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# New product similarity index development with application to an assembly system typology selection

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## Abstract

The choice of an adapted production system is essential in today's volatile market environment. For this choice the identification of common and distinct assemblies in between the product variants is of high importance. This paper presents four new similarity indices which are aggregated to categorize products. The categorization will support the choice of an assembly system type (dedicated, reconfigurable or hybrid) for a selection of product subassemblies when designing a new production facility. On this way, operational areas for a reconfigurable system can be defined. The novel approach is applied to an industrial case study in automotive industry.

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## 1. Introduction

First introduced by Koren et al [1], reconfigurable manufacturing systems (RMS) are the next evolution of production systems [2] and have become the upcoming manufacturing paradigm for the industry of the future. RMS is nowadays a well-known topic and in the center of interest of numerous publications which also gain more and more application in the industrial sector [3]. A very recent literature research carried out by Bortolini et al. [4] identifies five ongoing research trends. Out of these, this article focuses on the intersection of the following two trends:

- Reconfigurability level assessment,
- Applied research and field applications on, between others: layout, system configuration and product family formation.

As defined by Koren, reconfigurable manufacturing systems are dedicated to one product family. This implies the need for methods which support the identification of product families and clustering. The common modus operandi is the

analysis of a product set in regard of a commonality on the physical level. In general, the objective is to (re)group products in a family for X (e.g. for RMS, for delayed product differentiation, etc.). In contrast, the presented approach is not dedicated to a single production paradigm but aims at identifying the optimum one for a set of products. Even the combination of several paradigms in one production line is possible.

The presented research work is part of a PhD project which aims at measuring and improving the agility of assembly systems. The developed indices base on the product analysis part which has been presented by the authors in a previous publication [5] and contribute on the decision-making concerning assembly system related choices. They are a brick of a future integrated methodology.

This paper is structured as follows: in section 2, common similarity indices are presented and their application is discussed. The new similarity indices to support the choice of an assembly system type are introduced. In section 4, an application on a case study in automotive industry is presented. Section 5 gives the conclusion and describes upcoming research work.

## 2. Evolution of similarity indices

The measurement of similarity as presented in literature is marked by a wide range of definitions and methods. A fact also stated by Wazed et al. [6]. In general, commonality is defined as the number of parts/components that are used by more than one product and is determined for all product family [7]. Within a product/process family, the commonality index is a metric which assesses the degree of commonality. Based on the latter, product families can be created.

One simple commonality analysis method is proposed by Abdi and Labib combining Jaccard's similarity coefficient for product family identification with an analytic hierarchy process (AHP) application for evaluation, considering manufacturing and market requirements [8,9]. The Jaccard coefficient measures similarity between finite sample sets and is defined as the size of the intersection divided by the size of the union of the sample sets.

Beside the simple calculation of Jaccard's similarity, more sophisticated indices exist in literature. The most common ones are presented in Table 1, inspired by the comparison presented in [10]. The indices are sorted in order of their apparition, starting with the first publication (DCI – 1986) and finishing with the most recent one (S – 2016).

Table 1. Commonality indices – an overview.

Name and abbreviation	Commonality measure for	Reference	
Degree of Commonality Index	DCI	Product family	Collier [11]
Total Constant Commonality Index	TCCI	Product family	Wacker & Treleven [12]
Commonality Index	CI	Product family	Martin & Ishii [13,14]
Percent Commonality Index	%C	Product	Siddique et al. [15]
Product line Commonality Index	PCI	Product family	Kota et al. [16]
Commonality versus Diversity index	CDI	Product family	Alizon et al. [17]
Comprehensive Metric for Commonality	CMC	Product family	Thevenot & Simpson [18]
Component Part Commonality	CI <sup>(c)</sup>	Product family	Jiao & Tseng [19]
Synergy (interfaces)	S	Product family	Lafou et al. [20]

Considering the way of measuring commonality, eight of the nine above mentioned indices (except the CMC) have in common that they examine commonality on the component level, applying a one to one comparison. Therefore, commonality exists if exactly the same component appears in different products. In addition, to the component comparison, the CMC takes also into account material and assembly, but the commonality is fixed also on the criterion “exactly the same”.

Some questions remain: How to compare products which vary in number and characteristic of their components? That means how to consider products with a broad range of similar components, for example screws with different length and diameter, which are not the same, but which could be assembled by an adapted (reconfigurable) assembly system? And how to define what is an adapted assembly system?

To answer these questions, four new similarity indices are presented in the following section. Their use is different from the former ones: they aim at giving a decision support concerning the question how to conceive the assembly system architecture optimally for a set of given products.

## 3. New indices for assembly system type determination

The four new indices are named  $S_1$  to  $S_4$  and form two pairs of indices. One pair,  $S_1$   $S_2$ , impacts decisions on the level of one production line. Instead of a simple one-to-one comparison on the physical level, they compare products also on the functional level which eases the analysis of variety. The other pair,  $S_3$   $S_4$ , has an impact on the production line entity by considering assembly technologies. They are complementary to  $S_1$   $S_2$ . The following Table 2 synthesizes the level and impact of each pair of indices.

Table 2. Similarity indices

System level	Impact on	Indices
Production line	Production paradigm (RMS / DMS) Product range	$S_1$ & $S_2$
Production line entity	Manufacturing processes	$S_3$ & $S_4$

### 3.1. Similarity indices $S_1$ and $S_2$

The indices  $S_1$  and  $S_2$  are based on the physical and functional architecture (*PHARE*) of the product. It is generated based on a Datum Flow Chain (DFC) with information about functional subassemblies (FSA). These contain the components needed to perform a function. The FSA being in relation to each other, build the physical and functional architecture. The following figure gives an example of a DFC with FSA (named A-E) and its corresponding *PHARE* representation. The detailed *PHARE* approach is described by the authors in [5]. As the method needs a common definition of technical functions, it is limited to products on which the common definition can be applied. It is automatically restricted to products of the same domain depending on the function definition.

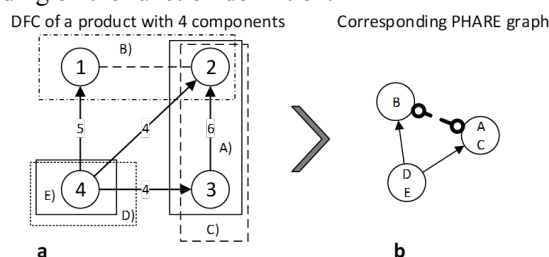


Fig. 1. (a) example of a DFC with FSA; (b) and its *PHARE* graph.

The calculation of  $S_1$  and  $S_2$  itself is based on the FSA matrix, here called GF. It is the matrix representation of the *PHARE* graph. One matrix represents one product. Similarity is evaluated concerning two aspects considering the different types of links: the relations between functional subassemblies ( $S_1$ ) on the one hand and the existence of common absent links ( $S_2$ ) on the other hand. A similarity value is calculated for each FSA to identify subassemblies which are similar in both products. Next, the application order is described.

1) Generation of the matrices representing the *PHARE*

- 2) Binary comparison of two matrices (for two products)
- 3) Input weighting
- 4) Similarity by functional group

At first, two different PHARE matrices are calculated according to equation (1),  $gf_{ij}$  being the entries of  $GF_1$  and  $gf_{mn}$  being the entries of  $GF_2$ .

$$GF_1 = \begin{pmatrix} gf_{11} & \dots & gf_{1j} \\ \vdots & \ddots & \vdots \\ gf_{i1} & \dots & gf_{ij} \end{pmatrix}, GF_2 = \begin{pmatrix} gf_{11} & \dots & gf_{1n} \\ \vdots & \ddots & \vdots \\ gf_{m1} & \dots & gf_{mn} \end{pmatrix}, gf_{ij} = \begin{cases} 3 \text{ si inclusion entrant} \\ -3 \text{ si inclusion sortant} \\ 2 \text{ si partition} \\ 1 \text{ si contact entrant} \\ -1 \text{ si contact sortant} \\ 0 \text{ sinon} \end{cases} \forall i, j, m, n \in \mathbb{N} \quad (1)$$

The proposed approach is a pairwise comparison. During this pairwise comparison, the entries of  $GF_1$  and  $GF_2$  are combined to build a new matrix  $GF_A$  for analysis. The entries of  $GF_A$  being  $gf_{op}$ . The building consists of two steps:

- 1) Identification of identic elements:

$$gf_{op} = 16 \text{ if } gf_{ij} = gf_{mn} \text{ for } gf_{ij}, gf_{mn} \neq 0 \forall i = m = o, j = n = p; \quad (2)$$

$$\forall i, j, m, n, o, p \in \mathbb{N}^6$$

With equation (2), all identical entries which are not zero are identified. Equation (3) identifies all identical entries equal to zero. The distinction is necessary to calculate the similarity indices  $S_1$  and  $S_2$ . The value of 16 is needed for the generation of matrix  $GF_A$  and is essential for weighting the entries.

$$gf_{op} = -16 \text{ if } gf_{ij} = gf_{mn} \text{ for } gf_{ij}, gf_{mn} = 0 \forall i = m = o, j = n = p; \quad (3)$$

$$\forall i, j, m, n, o, p \in \mathbb{N}^6$$

- 2) Identification of similar elements (equation (4)):

$$gf_{op} = |gf_{ij}| \cdot |gf_{mn}| \text{ if } gf_{ij} \neq gf_{mn} \forall i = m = o, j = n = p; \quad (4)$$

$$\forall i, j, m, n, o, p \in \mathbb{N}^6$$

The theoretic maximum absolute value of the operation  $gf_{ij} \cdot gf_{mn}$  is 16. To create the matrix  $GF_A$ , according to equation (5), all the entries are normalized by dividing them by 16.

$$GF_A = \begin{pmatrix} \frac{gf_{11}}{16} & \dots & \frac{gf_{1p}}{16} \\ \vdots & \ddots & \vdots \\ \frac{gf_{o1}}{16} & \dots & \frac{gf_{op}}{16} \end{pmatrix} \quad (5)$$

Therefore, identical elements have the value 1, identic elements modelling a common absent link have the value -1 and non-identical entries are in the range  $0 \leq x < 1$ . All possible values for  $gf_{op}$  are added in Table 3.

Table 3. Values for  $GF_A$

Combination		Equation	Absolute value	Normalised value
Entry 1	Entry 2			
Identity	Identity	Fixed value	16	1
Composition	Composition	Fixed value	16	1
Partition	Partition	Fixed value	16	1
Contact	Contact	Fixed value	16	1
No link	No link	Fixed value	-16	-1
Identity	Composition	$4 \cdot  \pm 3 $	12	0,75
Composition	Composition <sup>-1</sup>	$3 \cdot  -3 $	9	0,5625
Identity	Partition	$4 \cdot 2$	8	0,5
Composition	Partition	$ \pm 3  \cdot 2$	6	0,375
Identity	Contact	$4 \cdot  \pm 1 $	4	0,25
Composition	Contact	$ \pm 3  \cdot  \pm 1 $	3	0,1875
Partition	Contact	$2 \cdot  \pm 1 $	2	0,125
Contact	Contact <sup>-1</sup>	$1 \cdot  -1 $	1	0,0625
No link	Identity	$0 \cdot 4$	0	0
No link	Composition	$0 \cdot  \pm 3 $	0	0
No link	Partition	$0 \cdot 2$	0	0
No link	Contact	$0 \cdot  \pm 1 $	0	0

Fixed value means that the value is automatically set without calculations. The sign of the values depends on the direction of the arcs in the PHARE. If there is no sign, the arcs are undirected.

Now, the two similarity indices can be calculated. The first one,  $S_1$ , considers the similarity based on existing links between functional subassemblies, the second one,  $S_2$ , takes also into account the absence of links in both physical and functional architecture representations. The following formula (6) describes the way to calculate these indices for one functional subassembly, represented by one line in the  $GF_A$  matrix.

$$S_1 = \frac{\sum \text{values} > 0}{\text{Nb. of values} \geq 0} \quad S_2 = \frac{\sum \text{values} > 0 + \text{Nb. of values} = -1}{27} \quad (6)$$

The indices  $S_1$  and  $S_2$  take only into account the functional and physical product architecture, but they do not give any information about the assembly technologies which are used. This additional knowledge is necessary to decide the assembly system type to select.

### 3.2. Similarity indices for assembly technology

In the following, the indices  $S_3$  and  $S_4$  for assembly technology similarity are introduced. A value is calculated for each FSA to identify similar assembly technologies.

Index  $S_3$  evaluates the internal similarity of each functional subassembly. It considers the assembly technologies used in the functional subassembly and determines thus the way how it is realized. Index  $S_4$  evaluates the external similarity, i.e. the similarity in the relations which one functional group has to the others. It considers all assembly technologies which are used to position a functional subassembly, i.e. all entering arcs. In this way, the similarity of how de functional subassembly is assembled to the whole product is examined. The general approach to calculate is as follows:

- 1) Generation of a DFC (Whitney [21]) with functional subassemblies and assembly technology information on the arcs, as presented by the authors in [5]
- 2) Selection of arcs to evaluate
- 3) Generation of a matrix containing assembly technology and functional groups
- 4) Binary comparison of two matrices (representing the comparison of two products) to calculate  $S_3$  and  $S_4$
- 5) Similarity by functional group

Fig. 2 gives an example of a functional subassembly in a DFC with its different links and their signification. For  $S_3$ , all arcs belonging to a functional subassembly are evaluated (here called “internal arcs”). For  $S_4$ , the entering arcs are considered (“external” arcs).

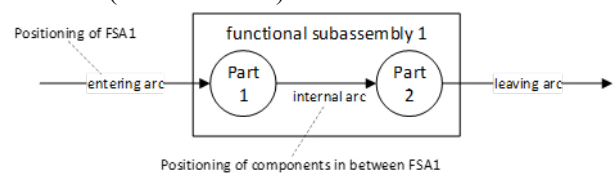


Fig. 2. Functional subassembly with its components.

The technology matrix  $T$  is built, where the rows represent all assembly technologies and the columns stand for functional subassemblies. The entries of matrix  $T$  are 1 if one technology  $i$  is used for a functional group  $j$ , and 0 else. The considered technologies are identified as described above. Two matrices  $T^{\text{int}}$  and  $T^{\text{ext}}$  have to be built for each product. Equation (7) illustrates two matrices  $T$ .

$$T_1^{\text{int/ext}} = \begin{pmatrix} t_{11} & \dots & t_{1j} \\ \vdots & \ddots & \vdots \\ t_{i1} & \dots & t_{ij} \end{pmatrix}; T_2^{\text{int/ext}} = \begin{pmatrix} t_{11} & \dots & t_{1n} \\ \vdots & \ddots & \vdots \\ t_{m1} & \dots & t_{mn} \end{pmatrix} \quad (7)$$

For the technology comparison, an analysis matrix  $T_A$  with its entries  $t_{op}$  is generated. If two entries in the compared matrices  $T_1$  and  $T_2$  are identic and equal to 1, i.e. the same assembly technology is used, the entry in  $T_A$  is 1, if the two entries are 0, i.e. no technology is used, then the entry in  $T_A$  is 0 and if the two entries differ, then  $t_{op}$  is -1. Equation (8) below details the entries  $t_{op}$  and equation (9) shows the analysis matrix  $T_A$ .

$$t_{op} = \begin{cases} 1 & \text{if } t_{ij} = t_{mn} \neq 0 \\ 0 & \text{if } t_{ij} \neq t_{mn} \\ -1 & \text{else} \end{cases} \quad \forall i=m=0, j=n=p; \forall i, j, m, n, o, p \in \mathbb{N}^6 \quad (8)$$

$$T_A^{\text{int/ext}} = \begin{pmatrix} t_{11} & \dots & t_{1p} \\ \vdots & \ddots & \vdots \\ t_{o1} & \dots & t_{op} \end{pmatrix} \quad (9)$$

Based on this, the similarity indices  $S_3$  and  $S_4$  are calculated.  $S_3$ , presented in equation (10), is based on  $T_A^{\text{int}}$ . It is calculated per functional subassembly, represented by a line in the matrix.

$$S_3 = \frac{\text{Sum of all entries } > 0}{\text{Number of entries } \geq 0} \quad (10)$$

$S_4$ , presented in equation (11), is based on  $T_A^{\text{ext}}$ . It is also calculated per functional subassembly, represented by a line in the matrix.

$$S_4 = \frac{\text{Sum of all entries } > 0}{\text{Number of entries } \geq 0} \quad (11)$$

The indices  $S_3$  and  $S_4$  compare the assembly technologies which are common of both products with the overall number of different assembly technologies which are used in both products. To homologize the vocabulary used to describe the assembly technology, the following list of different technologies has been identified in cooperation with the industrial partner.

### 3.3. Similarity index interpretation

The two indices  $S_1$  and  $S_2$  can be interpreted in the following way:

- 100% for  $S_1$  and 100% for  $S_2$ : The functional subassembly (FSA) exists within a similar architecture.
- 0% for  $S_1$  and 100% for  $S_2$ : The FSA does not exist in the examined products. Therefore, it is no longer considered.
- 0% for  $S_1$  and for  $S_2 < 100\%$ : FSA exists only in one of the two examined columns. Thus, it is not considered for further analysis.
- $0\% < x < 100\%$  for both indices: Domain of interpretation submitted to some uncertainty. Possible conclusions are shown in Fig. 3.

The conclusions have been verified through an industrial case study on two steering columns for the automotive industry. The interpretation scheme in Fig. 3 represents thus a first link of the developed indices with an industrial expert viewpoint. During this first evaluation, the combination of  $S_1$  and  $S_2$  leads, apart from the extreme values, to domains with overlapping frontiers. The indices  $S_3$  and  $S_4$ , however, can be interpreted in a simple way: if more than fifty percent of the assembly technology is used in common, then an integration of the two products on the same installation can be envisaged.

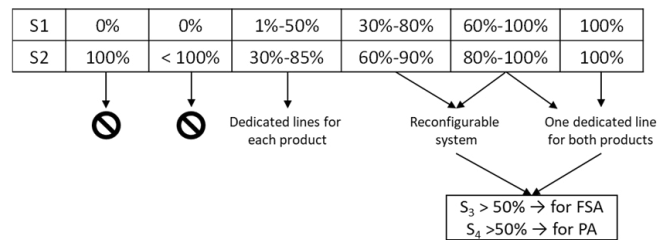


Fig. 3. Interpretation scheme of the similarity indices.

If  $S_3 > 50\%$  then a common installation for functional subassembly (FSA) can be recommended and if  $S_4 > 50\%$  then a common installation for the product assembly (PA), i.e. the connection of a functional subassembly with the other parts of the product, can be recommended. The values of 50% percent have been fixed during a first analysis with the industrial partner

## 4. Case study application

In this section, a similarity analysis with the above described four indices is applied on an industrial case study provided by thyssenkrupp Presta France, manufacturer of steering columns in the automotive sector. This case study is exemplary as the method is developed to be applicable also to other domains than the automotive sector. A preliminary analysis of their technical functions has revealed that a steering column can fulfill up to 22 different sub-functions belonging to seven main functions. Here, two steering columns which are related to two different product families are compared using the four new similarity indices.



Fig. 4. Case study steering columns – column 1 (left) and column 2 (right).

The first column, called “column 1”, is a mechanical column allowing height and length adjustment and having comfort components. The second one, called “column 2”, is a more basic mechanical column which does not possess any comfort components, and which allows only height adjustment. The former one is composed of 59 components fulfilling 25 different sub-functions. The latter one consists of 22 components fulfilling 19 sub-functions.



The two steering columns are illustrated in Fig. 4. The method application follows the description presented in section 3: based on the physical and functional architecture, the matrices  $GF_{\text{column1}}$  and  $GF_{\text{column2}}$  are generated and the analysis matrix  $GF_A^{12}$  is deduced. Finally, the similarity indices are calculated and interpreted. The interpretation has been confronted with the industrial practices.

Fig. 5 shows an excerpt of the matrix  $GF_A^{12}$  of the two columns. In detail the comparison of functional subassemblies FSA 12-16 (out of 22) with others. It illustrates the use of different values according to Table 3. Based on this matrix, the similarity indices  $S_1$  and  $S_2$  can be calculated for the two columns in our example.

Column 1-2	FSA12	FSA13	FSA14	FSA15	FSA16	FSA17
FSA16	-1,00	-1,00	-1,00	-1,00	-1,00	-1,00
FSA17	0,00	0,00	0,00	-1,00	-1,00	-1,00
FSA18	0,375	0,1875	0,375	-1,00	-1,00	-1,00

Fig. 5. Excerpt of analysis matrix  $GF_A^{12}$ .

For the calculation of  $S_3$  and  $S_4$  the matrices  $T^{\text{int}}$  and  $T^{\text{ext}}$  have to be generated. The figure below shows and extract of the matrix  $T^{\text{ext}}$  of the two steering columns in the case study.

Column 1-2	Bolted Assembly	Fitting	Charging Positioning	Riveting
FSA4	0	0	-1	-1
FSA5	0	1	1	1
FSA6	0	0	-1	0
FSA7	-1	-1	-1	0

Fig. 6. Excerpt of Matrix  $T^{\text{ext}}$  for the case study steering column.

Now, with help of the three matrices  $GF_A$ ,  $T^{\text{int}}$  and  $T^{\text{ext}}$ , the indices  $S_1$ - $S_4$  can be calculated. The results are shown in Table 4 which contains the indices for the 22 functional subassemblies.

Table 4. Case study result: Similarity indices

Functional subassemblies	$S_1$	$S_2$	$S_3$	$S_4$
FSA 1	67%	91%	0%	100%
FSA 2	67%	91%	0%	100%
FSA 3	30%	68%	0%	100%
FSA 4	0%	41%	partial function	
FSA 5	40%	70%	0%	100%
FSA 6	0%	77%	partial function	
FSA 7	0%	73%	partial function	
FSA 8	48%	76%	67%	0%
FSA 9	34%	70%	0%	0%
FSA 10	0%	77%	partial function	
FSA 11	0%	50%	partial function	
FSA 12	34%	58%	25%	67%
FSA 13	36%	83%	50%	50%
FSA 14	15%	65%	0%	0%
FSA 15	0%	100%	absent function	
FSA 16	0%	95%	partial function	
FSA 17	0%	68%	partial function	
FSA 18	59%	91%	0%	0%
FSA 19	50%	95%	0%	50%
FSA 20	26%	60%	0%	100%
FSA 21	75%	95%	0%	100%
FSA 22	14%	73%	0%	100%

The following conclusions can be taken, according to the interpretation scheme as presented in Fig. 3.

FSA 15 is absent in the two columns which means that their respective function is not realized. Thus, the indices  $S_3$  and  $S_4$  are not evaluated. The FSA 4, 6, 7, 10, 11, 16 and 17 are partially realized, i.e. they exist only in one of the two columns. Therefore, the indices  $S_3$  and  $S_4$  are not evaluated either. In these two cases, the assembly system has either to be separated for the assembly of the FSA or it contains modules which are not used at full charge.

For FSA 9 and 14, the values for  $S_1$  and  $S_2$  are poor. In addition, there is no common assembly technology used. So, it can be deduced that a separated dedicated assembly system is to envisage.

In the case of FSA 18, the values  $S_1$  and  $S_2$  indicate the need of a reconfigurable system. However, a closer look on  $S_3$  and  $S_4$  reveals that no common assembly technology is used which complexifies the reconfigurability of the assembly system.

The FSA 3, 5, 19, 20 and 22 have intermediate values of  $S_1$  and  $S_2$ , heading for a reconfigurable solution. The  $S_3$  indicator being 0%, the reconfigurable assembly solution is for the product assembly. The values of  $S_4$  being either 50% or 100% indicate that the reconfiguration task is more (50%) or less (100%) complex. The case of FSA 8 is similar, with the only difference that the assembly system is for the assembly of the FSA ( $S_3 > 0\%$ ,  $S_4 = 0\%$ ).

FSA 12 and 13 have intermediate values for each of the four similarity indicators. This evokes a reconfigurable solution which, on the one hand, has to cope with different assembly technologies, and on the other hand should be able to create the functional subassemblies as well as to assemble them with the rest of the product. This makes the reconfiguration task in this case the most complex in comparison with the other cases.

Finally, FSA 1, 2 and 21 have high values for  $S_1$  and  $S_2$ . This leads to the conclusion that a dedicated line for both products can be convenient. Analysis of  $S_3$  and  $S_4$  indicates that the assembly line is for the assembly of the FSA on the product ( $S_4 = 100\%$ ).

The conclusions have been presented to and discussed with industrial partner. They present a first interpretation of the four similarity indices. The confrontation with a real case permitted to identify that the conclusions indicated by the four indices are about to match with the experience of the industrial partner. Overall, the indices  $S_1$  and  $S_2$  have been calculated in 17 pairwise comparisons of steering columns and the indices  $S_3$  and  $S_4$  have been calculated in ten pairwise comparisons.

## 5. Conclusion and perspectives

For the design of manufacturing and assembly systems, it is important to know which products will be sent on one line, which production paradigm to choose and where in the assembly system the reconfiguration has its optimum placement. To answer the question of product mix, several commonality indices have been proposed in the past, ranging from simple part-by-part comparisons to evolved indices considering additional aspects as for example material.

But all these indices fail to answer the question which production paradigm to choose and where to integrate reconfigurability.

Addressing this research gap, a new similarity analysis approach is proposed in this article, based on the parallel analysis of four similarity indices:

- $S_1$  and  $S_2$  for a general view on the similarity of the product structure (functional and physical) which guide towards the production paradigm to choose and which give an idea about the complexity of the products in terms of technical functions.
- $S_3$  and  $S_4$  which detail the similarity on an assembly level. They give an information on the difficulty of reconfiguration (different or identic technologies) on the level of the assembly system installations.

The product modelling approach on which the similarity analysis is based has already been introduced by the authors in another publication [5].

In cooperation with the industrial partner, several case studies have been carried out. One is presented in this article. It underlines that a comparison of different products (differing in number and characteristics of their components) is possible. The confrontation of this first case study results with the experience of the industrial partner has revealed that the propositions are in concordance with what is considered possible and reasonable by the industrial partner.

As the indices are newly developed, the presented case study and results cannot be other than the beginning of the verification of the indices. Other case studies, comparing up to ten different products, will follow to verify the findings.

In addition, the calculations and interpretation domains are done by hand for instance. An automation of the calculus would be helpful in terms of reducing calculation time and avoiding input mistakes. A long-term perspective might be the link of the method with an CAD program to extract directly information about mechanical assemblies and technologies used. Concerning the uncertain domains, future work will consist of the determination of their frontiers. This work will be done in cooperation with the industrial partner in order to assure the correct interpretation. The frontiers can be determined by establishing fuzzy rules or using classification tools as for example support vector machine (SVM).

As the similarity indices are only a brick in the research work on the design of reconfigurable assembly systems, they will be integrated into the global approach. The next step after the similarity analysis, leading to a production paradigm and permitting clustering, will be the detailed design taking into account the system constraints and process information.

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## References

- [1] Koren Y, Heisel, U., Jovanova, F., Moriwaki, T., Pritschow, G., Ulsoy AG et al. Reconfigurable Manufacturing Systems. *CIRP Annals - Manufacturing Technology* 1999;48(2):527–40.
- [2] Mehrabi MG, Ulsoy AG, Koren Y, Shpitalni M. Reconfigurable manufacturing systems: Key to future manufacturing. *Journal of Intelligent Manufacturing* 2000;29(11):403–19.
- [3] Russo Spena P, Holzner P, Rauch E, Vidona R, Matt DT. Requirements for the Design of flexible and changeable Manufacturing and Assembly Systems: A SME-survey. *Procedia CIRP* 2016;41(41):207–12.
- [4] Bortolini M, Galizia FG, Mora C. Reconfigurable manufacturing systems: Literature review and research trend. *Journal of Manufacturing Systems* 2018;49:93–106.
- [5] Stief P, Dantan J-Y, Etienne A, Siadat A. A new methodology to analyze the functional and physical architecture of existing products for an assembly oriented product family identification. *Procedia CIRP* 2018;70:47–52.
- [6] Wazed MA, Shamsuddin A, Nukman Y. Commonality and its Measurement in Manufacturing Resources Planning. *Journal of Applied Sciences* 2009;9(1):69–78.
- [7] Ashayeri J, Selen W. An application of a unified capacity planning system. *Int Jnl of Op & Prod Mngemnt* 2005;25(9):917–37.
- [8] Abdi MR, Labib AW. Grouping and selecting products: The design key of Reconfigurable Manufacturing Systems (RMSs). *International Journal of Production Research* 2004;42(3):521–46.
- [9] Abdi MR, Labib A. Products Design and Analysis for Transformable Production and Reconfigurable Manufacturing. In: Dashchenko AI, editor. *Reconfigurable Manufacturing Systems and Transformable Factories: 21st Century Technologies*. Berlin Heidelberg: Springer Verlag; 2007, p. 461–478.
- [10] Thevenot HJ, Simpson TW. Commonality indices for product family design: A detailed comparison. *Journal of Engineering Design* 2006;17(2):99–119.
- [11] Collier DA. The measurement and operating benefits of component part commonality. *Decision Sciences* 1981;12(1):85–96.
- [12] Wacker JG, Treleven M. Component part standardization: An analysis of commonality sources and indices. *Journal of Operations Management* 1986;6(2):219–44.
- [13] Martin MV, Ishii K. Design for Variety: A Methodology for Understanding the Costs of Products Proliferation. *Proceedings of the 1996 ASME Engineering Technical Conference and Computers in Engineering Conference* 1996;96-DETC/DTM-1610:1–9.
- [14] Martin MV, Ishii K. Design for Variety: Development of Complexity Indices and Design Charts. *Proceedings of DETC97 ASME Design Engineering Technical Conferences* 1997;97-DETC/DFM-4359:1–9.
- [15] Siddique Z, Rosen DW, Wang N. On the Applicability of Product Variety Design Concepts on Automotive Platform Commonality. *Proceedings of DETC98 ASME Design Engineering Technical Conferences* 1998;98-DETC/DTM-5661:1–11.
- [16] Kota S, Sethuraman K, Miller R. A Metric for Evaluating Design Commonality in Product Families. *Journal of Mechanical Design - Transactions of the ASME* 2000;122(4):403.
- [17] Alizon F, Shooter SB, Simpson TW. Assessing and improving commonality and diversity within a product family. *Research in Engineering Design - Theory, Applications, and Concurrent Engineering* 2009;20(4):241–53.
- [18] Thevenot HJ, Simpson TW. A comprehensive metric for evaluating component commonality in a product family. *Journal of Engineering Design* 2007;18(6):577–98.
- [19] Jiao J, Tseng MM. Understanding product family for mass customization by developing commonality indices. *Journal of Engineering Design* 2010;11(3):225–43.
- [20] Lafou M, Mathieu L, Pois S, Alochet M. Manufacturing System Flexibility: Product Flexibility Assessment. *Procedia CIRP* 2016;41:99–104.
- [21] Whitney DE. *Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development*. New York, Oxford: Oxford University Press; 2004.