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PRODUCT PLATFORM PERFORMANCE IN MEETING WITH THE MANUFACTURING

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1. Introduction

A major trend in product design is the shift, from focusing on developing "one at a time" products to developing product families. This shift in design strategy give the opportunity to quicker release of new products variants, quick respond to new market needs and to utilise the manufacturing equipment in a better way. A product family is typically designed around a common product platform that shares the base structure, process or core competence and hence increases the reuse in the manufacturing.
Different methods to support variant design have been developed during the last decade. The view of these methods have mainly been focusing on customer satisfaction and "part" reuse, fig. 1. These methods create a product family that provides variations for the customer and internal commonality, by platform approaches [Simpson et.al. 2001] and modularisation approaches [Dahmus et.al. 2001, and Huang and Kusiak 1998]. The matching between the product family and the related manufacturing processes and technology have marginally been included in these design methods.

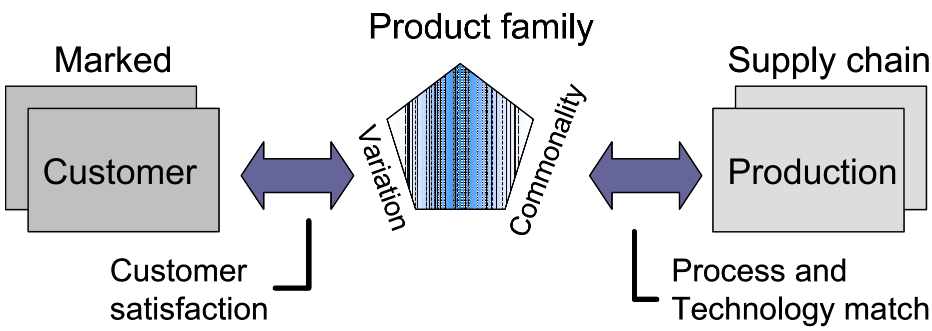

Figure 1. Product family relationships to the marked and supply chain

The manufacturing process have thus been extensively covered for "one at a time" products [Bootroyd et.al. 2002]. For a family of product some authors [Martin and Ishii 2002] and [Palani Rajan et.al. 2003] have established an indicator telling the cost or amount of redesign a component needs to meet the future marked. This information from their methods is related in some manner to the manufacturing process, but they do not cover that aspect in depth. Making the link between a product family and the belonging production sequence have been in some extend been discussed for modular product by [Gershenson et.al. 1999] and for a general product family by [Gupta and Krishnan 1998]. Their methods needs products that consist of many parts or modules in order to give valuable results.

The authors [Meyer and Dalal 2002] have thus extended the product platform definition to also incorporate nonassembled products that are process intensive, but no design method is presented. A methodology capable of indicating the product families match towards the supply chain is therefore missing.

This article will try to present a method that fills some of this gap. The aim is to develop a method that give the designers of process intensive products the possibility to do performance ranking of their product variants, both for new concepts and fine tuning of the design. Ranking the different product platforms with their ability to reuse manufacturing processes is important in order to establish a well evaluated and economical product platform, as well as finding limits and possibilities in the design.

2. Manufacturing Change Performance Index (MCPI)

The presented method is based on a study conducted for a company, producing crash boxes for the automotive industry, fig. 2. This is a product that is mounted behind the bumper beam of vehicles and absorbs energy in crash. The gatherings of data have been done by interviewing process development staff and study the complete production process for the in house products. The product designs have been studied for all of the company's products, a number of competitor's solutions, a total of 48 different solutions. This study of the products gave valuable information in finding the parameters that the customers wants to have options on, in order to give the design high flexibility. These variables were then used to evaluate the changes in the manufacturing. Due to the sensitivity of much of the data, they are only limited presented.

This study have been used to develop a method that is capable of evaluate the manufacturing process for product platforms. This method can be used to evaluate the flexibility for the manufacturing process or how different manufacturing processes affect the same product platforms. The method takes consideration to the reuse of parts, processes and in some extends knowledge. Extending the method to include more than only part reuse has been essential, since the crash box may consist of as few part as one. The proposed method consist of a two step approach; A mapping of customers demands to the corresponding engineering needs and performing the main manufacturing analysis on these needs. The analysis leads to indexes between 0-1, indicating how easy or difficult changes are to handle. A low score makes the changes easy to perform.

Figure 2. Crash box and its position in the car, behind the bumper on each side (illustration only)

2.1 Step 1: Mapping the Customers needs

The first step in this method is to find the functions in the product that the customer is interested in. For product delivered to other industry like original equipment manufacturer (OEM) the customer typical want individual specified performance of the product. Adapting products individually to each customer leads to a large portofolio. Step 1 consists of extracting all the different requirements that needs to vary in the portofolio. These are typically expressed as a change (n), illustrated in fig. 3. The product design is then compared to these needs, and the respective engineering needs that have an influence of satisfying the change are found and listed (m). These engineering needs are typical related to the products geometry or material (for example length), by physical laws. Often may the customers needs be satisfied by adjusting more than one variable. A mark (x) is used to illustrate the link.

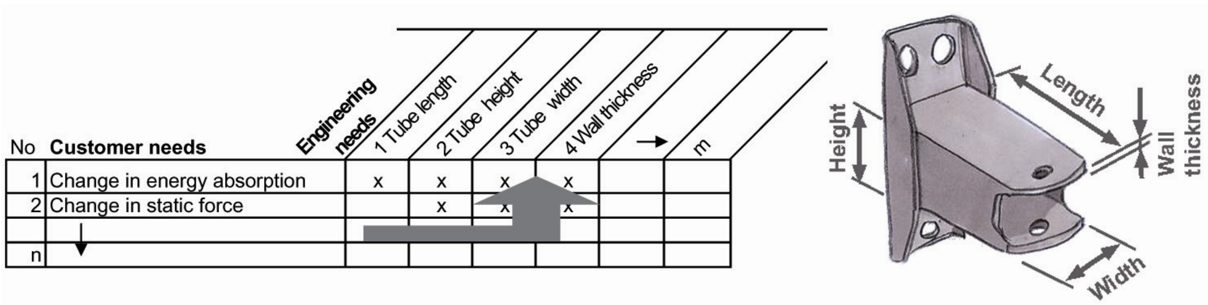

Figure 3. Customer needs mapped to the related Engineering needs

2.2 Step 2: Manufacturing change performance analysis

The second step is to perform the analysis and find the MCPI's. The flexibility of the platform is compared with respect to the chosen engineering needs, in step 1. By walking through each column in table 1, engineers are exploring the behaviour of the design and the belonging manufacturing process. The analysis table, consists of two main descriptive columns; Description of product variations, Description of manufacturing and Effect of change, and the calculation. The MCPI is calculated from a rating and cost (weighting) of each process steps the part goes through to be a product. Description of the columns is as follows:

Description of product variations: This main columns consists of three sub-columns; *No*., *Part*, and *Variation*. The *No*. indicates which of the engineering needs that are analysed. The *Part* describes which part or section of the product that needs to be changed to accommodate the customer needs. In the *Variation* column the type of variation (for example length) is described as well as the chosen variation band. Both the decided minimum- and maximum value must be specified and the already specified value on the platform should be indicated. Both extreme values should be selected wide, in order to investigate the solution space for the product platform. The transition within the band is either smooth or going in steps, depending on the product design and the manufacturing. This is indicated with, arrows for smooth transitions and double pointed line for steps, which gives a better visual view of the type of variation.

Table 1. Manufacturing analysis chart

Description of product variations			Description of Manufacturing and Effect of change					Change rate (rw)	MCPI
No.	Part	Variation	Extreme Values	Processes	Change needed to accomodate the variations	Rating of change (r) [0-10]	Cost of change (w)		
1	Tube	Length	Min Value	Extruding tube					
				Transport profiles					
		Min Value		Cutting					
				Welding	Process steps				
				Annealing	Change description				
				Forming					
		Exsisting value, or concept value		Washing					
				Heat treatment					
						Σr_i	Σw_i	$\Sigma r_i w_i$	***MCPI***
			Max Value	Extruding tube					
				Transport profiles					
				Cutting					
				Welding	Process steps				
				Annealing	Change description				
		Max Value		Forming					
				Washing					
				Heat treatment					
						Σr_i	Σw_i	$\Sigma r_i w_i$	***MCPI***

Description of Manufacturing and Effect of change: This column consists of five sub-columns; *Extreme values*, *Processes, Change needed to accommodate the variations, Rating of change* and *Cost of change*. The *Extreme values* are directly transferred from the variation column to the min and max analysis. In the *Processes* column all the process step for the part and its belonging assembly processes

is listed. They are identically repeated for the last extreme value. The detail level of the process should be at the same level for all the engineering needs analysed, in order to compare them better.
The *Change needed to accommodate the variations* is a field that describe the change each process steps have to accomplish, in order to satisfy the design as it uses the min/max value. This first evaluation of the manufacturing process is done by stating the change in a written form. The designers imagine that the proposed design is scaled to the min and max value. Such a design change, generate possible adjustment or challenges for the available manufacturing equipment. The change may lead to changes in one or several process steps, depending on the sensitivity the variable has to the production. These change are described to give the evaluation a written statement that later can be used by the numerical evaluation and give a traceability for the rating and MCPI index. The numerical rating follows the regular way of evaluating concepts and design, with a *Rating of change* and *Cost of change* columns. The rating is partly inspired from the Use-value analysis described by [Pahl & Beitz 1996] and is done with a scale from 0-10, as illustrated in table 2. The *Rating of change* column rate the difficulties it is to accomplish the needed change, as described in text form.

Table 2. Rating description

Rating	Description	Comments
0	No change required	The proposed value does not introduce any change in the existing process
1	Very minor	The change introduce only some minor adjustment in the exsisting process
2	Minor	The change introduce only minor adjustment and minor changes in fixture equipment
3	Very low change	The change introduce the need for adjustments, low changes in fixturing equipment, minor tool changes
4	Low change	The change introduce the need for changes in fixturing equipment, tool changes
5	Moderate redesign	The change introduce new fixture, changes in the tool and other minor changes
6	High level of redesign	The change introduce redesign of the tooling, based on exsisting solution
7	Very high level of redesign	The change introduce total redesign of the tooling and the related equipment
8	Total redesign with some reuse	The change introduce redesign of the process, but the equipment can be reused (tooling is replaced)
9	Total redesign	The change introduce redesign of the process, but the main equipment can be reused (tooling is replaced)
10	Total redesign of process and tools	The proposed value introduce total redesign of the process and the need to invest in new machine equipment (and belonging tool)

Cost of change is indicating the relative cost of doing changes to the process steps, without relating it to the rating. Each process steps needed to produce a product have usually different complexity; some steps may be cheap to change while other is costly to do only minor adjustments on. To capture this difference in cost of change, each process steps is assigned a percentage of 1. This percentage represents the average cost of change to adjust or replace the specific process steps. 1 is therefore the assumed cost sum for the complete manufacturing processes. This gives the opportunities to include all type of process steps, from small and simple to very advanced. The process steps that are costly to change are given a high percentage. The same weighting is always repeated, when the manufacturing sequence is the same. The evaluation on both extreme values uses therefore the same weighting.
Change rate: This column indicates the change rate each processes is given, by multiply the value of *Rating of change* and *Cost of change* columns. These values are summarised and gives the un-normalized MCPI index.
Normalized: In this column the summarized change rate index is normalised and gives the MCPI, for the manufacturing process. The index is calculated according to equation 1. and is normalized with the ideal solution (score 10 with this rating). Where r_i is Rating, w_i is Weighting and N is the number of process steps.

$$MCPI = \frac{\sum_{i=1}^{N} r_i w_i}{10 \times \sum_{i=1}^{N} w_i} \tag{1}$$

A low MCPI index indicates that the change is easy to accommodate and has a low cost related to it. The lowest value is 0. A well designed product platform has therefore a low MCPI index related to the important variable parameters. In the opposite case a change that need a comprehensive redesign of all process steps will have an index of 1.

3. Example of the MCPI on structural car parts

In this example the MCPI method is applied to crash box platforms. The MCPI method is illustrated completely for one platform and the results from three other product platforms is graphically compared. The crash boxes are build from one or several highly formed and shaped parts, as illustrated in fig. 2.

Step 1: Identification of the customers needs. In this example these needs come from the car manufacturer. Some of their needs are related to the energy the crash box can absorb in a crash, the static force needed to start deformation (secure that the box deform first) and packaging (the allowable space, avoid conflicts with other parts). Mapping these customers needs to engineering needs gives us different parameters to vary, as illustrated in fig 3; Tube length, Tube height, Tube Width, and Wall thickness. As illustrated with the mapping, customer needs may be related to the same engineering needs, introducing several possibilities of satisfying that need.

Step 2: The MCPI table is illustrated in fig. 4. for one of the engineering needs and the graph shows them all, as specified in step 1. The analysis presented is done with the engineering need, Tube length. The variation of the Tube length is in this analysis defined to span from the minimum length of 50mm and to the maximum of 200mm. If the product platform can handle this range it will have the opportunity to handle a wide spectre of energy absorption capabilities and be a versatile solution. The existing product on this platform has a length of 170mm, as indicated in the Variation column (the middle value). The length variation can be redesigned to accommodate all length between the boundaries, indicated with arrows, but there is need for a major shift in equipment above 170mm. This is indicated with a statement.

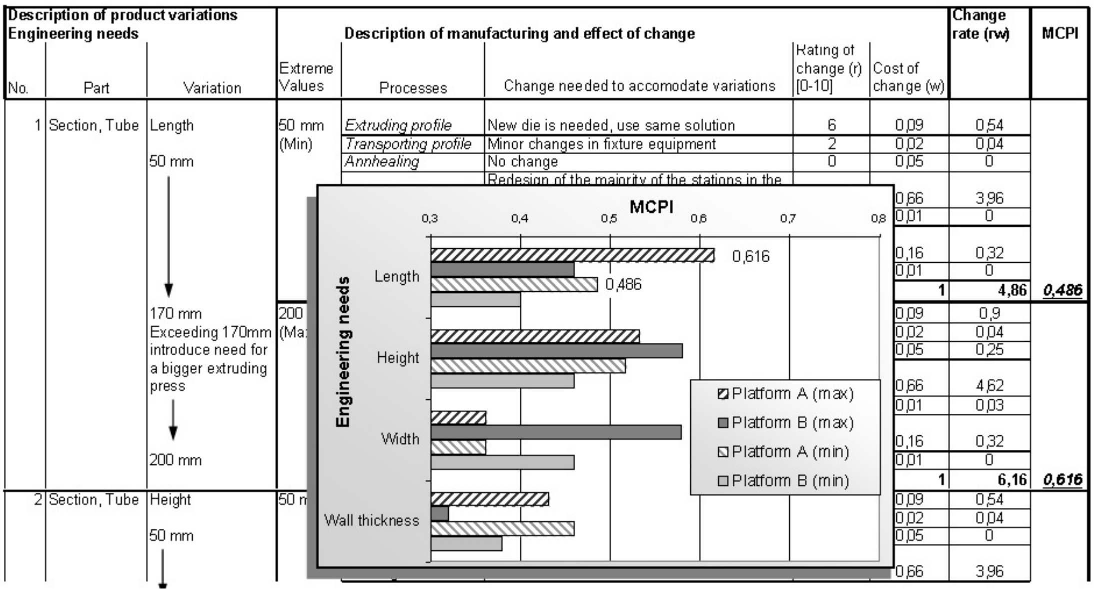

Figure 4. MCPI's for a crash box platform and these indexes are compared to a different product platform

In the description of the manufacturing and effect of change columns, the platform is analysed with the extreme values specified (50mm and 200mm). In the section of processes description, all forming, assembly and the major handling processes are listed. When the design is altered from today's tube length of 170mm to 50mm a new extruded aluminium profile is needed. The design can not be changed for this variation without having a new semi finished material (aluminium profile). This

generates the need for a new profile die for the extruding process. In this case, it can be developed from existing knowledge. Information like this is written down. After stating the needed change it is given a rate according to table 2, and it coincidence with the value 6.
The estimating of cost of change value, in each process steps, is done by comparing all the processes and find their average cost when the station is adjusted or replaced to new variants. This information is then scaled to match the total sum of 1. A process steps that is costly (high investment) or difficult to change (work consuming) are given a high value. These estimations must be done on the assumption of the average cost of change, and not linked to the rating. The change rate is calculated and in this case the MCPI index yield 0.486 (min value) and 0.616 (max value). This indicates that a change in reducing the length of the tube is much easier than lengthen it. Why this is the case should be part of the process description.
The graph presented in fig. 4, illustrates the MCPI for several engineering needs analysed for two different product platforms. The x-axis indicates the calculated MCPI and the y-axis list the engineering needs that describe the variation for the platforms. The platform analysed in the MCPI table is named platform A, and is presented together with platform B in the graph. Platform B is a similar product, but has differences in the manufacturing. The same type of analysis performed on both platforms gives indications on what variations that is easy to change and the difficult one. The increase in length variations for platform A is considerable more difficult to provide than for platform B. Comparing the two platforms when it comes to the variation width, platform A is significant easier to make changes to, both when it comes to increasing or decreasing that dimensions.
An example on using the MCPI method to compare different processes for the same product design is illustrated in fig. 5. The analysis is performed on crash box platform B and B*. Comparing the end product gives no indication that there should be differences in the production, but the number of process steps and sequence is different. The MCPI gives different values for how easy/difficult the change of the length is. Increasing the length of platform B* is the most difficult, while it is the easiest to shorten. Platform B is also easiest to shorten, but the difference in shorten or lengthen it is small. What to choose, must be evaluated when all variable parameters and their extreme values are compared.

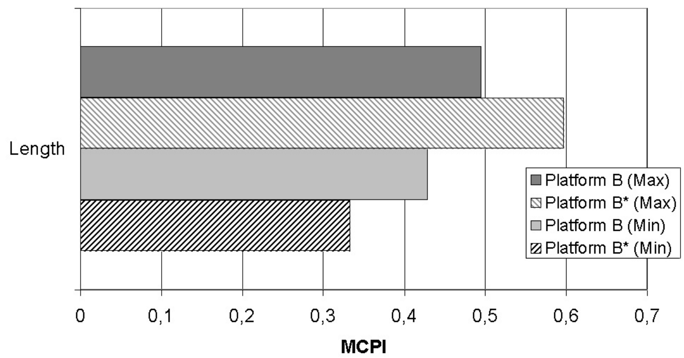

Figure 5. The MCPI used to illustrate the effect of changing the length, when different processes are compared, for the same design

4. Discussions

The products that we are surrounded with may be categories as change-, variety intensive, simple and dynamic [Sandeson and Uzumeri 1997]. Products often found in variety intensive consumer products (for example hand tools) are often made of "simple" parts. Towards the category simple (few types) one might find more complex products (for example structural car parts) with a slower changeover. Typicaly related to high volume production, where investment in equipment and process knowledge is large. Most of the existing methods use a decomposition approach, exploring the end product and then created the platform and family. This approach will not capture the processes and knowledge that lies behind each part. For products that have "simple" parts this is perhaps not so important, but for other, this is perhaps the most important aspect in platform design. Process intensive products have often the need to have high investments in manufacturing equipment and the knowledge to operate them. Taking this into account should be part of the product platform definition. The MCPI methods deal with this aspect. The method capture both the designs ability to adapt to changes and the manufacturing responds to the changes. In order to use the method properly a detailed knowledge about the processes is needed. Since the effect of the chosen parameters and their value must be evaluated. The method do however not treat the full effect of, change in one parameter and the introduction of needed changes in the neighboring parts/sections. One way of handling this is to introduce a comment to the description of the variance and process.

Under evaluation of new concepts the method gives several opportunities;

- The MCPI method can be used to explore the best suitable combination of common and variable parameters. In step 1. of the method the different customer and engineering needs is listed. Exploring each variable, giving a view of the changability to the variation parameters and hence which should be chosen.
- The MCPI method can be used to find the best suitable product platform for the existing manufacturing equipment. The type and value for the variations parameter are then very central. By finding the extreme values, the capability of the existing equipment and products is known and products can easily be derivate with low risk. If on the other hand the product required properties outside the checked range, it may need new investment and perhaps more research, leading to increased risk.
- Designing the product family and the belonging manufacturing process from scratch, the MCPI method can be helpful in finding the appropriate manufacturing equipment. Different manufacturing processes can be checked out, with regarding to their ability in handling the required variance. As the process sequence is established the product platform has been specified and hence is it possible to invest in production equipment that is not oversized. Production equipment that has a higher flexibility that is needed is usually more expensive in investment and may have a lower production rate.

The use of a rating and relative cost of processes, gives good sensitivity to capture large changes or very simple changes, in the manufacturing. The index in it self does not capture if there is one process steps or many small changes that together give the high MCPI index. Only way to verify this is to look at the rating and written comments. Using the written information should also be part of the evaluation of equal indexes. When performing the analysis it becomes important to state and be aware of jumps in technology or equipment need as the parameters values varies. Since this model uses a cost system of total 1. distributed across all processes, comparing different product platforms should be done at the same detail level and cost distribution of the same processes as equal as possible.

5. Conclusions and further work

In this paper we have shown an approach to evaluate product designs from a manufacturing point of view. The method explores the match of the product design and possible variations by looking at the respond from the manufacturing processes. This way of looking at variants in a product family is well suited for products consisting of a series of processes steps. Companies with such products can use the method to explore their design's solution space and find the most suitable way of providing variance to the customer, while securing high internal commonality. A known solutionspace for the design

gives also opportunities for quicker release of new variants with lower risk. The method evaluate each manufacturing process steps individually with respect to the parameters providing variation, indicating how easy or difficult the change is to fulfil. By having this type of performance description linking product design and its belonging manufacturing, one might explore different manufacturing processes, evaluate the solution space for different product platforms and finding out how flexible the manufacturing equipment should be. This MCPI method moves the design knowledge for product platform to also including the manufacturing processes, as often neglected by "part reuse" methods.
Further work will be done on setting the method in a more holistic picture, where the manufacturing processes is included as a more important member in the creation of a product family. Opening up the possibilities to swap the cost of change system over to handle real costs, would also be interesting. This will give data that is more accurate and capturing major investment steps better.

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