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Commonality and its Measurement in Manufacturing Resources Planning

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Abstract: The main objectives of this research are to study the commonality indices in manufacturing resource planning reported in literatures since 1980 and some useful insights including advantages and disadvantages of using commonality in manufacturing/production environment. It is observed that in designing a new family of products/processes or analyzing an existing family, commonality indices can often be used as a starting point. Systematic understanding and effective use of commonality and commonality indices can help managing inventory levels, uncertainties and cost dimensions.

Key words: Commonality index, uncertainty, manufacturing resources planning

INTRODUCTION

The underlying ideas for commonality and modularity are not really new. As early as 1914, an automotive engineer demanded the standardization of automobile subassemblies, such as axles, wheels and fuel feeding mechanisms to facilitate a mix-and-matching of components and to reduce costs (Fixson, 2007). Commonality, i.e., using the same type of component in different locations of product structure trees, is frequently encountered in manufacturing industries. It has long been known that using a common component can reduce the cost of safety stock. Basically, taking commonality into account a manufacturer can reduce the inventory level, shorten the time for reaching the market, decrease the set-up time, increase productivity and improve flexibility.

The commonality index is a measure of how well the product design utilizes standardized components. A component item is any inventory item (including a raw material), other than an end item that goes into higher-level items (Dong and Chen, 2005). An end item is a finished product or major subassembly subject to a customer order.

The global nature of the markets and competition has forced many companies to revisit their operations strategy. Companies have moved from centralized operations to decentralized operations in order to take advantage of available resources and to be closer to their markets.

International antagonism is forcing firms to attain world-class manufacturing in order to vie in global markets. Short manufacturing lead time is accepted as the central underlying factor for successfully accomplishing world-class manufacturing goals of on-time delivery (Blackburn, 1985), quality (Schmenner, 1991; Schonberger, 1986), flexibility (Stalk, 1988) and productivity (Wacker, 1987). The length of manufacturing lead time is frequently used as a measure of a firm's competitiveness.

Many factors characterize today's manufacturing environment, such as increased product variety, intensifying global competition, changing social expectations and rapid advancement of manufacturing technology. Manufacturing companies find themselves in a totally changed environment, so they must improve both of their products and their productivity by making their processes more efficient and effective to remain competitive as a matter of survival (Salaheldin and Francis, 1998; Towers *et al*., 2005). An important factor for improving these processes is the controlling of production operations.

Today's marketplace is highly competitive, global and volatile: customer demands are constantly changing and they seek wider varieties of products at the same price as mass-produced goods. This shift in the market has increased the need for product variety, in which variety and customization replace standardized products. This emerging paradigm has been names as mass customization, which Pine (1993) defined as at its limit, the mass production of individually customized goods and services. Nowadays, manufacturing companies need to satisfy a wide range of customer needs while maintaining manufacturing costs as low as possible and many companies are faced with the challenge of providing as much variety as possible for the market with as little

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variety as possible between the products. Although the benefits of commonality are widely known, many companies are still not taking full advantage of it when developing new products or re-designing the existing ones.

A compromising decision among the product variety, customers demand and costs should be reached to cope up with the market trend and customers expectations, eventually for survival in business. This study look into the issue of commonality as a key element to achieve the products/processes economy/safety in designing and production. As a consequence commonality indices, which measure and help to design/manage commonality, come into its consideration.

PERSPECTIVES OF COMMONALITY AND ITS MEASUREMENTS

The term commonality refers in literatures are shown in Table 1. The advantages and disadvantages of commonality are shown in Table 2.

Therefore, commonality is an approach in manufacturing, production and inventory management system where different components replace by common component(s) or same components are used for multiple products and thereby simplifies the management and control of resources and ease the analysis and improvement of existing products/processes or development of new products/processes at an optimize costs.

The actual measurement for commonality comes in variety of flavors. They range from measurements directly on the component level to measurements in very indirect or abstract dimensions. For example, some researchers suggest a simple fraction count: The ratio between the total number of product design modules and the product size (Nambisan, 2002). Mikkola and Gassmann (2003) developed their modularization function based on the number of components and the degree of coupling between them. Focusing on the interdependence between modules, Kaski and Heikkila (2002) constructed a similar measure. Kota *et al.* (2000) suggested a product line commonality index that measures the fraction of parts which is shared across a product family relative to the parts that could have been shared, adjusted for materials, manufacturing and assembly processes.

Pitfalls of increasing component proliferation: More and more evidences point to the pitfalls of expanding too aggressively in component proliferation when the process is not managed well. Rapid component proliferation greatly affects a company's ability to compete on a cost and time basis. It is stated that half of all overhead costs are in some way related to the number of different parts handled (Cooper and Turney, 1990). According to Ostrenga and Ozen (1992), manufacturers have estimated the annual administrative cost of each part number to be $10,000 or more. There are a number of negative effects generated by part proliferation. They are: Excessive design effort increased time-to-market, inefficient manufacturing, higher overhead costs, etc. The widely used and effective approach to component variety is to exploit commonality in components.

COMMONALITY INDICES

Several commonality indices are found in literatures to measure that within a family of products/processes. Commonality is defined as the number of parts/components that are used by more than one end product and is determined for all product family (Ashayeri and Selen, 2005). Within a product/process family, commonality index is a metric to assess the degree of commonality. It is based on different parameters like the number of common components, component costs, manufacturing processes, etc. Several component-based indices are shown in Table 3.

Table 1: Definition of commonality

Reference	Definition
Eynan (1996)	An approach which simplifies the management and control of inventory and also reduce inventory is component commonality
Meyer and Lehnerd (1997)	Commonality is a group of related products that share common characteristics, which can be features, components and/or subsystems. It is a set of subsystems and interfaces that form a common structure from which a stream of derivative products can be efficiently developed and produced
Ma *et al.* (2002)	Component commonality generally refers to an approach in manufacturing in which two or more different components for different end products (of perhaps the same product family) are replaced by a common component that can perform the function of those it replaces
Mirchandani and Mishra (2002)	Component commonality refers to a manufacturing environment where two or more products use the same components in their assembly. Commonality is an integral element of the increasingly popular assemble-to-order strategy that inventories certain critical components-typically, with long lead time and expensive- in a generic form
Labro (2004)	Commonality is the use of the same version of component across multiple products. It is a cost decreasing strategy in a stochastic-demand environment because by pooling risks the total volume of the common component can be forecasted more accurately
Ashayeri and Selen (2005)	Commonality is defined as the number of parts/components that are used by more than one end product and is determined for all product families

Table 2: Advantages and disadvantages of commonality

Advantages	Disadvantages
• Commonality substantially lowers the costs of proliferated product lines. Mitigate the effects of product proliferation on product and process complexity (Heese and Swaminathan, 2006) • Commonality reduces the cost of safety stock. Basically, taking commonality into account can reduce the inventory level, shorten the time for reaching the market, decrease the set-up time, increase productivity and improve flexibility (Zhou and Grubbstrom, 2004) • Even when the common part is more expensive, it is often still worthwhile to employ in the single-period case (Hillier, 2002b) • Demand is pooled into a smaller number of components, reducing the required number of order (or setups) (Hillier, 2002a) • Risk-pooling and lead time uncertainty reduction; improve the economy of scale through larger order sizes; simplify planning, schedule and control; streamline and speed up product development process (Ma *et al.*, 2002) • Increase work-in-process flexibility and greater product variety by shifting the push-pull boundary toward the customer. Reduce the number of setups, permit greater operating economies of scale, facilitates quality improvement, enhance supplier relationship and reduce product development time (Mirchandani and Mishra, 2002) • A design configuration with commonality can lower the manufacturing cost and design savings are obtained as a result of a common design effort (Desai *et al.*, 2001) Reduce the cost of safety stock (Hillier, 2000) • Commonality in the design of product family or generations of products provides the firm with a chance to meet diverse customer needs with less cost due to economies-of-scale in procurement, production and distribution (Kim and Chhajed, 2000) • Decreases setup costs via larger lot sizes, decreases the amount inventory held by taking advantages of risk pooling and decreases complexity cost by requiring fewer variants to be processed by the indirect functions of a company (Thonemann and Brandeau, 2000) • Commonality reduces the total inventory required to meet a specified service level. The optimal stock of the common component is lower than the combined optimal stocks, it replaces (Gerchak *et al.*, 1988) • Commonality potentially allows firm to reduce its investment in safety stock while maintaining the level of customer service (Baker *et al.*, 1986) • Commonality provides a way to offer high variety while retaining low variety in operations and thus to lower costs (Labro, 2004) • Commonality successfully reduces manufacturing lead time. Escalating commonality improves material availability and reduces system complexity (Maskell, 1991) • High commonality makes a greater portion of the product structure suitable for repetitive manufacturing, which in turn results in simplified planning and scheduling (Berry *et al.*, 1992) • Commonality leads to decreased manufacturing lead times (Sheu and Wacker, 1997) • Commonality lowers the setup and holding costs (Collier, 1981, 1982); decrease lead time and risk during product development • If commonality is too low, manufacturing costs can increase substantially (Simpson *et al.*, 2001)	• Commonality reduces product differentiation and revenues; Generally reduce the attractiveness of product line (Heese and Swaminathan, 2006) • Using the same component in different locations might require that the component is made more flexible and therefore, more expensive as compared to choosing tailor-made items for its respective locations. The manufacturing cost of commonality items may therefore be much higher because of its greater number of functions (Zhou and Grubbstrom, 2004) • This is usually not worthy to employ in the multi-period case when the common component is expensive (Hillier, 2002b) • Higher unit component cost due to excessive performance, higher workload variability (imbalance in workload) and more variable work-in-process inventory levels (Ma *et al.*, 2002) • A design with commonality may hinder the ability to extract price premiums through product differentiation (Desai *et al.*, 2001) • Excessive commonality can affect customer's valuation of products and can negatively affect the firm's profits if a product does not appeal to the customers for whom it is designed (Kim and Chhajed, 2000) • Increases production cost (Thonemann and Brandeau, 2000) • The combined optimal stocks of product specific components are higher with commonalty than without (Gerchak *et al.*, 1988) • If commonality is too high, products lack distinctiveness and their individual performance is not optimized (Simpson *et al.*, 2001)

Table 3: Commonality indices

Name	Developed by	Commonality measure for	No commonality	Complete commonality
Degree of commonality index DCI	Collier (1981)	The whole family	1	$\beta = \sum_{j=i+1}^{i+d} \Phi_j$
Total cost commonality index TCCI	Wacker and Treleven (1986)	The whole family	0	1
Product line commonality index (PCI)	Kota *et al.* (2000)	The whole family	0	100
Percent commonality index (%C)	Siddique *et al.* (1998)	Individual product with a family	0	100
Commonality index (CI)	Martin and Ishii (1996), Martin and Ishii (1997)	The whole family	0	1
Component part commonality ($CI^{(c)}$)	Jiao and Tseng (2000)	The whole family	1	$\alpha = \sum_{j=1}^{d} \sum_{i=1}^{i+d} \Phi_{ij}$
Comprehensive metric for commonality CMC	Thevenot and Simpson (2007)	The whole family	0	1

Degree of commonality index: The most common measure of the degree of commonality is the average places used for a distinct component, or the average number of parent items per distinct component part (Collier, 1981; Sheu and Wacker, 1997). This measure is known as the Degree of Commonality Index (DCI). It reflects the average number of common parent items per average distinct component Eq. 1:

$$\beta = \sum_{j=i+1}^{i+d} \Phi_j \tag{1}$$

Where:

Φ_j = No. of immediate parent component j has over a set of end items or product structure level(s)

d = Total No. of distinct components in the set of end items or product structure level(s)

i = The total No. of end items or the total No. of highest level parent items for the product structure level(s)

A component item is an inventory item other than an end item that goes into higher level items. An end item is the finished product or major subassembly subject to a customer order or sales forecast. Parent item is any inventory item that has component parts.

The DCI has no fixed boundaries, ranging between 1 and β, where, β is defined in Table 3.

The main advantage of the DCI is its ease of computation. However, it has two severe limitations; it is a cardinal measure without fixed boundaries and it does not consider component usage by changes in demand or quantity per assembly (Wacker and Treleven, 1986). It is difficult to estimate the increase in commonality while redesigning a family and to compare different families of products.

Different from Collier (1981) two types of commonality indexes are defined by Dong and Chen (2005). One is called component-level (denoted as CI_i), which is to provide an indicator on the percentage of a component being used in different products. The other is called product-level (denoted as CI_p). There are three variables that will affect the commonality index. These are: number of unique components (denoted as u), number of total components along the product line (denoted as c) and final number of product varieties offered (denoted as n). The formula used to calculate the component-level and product-level commonalities are shown in Eq. 2 and 3, respectively.

$$CI_i = \frac{\Sigma_j f_{ij} \times d_j}{\Sigma_{i,j} f_{ij} \times d_j} \tag{2}$$

$$CI_p = \begin{cases} \frac{CI_i}{u} \times (c-n) \text{ when } \max_i \{CI_i\} = \min_i \{CI_i\} \text{ and } c > u \\ [\frac{\max_i \{CI_i\} = \min_i \{CI_i\}}{u}] \times (c-n) \quad \text{Otherwisse} \end{cases} \tag{3}$$

Where:

f_{ij} = No. of component i in product j

c = The total No. component along the product line

u = No. of unique component

n = The final No. of product varieties offered

d_j = Demand of product j; $0 \le CI_i \le 1$

The lower bound of the component-level CI is 0 (no commonality). The upper bound on the degree of commonality is 1. Complete commonality results when the total number of distinct components (u) equals one. In reality, the number of total components along the product line is greater than final number of product varieties offered (i.e., c > n).

Total constant commonality index: The Total Constant Commonality Index (TCCI) is a modified version of the DCI (Wacker and Treleven, 1986). Contrary to the DCI, which is a cardinal index (and hence an absolute increase in commonality is not possible to measure), it is a relative index that has absolute boundaries ranging from 0 to 1 Eq. 4. The absolute boundaries of TCCI facilitate comparisons between product families and within a family of products during redesign:

$$TCCI = 1 - \frac{d-1}{\Sigma_{j=1}^{d} \Phi_j - 1} \tag{4}$$

$$PCI = \frac{\Sigma_{i=1}^{p} CCI_i - \Sigma_{i=1}^{p} MinCCI_i}{\Sigma_{i=1}^{p} MaxCCI_i - \Sigma_{i=1}^{p} MinCCI_i} \times 100 \tag{5}$$

Where:

CC_i = Component commonality index for component i = $n_i \times f_{1i} \times f_{2i} \times f_{ai}$

$MaxCCI_i$ = Maximum possible Component Commonality Index for component i = N

$MinCCCI_i$ = Minimum possible Component Commonality Index for component $= n_i \times \frac{1}{n_i} \times \frac{1}{n_i} \times \frac{1}{n_i} = \frac{1}{n_i^2}$

P = Total number of non differentiating components that can potentially be standardized across models

N = No. of products in the product family

n_i = No. of products in the product family that have component i

f_{1i} = Size and shape factor for component i = 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 (n_i)

f_{2i} = Materials and manufacturing processes factor for component i = 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 (n_i)

f_{2i} = Assembly and fastening schemes factor for component i = 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 (n_i)

The product line commonality index: Contrary to the indices that simply measure the percentage of components that are common across a product family (and hence penalizing families with a broader feature mix), the Product Line Commonality Index (PCI) measures and penalizes the differences in the non-unique components, given the product mix (Kota *et al.*, 2000). The PCI has fixed boundaries that range from 0 to 100 Eq. 5.

When PCI = 0, either none of the non-unique components are shared across models, or if they are shared, their sizes/shapes, materials/manufacturing processes and assembly processes are all different. When PCI = 100, it indicates that all the non-unique components are shared across models and that they are of identical size and shape, are made using the same material and manufacturing process and the assembly and fastening methods are identical. This index focuses on commonality that should exist between products that share common or variant components rather than on the unique components that differentiate the products. It provides a single measure for the entire product family, but it does not offer insight into the commonality of the individual products.

Percent commonality index: The Percent Commonality Index (C%) is based on three main viewpoints: component viewpoint, component-component association viewpoint and assembly viewpoint. Each of these viewpoints results in a percentage of commonality, which can then be combined to determine an overall measurement of commonality for a platform by using the appropriate weights for each item (Siddique *et al.*, 1998). The component viewpoint measures the percentage of components of a platform that are common to different models and is the percent commonality of components Cc (Eq. 6):

$$C_c = \frac{100 \times \text{Common components}}{\text{Common components} + \text{Unique components}} \tag{6}$$

$$C_n = \frac{100 \times \text{Common connections}}{\text{Common connections} + \text{Unique connections}} \tag{7}$$

The component-component connections viewpoint measures the percentage of common connections between components, C_n (Eq. 7):

Similarly, the assembly viewpoint measures the percentage of common assembly sequences. Two indices are used: Cl, to measure the percentage of common assembly sequences (Eq. 8) and Ca, to measure the percentage of common assembly workstations (Eq. 9): These four values can then be combined into an overall platform commonality measure; the weighted-sum formulation Eq. 10 is the most popular (Siddique *et al.*, 1998):

$$C_l = \frac{100 \times \text{Common assembly componentsloading}}{\text{Common assembly components loading} + \text{Unique assembly components loading}} \tag{8}$$

$$C_a = \frac{100 \times \text{Common assembly workstation}}{\text{Common assembly workstaion} + \text{Unique assembly workstation}} \tag{9}$$

$$\%C = \sum_{i=1}^{4} I_i \times C_i = I_C \times C_C + I_n \times C_n + I_l \times C_l + I_a \times C_a \tag{10}$$

Where:

I_i = Importance (weighting factors) where, $\Sigma I_i = 1$

C_i = %Commonality as previously described

The resulting %C ranges from 0 to 100. This index takes the manufacturing process into consideration; moreover, it can be adapted to different strategies using weighting factors. One disadvantage is that the measure is applied to each platform and not the family as a whole, which increases the computational expense of this measure.

Commonality index: Proposed by Martin and Ishii (1996, 1997), the Commonality Index (CI) is a measure of unique components that is similar to the DCI proposed by Collier (1981). CI ranges from 0 to 1 (Eq. 11):

$$\mathrm{CI} = 1 - \frac{u - \max P_j}{\Sigma_j^{v_n} P_j - \max P_j} \tag{11}$$

Where:

u = No. of unique components

P_j = No. of components in model j

v_n = Final No. of varieties offered

A higher CI is better since it indicates that the different varieties within the product family are being achieved with fewer unique components. The CI can be interpreted as the ratio between the number of unique components in a product family and the total number of components in the family.

Component part commonality index: Proposed by Jiao and Tseng (2000), the Component Part Commonality Index ($CI^{(C)}$) is an extended version of the DCI that takes into account the product volume, quantity per operation and the cost of each component Eq. 12.

The $CI^{(C)}$ has moving boundaries that range from 1 to α. The $CI^{(C)}$ gives very useful information, as it takes the cost of each component into consideration. For instance, a very expensive component commonality throughout a family has more influence than a component that is very cheap and different from one product to another. A disadvantage in $CI^{(C)}$ is in estimating the quantity and cost information needed to compute the index. It is also noteworthy that this index can subject to errors in some specific cases; a corrected version of the formula is proposed by Blecker *et al.* (2005).

Comprehensive metric for commonality (CMC): The CMC appears to be more information-intensive than other indices. The CMC is computed at the component level, but if the number of components becomes too large, the CMC can be computed at the module level, where each module is considered as a single entity rather than multiple components. Thevenot *et al.* (2007) defined CMC as Eq. 13.

Other commonality indices: Some other commonality indices are found in literatures, but they are much more information intensive and hence difficult to apply. Martin and Ishii (2002) proposed a Generational Variety Index to help identify which components are likely to change over time in order to meet future market requirements and a coupling Index to measure the coupling between these components. A functional similarity index was introduced by McAdams *et al.* (1999, 2002) to assist in concept development and modular product design. Finally, indices for measuring the degree of variation within a scale based product family have also been proposed by Mattson and Messac (2005) and Simpson *et al.* (2001).

COMMONALITY AND COMMONALITY INDEX-AN INSIGHT

Commonality is an integral element of Assemble-to-Order (ATO) strategy. This strategy identifies certain critical components and subassemblies that are inventoried in a generic form at a higher echelon. Typically these components are expensive and have a high manufacturing (or procurement) lead time. These components are Made-to-Stock (MTS) using forecasted requirements and are utilized as needed when the product demand materializes. Used in this manner, common component reduce inventory costs due to risk-pooling and the optimal allocation of component inventory (Eynan and Rosenblatt, 1996; Gerchak *et al.*, 1988). The common components also help in delaying the point of commitment of material to an individual product and thus increase the flexibility for meeting customer order specifications. Firms thus can deliver product variety by postponing the point of product differentiation to manage long throughput cycles and short delivery times (Lee and Tang, 1997).

In earlier studies (Baker, 1985; Baker *et al.*, 1986; Collier, 1982; Eynan and Rosenblatt, 1996; Gerchak *et al.*, 1988; Hillier, 2000, 2002b; Ma *et al.*, 2002; McClain *et al.*, 1984) the benefits of component commonality were almost solely associated with a decrease in inventory, safety stock and order costs due to the risk pooling effect and Jans *et al.* (2008) validated the importance of the development costs and unit production costs on the component commonality decision. Thonemann and Brandeau (2000) and Mirchandani and Mishra (2002) study part commonality in the component design and to satisfy service level constraints, respectively. Commonality increase the flexibility of the work-in-process, reduce setup and retooling times, improve operating economies of scale and simplifies the identification and reduction of production and quality problems. Common components also lead to easier part number administration and improved supplier relationships (Balakrishnan and Brown, 1996). Commonality helps in simplifying engineering design, in integrating the design of products and processes and in reducing new product development time.

$$CI^{(C)} = \frac{\Sigma_{j=1}^{d}[P_j \Sigma_{i=1}^{m} \Phi_{ij} \Sigma_{i=1}^{m} (V_i Q_{ij})]}{\Sigma_{j=1}^{d}[P_j \Sigma_{i=1}^{m} (V_i Q_{ij})]} \tag{12}$$

$$CMC = \frac{\Sigma_{i=1}^{p} n_i \times f_{1i} \times f_{2i} \times f_{3i} \times f_{4i} (C_i^{max} - C_i)]}{\Sigma_{i=1}^{p} n_i \times f_{1i}^{max} \times f_{2i}^{max} \times f_{3i}^{max} \times f_{4i}^{max} (C_i^{max} - C_i^{min})} \tag{13}$$

Where:

d = Total No. 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 components or the estimated cost of each internally made component part

m = Total No. 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

Φ_{ij} = No. of immediate parents for each distinct component part dj over all the products levels of product i of the family

$\sum_{i=1}^{m}\Phi_{ij}$ = Total No. of applications (repetitions) of a distinct component part dj across all the member products in the family

Q_{ij} = Quantity of distinct component part dj required by the product i

α = $\sum_{j=1}^{d}\sum_{i=1}^{m}\Phi_{ij}$

P = Total No. of components.

n_i = No. of products 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 number of models that have component i (n_i)

f_{2i} = Ratio of the greatest number of models that share component i with identical materials to the number of models that have component i (n_i)

f_{3i} = Ratio of the greatest number of models that share component i with identical manufacturing process to the number of models that have component i (n_i)

f_{4i} = Ratio of the greatest number of models that share component i with identical assembly and fastening schemes to the number of models that have component i (n_i)

f_{1i}^{max} = 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 schemes

f_{2i}^{max} = Ratio of the greatest number of models that share component i with identical materials to the greatest possible number of models that could have shared component i with identical materials

f_{3i}^{max} = Ratio of the greatest number of models that share component i with identical manufacturing processes to the greatest possible number of models that could have shared component i with identical manufacturing processes

f_{4i}^{max} = 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

$C_i = \Sigma_{j=1}^{ni} C_{ij}$ = Current total cost for component i

$C_{ij} = Q_{ij} \times c_{ij}$ = Total cost for component i variant j

Q_{ij} = Quantity of component i variant j

C_{ij} = Unit cost for component i variant j

$C_i^{min} = \Sigma_{j=1}^{ni} C_{ij}^{min}$ = Minimum total cost for component i (obtained when the component is common between all the products having component i)

$C_i^{max} = \Sigma_{j=1}^{ni} C_{ij}^{max}$ = Maximum total component cost (obtained when the component is variant in each of the products having component i)

Commonality generally reduces the attractiveness of a product line and ceteris paribus, leads to lower revenue. The component commonality problem also arises as a sub-problem in multiple echelon inventory management and stochastic MRP. In stochastic MRP problem, commonality can occur at several levels of the Bill-of-Materials (BOM) (Baker, 1993). For analytical tractability, most researchers have addressed this issue by either assuming a deterministic setting of by studying a convergent (reverse arborescent) structure, thus ignoring commonality. Finally, use of common components and modular design in spare parts service reduces training costs for customer engineers and simplifies diagnostic procedures (Cohen *et al*., 1990). Stock-outs of critically needed components during unexpected equipment breakdowns get reduced due to risk-pooling of the common spare parts and thus enhance customer service level.

There is a tradeoff between product performance and commonality within any product family (Hillier, 2002a). Instead of designing new products one at a time, which results in poor commonality/standardization and increases costs, designing families of products, allowing cost-effective development of a sufficient variety of products to meet customers' diverse demands. These measures and methods vary considerably in purpose and process: the nature of the data gathered (some are extensively quantitative while some are more qualitative), the ease of use and the focus of the analysis. However, they all share the goal of helping designers resolve the tradeoff between too much commonality (i.e., lack of distinctiveness of the products) and not enough commonality (i.e., higher production costs). In designing a new family of products or analyzing an existing family, commonality indices are often used as the starting point. These indices are intended to provide valuable information about the degree of commonality achieved within a family and how to improve a system's design to increase commonality in the family and reduce costs; however, there have been only limited comparisons between many of these commonality indices and their usefulness for product family (Thevenot and Simpson, 2006, 2007).

DISCUSSION AND RECOMMENDATIONS

Commonality is useful in more general manufacturing environments. Common components are useful in new product development. Automobile manufacturers use common components across model types and model years to reduce design cost, tooling cost and manufacturing complexity. Designing of products family is always better instead of designing a single product in term of development, cost, variety and customers expectations. Depending on the nature of available data, focus of analysis and ease of use these measures and methods differ considerably in purpose and process. However, they all share the goal of helping designers resolve the tradeoff between too much commonality (i.e., lack of distinctiveness of the products) and not enough commonality (i.e., higher production costs).

Component commonality issues also arise in the service sector. For example, surgery rooms in hospitals use several equipment many of them are very expensive. Thus the wide spread use of common components in the manufacturing and service sectors necessitate the in-depth understanding of commonality, its measurement and implementation process. Besides inventory management, there are several issues, primarily in product design, that arise as a result of using the common components and commonality indices are the base line of understanding, designing and managing this commonality.

Product variety and demanding customers in a competitive market have increased demand uncertainty. Despite the high investment in inventory, service levels are often not satisfactory due to the shortage of some components required for product assembly. Therefore, manufacturing companies are investing in expensive enterprise-wide transactional data management systems to manage their inventory. Software vendors are continuously enhancing the functionality of these packages by adding mathematical models that help in determining optimal inventory decisions. Component commonality in many circumstances works effectively to reduce the inventory level under uncertainty.

Commonality indices are effective instruments in designing new family of products or analyzing an existing family and very often, they are used as starting points. They are intended to provide valuable information about the degree of commonality achieved within a family and how to improve a system's design to increase commonality in the family and reduce costs.

Therefore, in designing new products/processes or analyzing and improving existing products/processes, reducing costs and managing uncertainties, the better understanding of commonality and commonality indices can ameliorate the situations.

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