MANAGING QUALITY AND LEAD TIME UNCERTAINTIES USING COMPONENT COMMONALITY IN A PRODUCTION ENVIRONMENT

M. A. Wazed, Shamsuddin Ahmed and Nukman Yusoff

Department of Engineering Design & Manufacture, Faculty of Engineering, University of Malaya (UM)
50603 Kuala Lumpur, Malaysia
E-mail: gwazed@gmail.com

ABSTRACT
Uncertainty is inevitable in manufacturing. Uncertainties like quality and lead time extensively affect the competitive outcomes of the system. For their statistically unpredictable nature and due to complex interrelationships between resources and operations, they have varied effects in manufacturing. Many factors of uncertainty have been reported in literatures. Component commonality is the use of same type of components in different levels of product structure. In different manufacturing settings, parts commonalities occur in their own ways or can be planned for their preferred occurrences. The main objectives of this article are: i) to augment the understanding of uncertainty factors and commonality, (ii) to explore the commonality indices and pertinent measuring tools in manufacturing resource planning, and (iii) to instigate fruitful solutions for managing cutthroat outputs under uncertainty and lead time uncertainties in production/manufacturing system where component commonality is applied. This paper is based on a comprehensive and up-to-date review of the recent literatures on uncertainty and commonality in manufacturing resource planning models. It is observed that the use of common components for different products and in different levels in production/manufacturing environment can dampen quality and lead time uncertainties to some extent.

Keywords: Quality, Component, Environment.

1. INTRODUCTION
The increasing of customers towards greater agility, improved quality, shorter delivery lead time and reduced cost have contributed to the need for proper production planning system such as MRP, MRPII, ERP and ERP II as a planning and scheduling tools. However, these systems were designed and developed to operate within a stable and predictable batch production/manufacturing environment and hence they are not capable of tackling uncertainty.

Uncertainty always present in manufacturing environment. Saad and Koh (2003a) defined uncertainty as any unpredictable event that disturbs the production process in a manufacturing system that is planned by MRP, MRPII, ERP or ERP II system.

Lead time refers to the time span from material availability at the first processing operation to completion at the last operation. This time is composed of processing, waiting and transportation times. However, lead time may different from early planned due to uncertainty. Lead time uncertainty may increase the total cost of the product because this uncertainty may provoke either some shortages or surplus in inventories which in turn increase either backlogging or holding cost respectively.

Quality of a product is a measure of perfection. Manufacturer must produce a product within a certain specification to conform the customer satisfaction. The effect of quality problem in a system is troublesome. The production system may show work-in-progress (WIP) congestion, quantities of product awaiting rework and inspection, and perhaps even confusing between conforming, non-conforming and reworked products. Even if careful final inspection is able to ensure that only good products leave the factory, the customers will probably be troubled by late delivery. This results an increase in total production cost (stoppages, rework, inspection bottlenecks, unnecessary excess capacity, the requirement for additional stockholding).

The underlying ideas for commonality 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 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 beneficial performance characteristics of commonality are simplified by planning and scheduling
(Berry et al., 1992), lower setup and holding costs (Collier 1981, 1982), lower safety stock (Baker, 1985), reduction of vendor lead time uncertainty (Benton and Krajewski, 1990) and order quantity economies (Gerchak and Henig, 1989; Gerchak et al., 1988). High commonality manufacturing systems are beneficial when system complexity is reduced, leading to lower setup times, and they are detrimental by increasing reliance on fewer parts, leading to higher variations within the production system (Sheu and Wacker 1997).

The use of common components can decrease lead-time and risk in the product development stage since the technology has already been proven in other products (Collier 1981, 1982). Inventory and handling costs are also reduced due to the presence of fewer components in inventory. The reduction of product line complexity, the reduction of set-up and retooling time, and the increase of standardization and repeatability improve processing time and productivity, and hence reduce costs (Collier 1979, 1981). Fewer components also need to be tested and qualified (Fisher et al., 1999; Thonemann and Brandeau, 2000).

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 each model 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, complexity, resulting in unnecessary waste (Krishnan and Gupta 2001). Finally, commonality can adversely impact a company’s reputation.

In this paper, the authors have studied the factors for uncertainties, commonality- it’s effects on the system and finally the prospect of commonality as a tool for dampening the quality and lead time uncertainty in manufacturing resources planning on the basis of literatures.

**2. COMMONALITY PERSPECTIVES**

In practice, commonality can be categorized 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 of them, or a cluster of equivalent components, one of which substitutes all the others. The common component must at least provide all the functionality of 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 term ‘commonality’ refers in literature are shown in Table 1.

The major features of using commonality are:

- Commonality substantially lowers the costs of proliferated product lines. Mitigate the effects of product proliferation on product and process complexity (Heese and Swaminathan 2006b).

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).

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**Table 1.** Major features of using commonality are shown in literature.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market</td>
<td>Decrease the set-up time, increase productivity, and improve flexibility</td>
</tr>
<tr>
<td>Demand</td>
<td>Pooled into a smaller number of components, reducing the required number</td>
</tr>
<tr>
<td>Risk-pooling and lead time uncertainty</td>
<td>Reduction; improve the economy of scale through larger order sizes</td>
</tr>
<tr>
<td>Design configuration</td>
<td>Simplify planning, schedule and control; streamline and speed up product</td>
</tr>
<tr>
<td>Manufacturing cost</td>
<td>Lower due to economies-of-scale in procurement, production and distribution</td>
</tr>
<tr>
<td>Reduce the cost of safety stock</td>
<td>Reduce</td>
</tr>
<tr>
<td>Commonality in the design of product family</td>
<td>Provides the firm with a chance to meet diverse customer needs with less</td>
</tr>
<tr>
<td>Commonality reduces the total inventory</td>
<td>Required to meet a specified service level</td>
</tr>
<tr>
<td>Decreases setup costs via larger lot sizes</td>
<td>Decreases the amount inventory held by taking advantages of risk pooling</td>
</tr>
<tr>
<td>Decreases complexity cost</td>
<td>Decreases complexity cost by requiring fewer variants to be processed</td>
</tr>
<tr>
<td>Optimal stock</td>
<td>Common component is lower than the combined optimal stocks</td>
</tr>
<tr>
<td>Commonality potentially allows firm to</td>
<td>Reduce its investment in safety stock while maintaining the level of</td>
</tr>
<tr>
<td>Maintain the level of customer service</td>
<td>Safety stock while maintaining the level of customer service</td>
</tr>
</tbody>
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Online at http://ejum.fsktm.um.edu.my
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., 2001a)

2.1 Parts commonality measurement
The parts commonality measurement includes the process for evaluation of product commonality and methods to achieve commonality in 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 resolve the trade-off between too much commonality (i.e. lack of distinctiveness of the products) and not enough commonality (i.e. higher production costs). Commonality index are found in literatures to measure the commonality within a family of products/processes.

2.2 Commonality indices
The commonality index is a measure of how well the product design utilizes standardized 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 reported literatures to measure 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 all product family (Ashayeri and Selen, 2005). Within a product 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. In designing a new family of products or analyzing 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 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, 2004, 2006). Several component-based indices are summarized in Table 2.

Table 1: Definition of commonality

<table>
<thead>
<tr>
<th>Reference</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eynan (1996)</td>
<td>An approach which simplifies the management and control of inventory and also reduce inventory is component commonality.</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>
<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, with long lead time and expensive- 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 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>
Table 2: Commonality indices

<table>
<thead>
<tr>
<th>Name</th>
<th>Developed by</th>
<th>Commonality measure for</th>
<th>No commonality</th>
<th>Complete commonality</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCI</td>
<td>Degree of commonality index</td>
<td>Collier (1981)</td>
<td>The whole family</td>
<td>1</td>
</tr>
<tr>
<td>TCCI</td>
<td>Total const commonality index</td>
<td>Wacker and Treleven (1986)</td>
<td>The whole family</td>
<td>0</td>
</tr>
<tr>
<td>PCI</td>
<td>Product line commonality index</td>
<td>Kota et al. (2000)</td>
<td>The whole family</td>
<td>0</td>
</tr>
<tr>
<td>%C</td>
<td>Percent commonality index</td>
<td>Siddique et al. (1998)</td>
<td>Individual product with a family</td>
<td>0</td>
</tr>
<tr>
<td>CI</td>
<td>Commonality index</td>
<td>Martin and Ishii (1996); (1997)</td>
<td>The whole family</td>
<td>0</td>
</tr>
<tr>
<td>CI(C)</td>
<td>Component part commonality</td>
<td>Jiao and Tseng (2000)</td>
<td>The whole family</td>
<td>1</td>
</tr>
<tr>
<td>CMC</td>
<td>Comprehensive metric for commonality</td>
<td>Thevenot and Simpson (2007)</td>
<td>The whole family</td>
<td>0</td>
</tr>
</tbody>
</table>

\[
\beta = \sum_{j=i+1}^{i+d} \phi_j
\]

\[
\alpha = \sum_{j=1}^{d} \sum_{i=1}^{i+d} \phi_{ij}
\]

3. PERSPECTIVES OF UNCERTAINTY

Uncertainty is utilized to measure the difference between the model and the real system or between the estimation of variables and their true values. The uncertainty can be caused by the errors associated with the model itself and the uncertainties of the model inputs. One of the challenges of uncertainties in manufacturing system is the propagation and accumulation of uncertainty, which affects the reliability of the outputs. Modern manufacturing enterprises are facing increasing pressure to respond to production dynamics caused by disruption of uncertainty (Koh and Saad, 2003b). This section reviews the definitions, sources, factors, effects and measures of uncertainty in production/manufacturing systems.

3.1 Definition of uncertainty

Uncertainty has unlike meanings to dissimilar people. For example the error guesstimates of a measurement are referred to as uncertainty (Figliola and Beasley, 1991). Yen and Tung (1993) ascribed uncertainty mainly to a lack of perfect indulgent with regard to phenomena or processes. Ayyub and Gupta (1994) exemplified uncertainty as an inseparable companion of any measurement at the experimental level, and as the indistinctness and incompleteness of understanding of complex real problems at the cognitive level. Zhao et al. (1995) defined uncertainty as the differences or errors between models and the veracity. Oberkampf et al. (1999) portrayed uncertainty as a potential paucity in any phase or activity of a modelling process due to lack of knowledge. Delaurentis and Mavris (2000) provided the definition of uncertainty as incompleteness in knowledge (either in information or context) which causes model-based prophecy to differ from the reality in a manner depicted by some distribution functions. Zimmermann (2001) defined stochastic uncertainty as the unknown of the future circumstances of a system due to lack of information and fuzziness; uncertainty as the vagueness concerning the description of the semantic meaning of events, phenomena or statements themselves. Some researchers referred to uncertainty as a form of fracas (Frizelle et al., 1998; Lindau and Lumsden, 1995; Saad and Gindy, 1998). Definitions of uncertainty found in literature are recapitulated in Table 3.

Table 3: Definition of uncertainty

<table>
<thead>
<tr>
<th>Definition</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncertainty can be defined as any unpredictable event in manufacturing</td>
<td>(Koh and Saad 2002)</td>
</tr>
<tr>
<td>environments that disturbs operations and performance of an enterprise.</td>
<td></td>
</tr>
<tr>
<td>Uncertainty is defined as any unplanned events that occur during production, which disrupt orders execution.</td>
<td>(Koh and Saad 2003b)</td>
</tr>
<tr>
<td>Uncertainty is defined as any unpredictable event that disturbs the production process in a manufacturing system that is planned by MRP, MRP II or ERP system.</td>
<td>(Koh and Saad 2003a)</td>
</tr>
<tr>
<td>Uncertainty can be defined as any unpredictable event that disturbs the operation and production in a manufacturing system.</td>
<td>(Koh 2004)</td>
</tr>
<tr>
<td>Uncertainty is the dissimilarity between the amount of information required to execute a task and the amount of information already infatuated.</td>
<td>(Mula et al. 2006a)</td>
</tr>
</tbody>
</table>

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Situation where the current state of knowledge is such that (1) the order or nature of things is unknown, (2) the consequences, extent, or magnitude of circumstances, conditions, or events is unpredictable, and (3) credible probabilities to possible outcomes cannot be assigned.

Degree to which available choices or the outcomes of possible alternatives are free from constraints.

Situation where neither the probability distribution of a variable nor its mode of occurrence is known.

### 3.2 Factors of Uncertainty

Uncertainty can be measured by the frequency of its happening, and analyzing the relative contribution and resulting effect on delivery performance can quantify whether the impact is minor or major. Koh and Saad (2003b) found eight uncertainties that are most likely to affect customer delivery performance. These are external late supply, internal late supply, planned set downs, demand batch size enlargement, labor unavailability, tooling unavailability, demand batch size enlargement and customer design changes. Their simulation output highlighted four uncertainties that have significant effects to PDL (parts delivered later) and FPDL (finished product delivered late). These are external late supply, machine break-downs, demand batch size enlargement and customer design changes. The factors for uncertainty reported in literatures are summarized in Table 4.

<table>
<thead>
<tr>
<th>Factor(s) of uncertainty considered</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>System uncertainty</td>
<td>(Hsu and Wang 2001; Miller et al., 1997; Reynoso et al., 2002; Sommer, 1981)</td>
</tr>
<tr>
<td>Lead time uncertainty</td>
<td>(Brennan and Gupta 1993; Dolgui and Ould-Louly 2002; Huang et al., 1982; Koh and Gunasekaran 2006; Mohebbi and Choobineh 2005; Ould-Louly and Dolgui 2004)</td>
</tr>
<tr>
<td>Environmental uncertainty, Supply uncertainty</td>
<td>(Billington et al., 1983; Ho et al., 1995)</td>
</tr>
<tr>
<td>Operation yield uncertainty</td>
<td>(Huang et al., 1985)</td>
</tr>
<tr>
<td>Interrelationship between levels</td>
<td>(Kim and Hosni 1998)</td>
</tr>
<tr>
<td>Demand uncertainty</td>
<td>(Agatz et al., 2008; Ahmed et al., 2003; Anosike and Zhang 2007; Arruda and do Val 2008; Balakrishnan and Cheng 2007)</td>
</tr>
</tbody>
</table>

Table 4: Uncertainty factors

### 4. RELATED STUDIES

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. From the literatures two streams of research with respect to commonality are distinct. One stream of research is on the design of the system or product and another stream of research covers efficient operation, given the design of the system.

Lin et al. (2006) have setup a multi-period model of component commonality with lead time. They analyzed the quantitative relationship between lead time and the inventory level of common component and find some efficient ways to: customization level, optimize inventory management and lower costs. Under deterministic lead time, when using component commonality, the total inventory cost is larger than in the system without
component commonality. Subtle change of lead time will get different results. As a matter of fact, it is economic to use component commonality in some special conditions

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

Ma et al. (2002) have formulated a multi-period 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 have 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.

Zhou and Grubbstrom (2004) have focused on the effect of commonality in multi-level production–inventory systems, especially assembly systems. They have considered deterministic demand and ignored capacity constraints and assume that no backlog is allowed. They confined their attention to two cases of different complexity, the first 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 sub-case being when purchased items are not available until after some delay.

Mohebbi and Choobineh (2005) have 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, it shows that component commonality significantly interacts with existence of demand and supply chain uncertainties, and benefits of component commonality are most pronounced when both uncertainties exist. They consider a two-level ATO environment that produces three finished products only. This paper investigates the desirability of increasing component commonality in ATO systems when product demand and component procurement lead times are random variables. We conduct a comprehensive simulation study to reveal the level of complex interactions among factors affecting the performance of an ATO system.

Heese and Swaminathan (2006a) have analyzed a stylized 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.

Porteus (1986) demonstrated that lower setup costs can benefit production systems by improving quality control. The author has introduced a model that captures a significant relationship between quality and lot size: while producing a lot, the process can go "out of control" with a given probability each time it produces another item. Once out of control, the process produces defective units throughout its production of the current lot. The system incurs an extra cost for rework and related operations for each defective piece that it produces. Thus, there is an incentive to produce smaller lots, and have a smaller fraction of defective units. The author also introduces three options for investing in quality improvements: (i) reducing the probability that the process moves out of control (which yields fewer defects, larger lot sizes, fewer setups, and larger holding costs); (ii) reducing setup costs (which yields smaller lot sizes, lower holding costs, and fewer defects); and (iii) simultaneously using the two previous options.

Diverse approaches are used to tackle the outcome of uncertainty, e.g. overtime production, subcontracting, outsourcing, holding safety stock, and keeping safety lead-time. These modus operandi are adopted to minimize the consequences of uncertainty on delivery to customer. The well known techniques are: buffering and dampening (Frizelle et al., 1998; Koh and Gunasekaran, 2006; Koh and Saad, 2006; Lindau and Lumsden, 1995; Saad and Gindy, 1998). Buffering technique is referred as a more corporeal display, e.g. inventory buffer; whilst dampening technique is referred as a relatively elusive display, e.g. safety lead-time (Koh and Gunasekaran 2006; Koh et al., 2000).

The most flavourful techniques used by many researchers and practitioners to deal with uncertainty are safety stock and safety lead-time (Guide and Srivastava, 2000). This rationalizes the research effort in applying safety stock or safety lead-time to cope uncertainty. But more system nervousness might be produced when using safety stock (Sridharan and LaForge, 1989). This finding ally with the conclusion from Ho et al., (1995). Buzacot and Shanthikumar (1994) found that the use of safety lead-
time is favored than safety stock when it is possible to make precise forecasts of future obligatory shipments over the lead-time. These findings limit the sturdiness of safety stock and safety lead-time with the constriction of the lead-time variation information (Koh and Gunasekaran, 2006). Guide and Srivasta (2000) and Koh et al. (2000) suggested the use of safety stock when countenanced with quantity uncertainty or safety lead time when facade with timing uncertainty, within MRP controlled batch-manufacturing environment using simulation modelling. Overtime and multi-skilling labor techniques are as well originated to be exploited by practitioners, though they have inconsistent role on delivery performance (Koh et al., 2000). SMEs habitually apply fire-fighting techniques to cope with uncertainty (Koh et al., 2000). This implies that they do not administer uncertainty systematically and hence do not prepare themselves for the future if the same uncertainty reappear (Koh and Saad, 2006). Today’s manufacturing enterprises must be receptive and be able to tackle uncertainty quickly and vigorously in order to uphold and boost business competitiveness. In order to respond to uncertain demand, supply and production process, the role and performance of a production planning and control system within a manufacturing enterprise will be confronted (Koh and Gunasekaran, 2006).

Ho et al. (1995) developed an uncertainty-dampening framework to reduce system nervousness caused by external supply uncertainty, external demand uncertainty and internal supply uncertainty. It was found that holding safety stock, safety lead-time and rescheduling are useful to buffer and dampen these uncertainties.

Billington et al. (1983) and Chung and Krajewski (1984) commenced the mathematical programming (MP) approaches to cope with capacity constraints. They considered the lead time is an implicit outcome of the alteration of demand and finite capacity. The models are used in a rolling schedule milieu for uncertainty in demand. This moved many authors to assess surrogate planning models in a rolling schedule context (Spitter et al., 2005). Similarly, Belvaux and Wolsey (2001) bestow assorted models for lot sizing under capacity constraints, where the lead times are implicit outputs of the optimization procedure.


Mula et al., (2006b) presents a new linear programming model for medium term production planning in a capacity constrained MRP, multi-product, multi-level and multi-period manufacturing environment. The concept of ‘yield factor’ is used to embrace system uncertainties. A composed yield factor relates the quantities of required inputs to satisfy a demand of specified output when the system uncertainties cause losses of articles in different levels of the production process. The composed yield factor therefore is a function of the production factors in the different stages of the process (Mula et al., 2006a). Arruda and Val (2008) represented a discrete event model of a multi-stage, multi-product P&S (production and storage) system. The time periods involved are random and the sources of randomness are: demand for the end products and the variability in the time length to complete each stage. Lusa et al., (2008) presents a multistage scenario stochastic optimization model that takes into consideration demand uncertainty when planning working time under annualized hours (AH).

Wilhelm and Som (1998) have analysed underlying stochastic processes, described operation of a single-stage, single-product assembly system that operates in an MRP-controlled environment. In particular, a model is developed, allowing production times to be treated as general, independent random variables. The inventory position process is identified as a Markov renewal process, and this structure is exploited to determine system performance measures such as average inventory level, average backorder level, and the probability distribution of the end-product inventory position. They showed that poor coordination of material flow occur due to longer lead time.

Inderfurth (1995) has focused on determining safety stocks in multistage manufacturing systems with serial or divergent structures, where end-item demands are allowed to be correlated both between products as well as in time. He showed that these types of correlation have contrary effects on the distribution of safety stocks over the manufacturing stages and that neglecting the correlation of demand can lead to significant deviation from the optimal buffer policy. The author demonstrated in an example for auto correlated demands of a moving average type, there are specific solution properties that drastically reduce the computational effort for safety stock planning. Safety stocks determined in that way can be used as an appropriate protection against demand uncertainties in material requirements planning systems.
Product families are a response to the paradox of mass production in the current era of customization by allowing companies and designers to provide a variety of products for the marketplace while reducing variety within the enterprise (Simpson et al., 2001b). A product family is a novel way to meet diverse demand with shorter lead times and lower costs. A product family is a group of related products that satisfy a variety of market niches yet share common features, components, and subsystems.

5. DISCUSSIONS AND CONCLUSIONS

It is very important to explore how the commonality dampens the lead time and quality variations. Figure 1 and Figure 2 respectively show the impact of component commonality on the total cost when lead time is deterministic and when it is uncertain for product specific components.

Figure 1: The impact of component commonality on costs (Song and Zhao 2006)

Figure 1 shows that the value of component commonality tends to decrease as \( \frac{c}{c'} \) increases for most of the cases of \( \frac{L'}{L} \) (where \( L \) and \( L' \) stand for lead times of product specific and common components respectively). As long as \( L' \) is kept the same, the value of component commonality converges to the same limit for different \( L \) as \( \frac{1}{c'} \) tends to zero. When \( c >> c' \), the value of component commonality converges to zero for all \( \frac{L'}{L} \) and indicates an impact on the value of component commonality. The impact can be substantial, when \( \frac{c}{c'} \) is moderate. When \( L' >> L \), the value of component commonality tends to increase as \( \frac{L'}{L} \) increases. That is, if the lead time of the common component is longer than those of the product specific components, the value of component commonality tends to increase as the lead time difference increases. However, when \( L' \leq L \), the trend is not clear.

Figure 2: The impact of component costs and Lead times (Song and Zhao 2006)

Figure 2 shows that the value of component commonality tends to decrease as \( \frac{c}{c'} \) increases for most of the cases of \( \frac{L'}{L} \) (where \( L \) and \( L' \) stand for lead times of product specific and common components respectively). As long as \( L' \) is kept the same, the value of component commonality converges to the same limit for different \( L \) as \( \frac{1}{c'} \) tends to zero. When \( c >> c' \), the value of component commonality converges to zero for all \( \frac{L'}{L} \) and indicates an impact on the value of component commonality. The impact can be substantial, when \( \frac{c}{c'} \) is moderate. When \( L' >> L \), the value of component commonality tends to increase as \( \frac{L'}{L} \) increases. That is, if the lead time of the common component is longer than those of the product specific components, the value of component commonality tends to increase as the lead time difference increases. However, when \( L' \leq L \), the trend is not clear.

Figure 3: The impact of stochastic lead times (Song and Zhao 2006)
Figure 3 shows that $c'$ have a similar impact on the value of component commonality for stochastic lead times, as for deterministic lead times. The variability of lead time has an impact on the percentage savings. The impact is substantial, especially at $c << c'$ where higher variability clearly results in lower percentage savings. But when $c >> c'$, the percentage savings converge to zero in all cases and the impact of lead time variability is less clear.

Figure 4: The relationship of the average lead time and TCI coefficients (Sheu and Wacker 1997)

Figure 4 shows that the average lead time decreases by 15.11% when TCI increases from the lowest value of 0.0196 to the highest value of 0.7519 and coefficient of demand variation of 0.29. Similar behaviour is also presented with higher coefficients of demand variation: 0.72 and 1.14. The relationship between TCI, demand variations, and the average lead time is tested using a two-way ANOVA (Table 5) which summarizes the result and concludes that the correlation between TCI and average manufacturing lead time is statistically significant over different coefficients of demand variations.

Table 5: Two-way ANOVA for average lead times with all TCI coefficients

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of squares</th>
<th>DF</th>
<th>F ratio</th>
<th>Probability &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCI</td>
<td>22421.340</td>
<td>24</td>
<td>15.836</td>
<td>0.0000</td>
</tr>
<tr>
<td>DV</td>
<td>20448.173</td>
<td>02</td>
<td>173.313</td>
<td>0.0000</td>
</tr>
<tr>
<td>Error</td>
<td>4778.346</td>
<td>81</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

From the literatures, the reasons for quality variations are summarized in Figure 5. Literatures show that commonality has positive impact on the factors cause variations in quality.

Figure 5: The factors of quality variations

Two basic sources of uncertainty affect directly production/manufacturing system performance: demand and supply uncertainty. In either of the two scenarios, uncertainty may exist in quantity/quality and/or in timing. Situations occur where there is some uncertainty in demand and/or in the quality and time between the placing of an order and the receipt of that order to replenish inventories. In these cases the effect of uncertainty of lead time and quality implies the use of some safety or buffer stocks to try to prevent a stock out situation. Assuming a variable demand or usage rate and fixed replenishment lead time, a possible stock out situation can occur since few defective products may produce for many reasons and demand during the lead time period may be greater than expected, thus reducing stock to zero before replenishment. A situation in which the demand or the usage rate is fixed but replenishment lead time is variable will occur when an order is placed at such time that items are received for replenishment stock and by this time the constant rate of demand has depleted stocks to zero. However, it is possible that because lead time is greater than expected, the constant rate of demand has in fact reduced stocks to zero and a stock out situation thus exists before items are obtained to replenish stock. Finally, a situation where both, demand or usage rate and replenishment lead time are variable, may cause a stock out because of the combination of the two situations described above.

A third possible source of uncertainty is the delivery batch quantity. In a purchasing process it is possible that even though a particular batch quantity is ordered to replenish stock, a different batch quantity/quality may eventually be received into stock. In periodic review, where it is almost universal for MRP systems to be based on, orders are placed to replenish stock to a particular level; so delivery of a quantity/quality different from expected can increase the risk of stock out before the next replenishment is received. With MRP the only materials in stock are those that are needed for the specified master schedule. If plans are suddenly changed the necessary materials will not be available; consequently, the response to market changes may be slower. In practice, flexibility may be improved by regular updating of the MRP schedule. This updating can be done with a “regenerative MRP” or with a “net
change MRP”. However, those procedures could contribute to the instability and uncertainty in the MRP plans.

Under the circumstances, the use of component commonality is one of the best tools to manage uncertainties in quality and lead time.

REFERENCES


Song, Jing-Sheng and Yao Zhao. 2006. "Lead Times and the Value of Component Commonality." In M&SOM Conference. Georgia Tech College of Management, Atlanta, Georgia, USA.


