Commonality in manufacturing resources planning – issues and models: a review

Md. Abdul Wazed*
Department of Engineering Design and Manufacture
Faculty of Engineering
University of Malaya (UM)
50603 Kuala Lumpur, Malaysia
Fax: +603–7967–5330
E-mail: awazed@gmail.com
*Corresponding author

Shamsuddin Ahmed and Yusoff Nukman
Department of Engineering Design and Manufacture
Faculty of Engineering
University of Malaya (UM)
50603 Kuala Lumpur, Malaysia
E-mail: ahmed@um.edu.my
E-mail: nukman@um.edu.my

Abstract: Purpose – The main purposes of this paper are to enhance the understanding of commonality models in manufacturing resource planning by documenting the current state of affairs and to stimulate fruitful future research by identifying gaps between the relevant issues and the available academic literature.

Methodology – This paper is based on a comprehensive review of the articles from authentic publications on resources commonality for the various product mixes and the pertinent models. The papers are analysed to identify the current scenarios and draw future research directions in the area.

Findings – The use of common components for different products in a company is important for managing product variety and maintaining competitiveness in this age of mass customisation and supply chain management struggles. The paper finds that the development of a mathematical model to study the effects of commonality in multistage systems with multiple products and multiple common items remains in the virgin area of research. Effects of uncertainty factors on the models are other issues not yet covered in the literature. Experiments and empirical studies in this gap also need further attention.

Originality/Value – The contribution of this paper is to provide a summary of the current state of affairs in component commonality and its models and predict the future research trends. This review also focuses on the expanding and complex area of demand, which identifies the issues in the area.

[Received 03 October 2008; Revised 27 December 2008; Revised 20 March 2009; Accepted 02 April 2009]

Keywords: commonality; manufacturing resource planning.

Biographical notes: Md. Abdul Wazed is a PhD candidate in the Department of Engineering Design and Manufacture, University of Malaya (UM), Malaysia. He acquired his Master in Engineering (Industrial Management) degree from the Katholic University of Leuven (KULeuven), Belgium in 1999. He graduated in Mechanical Engineering from Chittagong University of Engineering & Technology (CUET) (erstwhile Bangladesh Institute of Technology (BIT), Chittagong), Bangladesh. He has been working as a faculty in the Department of Mechanical Engineering at CUET since his graduation (presently on study leave).

Shamsuddin Ahmed is currently an Associate Professor in Manufacturing at the University of Malaya (UM), Malaysia. He obtained his first, second and tertiary degrees from different reputed institutions of higher learning in different countries. He has been in graduate-level teaching since 1986. At present, six PhD and several Master and undergraduate students are working under his supervision. He published more than 60 papers/articles in different international, regional and national journals, conference proceedings and bulletins. He assessed a good number of papers for a few journals, including some Emerald journals.

Yusoff Nukman is currently a Lecturer in the Department of Engineering Design and Manufacture, University of Malaya, Malaysia. He was appointed HOD in 2007 and is actively doing research in the field of laser materials processing (continuation of PhD thesis). He acquired his Master in Engineering Science (Mechatronics) from DeMontFort University, Leicester, UK in 1998. Since then he has been teaching at the undergraduate level in the field of CAD/CAM and manufacturing. He has also been teaching at the graduate level since 2007. He has published more than 15 papers and articles in different international, regional and national journals, conference proceedings and bulletins and is the co-author of a technical book.

1 Introduction

The underlying ideas for commonality are not really new. As early as 1914, an automotive engineer demanded the standardisation 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 stocks. Basically, taking commonality into account can reduce the inventory level, shorten the time to reach the market, decrease the setup time, increase productivity and improve flexibility.

The Commonality Index (CI) is a measure of how well the product design utilises standardised 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 beneficial characteristics of commonality include simplified planning and scheduling, lower setup and holding costs, reduction of vendor lead time uncertainty, order quantity economies, lower safety stocks, processing time and productivity. While commonality can offer a competitive advantage for a company, too much commonality within a product family can also have major drawbacks. First, consumers can be confused between the models if they lack distinctiveness. Commonality can also hinder innovation and creativity and compromise product performance: it increases the possibility that common components possess excess functionality in terms of increased weight, volume, power consumption and complexity, resulting in unnecessary waste (Krishnan and Gupta, 2001). Finally, commonality can adversely impact a company’s reputation (for additional details and information, we refer the reader to Collier, 1979; 1981; 1982; Baker, 1985; Gerchak et al., 1988; Gerchak and Henig, 1989; Benton and Krajewski, 1990; Maskell, 1991; Berry et al., 1992; Sheu and Wacker, 1997; Fisher et al., 1999; Kim and Chhabed, 2000; Thonemann and Brandeau, 2000; Desai et al., 2001; Simpson et al., 2001; Hillier, 2000; 2002a–b; Mirchandani and Mishra, 2002; Labro, 2004; Zhou and Grubbström, 2004; Heese and Swaminathan, 2006).

The authors have studied the models of commonality in manufacturing resource planning since 1979. In this paper, the authors begin with an overview of the main approaches to commonality and its models and then review the relevant issues and the state of the art in manufacturing resource planning. Finally, the authors inspire fruitful future research by identifying the gaps between relevant issues and available literature. Throughout the presentation, the authors point out the fundamental issues of modelling philosophies in commonality in manufacturing resource planning.

2 Commonality perspectives

In practice, commonality can be categorised from two perspectives, namely, engineering and management. From an engineering perspective, commonality refers to cases where several different components are replaced by a newly designed component that can perform the function of each one, or to a cluster of equivalent components, any of which can substitute for all the others. The common component must at least provide all the functionalities of the component it replaces. From a managerial perspective, commonality is present when some Stock-Keeping Units (SKUs) of a manufacturing system are used in more than one finished product. The definitions of the term ‘commonality’ in the literature are shown in Table 1.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eynan (1996)</td>
<td>Commonality is an approach which simplifies the management and control of inventory and also reduces inventory.</td>
</tr>
<tr>
<td>Meyer and Lehnerd (1997)</td>
<td>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.</td>
</tr>
</tbody>
</table>
Table 1 Definitions of commonality (continued)

<table>
<thead>
<tr>
<th>Reference</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ma et al. (2002)</td>
<td>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.</td>
</tr>
<tr>
<td>Mirchandani and Mishra (2002)</td>
<td>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 expensive and with long lead times – in a generic form.</td>
</tr>
<tr>
<td>Labro (2004)</td>
<td>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.</td>
</tr>
<tr>
<td>Ashayeri and Selen (2005)</td>
<td>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.</td>
</tr>
<tr>
<td>Humair and Willems (2006)</td>
<td>For the manufacturing echelon, commonality refers to the parts or subassemblies that are shared among different items. For distribution echelons, it refers to the end items that are knitted together or bundled as assortments to customers.</td>
</tr>
</tbody>
</table>

3 Parts commonality measurement

The parts commonality measurement includes the process for evaluating product commonality and methods to achieve commonality in a product family. 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 to 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 the literature, there are many commonality indices to measure the commonality within a family of products/processes.

3.1 Commonality indices

The CI is a measure of how well the product design utilises standardised components. A component item is any inventory item other than an end item which goes into higher-level items (Dong and Chen, 2005). Several commonality indices are found in the literature for measuring the commonality within a family of products. Commonality is defined as the number of parts/components that are used by more than one end product and is determined for an entire product family (Ashayeri and Selen, 2005). Within a product family, the CI 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. In designing a new family of products or analysing an existing family, these indices are used very often as a starting point. 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 the 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 families (Wazed et al., 2009; Thevenot and Simpson, 2006; 2004). Several component-based indices are summarised in Table 2.

Table 2  Commonality indices

<table>
<thead>
<tr>
<th>Name</th>
<th>Commonality measure for</th>
<th>No commonality</th>
<th>Complete commonality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degree of Commonality Index or DCI (Collier, 1981)</td>
<td>The whole family</td>
<td>1</td>
<td>( \beta = \sum_{j=1}^{d} \phi_j )</td>
</tr>
<tr>
<td>Total Constant Commonality Index or TCCI (Wacker and Treleven, 1986)</td>
<td>The whole family</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Product Line Commonality Index or PCI (Kota et al., 2000)</td>
<td>The whole family</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Percent Commonality Index or %C (Siddique et al., 1998)</td>
<td>Individual product with a family</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Commonality Index or CI (Martin and Ishii, 1996; 1997)</td>
<td>The whole family</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Component Part Commonality or CI((c)) (Jiao and Tseng, 2000)</td>
<td>The whole family</td>
<td>1</td>
<td>( \alpha = \sum_{j=1}^{d} \phi_j )</td>
</tr>
<tr>
<td>Comprehensive Metric for Commonality or CMC (Thevenot and Simpson, 2007)</td>
<td>The whole family</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

3.2  Commonality models

The use of common components in design, production and assembly operations has become more prevalent in the last few years. Research in this area has also blossomed and researchers have addressed a variety of operations-related issues. The authors reviewed the papers that are directly relevant and also discuss component commonality issues considered in other research streams in inventory management. The number of common components, number of products, number of levels in bill-of-material or number of echelons in assembly, number of components used per unit of product, planning horizon, demand distribution of products, cost measure, service-level metrics, objective and common component allocation policy can be used to classify the commonality models.

3.2.1  Two product–single common component models

Baker et al. (1986) studied the effect of commonality in a two-product, two-level model with independent and uniformly distributed demand- and service-level requirements. Their model minimises the total components safety stock subject to service-level constraints. Implicitly they assumed that all components have equal costs and equal usage. Gerchak et al. (1988) further investigated and extended Baker et al.’s (1986) model to consider the general demand distribution for any number of products and minimise the total inventory cost. They found that some important properties do not hold
when the component costs are arbitrary. They showed that a decrease in total inventory cost resulted from the use of commonality. Bagchi and Gutierrez (1992) maximised the aggregate service level subject to a constraint on the total component availability when the product demands have exponential or geometric distributions. They found that, for the two-product case, replacing product-specific components with common components leads to increasing marginal returns on the aggregate service level. They also considered minimising the inventory holding cost subject to service constraints and deriving the properties of the optimal total cost. Eynan and Rosenblatt (1996) studied the economic implications of component commonality in a single-period problem. They compared the total component acquisition cost for two products in three different situations, distinguished by the number of common components (none, one and two) subject to an aggregate service-level constraint. The cost of common components is allowed to be greater instead of equal to product-specific components, as in early studies like Baker et al. (1986), Gerchak et al. (1988) and Bagchi and Gutierrez (1992). Eynan (1996) shows analytically that commonality results in larger savings for the negatively correlated demand case and small savings for the positively correlated demand case when compared with the independent demand case. They minimised a cost measure subject to service-level constraints. In this article the authors used correlated demands instead of independent demand as considered in the earlier studies. These studies have restricted their focus on the qualitative and quantitative investigation of inventory effects of making use of commonality in the assemble-to-order system under various demand patterns and they focus on the service level and safety stocks only. But the scenario with the parts price, their quality, the uncertainty of their arrival, the sensitivity of the finished products, etc., is not incorporated in the model. A dependent demand situation and uncertainty are overlooked.

Desai et al. (2001) analysed design configurations by formulating a model that incorporated the marketing and manufacturing trade-offs. They developed a model for three possible design configurations: unique, premium-common and basic common. One of the two components can potentially be common between the two products or go as a distinct component in each of the two products. The analysis covered only the quality issues of the common component and costs; uncertainty was not incorporated.

Mirchandani and Mishra (2002) developed an optimisation model considering a two-stage assemble-to-order system with two products having a uniformly distributed demand, one common component and product-specific components. Each product has a desired product-specific service level, which is also referred to as the order fill rate, and each component incurs an acquisition cost that equals the product of its unit cost and its order quantity. The authors considered the same demand distribution for each product and a constant lead time in the assemble-to-order environment.

Van Mieghem (2004) analysed a single unified model with five inputs and two products under the no-commonality and with-commonality conditions. This introduces the revenue-maximisation option of commonality as a second benefit that is independent of the traditional risk-pooling benefit. Pure commonality strategies (where each product requires one dedicated and one common component) are never optimal unless complexity costs are introduced. He considered the probabilistic forecast of demand, financial data (price minus any marginal assembly and transportation costs; the inventory incurs unit purchasing and holding costs and unmet demand incurs shortage costs) and network data. Uncertainties in other parameters such as lead time and quality were not considered.
Lin et al. (2006) set up a multiperiod model of component commonality with lead time. They analysed the quantitative relationship between the lead time of a common component and the inventory level and found some efficient ways to: customise the level, optimise inventory management and lower costs.

### 3.2.2 Multiple product–multiple component models

Baker (1985) used a two-level bill-of-materials to illustrate that in an assemble-to-order situation for multiple products with uncertain demand, commonality reduces the total safety stock. However, component commonality complicates the determination of the product-specific service levels. His study indicated that the optimal safety stock strongly depends on the correlation of external demands for different items and commonality. Gerchak and Henig (1986) modelled a multiple-period, multiple-product and multiple-component problem as a stochastic dynamic program. Their profit maximisation objective function considered the component acquisition cost and revenue from product sales. They showed that commonality always results in an increase in the safety stock of product-specific components, as compared to the no-commonality case. Gerchak and Henig (1989) further studied the impact of commonality in a more general setting. They showed that the multiple-period problems allowing for partial backlog, shortage costs, component-dependent holding cost and partial spoilage also have a myopic solution. They identified their model as a stochastic program but did not solve it. Srinivasan et al. (1992) considered a multiperiod problem in which the inventory holding cost in each period is minimised subject to product-specific service-level constraints. First they formulated the problem as a stochastic program with chance constraints. They then reformulated using ‘cumulative up to period t’ variables that allow a heuristic decomposition of the problem by time period. They showed that, in large problems, ignoring commonality can increase the inventory-related costs enormously. These studies mainly concentrated on the effects of commonality on stocks under demand variations.

Jonsson and Silver (1989b) minimised the number of products short, subject to a budget constraint on the number of components in stock. Assuming a normally distributed demand, the authors used numerical integration to determine the optimal solution. The model maximises the profit subject to a budget constraint on the value of the components. Jonsson et al. (1993) also considered this problem but used a scenario aggregation approach to formulate the problem and an augmented Lagrangian relaxation to provide a good solution to it. The authors incarnate a budget limitation for materials used for a specific demand distribution in an assemble-to-order environment.

Zhang (1997) has studied a general multiple-period, multiple-product, multiple-component model with deterministic lead times. The objective is to minimise acquisition costs subject to product-specific order fill rates. Unsatisfied demand is back-ordered. He used a multivariate normal distribution to characterise the demand in each period.

Hillier (1999a) developed a simple multiple-period model with service-level constraints to compare the effects of commonality in single-period and multiple-period cases. The results are drastically different for these two cases. When the common component is more expensive than the components it replaces, commonality is often still beneficial in the single-period model, but almost never in the multiple-period model. Hillier (2002a) developed a model that considers purchasing, ordering, inventory and
shortage costs, where components are replenished independently according to lot-size and a reorder point policy. He showed that order pooling is a significant benefit under commonality; in many cases it is much more important than the risk-pooling benefit.

Ma et al. (2002) formulated a multiperiod and multistage assembly network model with multiple products and stochastic demands, and proposed a scheme to express the desired base-stock level at each stocking point as a function of the corresponding achieved fill rate. They demonstrated analytically whether introducing commonality at a particular stage or delaying the point of differentiation by one more stage can be justified. They concluded that a key factor for commonality and postponement decisions is the interactions between processing and procurement lead times.

Mohebbi and Choobineh (2005) studied the impact of introducing component commonality into an assemble-to-order environment when demand is subject to random variations, and component procurement orders experience random delays. By using simulated data, they showed that component commonality significantly interacts with existing demand and supply chain uncertainties, and that the benefits of component commonality are most pronounced when both uncertainties exist. They consider a two-level assemble-to-order environment that produces three finished products only.

Chew et al. (2006) studied the trade-off between the gain through risk pooling and the loss due to a mismatched component in a two-echelon assemble-to-stock system when component sharing is allowed. They studied these conflicting effects by comparing a particular component-sharing policy, namely the equal-fractile allocation policy, with a make-to-stock system which does not allow the allocation of common components.

Nonas (2007) considered the problem of finding the optimal inventory level for components in an assembly system where multiple products share common components in the presence of random demand. The inventory problem considered is modelled as a two-stage stochastic recourse problem, where the first stage is to set the inventory levels to maximise the expected profit, while the second stage is to allocate components to products after observing demand.

3.2.3 Other component commonality models

Researchers have included common components in several other studies with substantially different research objectives. These studies describe the implications of commonality, measure the extent of commonality or study inventory problems with common components.

Dogramaci (1979) investigated detailed mathematical programming formulations and captured more production realities that include setup costs and design complexity costs. He showed that commonality is beneficial because it decreased the standard deviation of demand forecast for components and hence reduced inventory costs.

Collier (1981) studied the effect of the degree of part standardisation on manufacturing resource planning system performance. He defined a measure called DCI as the average number of immediate parents for each component divided by the number of products. He first introduced the DCI and used statistical methods to show the relationship between the DCI and the setup and holding costs. In a subsequent study, Collier (1982) used DCI to evaluate the impact of commonality on the safety stock. He showed that when a common component replaces product-specific components,
the aggregate safety stock reduces by $\sqrt{DCI}$. The same service level can be maintained with the reduced safety stock when commonality is increased. But the results are based on very restrictive assumptions according to what have been pointed out in McClain et al. (1984) and Collier (1984).

Cohen et al. (1989) studied stocking policies for spare parts. They used heuristic approaches to determine the base stock inventory for each component to minimise the expected ordering, holding, shortage and transportation costs. Cohen et al. (1992) proposed an extension of their model to develop (s, S) policies for a convergent spare parts logistics system, with item fill rate constraints, to a multiple-product system with a component commonality. Tang (1992) has developed a production rule for a multistage assembly system containing common components to determine the inventory of the components and their allocation to the products when there is a yield loss and uncertain end product demand.

Grotzinger et al. (1993) considered the commonality problem with a single common component and multiple products in an assemble-to-forecast environment. The components are allocated to products when the demand is uncertain, but the common component can be re-allocated to different products when demand changes. Balakrishnan et al. (1996) developed bisection algorithms which included commonality to determine integer-assembly release quantities in an assemble-to-forecast environment under known inventory and demand distributions during procurement and known assembly lead times. Vakharia et al. (1996) used simulation to investigate the impact of component commonality on the workload of a firm using an MRP system. They found that it decreases the average shop load, particularly when the number of setups is high, but increases the variability in loadings and system disruption.

Lee and Tang (1997) proposed standardisation, i.e., the use of common components or processes, besides modular design and process restructuring, as a means to postpone the point of product differentiation. They illustrated the costs and benefits of these approaches using a simple model. Ha (1997) studied the allocation of common components in a make-to-stock production system with two priority demand classes and back-ordering. Ha (1997) also studied a similar problem for several demand classes with lost sales.

Hillier (1999b) considered the possibility of replacing a number of different parts by a single common part. In the single-period case, it is shown that even when the common part is somewhat more expensive, it might still be cost-effective to utilise. However, in the multiple-period case, it is shown that the break-even cost of the common part is often just a few percentage points more expensive than the unique parts. The added purchasing costs over multiple periods quickly dominate any holding cost savings achieved through risk pooling. Hillier (2000) developed a multiple-period single-stage model for the multiple-product scenario with a single common item under a general demand distribution for an uncapatcitated, periodic review, assemble-to-order inventory system.

Thonemann and Brändeau (2000) modelled the component design problem as a mathematical program that considers production, inventory holding, setup and complexity costs (the cost in indirect functions caused by component variety). This study showed that an optimum design achieves high cost savings by using significantly fewer variants than a no-commonality design, but significantly more variants than the full commonality design.
Hillier (2002b) analysed the effect of commonality on costs when the common part is more expensive than the parts it would replace in a multiple-period case. He investigated the possibility of using both cheaper unique parts and a more expensive common part. Initial demand is met with the unique part. The common part is used only as backup, when one or more of the unique parts stock out. This paper concluded that the strategy of using commonality as backup dominates the strategy of no commonality or pure commonality and it is worthwhile even if the common part is significantly more expensive than the unique parts.

Labro (2004) reviewed the component commonality literature through a management-accounting lens, focusing on the cost effects of an increase in the use of the same version of a component across multiple products. He presented a review of the Operations Management (OM) literature and reconciled it with the management-accounting literature on cost drivers and the cost of complexity. ABC is introduced as a framework to classify the effects of an increase in component commonality on the costs identified in the existing literature. Zhou and Grubbstrom (2004) focused on the effect of commonality in multilevel production–inventory systems, especially assembly systems under deterministic demand, capacity constraints and no backlog conditions. This study is confined to two cases of differing complexity. The first is when commonality only involves purchased items with lead times that can be disregarded. The second is when commonality affects items which are subject to some kind of processing, the simplest subcase being when purchased items are not available until after some delay.

Heese and Swaminathan (2006) analysed a stylised model of a manufacturer who designs a product line consisting of two products for sale to two market segments with different valuations of quality. They investigated what circumstances support component sharing as a profitable strategy and, more specifically, which components are the best candidates for commonality. The manufacturer determines the component quality levels, the amount of effort to reduce production costs and whether to use common or different components for the two products.

Kranenburg and Van Houtum (2007) developed a multi-item, single-site/single-stage spare parts inventory model with multiple groups to study the effect of commonality on the spare parts provisioning costs for capital goods under the service-level constraints. The study shows that the savings obtained by shared stocks are significantly affected by the commonality percentage and the degree to which the commonality occurs in the expensive SKUs.

Jans et al. (2008) proposed a mixed integer nonlinear optimisation model to find the optimal commonality decision in an industrial production-marketing coordination problem. They focused on production and development cost savings instead of inventory cost savings and integrated information from different functional areas such as production, marketing and accounting.

The current authors have reviewed the articles chronologically. It is observed that all of the studies have restricted views on costs and/or safety stocks under the service-level constraint with known distribution of demand. However, few studies have considered the lead time (Zhang, 1997; Ma et al., 2002; Lin et al., 2006) and the quality (Heese and Swaminathan, 2006) of common components. In an assemble-to-order environment, all of the studies except Mohebbi and Choobineh (2005) considered only uncertainty in demand.
3.2.4 Process commonality and modelling

Two sources of commonality are identified: the $CI^{(c)}$ and the process commonality. The formulation of the $CI^{(c)}$ is based on the mindset of counting the average applications per component part and taking into account product volume, quantity per operation and the price/cost of the component part. The process $CI$ incorporates such concerns as process flexibility, lot sizing and scheduling sequencing into one analytical measurement (Jiao and Tseng, 2000). The measure of process commonality is similar to that of component commonality. The fewer processes involved in the production of a product and in the production of the entire plant, the more flexible the plant can be to customer needs. The number and diversity of component parts and the corresponding processes reflect the complexity of the product design and that of production planning and control.

Tsubone et al. (1994) discerned the process commonality from the $CI^{(c)}$ and integrated these two types in assessing manufacturing performances. The authors pointed out the necessity to clarify the two different sources of commonality for systematic studies of the product family. However, their measurements of commonality are only suitable for a two-level product model, which is of little use for practical purposes. Wacker (1987) also advocated distinguishing process commonality from $CI^{(c)}$. Unlike with $CI^{(c)}$, to have a high process commonality, a great similarity of components is not necessary, since one process can produce diverse components. In addition, it may be argued that a high commonality of internally produced component parts would necessitate a high commonality of the processes involved. However, the reverse is not true, such as for externally purchased parts. Furthermore, unique (distinct) items may share similar (or in the extreme case, identical) processes.

The managerial implications of the process $CI$ can be manifested at both strategic and operational levels. At the strategic level, the process $CI$ could be used to evaluate the impact of product family designs on existing process capabilities and vice versa.

Process models are often multistage procedures to conduct all or portions of the design process when designing products with commonality, platforms, or product families in mind. For example, Jiao and Tseng (1999) present a detailed process to establish product families and Germani and Mandorli (2004) propose a procedure leading to self-configuring components in product architecture design. Another five-step model for product family design is presented by Farrell and Simpson (2003). Yet a different approach to commonalise product subsystems has been suggested by Qin et al. (2005). They use actual data on the critical parameters of existing products to construct similarity matrices which, in turn, enable cluster formation, i.e., a common platform definition. The engineering literature, in general, and textbooks, in particular, tend to provide detailed step-by-step advice on how to proceed when designing modular products and products with common components (Kamrani and Salhieh, 2002; Ulrich and Eppinger, 2000).

Connecting both product and process, Jiao et al. (2000) proposed a data structure that integrates the bill-of-materials with the bill-of-operations. Jiao and Tseng (2000) developed a process $CI$ that incorporates concerns such as process flexibility, lot sizing and scheduling sequencing into their measurement instruments. Balakrishnan and Brown (1996) viewed “commonality across products as shared set of processing steps from ingot casting to some intermediate hot or cold forming step” in their work on aluminium tube manufacturing.
4 Product platform for part/process commonality

A component is defined as a manufactured object that is the smallest (indivisible) element of an assembly and is represented by a set of design variables. A product is an artefact that is made up of components. The product architecture is the configuration (or topology) of components within the product. A module is a component or subassembly that can be interchanged within the product architecture to produce a variety of similar products. A product platform is the set of all components, manufacturing processes and/or assembly steps that are common in a set of products.

The product family is a group of related products that share common characteristics, which can be features, components and/or subsystems. The key to designing a successful product family is the product platform. In general, a platform is “the lowest level of relevant common technology within a set of products or a product line” (McGrath, 1995), but a slightly broader definition 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” (Meyer and Lehnert, 1997).

Platforms increase business flexibility through platform scaling up and down. Indeed the platform approach allows aggressive market strategies, reduced costs and time in developing new derivative products. Compaq (Meyer and Lehnert, 1997) represents an outstanding case in which the company succeeded in leveraging one basic platform through different market segments. In particular, the company extended its ‘beachhead’ platform in both segments of customers and tiers of performance level.

The product platform is the common core of the family – including form, components, interfaces and technology base – from which derivative products can be generated through modification, augmentation and renewal. But focusing on custom products can result in “a failure to embrace commonality, compatibility and standardization” (Meyer and Lehnert, 1997). As Robertson and Ulrich (1998) point out, “by sharing components and production processes across a platform of products, companies can develop differentiated products efficiently, increase the flexibility and responsiveness of their manufacturing processes, and take market share away from competitors that develop only one product at a time”. Companies such as Sony (Sanderson and Uzumeri, 1995), Hewlett-Packard (Feitzinger and Lee, 1997), Kodak (Wheelwright and Clark, 1995), Black and Decker (Meyer and Lehnert, 1997) and Volkswagen (Bremmer, 1999) have successfully employed product platform strategies to increase product variety while reducing development costs, manufacturing costs and time-to-market. A key feature in a product family is platform commonality.

The concept of a product platform has been receiving increased attention in product development and OM. Several authors have been concerned with it (Meyer and Lehnert, 1997; Wheelwright and Clark, 1992; Nobeoka, 1993; Meyer and Utterback, 1993; Sundgren, 1995; 1998; Robertson and Ulrich, 1998). Reviewing the definitions of the platform concept which are provided in the literature, a substantial difference is immediately evident in the approaches which researchers adopt. A possible way for clustering them is considering the degree of generality of the platform definition that researches provide.
Considering the similarity of a set of products, the product platform can include two cases:

1. a product platform for a set of products with similar functions and close parameters
2. a product platform for a set of products with the same function and different parameters.

The product platform can be seen as the common items shared by a set of products. Therefore, product platform building can essentially be seen as a process by which common items are identified by some means. From the aspect of product design, the common items can be parameters, the structure, the form, parts and components, or the modules of a set of similar products. From the aspect of product manufacture, the product platform includes those fixed tools and processes to produce the common parts and components (Huangao et al., 2006).

Platform-based product development offers a multitude of benefits, including reduced development time and system complexity, reduced development and production costs, and improved ability to upgrade products (Wei et al., 2009). According to different platform-leveraging strategies, there are two basic types of platforms: the module-based and the scale-based.

5 Simulations, experiments and empirical studies

Three types of simulations can be identified in the selected set of references. The first type is found in papers using mathematical modelling approaches that supplement and test their models with numerical simulations. For example, considering downward substitution in their multiple-period model, Rao et al. (2004) demonstrate the size of the inventory saving that their model predicts with simulation. Similarly, Dong and Chen (2005) illustrate the impact of component commonality on the order fill rate, delivery time and total cost via simulation. A second type of simulation that has experienced an increase in popularity recently is agent-based modelling. A number of recent studies have used agent-based modelling in the framework of complex adaptive systems (Kauffman, 1995). For example, Ethiraj and Levinthal (2004) explore the performance effect of what they called under- and overcommonality. Finally, a third type of simulation study uses real data to simulate the effects of commonality. For example, Lin et al. (2000) study the inventory reduction effects on different complexity reduction approaches, such as feature elimination, feature substitution and feature postponement, with data on an IBM midrange computer family with over 200 members and hundreds of feature codes.

The use of experiments in the study of commonality is atypical. The impact of parts commonality on customers’ product valuation is studied by Kim and Chhajed (2001). So far, this is an available example in literatures where the authors have conducted an experiment. Studying the effects of commonality in vertical line extensions from both low-end and high-end products, they find that the use of commonality can increase the valuation of the low-end product, but decrease the value of the high-end product.

Commonality and its effects have been studied empirically in rare cases. Safizadeh et al. (1996) studied the product-process matrix. In their empirical study, they found that part commonality allows sustaining a high plant performance
despite violating the alignment between product and process. The view that increasing component commonality in real organisations can actually be quite difficult due to the lack of downstream information and often misfitting incentive structures is supported through a couple of case studies by Nobelius and Sundgren (2002).

6 Discussion and future research directions

In the preceding sections, the authors reviewed the commonality models and pertinent questions in the manufacturing environment. The major features of various distinguished commonality models are summarised in Appendices A and B. The main issues in the commonality (part/process/platform) models are cost parameter, service level, capacity limit, number and level of common parts/processes, and production stages. The authors would like to highlight the following issues from their understanding:

- From the literature, two streams of research with respect to commonality are distinct. One stream of research is on the design of the system or product and the other stream covers efficient operation, given the design of the system. The models can also be classified broadly as conceptual models, artificial intelligence-based models, simulation models and analytical models. Most of the models in the literature belong to the simulation and analytical categories, though they cover part commonality in the initial stage of the production system.

- Most of the earlier studies that developed analytical solutions for part commonality assumed only one unit of a common component to assemble a product. The independent uniform distribution of product demand, an assemble-to-order manufacturing environment, a single- or two-stage production system are often assumed for analytical solutions to reduce the complexity of analysis. The part, process and platform commonality have not been considered yet in a single study to analyse the holistic effects. Though the commonalities have been analysed independently in some researches, no one has addressed the multistage production system under uncertain conditions. Multiple common parts are also ignored.

- The purchase cost, holding cost and shortage cost are considered in the component commonality literature. The holding cost or inventory carrying cost included the material handling and storage costs; the opportunity cost of locked capital, insurance, taxes and cost of obsolescence; deterioration and additional staffing. A shortage cost is incurred when the product demand cannot be met due to the stock-out of one or more components. Ordering or fixed setup costs were incurred to either procure or produce components. The price of components was considered when the objective was cost minimisation or profit maximisation. So far there is no study that incorporates all cost components together for analysing combined outcomes in any analytical research.

- The order fill rate is the common service metric which is used in component commonality studies and modelled as a service constraint. It is defined as the probability of no stock-out during a replenishment cycle and is also called the cycle fill rate or $\alpha$ service level. This metric could be applied to an individual product or to all products simultaneously. Product-specific and aggregate service levels are
Commonality in manufacturing resources planning – issues and models: a review

reported in the literature. Other popular service metrics in the inventory literature are (Schneider, 1981) the item fill rate ($\beta$ service level), which is the fraction of the demand satisfied (not lost or back-ordered from stock), and the $\gamma$ service level, which is the mean cumulative fraction of demand satisfied each period.

In sum, the scope of the researches are as follows:

- Analytical study of the effects of multiple common items in multiple-period and multiple-stage production systems with multiple end products. The effects of commonality in the higher stages of the production system need to be analysed. The available researches have considered the entry stage only. The holistic impacts of part, process and platform commonality also are in the gap of investigation.

- No research has yet considered all cost components (e.g., purchase, holding, shortage, etc.) for the analytical exploration of commonality (product/process/platform) in a multistage production environment. The impact(s) of the incorporation of aggregate/product-specific service levels in the models urge further journeying.

- Previously most of the mathematical models hardly considered two-stage cases with a single common component and single/multiple periods in deterministic conditions. The effect of uncertainty factors (e.g., lead time, quality, breakdown, etc.) in commonality models was completely ignored in the earlier researches. Therefore, the development of mathematical models for multiple-period and multistage production systems with multiple end products and multiple common components under uncertain conditions is in the virgin area of research and the field of knowledge. Experiments and empirical studies on this topic also need further attention.

References


Commonality in manufacturing resources planning – issues and models: a review


# Appendix A

## Main features of various commonality models

<table>
<thead>
<tr>
<th>Study</th>
<th>No. of common components</th>
<th>No. of products</th>
<th>No. of time periods</th>
<th>Product demand distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baker (1985)</td>
<td>One</td>
<td>Two</td>
<td>Single</td>
<td>Uniform</td>
</tr>
<tr>
<td>Baker et al. (1986)</td>
<td>One</td>
<td>Two</td>
<td>Single</td>
<td>Uniform</td>
</tr>
<tr>
<td>Gerchak and Henig (1986)</td>
<td>Multiple</td>
<td>Multiple</td>
<td>Multiple</td>
<td>General</td>
</tr>
<tr>
<td>Gerchak et al. (1988)</td>
<td>One</td>
<td>Two; multiple</td>
<td>Single</td>
<td>Uniform; general</td>
</tr>
<tr>
<td>Gerchak and Henig (1989)</td>
<td>Multiple</td>
<td>Multiple</td>
<td>Multiple</td>
<td>General</td>
</tr>
<tr>
<td>Jonsson and Silver (1989a)</td>
<td>Multiple</td>
<td>Multiple</td>
<td>Single</td>
<td>Discrete (binomial)</td>
</tr>
<tr>
<td>Jonsson and Silver (1989b)</td>
<td>One</td>
<td>Two</td>
<td>Single</td>
<td>Normal</td>
</tr>
<tr>
<td>Bagchi and Gutierrez (1992)</td>
<td>One</td>
<td>Two</td>
<td>Single</td>
<td>Exponential; geometric</td>
</tr>
<tr>
<td>Jonsson et al. (1993)</td>
<td>Multiple</td>
<td>Multiple</td>
<td>Single</td>
<td>Discrete (binomial)</td>
</tr>
<tr>
<td>Eynan and Rosenblatt (1996)</td>
<td>One</td>
<td>Two</td>
<td>Single</td>
<td>Uniform</td>
</tr>
<tr>
<td>Eynan (1996)</td>
<td>One</td>
<td>Two</td>
<td>Single</td>
<td>Uniform; correlated</td>
</tr>
<tr>
<td>Ma et al. (2002)</td>
<td>Multiple</td>
<td>Multiple</td>
<td>Multiple</td>
<td>Random and independent for other periods for other products</td>
</tr>
<tr>
<td>Mirchandani and Mishra (2002)</td>
<td>One</td>
<td>Two</td>
<td>Single</td>
<td>Independent and uniformly distributed</td>
</tr>
<tr>
<td>Hillier (2002b)</td>
<td>One</td>
<td>Multiple</td>
<td>Multiple</td>
<td>General distribution</td>
</tr>
<tr>
<td>Hillier (2002a)</td>
<td>Multiple</td>
<td>Multiple</td>
<td>Multiple</td>
<td>Stochastic</td>
</tr>
<tr>
<td>Chew et al. (2006)</td>
<td>Multiple</td>
<td>Multiple</td>
<td>Single</td>
<td>Random</td>
</tr>
<tr>
<td>Lin et al. (2006)</td>
<td>One</td>
<td>Two</td>
<td>Multiple</td>
<td>Followed a specific distribution</td>
</tr>
<tr>
<td>Kranenburg and Van Houtum (2007)</td>
<td>Multiple</td>
<td>Multiple</td>
<td>Single</td>
<td>Random</td>
</tr>
<tr>
<td>Nonas (2007)</td>
<td>Multiple</td>
<td>Multiple</td>
<td>Single</td>
<td>Random</td>
</tr>
</tbody>
</table>
## Appendix B

### Main features of various commonality models

<table>
<thead>
<tr>
<th>Study</th>
<th>Costs considered</th>
<th>Service-level metric</th>
<th>Allocation policy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baker (1985)</td>
<td>Component acquisition</td>
<td>Product specific</td>
<td>Prioritised (not solved optimally)</td>
</tr>
<tr>
<td>Baker et al. (1986)</td>
<td>Component acquisition</td>
<td>Aggregate; bottleneck</td>
<td>Smallest demand first</td>
</tr>
<tr>
<td>Gerchak and Henig (1986)</td>
<td>Component acquisition, product revenue</td>
<td>–</td>
<td>Stochastic program (not solved)</td>
</tr>
<tr>
<td>Gerchak et al. (1988)</td>
<td>Component acquisition</td>
<td>Aggregate; bottleneck</td>
<td>Randomised</td>
</tr>
<tr>
<td>Gerchak and Henig (1989)</td>
<td>Component acquisition, product revenue</td>
<td>–</td>
<td>Stochastic program (not solved)</td>
</tr>
<tr>
<td>Jonsson and Silver (1989a)</td>
<td>Component acquisition, product revenue</td>
<td>–</td>
<td>Stochastic program (Bender’s decomposition; heuristic)</td>
</tr>
<tr>
<td>Jonsson and Silver (1989b)</td>
<td>–</td>
<td>Expected units short</td>
<td>–</td>
</tr>
<tr>
<td>Bagchi and Gutierrez (1992)</td>
<td>–</td>
<td>Aggregate</td>
<td>–</td>
</tr>
<tr>
<td>Jonsson et al. (1993)</td>
<td>Component acquisition</td>
<td>Aggregate</td>
<td>–</td>
</tr>
<tr>
<td>Ma et al. (2002)</td>
<td>Purchasing, inventory holding (work-in-process, component and product) costs</td>
<td>Aggregate</td>
<td>–</td>
</tr>
<tr>
<td>Hillier (2002b)</td>
<td>Purchasing, inventory and shortage costs</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Hillier (2002a)</td>
<td>Purchasing, ordering, holding and shortage costs</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Van Mieghem (2004)</td>
<td>Assembly, transportation, inventory (purchasing and holding) and shortage costs</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Chew et al. (2006)</td>
<td>Trade-off between gain through risk pooling and loss due to component mismatch</td>
<td>–</td>
<td>Equal-fractile allocation policy</td>
</tr>
<tr>
<td>Lin et al. (2006)</td>
<td>Responsive costs</td>
<td>Considered</td>
<td>–</td>
</tr>
<tr>
<td>Kranenburg and Van Houtum (2007)</td>
<td>Inventory holding and transportation costs</td>
<td>Product section</td>
<td>Triggered</td>
</tr>
<tr>
<td>Nonas (2007)</td>
<td>Profit maximisation</td>
<td>–</td>
<td>Deterministic program</td>
</tr>
</tbody>
</table>

Note: Unless mentioned otherwise, product demands are independent and the default service level is the order fill rate.