A proposed index to assess commonality among aircraft product families

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Abstract. Market increasing competition escalate the challenges facing aeronautics companies to satisfy the diversity of aircrafts applications while keeping design and manufacturing cost of Aircrafts as low as possible. Modularity and commonality in Aircrafts design have been recognized as solution for the stated challenge. Commonality in aeronautics result in offering different Aircrafts models at lower costs that broader the use of Aircrafts. For modular product design the need to assess the degree of modularity or commonality arises, and many researchers have been motivated for designing various commonality indices for specific focus to assess commonality to evaluate the benefits and compare between the degree of commonality among various product families. This paper proposes new commonality index within design concern that take into account products production quantities. Commonality is assessed for different products quantities patterns using one of previous design concern index (e.g. DCI) and using developed CPF. CPF give consistent commonality assessment unlike any design focus commonality index such DCI. Consequently, it is concluded that commonality assessment must be based on the actual production quantity of common modules used unlike previous approaches that based their commonality assessment on the number of times common modules can be used in the fixed design of products within product family. Therefore, the developed index could assess
the commonality across various Aircrafts product families more effectively than previous measures.

KEYWORDS: Aeronautics applications – Assessing Aircrafts commonality, Automotive applications- Electrical appliances & electronics applications – Commonality assessment.

1. Introduction
Market competition obligates diversifying products within the same product family, this enables companies to provide a variety of products on the expenses of cost, one strategy to decrease cost is to increase commonality within product families. Automotive designers utilized product commonality since 1914, when they suggested standardization of automobile subassemblies, such as: axles, wheels … etc. to facilitate the mix-and-matching of components and to reduce costs [1].

Many definitions of product commonality can be found in literature, yet the definition made by [2] who defined commonality as “the number of parts/components that are used by more than one product and is determined for all product families”, and by [3] who defined commonality as “the use of the same version of component across multiple products” gives simple and good understanding to product commonality concept. Utilizing commonality across product families may lead to financial benefits [4], where Volkswagen has noted a $1.7 billion savings from the use of product architecture commonalities [4]. Other beneficial characteristics of commonality were highlighted by [5], as simplified planning and scheduling, lower setup and holding costs, reduction of vendor lead time uncertainty, order quantity economies, lower safety stocks, processing time and higher productivity. Therefore, many researchers were concerned with commonality research among which how to measure product commonality among a product family through defined indices. Commonality Index is defined by [6], as a measure of how well the product design utilizes standardized components. A component is any inventory item (including a raw material), other than an end item (finished product), that goes into higher-level items.

Different indices were developed to satisfy different companies’ focus and perspective [7], each is representing proper measurement with respect to companies’ related criteria. The authors categorized the commonality indices into two main categorizes. The first category of commonality indices targeted for measuring commonality in existing product lines to compare product families or assess improvement of a redesign. The second category involved the commonality definition within the context of optimization that involved the trade off between commonality and the ability of achieving distinct performance targets.

Six commonality indices were compared by [8] from the literature based on their ease of data collection, repeatability and consistency. Each index measure commonality from different perspective, where the selection of an index involves consideration of the company focus and viewpoint when designing the product family. Commonality indices can be categorized into three main categories according to the parameters considered to calculate the index, which are: 1) design parameters, 2) design and operational parameters, 3) design, operational and cost parameters.
1.1. Commonality index within Design concerns

Commonality indices based on design perspective are concerned with product(s) design represented in its BOM, the nature of components/modules (can be common within the products family or not) and their relative usage with respect to other components or products. Degree of Commonality Index (DCI) is introduced with [9], where its computation is easy that based on information contained in the product family bill of materials. It assesses commonality based on the ratio between the number of common components in a product family and the total number of components. The DCI was used by [10] to evaluate the commonality between two products. Similar index is introduced by [11] as they used a degree of commonality measure which is the number of common modules among the product family. Also, other commonality index based on the DCI introduced by [12] that measures the relative commonality between two products.

One of its drawbacks account to the fact that each family will have a different maximum possible DCI value because it is based on different number of components used. So each family will have different moving boundaries that complicated the distinguishing between the relative increase of commonality when comparing these families of products. In contrary to the cardinal DCI measure, Total Constant Commonality Index (TCCI) is introduced by [13], which is a modified (normalized) version of DCI, it is a relative index with fixed boundaries ranging from 0 to 1. Zero means no items are being shared in the product family; one means that all common items are shared in all possible products. Therefore, TCCI facilitates comparisons between families (benchmarking) and between competing designs. TCCI is used by [14] to measure commonality while developing method for designers that aid their decision beyond product family platform selection within their targeted quality modular products architecture and commonality. The Commonality Index (CI) is introduced by [15,16], which is also a modified version of DCI, it is based on measuring the number of unique parts required to produce different varieties. It assesses commonality based on the ratio between number of unique parts to total number of parts in a product family. CI ranges from 0 to 1; where as the commonality increases the value of the measure decreases. CI is modified by [17] in order to promote more commonality among product families, they developed a measure that take into consideration the Cross commonality between products among products families. The developed Cross Commonality Index (CCI) proved to effectively capture the impact of having cross commonality among products families.

Total Commonality Index (TCI) is introduced by [18] which is a novel idea index that in contrary to the index that is based on product family bill of material (PBOM), it is based on the generic bill-of-materials (GBOM) of a product family. GBOM incorporate all possible products variants into consideration using probabilities of using different variants across products. It is preferable for assemble-to-order systems. In this manner, the entire product family is considered, even though a portion of the possible product variants may actually be unperceived by customers.

1.2. Commonality index based on Design and operational Perspective

In addition to the main design perspectives considered by DCI, TCCI, CI, CCI and TCI the second category of indices added other design parameters such as module size and shape, and operational parameters such as manufacturing and assembly processes. Therefore, these indices could be considered mixed perspectives between design and operational commonality. Product
Line Commonality Index (PCI) is introduced by [19] taking into consideration specific information about product line such as number of products that use the common part and whether these parts have identical size, shape, and materials. Also, it considers if the parts used within products shared identical manufacturing processes, assembly, and fastening schemes or not. PCI is a contrary to the indices that evaluate percentage of common parts used within the product family that penalize the broader feature mix families; PCI penalizes the difference that should be ideally common. PCI ranges from 0 to 100, the zero value of PCI means that all non-differentiating parts are either not shared or they are shared and have different material, size, manufacturing and assembly processes. The 100 value of PCI means that all the non-differentiating parts are shared across models with identical size shape, shape, and they are made using same materials, identical fastening methods, same assembly and manufacturing processes. PCI is integrated by [20 with Generational Variety Index (GVI), and Design Structure Matrix (DSM) to prioritize components for redesign based on variety and commonality needs in a family of products.

Percent Commonality Index (%C) is introduced by [21] that is based on four main perspectives; they are common components, common connections, and assembly sequence and workstation. The %C computes the total commonality as weighted-sum of four terms, they are: 1) Percentage of shared components across different variants in a platform; 2) Percentage of common connections among components; 3) percentage of common assembly sequences; and 4) percentage of common assembly workstations. It ranges from 0 to 100. Zero means no commonality while 100 means complete commonality.

1.3. Commonality index based on Design and economic Perspective

In this category some economic parameters are used in commonality index calculations, which measure the economics of having commonality within the product family. Component Part Commonality Index (CI_C) is introduced by [22] as extension of DCI. It considers critical factors such as component parts cost, production volume, and quantity per operation. This index captures more information per each component in order to evaluate each component effect on the overall level of commonality and diversity in the product family. Comprehensive Metric for Commonality (CMC) is introduced by [23] as an integration of various aspects that considered within most of aforementioned indices into a single measure. It targeted to capture more information for each component in order to evaluate each component impact on the overall level of commonality and diversity in the product family. Similarly to CI_C, CMC considered the components costs, and in addition, it considered components size, geometry, their material as well as their manufacturing process, and their assembly scheme. The CMC ranges from 0 to 1. The highest value of the CMC is obtained when all the non-differentiating components are common between all the products, and they use the cheapest variant available.

Other approaches were done by researchers in their attempts to measure commonality, [24] introduced an index measures the commonality and diversity for each component of each function, The Commonality Diversity Index (CDI) is based on determining common or specific (variant or unique) components within the product family and the optimal tradeoff between commonality and diversity based on the functions required to exist in the product family. This tradeoff is based on the value of the design requirements specified from market analysis. CDI is scored from 0 to 1, where 1 indicates a perfect utilization of the commonality–diversity and 0
indicates a failure to do so. Their results showed that CDI enables designers to penalize the score when the commonality and the diversity are not respected regarding the specification of marketers.

From the previous review it is clear that the commonality indices are mainly used in product design or redesign, they are seldom used in planning of supply chain operations. The design perspective indices did not account for the production quantities of products thus it is not beneficial in planning for supply chain operations. Other indices may include the production quantities of products, yet they considered other parameters in details, which are: 1) Design parameters such as modules size, shape and materials, although the introduction of these parameters may not be beneficial as usually the common module design do not change as it is used in different products. 2) Production parameters such as processing and assembly processes, in this case if the common module is manufactured with different methods it is not considered as common, which may not be the case especially in global supply chain environment. 3) Financial parameters as module cost and processing costs, yet such costs may be affect by the commonality decision as the common product may be more expensive but using it in more than one product increases the economies of scale in purchasing and manufacturing. In addition considering such detailed parameter complicated the calculation of the indices [25].

The objective of this paper is to propose new simple commonality index within design perspective, that take into account the production quantities of the products, the proposed index will be compared with DCI to show that design perspective commonality indices may fail in representing the actual numbers of used (or expected to be used) common modules under various demands. The rest of this paper is organized as follows: the proposed commonality index is demonstrated in section 2, numerical experiment in section 3, results and discussion in section 4 and finally conclusion in section 5.

2. Proposed Commonality Index
2.1 Notations
Sets
- \( I \): Set of products composing the product family
- \( J \): Set of all modules that can be used in all products
- \( C \): Set of High-end modules that are used as Common modules across products \( C \in J \)

Parameters
- \( \beta_{i,c} \): Binary parameter equals 1 if high-end module \( c \) is originally one of the modules that composing product \( i \), 0 otherwise.
- \( X_{i,c} \): An input parameter equals 1 if high-end module \( c \) is considered as a module composing product \( i \); 0 otherwise.
- \( X_{i,j} \): An input parameter equals 1 if module \( j \in J \) is composing product \( i \); 0 otherwise.
- \( N_i \): Actual Quantity of product \( i \) assembled
- \( O_j \): Produced Quantity of module \( j \in J \)
- \( O_c \): Produced Quantity of common module \( c \in C \)
- \( OQ_c \): Total quantity of module \( c \) whose \( \beta_{i,c} = 1 \)
2. 2 Proposed Commonality Measure

A manufacturer produces a product family that composed of number of products, each product composed from a number of modules. The set of all modules that constituting all products are categorized into two main subsets: unique modules and variant modules. Any unique module cannot be replaced by any other module in the product structure, on the other hand, variant module(s) can be replaced by High-end module which is another variant module of higher features; for the purpose of increasing commonality. High-end module must exist at least in one product to satisfy the commonality definition. The proposed commonality index is a ratio between the produced quantities of common high-end modules to the total modules used to produce enough quantities meeting the demand. The mathematical formulation of the proposed commonality index is given in equations (1-4).

\[ O_j = \left( \sum_{i \in I} X_{i,j} \cdot N_i \right) \quad \forall j \in J \quad (1) \]

\[ O_c = \left( \sum_{i \in I} X_{i,c} \cdot N_i \right) \quad \forall c \in C \quad (2) \]

\[ OQ_c = \left( \sum_{i \in I} \beta_{i,c} \cdot N_i \right) \quad \forall c \in C \quad (3) \]

\[ CPF = \frac{\sum_c O_c - \sum_c OQ_c}{\sum_j O_j} \quad (4) \]

Equation (1), computes the quantity produced from module \( j \in J \) which equals the summation of the quantities of products \( i \in I \) that used module \( j \in J \) in their composition. Equation (2), gives total quantity produced from high-end module \( c \in C \) which equals the summation of the quantities of products \( i \in I \) that selected module \( c \in C \) in their composition. In equation (3) the quantity of high-end modules \( c \in C \) that are originally composing products \( i \in I \) are given. Equation (4), gives the proposed Commonality of Product Family (CPF) index, which equals to summation of quantities of high-end module produced for all products minus those originally exited in the product structure of the products divided by summation quantities of all modules produced. This index starts from zero scale, where zero indicates no common module is shared across more than one product. Higher values indicate higher commonality, but it will never end by one.

3. Numerical Experiment:

In order to verify that the developed index can be used to assess commonality across product family on considering products’ produced quantities, a product family consists of four products is assumed as given in figure 1. Each product is composed from three modules, where the set of unique modules is \{M2, M3, M5, M6, M7, M8, M10, M11\}, the set of variant modules is \{M1, M4, M9, M12\} and M4 is the high-end module, i.e. can replace M1, M9 and/or M12. Four commonality scenarios will be tested M4 will replace no variant modules in scenario (1), while replacing M1 in scenario (2), replacing M1 and M9 in scenarios 3 and replacing M1, M9 and M12 in scenario 4. These scenarios are given in table 1. Four production quantities patterns, as shown in table 2, will be tested for each commonality scenario, and commonality is assessed
using the DCI and CPF. The DCI is selected for comparison as it is a product design focused index and both the total Constant Commonality Index (TCCI), and Product Line Commonality Index (PCI) were developed as an extension of DCI, yet they did not consider the production quantities. Also, as stated by Thevenot et al 2007, despite the modified benefits of TCCI over DCI, TCCI it is a cardinal index which cannot evaluate an increase in commonality. All other indices use a cost related values which is not what being tackled in this paper.

Figure 1: Product family considered

Table 1: number of times each module used in each of the stated Scenario.

| Scenario | M1 | M2 | M3 | M4 | M5 | M6 | M7 | M8 | M9 | M10 | M11 | M12 |
|----------|----|----|----|----|----|----|----|----|----|-----|-----|-----|
| 1        | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1   | 1   | 1   |
| 2        | 0  | 1  | 1  | 2  | 1  | 1  | 1  | 1  | 1  | 1   | 1   | 1   |
| 3        | 0  | 1  | 1  | 3  | 1  | 1  | 1  | 0  | 1  | 1   | 1   | 1   |
| 4        | 0  | 1  | 1  | 4  | 1  | 1  | 1  | 0  | 1  | 1   | 1   | 0   |

Table 2: Products produced quantities Considered

| Demand Pattern | Products produced quantities |
|----------------|-----------------------------|
|                | Product 1 | Product 2 | Product 3 | Product 4 |
| 1              | 2000      | 2000      | 2000      | 2000      |
| 2              | 2000      | 4000      | 1000      | 1000      |
| 3              | 2000      | 2000      | 3000      | 3000      |
| 4              | 10000     | 2000      | 8000      | 6000      |

4. Results and Discussion:
The values of DCI and CPF for different scenarios and different produced quantities patterns are given in table 3, it is clear that the values of DCI, CPF are increasing with the increase of common modules used in the product family. However, the starting boundary of each measure is different. CPF start with zero in case 1 because no common module is shared in more than one
product, while DCI start from one which also reveals no commonality across products, yet the numerical value of the index may not be representative in terms of commonality. It is also clear that the values of DCI varies from one scenario to another, yet it did not change with products produced quantities changes, since the DCI (and all design focus indices) does not consider the products’ produced quantities therefore it is not insensitive to produced quantities changes. On the other hand, the CPF values varies with different produced quantities patterns for the same commonality scenario, which indicates that the proposed model is able to account for products’ produced quantities while assessing commonality.

Table 3: DCI, CPF For Different Commonality Scenarios and produced quantities Patterns

| Scenario | Pattern 1 | Pattern 2 | Pattern 3 | Pattern 4 |
|----------|-----------|-----------|-----------|-----------|
|          | DCI       | CPF       | DCI       | CPF       | DCI       | CPF       | DCI       | CPF       |
| 1        | 1         | 1         | 0         | 1         | 0         | 1         | 0         | 1         |
| 2        | 1.0909    | 0.08      | 1.0909    | 0.0833    | 1.0909    | 0.0666    | 1.0909    | 0.1282    |
| 3        | 1.2       | 0.167     | 1.2       | 0.1250    | 1.2       | 0.1666    | 1.2       | 0.2307    |
| 4        | 1.3333    | 0.25      | 1.3333    | 0.1666    | 1.3333    | 0.2666    | 1.3333    | 0.3077    |

Figure 2: DCI and CPF for produced quantities Pattern 1

In figures 2-5 the change of DCI and CPF is given against the total number of common modules used. It is obvious that the DCI is increase with the increase of the number of common modules used, yet this increase is not linear, and it does not follow a specified trend. On the other hand, proposed CPF increases with the increase of the number of common modules used in a linear pattern, which implies that the proposed index is able to represents the quantity of common modules within the product family accurately and consistently.
Figure 3: DCI and CPF for demand Pattern 2

Figure 4: DCI and CPF for demand Pattern 3
5. Conclusion

The developed CPF is proven to assess commonality among product family taking into consideration products’ produced quantities. CPF gives consistent commonality assessment unlike any design focus commonality index such DCI. Consequently, it is concluded that commonality assessment must be based on the actual production quantity of common modules used unlike previous approaches that based their commonality assessment on the number of times common modules can be used in the fixed design of products within product family. Therefore, the developed index could assess the commonality across various Aircrafts product families more effectively than previous measures.

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