to produce a DFX method which should be used to increase the commonality in the product family. The research presented in this article is based on commonality index calculation methods known in the literature. The commonality index calculation methods are used to measure the existing commonality and to identify the components with highest influence to the commonality. From the commonality point of view results of three methods (CI, TCCI, PCI) have high values regardless of the used method. The communality index calculated on the product family level does not identify how the components influence on the commonality. Therefore the calculations of communality index should be applied on the function levels to identify the components which have the greatest influence in the commonality value. The study made to the case product family during this research bred two different kinds of new architectures. The first one was structurally similar to the existing one but it had major enhancement in the part level. The second one was essentially a new concept of the product family. It actually increased the number of parts per product variant but when considering the whole product family the new architecture reduced the total number of components.

Keywords: Commonality index, product family, product variant, functions

1 INTRODUCTION
Product family is a set of products, which beneficially are created from a common set of components. It is developed for obtaining a range of product variants, which are able to cover certain market segments ([1], p. 20). An important matter during the development of the product family is the aspiration of higher producibility, meaning fewer parts to manufacture; smaller number of items; easier data management; stock reduction and simplified material handling in the manufacturing.
One of the tasks in the development of product family is to define the common components, which are re-used in the product variants. Analyzing only the technical documentation is not enough to get an answer on the question of which components are common and what components should be redesigned in product family. Therefore the key factor of product family development is the process of identification of common components which are more reused in the product variants than in the individual products.
In this research an industrial case was used for the analyses of commonality in a product family. The company had already made improvements to the existing product family, but the improvements were made based on assumptions and tacit knowledge. There was not any actual analysis carried out for basis of the improvement. Thus they were not able to repeat the improvements in a different product family and therefore the company was looking for a systematic method to be used in the development of product families.
The overall goal of the research is to produce a DFX method which should be used to increase the commonality in the product family. The research presented in this article describes the first step of the product family development method and it is based on commonality index calculation methods known in the literature. It is assumed that a method for calculating commonality indexes can be implemented in order to increase the commonality of the product family. The commonality index calculation methods are used to measure the existing commonality and to identify the components with highest influence to the commonality. Identified components which decrease the value of commonality index has to be further analysed and redesigned. The redesign process results with new consolidated

components that merge the set of similar existing components. Thus, the commonality is increased in product family and the new components are reused more often in product variants than the old, i.e. replaced, components were. The objective of this research is to identify the guidelines for analysing the group of existing products with a focus to increase the commonality in product family.

2 OVERVIEW OF COMMONALITY INDICES

In this chapter the four commonality indices used in the research is presented. Those are commonality index (CI) by Martin and Ishii [5], total constant commonality index (TCCI) by Wacker and Trevelan [8], product line commonality index (PCI) by Kota et al., [4] and component part commonality ($CI^{(C)}$) by Jiao and Tseng, [3]. Detailed comparison overview of the commonality indices can be found in [7].

2.1 Commonality index (CI)

The Commonality Index is a measure of unique parts used in the total number of product variants.

$$CI = 1 - \frac{u - \max p_j}{\sum_{j=1}^{v_n} p_j - \max p_j} \tag{1}$$

u = number of unique parts,

p_j = number of parts in product j,

v_j = final number of product variants offered.

2.2 Total constant commonality index (TCCI)

The Total Constant Commonality Index relates the total number of distinct component j has over a set of end items (d) to the number of immediate parents component j has over a set of end items of product structure level (Φ_j).

$$TCCI = 1 - \frac{d-1}{\sum_{j=1}^{d} \Phi_j - 1} \tag{2}$$

$d =$ total number of distinct component j has over a set of end items,

$\Phi_j =$ number of immediate parents component j has over a set of end items of product structure level.

2.3 Product line commonality index (PCI)

The Product Line Commonality index provides a percent common of non-differentiating components. It penalizes those differences that should be common, given the product mix ([4], p406).

$$PCI = \frac{\sum_{i=n}^{P} n_i \cdot f_{1i} \cdot f_{2i} \cdot f_{3i} - \sum_{i=1}^{P} \frac{1}{n_i^2}}{P \cdot N - \sum_{i=1}^{P} \frac{1}{n_i^2}} \cdot 100 \tag{3}$$

$P =$ total number of non differentiating components that can potentially be standardized across models,

$N =$ number of products in the product family,

$n_i =$ number of product in the product family that have component i,

$f_{1i} =$ ratio of the greatest number of models that share component i with identical size and shape to the greatest possible number of models that could have shared component i with identical size and shape (ni),

$f_{2i} =$ ratio of the greatest number of models that share component i with identical materials and manufacturing processes to the greatest possible number of models that could have shared component i with identical materials and manufacturing processes (ni),

$f_{3i} =$ ratio of the greatest number of models that share component i with identical assembly and fastening schemes to the greatest possible number of models that could have shared component i with identical assembly and fastening schemes (ni),

2.4 Component part commonality index ($CI^{(C)}$)

The Component Part Commonality Index represents the degree to which common part costs have been distributed across all products in a product family ([3], p. 235). It depends on more dimensions than only repetition, such as the cost or price of each component part, the volume o the final product and the quantity per operation ([3], p. 229).

$$CI^{(C)} = \frac{\sum_{j=1}^{d}\left[P_j \sum_{i=1}^{m}\Phi_{ij}\sum_{i=1}^{m}\left(V_i Q_{ij}\right)\right]}{\sum_{j=1}^{d}\left[P_j \sum_{i=1}^{m}\left(V_i Q_{ij}\right)\right]} \tag{4}$$

$d =$ total number of distinct component parts used in all the product structures of a product family,
$j =$ index of each distinct component part,
$P_j =$ price of each type of purchased parts or the estimated cost of each internally made component,
$m =$ total number of end products in a product family,
$i =$ index of each member product of a product family,
$V_i =$ volume of end product I in the family,
$\sum_{i=1}^{m}\Phi_{ij} =$ number of immediate parents for each distinct component part dj over all the products levels of product i of the family,
$Q_{ij} =$ quantity of distinct component part dj required by the product i.

3 METHODOLOGY FOR IDENTIFICATION OF COMMON COMPONENTS

The methodology we present in this article begun with the analysis of internal and external variety among the products. External variety is defined from the existing group of products and it represents the necessary variety seen from the customers', i.e. market, viewpoint. The required internal variety is defined based on the external variety, so that it represents the necessary variety seen from the company's viewpoint. The realised internal variety is defined at the latest phase of product family development.

After the external and internal variety is defined the commonality index was calculated. For the analysing of the existing product variants the function-assembly decomposition structure (FADS) was established. It became the basis of the analysis. The initial value of commonality index was calculated using the methods from Martin & Ishii [5], Wacker and Trelevan [8], and Kota et al. [4].

Based on the collected data the new commonality index was calculated toward the method proposed by Jiao & Tseng [3]. The new commonality index was used to indicate the trend of the components on the value of commonality index. Some components increase and some decrease the value of the commonality index. The aim was to identify components which decrease the commonality index. Those components should be redesigned to increase the commonality index.

The process of identification, analysis and redesign of components is repeated until the level of re-usage of the components is high enough within the product family. Those components are now candidates for modules in product variants. The methodology of identification of common components in product family will be detailed explained in the following chapters.

3.1 Determination of external variety

In the beginning of the product family analysis two different varieties has to be examined. Firstly the product variety what the company is offering to the markets (the existing product variety at the moment) and secondly the product variety what is actually needed to fulfil the customers requirements in the future [2]. The offered variety is documented in catalogues, technical specifications, brochures etc.

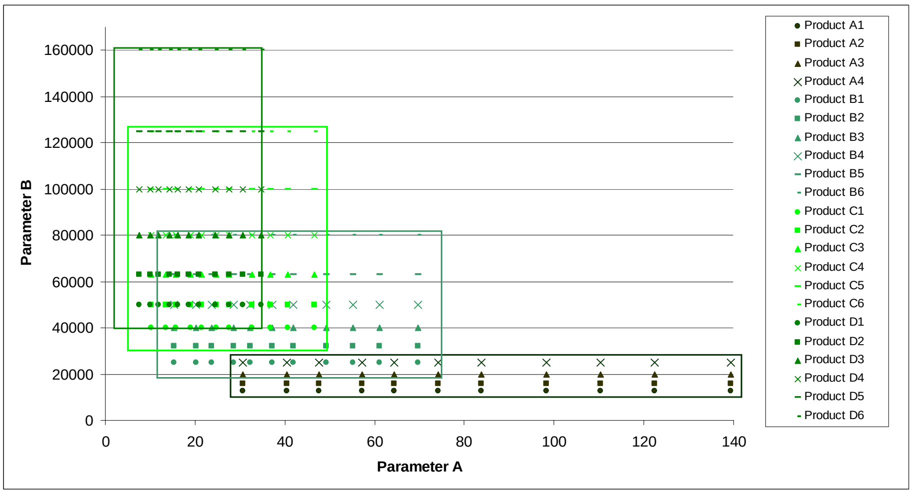

Figure 1. Existing product variety - product variety which companies has on the market

Secondly, it is equally important is to explore the realised variety, meaning the product variants which have been sold in the past. Usually companies try to operate in certain market segments, but the realised variety truly shows the requisite variety from the customer point of view.

When the external variety is found out, it is compared with the realised product variety. The result indicates how well the variety company is offering meets the required variety. Every item in the PLM system costs extra and therefore it is important to exclude all unnecessary components from the system.

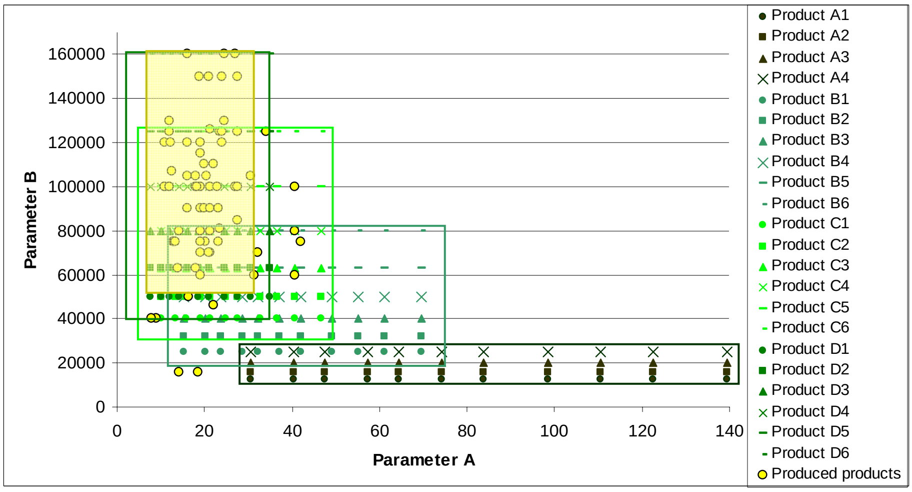

Figure 2. Realised external variety i.e. needed variety from market point of view

For the visualisation of the difference between external and realised variety two types of parameters, which represents the customers' requirements, has to be defined. There exist independent and dependent parameters. The independent ones do not influence to any other parameters whereas the dependent ones influence and are influenced by other parameters. The figure 1 presents the link between three different parameters of the product variants' external variety.

Visualization of existing variety has the benefit of discovering overlapping areas. Overlapping areas represent the unnecessary product variety that, in principle, should be minimized. From the customer's viewpoint, unnecessary variety increases the difficulty of making the decision about the right variant and from the companies' viewpoint in increases the costs when maintaining the unnecessary variety.

In the figure 2 the external and realised product varieties are presented in the same chart. It can be easily seen that in this case the external variety is much greater than the realised one. In this kind of situation the external variety should be reduced and when the situation is opposite the external variety should be increased.

3.2 Determination of internal variety

The limits of needed internal variety can be seen from the determined external variety. The realised product variety shows the area where to focus in the development process. Naturally the best-selling product variants are the crucial ones. In the figure 3 is presented two main parameters of the realised products. The limits of the internal variety will be 1-4 and the parameter variants are 1, 2, and 4. In case that the realised variety is spread more evenly the design team have to estimate the best step size inside the limits.

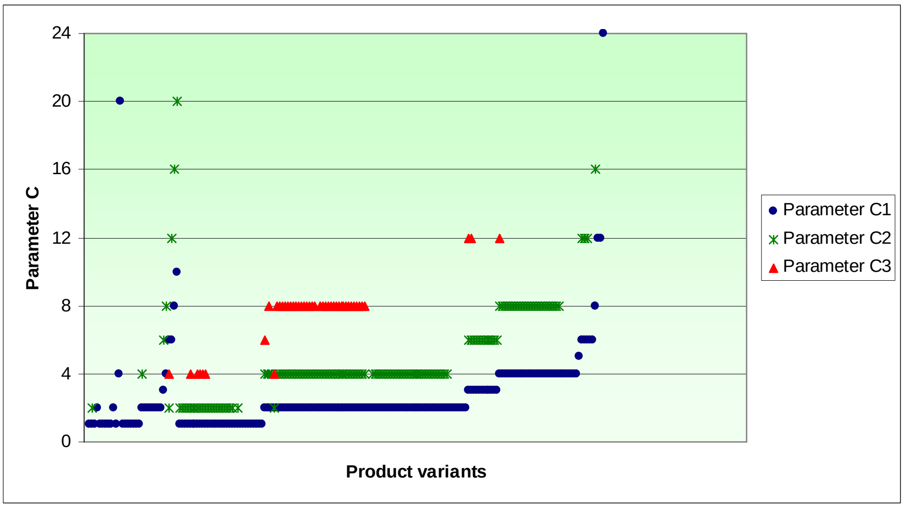

Figure 3. Internal variety

In situations like presented in the figure 3 it is obvious where the development has to be focused. The variants which are outside of the focus area should be taken under consideration after the main variants are developed. The improved variants are still the base for the more rare variants and those have to be developed on top of the existing components, so that the commonality stays high. This development process is very iterative and the development order follows the pattern of the realised variants. The fewer times the variant has been produced, the latter it should be included to the developed product family, meaning designers have to focus on the areas which benefit most the company.

The new external variety is defined based on the decision about the internal variety. It is possible that the external variety stays the same, but the internal variety is improved in sense of reducing the overlapping area. Also by significant changes in the structure of the product the external variety can be encompassed with less product variants.

3.3 Determination of functions in product variants

Analyse of the product variants is based on functions of the products and on the solutions of the functions. Solution of the function is a component which is an assembly or a part. The components are classified in three different types: identical, variant, and unique. The identical components are the ones which are always the same in all the variants in which they are used. Variant components are the components fulfilling the same function in multiple variants but the material, shape, or size can vary. The unique components represent component which is used only in one variant.

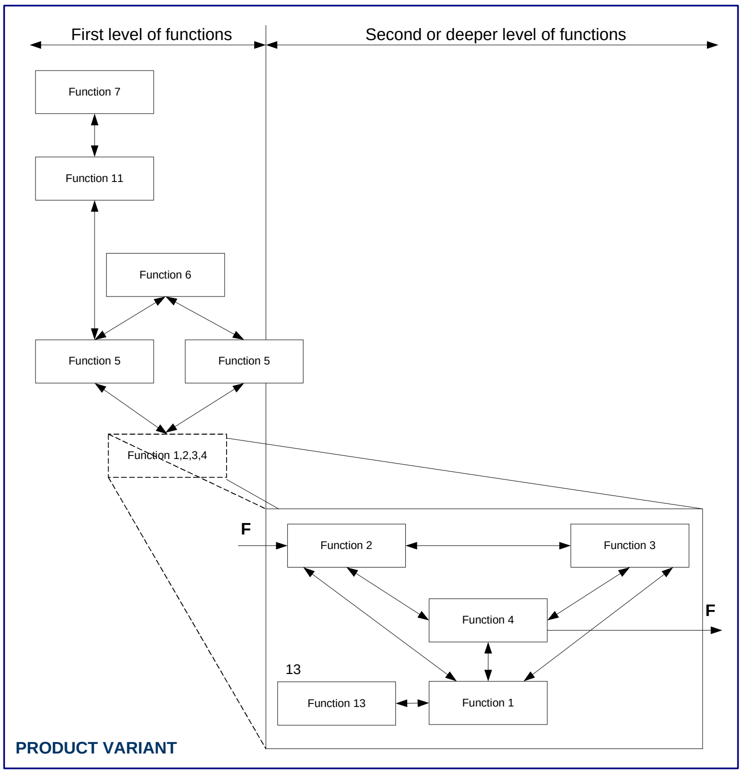

Figure 4. Levels of functions

Each product has functions which can be classified on multiple levels as shown on figure 4. The level until which it is necessary to define the functions depends on the differences between the product variants. The first level consists of the functions which have identical and/or variant components in product variants. For the functions with identical components deeper levels are not compulsory. Thus the solutions of the sub functions are also identical in the product variants. The functions with variant components on the first level have to be decomposed into second or deeper levels. The decomposition repeats until the level where only identical or unique components exist.

3.4 Function-assembly decomposition structure

Based on the determinate functions (figure 4.) structure for analysing the product variants should be defined. Function structure defined by Pahl and Beitz [6], represents the relationship between the functions. Relations that are based on the material, energy and signal connections between functions do not express the relation between the components in the product. The information about the component relations are required in the systematic commonality analyses. Therefore only the function structure does not enable a systematic way of analysing a group of products. The systematic analyses of commonality indices require structure which integrates the relations between the functions and the components.

Function-assembly decomposition structure (FADS) represents the structure with characteristics of functions and hierarchy of components in the product. The function-assembly decomposition structure consists of functions in first and lower levels. The rules of creating the function-assembly decomposition structure are:

- The functions at the first level:
  - represents all functions which have identical components in product variants;
  - represents all functions which have variant components in product variants;
  - the quantity number is needed if the solution of the function is used more than once in the same level.
- The functions at the lower levels:
  - exist if the functions at the higher levels have variants components in product variants;
  - The levels of functions are subdivided until the components are identical or unique in product variants.

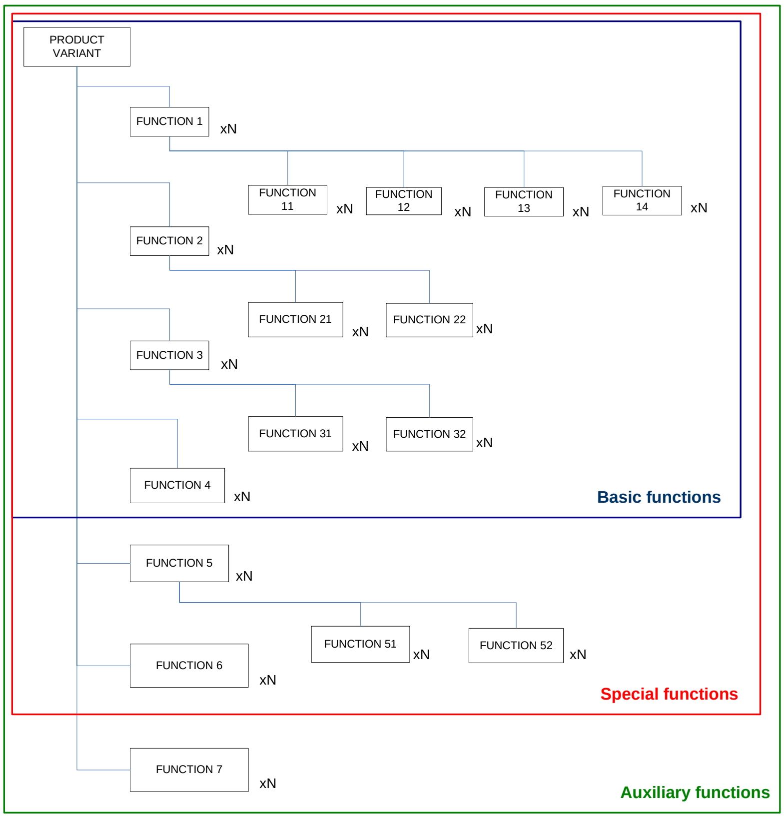

Figure 5. Function-assembly decomposition structure

The goal of defining the function-assembly decomposition structure is to create a structure by which all the product variants can be represented. Such structure enables the analysing of the product variants with equal criteria.

3.5 Relations between the functions and components

Heretofore we have been explaining the external and internal variety and the functions and function structure of the product variants. The functions identified in the function-assembly decomposition structure have to be related with the components used in the product variants. The matrix presented in the figure 6 illustrates this relation.

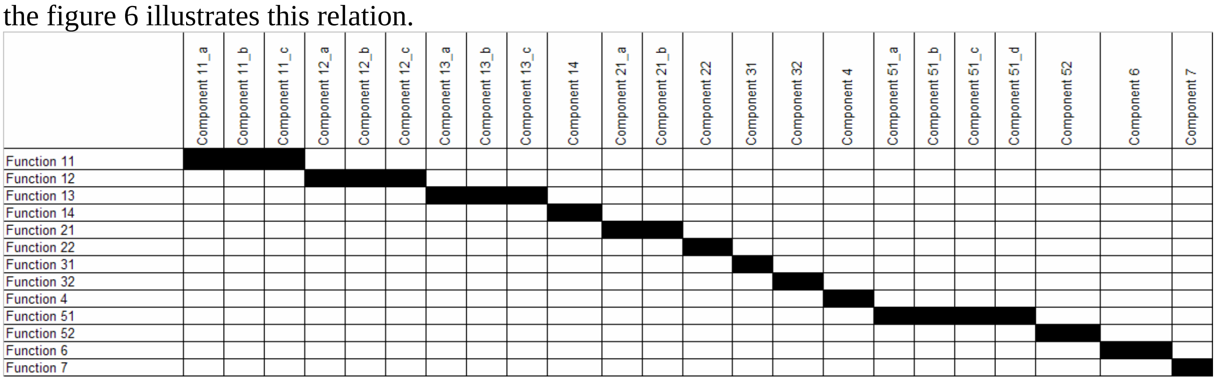

Figure 6. Function assembly matrix

Based on the functions and components a data table is created for collecting all the information needed for communality index calculations.

3.6 Data table

Table for gathering information for commonality index calculations consist of product variants' data. The data is classified as functions, components and product variants. The functions and components are presented in rows and the product variants in columns. The functions at the lowest levels of each branch in the function-assembly decomposition structure are placed in the first column. The second column contains components which represent the physical solutions of the listed functions. The third column contains the price of each purchased component or the estimated cost of each internally made component.

The product variants have two types of data. The first type of product variant data is the number of produced product variants and it is placed in the first row. The second type is the data about the components' characteristics used in the product variants and they are placed in three columns. The first column (left) shows the identification of immediate parent, the second (middle) one shows the number of immediate parents in the variant, and the third (right) column presents the required quantity of the component used to fulfil the function. The last row in the table indicates the number of unique components in the product variant.

			Product variant 1			Product variant 2			Product variant 3			Product variant 4			No. Of different parents	No of component repetition in different assemblies within all variatns
		Costs	20			1			1			51				
Function 11	Component 11_a	320	A1	1	2							A1	1	2	1	3
	Component 11_b	500				A2	1	2							1	3
	Component 11_c	660							A3	1	2				1	3
Function 12	Component 12_a	176	A4	1	1							A4	1	1	1	3
	Component 12_b	256				A5	1	1							1	3
	Component 12_c	320							A6	1	1				1	3
Function 13	Component 13_a	13	A7	1	2							A7	1	2	1	3
	Component 13_b	23,2				A8	1	2							1	3
	Component 13_c	32							A9	1	2				1	3
Function 14	Component 14	24	A10	1	2	A11	1	2	A12	1	2	A13	1	2	4	9
Function 21	Component 21_a	20	A14	1	1	A14	1	1	A14	1	1	A14	1	1	1	9
	Component 21_b	22	A15	1	1	A15	1	1	A15	1	1	A15	1	1	1	9
Function 22	Component 22	21,4	A16	2	2	A16	2	2	A16	2	2	A16	2	2	1	18
Function 31	Component 31	5	A17	1	1	A17	1	1	A17	1	1	A17	1	1	1	9
Function 32	Component 32	102										A18	1	2	1	6
Function 4	Component 4	100										A19	1	2	1	6
Function 51	Component 51_a	4										A20	1	2	1	6
	Component 51_b	3													1	3
	Component 51_c	2										A21	1	2	1	3
	Component 51_d	2													1	3
Function 52	Component 52	200	A22	1	1	A22	1	1	A22	1	1	A22	1	1	1	9
Function 6	Component 6	20										A23	1	2	1	6
Function 7	Component 7	4										A24	1	3	1	6
					9			**9**			**9**			**15**	**• • •**	

Figure 7. Data table

The two far right columns of the table shown in the figure 7 are used for calculating the data from the product variant columns. In the first column are calculated the number of different parents for each component. The calculation is the sum of different immediate parents presented in the first (left) columns of product variants. In the second column are calculated the number of component repetition in different assemblies. The calculation is the sum of number of immediate parents presented in the second (middle) columns of product variants.

3.7 Commonality index

Three different commonality indices were used to calculate the commonality of the product family. All of the methods were used to compare the results of each method. All the results of the calculations, shown on the figure 8, have value over 70%. From the commonality point of view these results of the analysed product family have high values regardless of the used method. All of these three methods tread the components equally regardless the cost, size or complexity. Therefore product family with large number of small components which have higher possibility to be reused in the variants increase the commonality index.

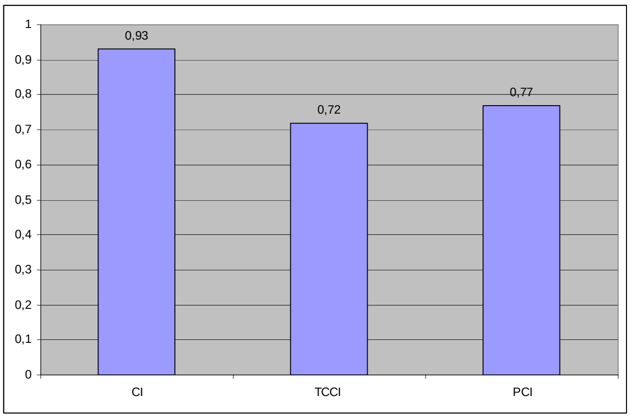

Figure 8. Commonality indices

The communality index calculated on the product family level does not identify how the components influence on the commonality. Therefore the calculations of communality index should be applied on the function levels to identify the components which have the greatest influence. The $CI^{(C)}$ method was chosen in purpose to accentuate the parameters of the components in the commonality calculations.

3.8 Identification of components' effect on the commonality

The $CI^{(C)}$ method was used to calculate the commonality index of the product family and to identify the components' effect on the commonality. The value of commonality index is not relative, thus in cannot be compared with the results of the previous methods. The calculated value of commonality index (average value of the product family) is used to compare the effect of components to the overall commonality.

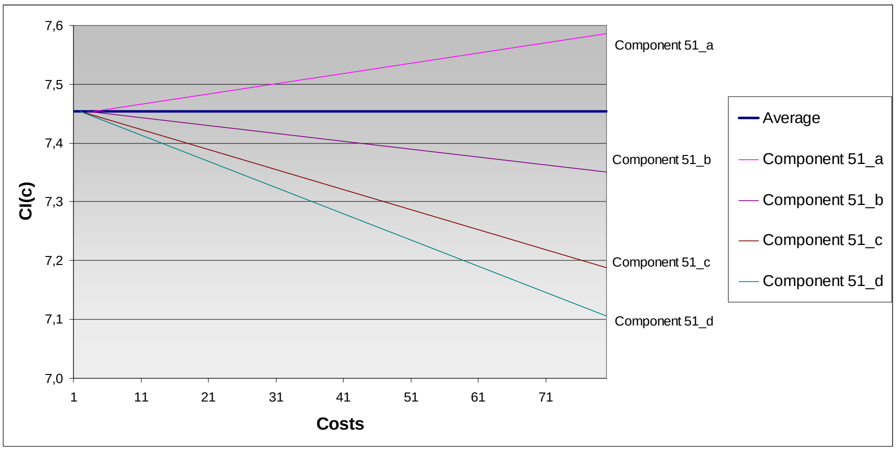

Figure 9. Positive and negative trends of the components on the commonality

The commonality index was calculated separately for all the components of the functions at the lowest levels in the function-assembly decomposition structure. This value was then compared to the average value of the product family to see the effect on the commonality. By increased the values of the components' parameters the new values of commonality index were calculated. When the new values are higher than the average value of commonality index the component has a positive trend i.e. the component increases the commonality while components parameters are increased (component 51_a in figure 9). The components with positive trend are identified as components which should be kept as they are. The components which decrease the commonality should be further analysed and redesigned.

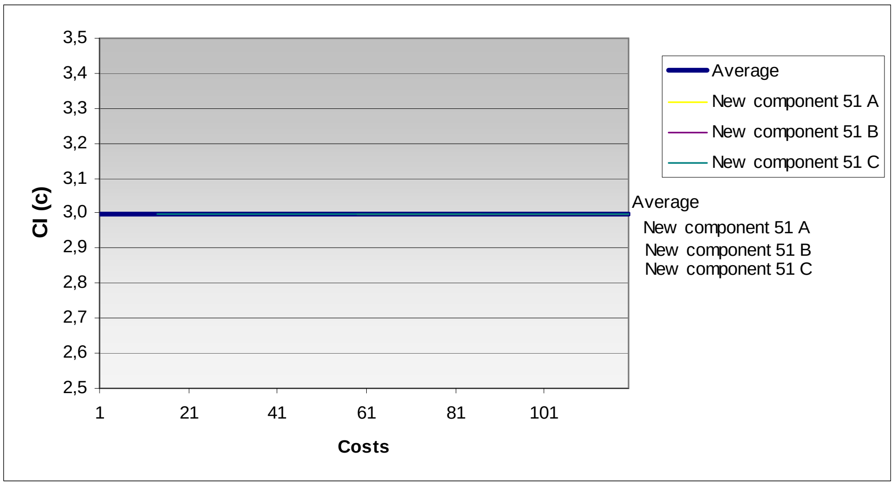

Figure 10. Ideal situation of commonality

In practice it is not possible that all the components increase the commonality index at the same time. Reason for this is the fact that in the ideal situation (from the commonality point of view) all the components would be used in all of the product variants and then the commonality index does not change when the components' parameters are increased (figure 10).

4 RESULTS

4.1 Results in the case

The study made to the case product family during this research bred two different kinds of new architectures. The first one was structurally similar to the existing one but it had major enhancement in the part level. The commonality in the product family was better, meaning there were fewer parts to produce. The second one was essentially a new concept of the product family. It actually increased the number of parts per product variant but when considering the whole product family the new architecture reduced the total number of components.

4.2 Results in the methodology

All of three methods (CI, TCCI, PCI) tread the components equally regardless the cost, size or complexity. Those methods are measuring the same characteristics of the components in the product family, but from little bit of different point of view. From the commonality point of view these results of the analysed product family have high values regardless of the used method. Therefore product family with large number of small components which have higher possibility to be reused in the variants increase the commonality index. The communality index calculated on the product family level does not identify how the components influence on the commonality. Therefore the calculations of communality index should be applied on the function levels to identify the components which have the greatest influence in the commonality value.

5 CONCLUSION

Without the detailed analyses it would not have been possible to come up with the mentioned results. It is now obvious that the detailed analyses are a mandatory when genuinely developing the product family. And an efficient method for analysing the product family is the usage of the commonality indexes. They reveal, when correctly used, the weak points of the product family in a sense of producibility. Some indexes showed the overall commonality whereas other indexes took the features (masses, costs, etc.) also to consideration. Hence usage of just one index might lead the development into wrong direction.

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