Chapter 10
Production Planning and Control for Mass Customization – A Review of Enabling Technologies

Mitchell M. Tseng[1] and Andreas M. Radke[2]

Mitchell M. Tseng
Advanced Manufacturing Institute, Room 2591
Industrial Engineering and Logistics Management Department
Hong Kong University of Science & Technology
Clear Water Bay, Kowloon, Hong Kong
tseng@ust.hk

Andreas M. Radke
Advanced Manufacturing Institute, Room 2591
Industrial Engineering and Logistics Management Department
Hong Kong University of Science & Technology
Clear Water Bay, Kowloon, Hong Kong
amradke@ust.hk

Abstract Production planning and control (PPC) is critical to the success of mass customization (MC). It ensures production systems fulfill individual customer orders while meeting specifications, remaining within budget, and delivering on time.

---

[1] Dr. Mitchell M. Tseng is Chair Professor and Director, Advanced Manufacturing Institute, Hong Kong University of Science and Technology. He is also an Adjunct Professor of MIT–Zaragoza Logistic Program. After serving in the industry for two decades, he joined HKUST in 1993 as the founding department head of Industrial Engineering. He is an elected Fellow of the International Academy of Production Engineers (CIRP), and American Society of Mechanical Engineers (ASME). Professor Tseng is internationally known for his research in mass customization, high mix low volume (HMLV) production, and global manufacturing.

[2] Andreas M. Radke graduated in 2007 from the University of Karlsruhe (TH), Germany, with the degree Diplom Wirtschafts-Ingenieur. He is currently a full-time PhD student at the Advanced Manufacturing Institute (AMI), Department of Industrial Engineering and Logistics Management at Hong Kong University of Science & Technology. His main research interests are operations management for mass customization and inventory management under component commonality consideration. He has been working on industry projects and contributes regularly to academic studies. Before embarking on his Ph.D. studies, Andreas worked briefly in the automotive and electronics industry in Germany and Brazil.

Though the objectives of PPC for MC remain the same as for conventional production, the highly diversified customer orders create new challenges: (1) difficulties in forecasting, (2) altered economies of scale, and (3) shortened lead time.

This review chapter addresses these challenges by surveying literature with relevant topics that can potentially enable MC to meet these challenges. It is concluded with an outline of research gaps and opportunities for future work.

Abbreviations

AMT	Advanced manufacturing technology
ATO	Aassemble-to-order
ATP	Available to promise
BOM	Bill of materials
BOMO	Bill of materials and operations
CPFR	Collaborative planning, forecasting, and replenishment
DBC	Design by customer
FCP	Finite capacity planning
FMC	Flexible manufacturing competence
FMS	Flexible manufacturing systems
GBOM	Generic bill of materials
IDIB	Information, decision-making, implementation, buffer
LP	Lean production
MC	Mass customization
MP	Mass production
MRP	Material requirements planning
OIP	Operational improvement practices
PPC	Production planning and control
TQM	Total quality management

10.1 Introduction

MC deals with the production of items that best serve customers preferences within their budget and lead time requirements (Tseng and Jiao 1996). This requires the combination of product customization of the one-of-a-kind production and the process efficiency of mass production (MP). To meet customers' requirements more closely translates into a new trend that companies have not been well equipped to deal with, particularly those companies that have traditionally relied on MP. Furthermore, with dynamic changes in the market place manufacturers are confronted not only with the proliferation of a wide range of products but also the pressure to fulfill customer needs within a short period of time that is much less than the traditional lead time for production. The result is a much larger decision space for companies and customers (Figure 10.1).

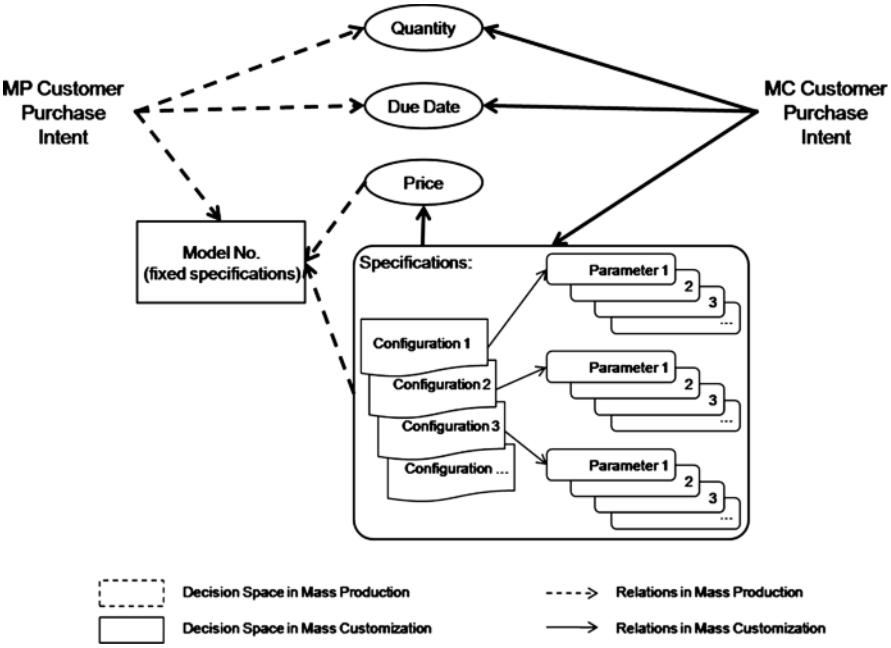

Figure 10.1 Decision space of MP *vs*. MC

Given that mass produced products tend to be commodity-like items, the order information for MP revolves around the product model number (representing a fixed set of specifications), quantity, and due date (see the left-hand side of Figure 10.1). Following the engineering approach to cost, the price is set by the marketing and sales department in advance and the product subsequently designed to accommodate cost and profit margin. Price and all other parameters can be forecasted or predicted with reasonable accuracy. However, customers increasingly demand products tailored to their individual needs. As depicted on the right-hand side of Figure 10.1, in MC product configuration replaces a fixed set of specifications. Customers order a product that incorporates their desired configuration, which is based on setting the corresponding parameters. Thus, the specification of the ordered product influences the quoted price. Due to the many different configurations, influenced by an even wider variety of parameters, the decision space inflates.

MC highly diversified customer orders create new challenges for those managing the PPC function, on three fronts: economies of scale, lead time, and forecasting. The high variety present in customer orders may considerably alter the economy of scale. Although finished products are not stocked, customers still expect lead time to delivery to be short, even shorter than the traditional lead time of MP. Because it is difficult, if not impossible, to forecast at the end product level, customers may be exposed to the full order fulfillment lead time.

To illustrate the deterioration of economies of scale induced by product variety, consider the case of car manufacturers. Currently, several automotive companies attempt to offer choices of different models with options of almost every possible attribute to the customer. The number of options is indirectly further increased by the laws and regulations in different market regions. Additionally, some adjustments need to be made to prepare the car's technology for climate. For example, markets near the equator have a hotter climate than northern regions and require the installation of additional radiators. However, also the operational environment changes: gasoline quality is superior in developed countries, road conditions less favorable in many parts or the world, *etc*. For some models the results are mind-boggling numbers of theoretical product variants. However, not all combinations are sensible and not all information needs to be queried. For example, a powerful engine with a small gas tank will hardly be recommended. The finite sets of choices could also come from compliances and rules and regulations; an order from Northern Europe, for instance, already locks in the rules regarding choices of head-lights, radio and mobile phone antenna, and engine settings to use. Thus, in practice, the actual number of options is immensely reduced.

Figure 10.2 provides a simple mathematical example of the explosion of the number of product variants for different numbers of components and different numbers of component options. Assume a case in which components can be combined without restrictions. Then the number of variants can be calculated as the number of options to the power of the number of components. That is, a product with two components and three options each can result in $3^2 = 9$ product variants. If the number of options is reduced to two there will be only $2^2 = 4$ product variants, *i.e.*, the number of product variants is reduced by $9 - 4 = 5$. For three components the product variants reduction is 19; for four components there will be 65 less product variants, and so on. Returning to the earlier example, it should be noted that for many premium car manufacturers, there is a small chance of two identical cars coming off the assembly line over the entire life cycle of each product generation.

Concerning the second challenge, long lead times, if MC production can only start after customers have placed the order and committed to the specifications, then customers have to be exposed to the entire lead time from product design, to

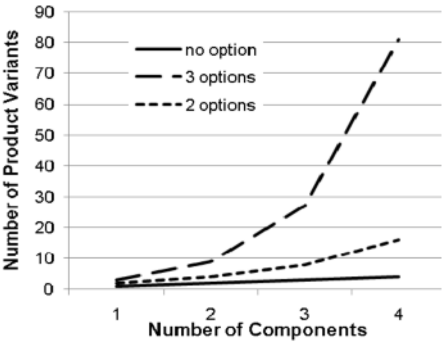

Figure 10.2 Increase of product variants based on number of components and number of component options

procurement, to manufacturing, to delivery. The vast majority, however, is not willing to wait that long. As an illustration of the significant importance of lead time on the purchase decision, in particular its trade-off potential in terms of specifications, consider the scrappage schemes that have been introduced by a number of governments in an attempt to support car manufacturers and/or providing incentives towards more fuel-efficient cars. Although a car is for many people one of the most expensive purchases in their life, potential customers not only accept massive deviations from their original specifications but even pay a considerable premium for reducing lead time. If they were not to accept these trade-offs, they might lose eligibility for the scrappage scheme as most of these are capped to a limited number of purchases.

However, the major challenge in MC is that because of the high product variety and the lead time contraction, building products to forecast is not practical to meet the diverse requirements of customers within the lead time and budget acceptable to them. Attempts to rely on ever more sophisticated enhancements of the regular MRP approach have also proven to be futile. Likewise, the existing just-in-time system cannot cope with demand fluctuations of the high-mix low-volume MC environment. This leaves companies that rely on standard approaches to PPC exposed to the challenges of MC.

Nevertheless, abandoning production planning and control altogether is not an option because it is PPC that has the most impact on realizing economies of scale and scope. PPC methodologies make the inevitable fixed costs tractable and can greatly increase efficiency. What is needed is a holistic approach to the MC production system, preparing the firm's make up for MC and providing the organization with the necessary tools to leverage economies wherever they appear.

Da Silveira *et al.* (2001) identified six success factors for MC, categorized as market-related and organization-based. On the market side customers demand for variety and customization must exist and more generally the market conditions must be appropriate. On the organization side the value chain should be ready, relevant technology must be available, the products must be customizable, and knowledge must be shared.

While the market-related factors are given in most businesses, today there seems to be uncertainty about how the organization-based factors map into enabling technologies and methodologies.

This chapter provides a review of the technologies and methodologies enabling PPC for MC production systems to achieve the seemingly conflicting goals of meeting individual requirements and achieving efficiency that is comparable to MP at the same time. The authors focus on the issues arising in the manufacturing industry. By reviewing the related literature the following questions are addressed:

1. What enablers can help overcoming the challenges posed by mass customization?
2. What features must these enablers show?
3. How can they be characterized?
4. What issues have not yet been addressed by or within these methodologies?

In order to bring the methodologies and technologies presented into a coherent framework, the authors first propose a categorization into three value chain segments versus the scope of enablers. The subsequent section presents a selection of the most relevant MC literature in each category. The conclusions section summarizes the findings and proposes some promising further research.

10.2 Enabling Framework for MC Production Planning and Control

The key idea of MC is to provide the customer with products that best fit his/her specifications, at a near MP efficiency. However, the increased variety, in addition to the cost and schedule constraints, demands a new set of production systems. Blecker and Abdelkafi (2006) proposed a sequence of strategies to manage the variety, making the system more decoupled and enabling it to cope with the variety induced complexity.

While being a first step, the focus of this sequence of strategies is on product design. However, to fully prepare the organization a holistic value chain setup is required. Having a state-of-the-art machine park and operational management practices is a necessary but not sufficient condition for success in the MC business. The customer must be provided with an interface to the company's offering that not only gives a comprehensive map of what the company offers, but is at the same time easy to use. Offering the customer to select particular options or introducing new ones into the product without already incorporating relatively easy adaptability in the product design stage will require product engineering for each new customer. This approach increases costs for the company and waiting times for the customer. However, once these steps have been successfully solved, the corporate strategy may still fail because suppliers are not responsive enough or simply unable to provide the input factors as required *by the customer*. Thus, enablers for manufacturing in MC necessarily must also include those focusing on product design, customer interaction, as well as the supply chain. Figure 10.3 provides an overview of the issues to be addressed in order to fulfill the production management.

The first block of enablers in Figure 10.3 focuses on preparing the product design for MC in a strategic scope. This includes such measures as organizing the company's entire product range according to product families. Furthermore, each product should be modularized. These two steps allow a product assembly similar to putting together a model construction kit but which eventually exhibits the customer's preferences. Supplementing these economies of scope, economies of scale can be enhanced by standardizing part components or even sub-assemblies across the different product families. This can be further enhanced by considering the commonality across different product generations. Economies of scale can be further increased by considering the commonality of production processes and grouping parts and components, accordingly.

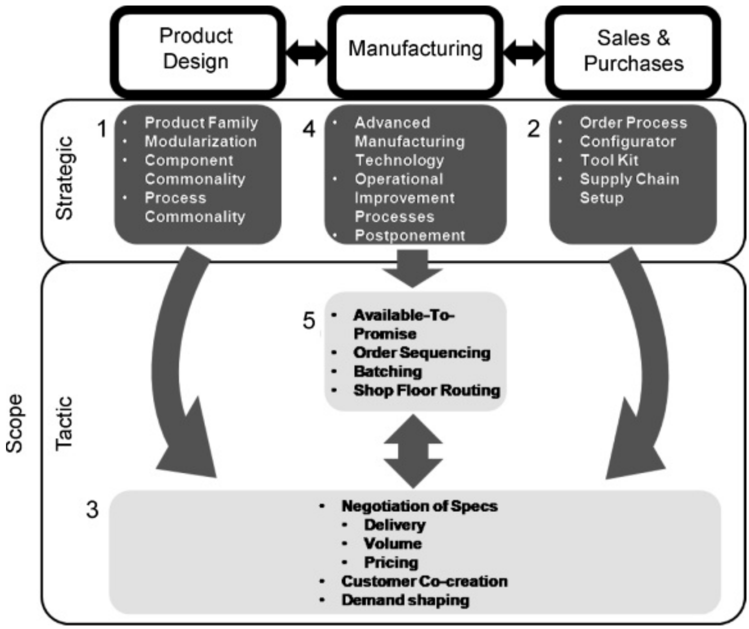

Figure 10.3 Proposed framework for the categorization of MC enablers

The second block focuses on the customer and is concerned with the strategic aspects of the sales and purchasing function. The company has to prepare its sales function by finding adequate measures for capturing customers' needs efficiently and effectively. To do so, configurations and entire "innovation toolkits" (Hippel and Katz 2002) have been proposed. Here we find the necessary approaches implemented to increase the fill-rate, in particular the demand shaping, but which are also used in the tactical side and, hence, will be described there. Using the acquired customer information on the supply side requires an adequate supply chain setup with sufficient variability and information sharing. At the end of each fulfilled project/customer order a step has to follow that identifies potentially reuseable knowledge and retains it in a knowledge base for future projects.

On the tactical level product design as well as sales and purchases both surround customer co-creation. This explains why it is difficult, if not impossible, to separate the tactical aspects of product design from those of the sales and purchases. Another focus is the company's actual negotiation of the specifications with the customer. Using the right demand shaping techniques can tremendously increase customer satisfaction by reducing the time he/she has to wait until delivery.

The manufacturing segment of the value chain and the strategic and tactical enablers will comprise the main part of this discussion.

The strategic measures of manufacturing enablers should increase the flexibility of the company's manufacturing capability. A first step is to set up and use the right machinery and equipment in the factory. This refers to the use of advanced manufacturing technology (AMT). However, to really employ the new flexibility capabilities and achieve agile manufacturing capability, companies have to implement operational improvement practices (OIP) to leverage the inherent agility in the equipment. Both AMT and OIP promise to reduce the production fixed costs seeking to make practices such as batching superfluous. Another strategic enabler is postponement. If a product can be differentiated in later production stages, without significantly increasing the value of the semi-finished product, the overall manufacturing process is more flexible to satisfy customer orders. Depending on the particular case this can be achieved by a re-evaluation sequence of the production steps. Combined with a re-evaluation of the product design itself, even later differentiation can become feasible. It should be noted that a coherent information flow between the sales side and the manufacturing center offers visibility through the production and sales pipeline, respectively. With the right tactical approaches, significant improvements in responsiveness to the customer can be gained.

The tactical scope of the manufacturing enablers is to leverage on the capabilities of the strategic measures to better serve the customers. The first element is to schedule resources in order to support the needs of different tasks. The discussion includes not only the sequencing step of the PPC, its methodology and parameterization. It also includes the role of the scheduler and the frequently neglected issue of aligning employee incentives with the employed PPC policy. The routing and batching factors not only benefit from the agility of the machine park but also from the product design that has been "optimized for MC" by using the strategic product design enablers. The available to promise (ATP) engine links the customer side to the strategic sales and purchases enablers. While some tactical sales enablers smooth the demand pattern, ATP can further balance demand and supply.

Given the vast amount of literature available towards enabling PPC for mass customization, the following review only presents the most relevant recent literature.

10.3 Enablers for Mass Customization

For this chapter we found a significant number of studies investigating the MC enablers included in the above framework. We also found other studies that have similarly explored those issues but are not directly associated to MC. We have tried to identify the most relevant sources, with the risk of missing several important works.

Furthermore, though other stages of value chain have equal or significant impacts to the smooth running of MC systems, the focus of this book chapter is on the manufacturing function. Therefore, the authors will only briefly discuss works that are focused on alternative value chain segments.

10.3.1 Strategic Enablers in Product Design

The “order penetration point” (Sharman 1984) provides an initial concept of to what extent a value chain has to react to provide for a given customer order. The goal is to reduce the impact an order has on the value chain. One way to achieve this is to design the product in a way that makes additional design or engineering efforts unnecessary for new orders.

A product family is a grouping of rather similar products in the company’s entire product range. It is often particularly interesting to introduce a product platform as a basic component that is shared among each member of the product family. A difficulty is posed by the different requirements each particular member has towards the product platform. This strategy is only feasible if it does not increase the cost of product lines. A broad review of product family design is provided by Jiao *et al.* (2007), who define the methodology and group the existing literature according to five segments. First, there are the underlying motivations for product family; then, the positioning of a company’s product offering and segmentation into product families. The design approach for platform-based product families is covered in the third group. The fourth and fifth groups address the manufacturing and upstream supply chain parts, respectively.

Employing a modular product design aims to specialize each component of the product to deliver specific functional requirements. It is thus possible to separate the design process for different components, which is particularly useful for the introduction of new technologies. Modular designs can also facilitate the standardization of components and the sharing of same component types across many different products. Kamrani and Salhieh (2000) explore different approaches to modular product design.

The effect of modularization and MC (among other issues) on the supply chain integration is studied in Mikkola and Skjott-Larsen (2004). They propose the “modularization characteristic curve” to identify opportunities for modularization and their interaction effects on interface constraints.

Another key advantage of modular designs is the opportunity to use readily available standardized parts in the product. This relieves the design and engineering function from actually designing every part of a new product and can speed up the design process at least for some products (Anderson 2003, Chapter 10).

Once the product range has been grouped into families and each product is designed on the basis of modules, major improvements can be achieved by standardizing part components and sharing their design among several different products, across product lines or even product generations. This is commonly known as component commonality. Component commonality is a concept attributable to parts, components, or sub-systems that are standardized so that they can be directly employed in different product designs, either of different products or different product generations.

In the early 1980s research began on the effects of component commonality. Collier (1982) and Baker (1985), among others, studied the effects of component commonality on safety stocks. The result was that, similar to an investment portfolio, demand risk could be pooled. Due to the overlapping of independent demand for the common component, demand fluctuations were reduced and hence a lower safety stock for the common component was sufficient in order to achieve the same service level. The more general effect of commonality on inventory costs was studied by Eynan and Rosenblatt (1996) who suggested that standardization should not always be sought. Mirchandani and Misha (2002) studied the minimization of inventory costs under given product-specific service levels and compared their results to models using aggregate service levels. Some practical advice for sourcing common components and achieving commonality ("design for manufacturability") can be found in Anderson (2003), Chapters 7 and 10, respectively.

By applying component commonality in product design to higher product hierarchies (such as modules or sub-assemblies) the deployment of tried and proven methodologies in PPC at the aggregate levels instead of end product levels is facilitated. Assuming an assemble-to-order (ATO) production system with sufficiently short assembly times (or sufficiently long customer tolerance time), PPC should shift from focusing on the many finished good variants towards the often common components. A case study followed by a simulation by Nagarur and Azeem (1999) shows that the introduction of component commonality into a production system improves its performance. A second result is the identification of the value of flexibility in manufacturing processes, which will be discussed later in this chapter. Furthermore the exploratory study of Meixell (2005) showed that, among other strategies, also component commonality may reduce scheduling problems and improve the stability of rolling schedules.

Manufacturing processes is another area that can benefit from standardization. The sources of process commonality have been investigated by Treleven and Wacker (1987). They developed metrics to measure the degree of commonality – or variety – and analyzed their managerial implications. Their study leads directly to the striving for flexible manufacturing competence, to be addressed later.

However, achieving commonality in components and processes requires the integration of both in the routing decision to benefit the company. In that direction, Jiao *et al.* (2004) propose a model to support the process selection decision based on a particular product configuration. They also describe requirements regarding the data and information flow within the company that make this integration meaningful. Huang *et al.* (2005) further integrate the decision to make or buy, offering a decision support model integrating the modularized product, processes and supply chain decisions aiming at minimizing costs. The integration of information from further domains into the decision process requires enhancements in the bill of materials (BOM).

To regain visibility over the proliferation of product and process variety, commonality (or uniqueness) of the BOM and production routings, the generic bill of materials (GBOM) was proposed. It is an approach to systematically manage product and process variety encompassing components, machinery, operations, and know-how. The integrated decision support model of Huang *et al.* (2005) employs the same approach. Jiao *et al.* (2000) propose a bill of materials and operations

(BOMO) to capture the information of material and routing in a single data structure. By doing so, they can synchronize the different perspectives of variety from the order, engineering and production planning domain. Zhang *et al.* (2005) used a GBOM to conduct a study on the organizing of product variety knowledge through GBOM. They continue the study by proposing master processes to address product variety. Du *et al.* (2005) propose an integrated BOM and routing generator for an ATO environment in order to synchronize product and process variety.

10.3.2 Strategic Enablers in Sales and Purchases

After reviewing the first step in the order process, *i.e.*, the capturing of a customer's specifications, the discussion first turns towards the steps to prepare the supply chain to deliver customized orders.

The effect of product variety on supply chain performance has been studied by Thonemann and Bradley (2002). They propose an approach to optimize the decision on how much product variety to offer. An explicitly multinational corporation point of view, characterized by considerably longer transportation links and increased demand uncertainty, is taken by Er and MacCarthy (2006)[3]. Once the effect of variety on supply chains is understood, the key idea to manage the impact of an order is to apply best practices for a high mix product supply chain in supply chain design and order taking. One such best practice is flexibility, another is close collaboration.

Although the benefits of a more flexible supply chain appear intuitive, the question of how much flexibility is needed has only recently been addressed by Tang and Tomlin (2008). The authors examined the effects of strategies to increase the agility of a supply chain by adding suppliers, engaging in flexible supply contracts, employing flexible manufacturing processes, postponing product differentiation (discussed later in this chapter), and responding to market and/or supply conditions by price adjustments. Under their assumptions, it turns out that small increases in flexibility can lead to significant reductions in the likelihood or the impact of risks, which in our case include demand uncertainty in terms of quantity, time, and product specification.

In order to facilitate the design of the supply chain when postponement (to be described later) and product modularization is pursued by a company, Ernst and Kamrad (2000) evaluate different supply chain structures by quantifying the total cost differential among them. The taxonomy they propose for the supply chain structures is rigid, postponed, modularized, and flexible, and spans upstream as well as downstream. Focusing more on the operational aspects towards and between the upstream parts of the supply chain, Schwarz (2005) proposes the "IDIB Portfolio". It supports the planning process by categorizing the decision process into four parts: the employed information system (I), the decision-making system (D), implementation systems (I), and buffer systems (B).

[3] Er and MacCarthy (2006) also stress that forecasting remains the biggest problem in supply chain coordination.

Some authors, such as Anderson (2003, Chapter 7), suggest that forecasting should be ignored altogether. However, this will almost certainly remain an idealistic goal as not every process can be designed to offer minimal lead times. For example, some components in the semiconductor equipment industry have a production time of 6 months, yet they are needed for installation within days. Without forecasting this problem is not solvable. Thus, the question is rather how to improve forecasting instead of abolishing it, and more generally how to improve the performance of the supply chain.

The best way to do so appears to be information sharing. More general discussions about the value of information sharing are provided by Cachon and Fisher (2000), Chen *et al.* (2000), and Lee *et al.* (2000). The research of Song and Zipkin (1996) focuses more directly on sharing information about demand and inventory levels. Preparing (or supporting) the CPFR initiative are in the studies of Aviv (2001, 2002) evaluate the benefits of collaborative forecasting on the supply chain performance.

More recently, Attaran and Attaran (2007) give a brief history of CPFR and offer an overview of state of the art supply chain management systems. They also highlight that companies experiencing variation in demand, buying or selling a product periodically, and the ones offering highly differentiable products can benefit the most. The success factors for the effectiveness of collaborative planning have been surveyed and their relationship analyzed by Petersen *et al.* (2005). They conclude – as an extension to Sherman (1998) and similar to the discussion on PPC that will follow later in this chapter – that "while IT is critical […] technology cannot be the complete solution". Additionally, the right strategies and processes need to complement the technological infrastructure.

While the above literature promotes the benefits of CPFR on the supply chain performance, it assumes that all parties involved can contribute to the synergy of such a close collaboration. But this may not necessarily be the case, and so Bititci *et al.* (2007) propose a synergy model based on strategic, operational, cultural, and commercial dimensions, for which they develop a framework to assess the readiness for collaboration.

The major limitation of CPFR is the focus on the supply-side. The initiative does not explicitly include the customer side, nor extract information from it more directly. In the automotive industry this has led to the highly effective and efficient production of products that the customer does not want (Holweg and Pil 2004). More generally, for companies operating in the MC business the task is (for different reasons) even more obvious: extract information on the customer side first before feeding it through to the supply chain. Capturing such necessary customer information leads to the development of the configurator.

Capturing the customer needs by a sales person has been the standard approach and may well remain the standard in many industries. The main focus in this discussion, however, is the availability of the customer information concerning his or her product specifications that need to be entered into an order system. While this can be done by a salesperson, it can also be done by the customer if the system is good enough. Hence, the use of configurators has received wider attention in academia and industry.

A brief overview of the possibilities and promises of configurators can be found in Anderson (2003, Chapter 9, pp. 286–288). Khalid and Helander (2003) stress that the options offered by the manufacturer must be really relevant to the customer. Also, web pages soliciting customers' input must be easy to navigate, easy to use, and allow easy selection of design elements. Although every customer may have slightly different ideas about his or her product's specifications, often repetitive features are included. An (additional) tool documenting each configuration project offers the capturing of each customer's design. The more configuration projects have been realized, the broader the knowledge base, the more meaningful the potential support turns out to be. An example of such a tool is presented in Hvam and Malis (2003).

The interactions between the product nature and the available programming possibilities determine the best choice for a configurator (Anisic *et al.* 2005). The same paper gives an introductory overview of key configurator characteristics employed by leading companies. Based on the evaluation of three websites, a more thorough discussion of desirable features of a configurator, specifically for the design by customer (DBC) (Du *et al.* 2003) approach, is given in Bee and Khalid (2003).

It turns out that the customer's needs are often not readily retrievable, but rather have to be revealed. Thus, the "configuration overload" (Matzler *et al.* 2007) has received attention recently. It describes the risk that the vendor's use of the configurator demands too much product knowledge prior to the purchase. The result would be customer confusion; the customer would tend to fall back on coping strategies like sharing/delegating the decision, seeking additional information, choosing a standard configuration if available, choosing low-price offers, or – worst of all – abandoning the decision. Therefore, it is not enough just to set up a configurator; it also has to invite the customer to an enjoyable design experience, a key pre-requisite for customer co-creation.

Gathering the customer needs is, according to a generic quotation process model by Bramham *et al.* (2005) only the first in four steps to manage product variety in the quotation process. Then, a request has to be classified into whether it is an all new design and who the expert in the company is, what the extent of modifications to existing product designs are, or whether a similar product can satisfy the needs. Next, resources need to be assigned to each customer request. Finally, reusable information has to be retained if it is useful for future customers/orders. Only when all these steps are performed by an organization, is the company ready to efficiently and effectively interact with the customer in the MC environment.

10.3.3 Tactical Enablers in Product Design, Sales, and Purchases

Differentiating between tactical product design enablers and tactical sales and purchases enablers is difficult, if not impossible. They both are directly linked to the product to be produced, and thus employed in the product creation process. In essence, both act as interface between the factory floor and the customer.

A particular problem in the procurement of customized goods is the need for collaboration between customer and company in designing the most suitable product for the former, and the basically competitive nature of acquiring sales and contracting. The interdisciplinary nature of this problem has been addressed in a dissertation by Chen (2008), who developed a framework to acknowledge good design with competitive pricing. The author advocates two different negotiation schemes: the first scheme treats the customer's specifications as constraints; the second as the objective function.

MC shifts the product design process in part or entirely to the customer, offering him/her more freedom in receiving a product that incorporates his/her specifications. Such a "design by customer" approach is presented in Tseng and Du (1998). Improving communication between a MC company and its customers aims at matching the company's current capabilities with customer demands. Innovation for new design often comes from "lead users" who identify a need earlier than other customers. Supporting their innovative potential led to a stream of research on "innovation toolkits" (Hippel and Katz 2002). Hippel and Katz (2002) elaborate on the characteristics such toolkits have to offer, where they are most beneficial, how to develop them and what their competitive value is. An application of such a toolkit is presented in Franke and Hippel (2003). Recently, it has been noted that opening the one-on-one dialogue between company and customer allowing peer customers to provide information in this process is highly beneficial. The peer users can support the evaluation of a customer's self-design and even spark a product idea in the first place.

During the creation of the detailed product specifications, it may easily occur that the customer chooses a combination of options not readily available. In order to avoid delays either the salesperson or the configurator should include knowledge from the supply side. ATP offers such visibility on the supply side and will be described in the section dealing with tactical manufacturing enablers. The contribution of ATP is dependent on some degree of customer flexibility. Utilizing this flexibility to increase due date reliability and corporate revenue is the domain of the research area on demand reshaping.

The first of two main approaches is to facilitate the convergence of customers' needs and product offerings by various players of the supply chain before the purchase intention materializes. This effort can either be directed at the customer directly, as examined in Gerchak and Parlar (1987) and Balcer (1983), or indirectly towards the retailer (Taylor 2002) – assuming there is one. For MC these studies need to be extended from considering the finished good towards considering the component level, *i.e.*, the product configuration. The second approach has an on-the-spot characteristic because it is used during or after the customer made up his/her mind. It focuses on incentives like price discounts (Balakrishnan *et al.* 2005). More generally, Eynan and Fouque (2003) study the effect that changes in customer preference have before stock out occurs. Even if only a small number of customers can be convinced to alter their specification, considerable increases in profit and service level can be realized. However, they don't specify how customers are convinced to switch to a product that better suits the company's current work in process of supply chain pipeline. Merging this concept with a modularized product design may enable a company to stay closer to the original product specification because only a single component needs to be exchanged.

In computer manufacturing, for example, it is not unusual that customers demand a very popular combination of options. For many different reasons, some component may be close to stock out, *e.g.*, a hard disk. Then the manufacturer tries to make the customer accept a larger or smaller hard disk for a reduced premium or a discount, respectively.

Demand reshape practices will be addressed again later in this chapter, when the PPC aspects and the due date management in particular are covered.

10.3.4 Strategic Enablers in Manufacturing

Besides the earlier question of how much flexibility is needed to mitigate uncertainty, a key issue of operational flexibility is that customers don't necessarily perceive or benefit from a company's investment in flexible technologies and methodologies. The relationship between the so-called flexible competence (what the customer experiences) and flexible capability (the technologies and methodologies) is discussed in Zhang *et al.* (2006). Thus, this section on strategic manufacturing enablers will describe how to acquire flexible manufacturing competence (FMC), and how to increase flexibility in the production process steps by postponement. FMC is the key to reduce fixed costs in the production process and facilitate the application of tactical manufacturing enablers.

Because of the variability of customized orders in terms of time, quantity and configuration, Anderson (2003) introduces the term "on-demand supply chain" to describe a highly responsive supply chain. In Chapter 8 the author gives four main characteristics of such a supply chain: the elimination of setup, a batch size of one, one-piece flow production, and leveling production. This can be paraphrased as FMC. Yet, a remarkable feature of the discussion about FMC is that there appears to be no generally accepted definition of what it comprises. D'Souza and Williams (2000) propose taxonomy along (only) four flexibility dimensions: volume, variety, process, and material handling. The most general notion is probably that FMC strives to increase variety while reducing changeover cost and changeover time.

The experience from achieving LP suggests that FMC involves not only the use of AMT but also the implementation of OIP. An extensive overview of methods and technologies can be found in Zhang *et al.* (2006), who categorize AMT into the areas of product and process design, manufacturing, planning and control, and integration between functions and between processes. Research on AMT can be organized in groups as follows. Literature in the product and process design group supports the design and engineering activities: *e.g.*, Adler (1988), Boyer *et al.* (1996), Dahan and Hauser (2002), Huang and Mak (1999), Lei and Goldhar

(1991), and Meredith (1987). The manufacturing group encompasses literature on particular production technologies: *e.g.*, Gunasekaran and Love (1999), Kotha and Swamidass (2000), Lei and Goldhar (1991), Meredith (1987), Saraph and Sebastian (1992), and Sun (2000). The planning and control group covers literature on technologies to design and manage production activities: *e.g.*, Adler (1988), Boyer *et al.* (1996), Cunningham (1996), Lei and Goldhar (1991), Meredith (1987), and Saraph and Sebastian (1992). The technologies integrating functions and processes are described in Ettlie and Reifeis (1987), Huang and Mak (2003), Jonsson (2000), Melnyk and Narasimhan (1992), Nemetz and Fry (1988), Parthasarthy and Sethi (1992), and Small and Chen (1997).

OIP encompasses the LP concepts with the building blocks of lean manufacturing (Womack and Jones 2004), total quality management (TQM) (Crosby 1979), time-based competition (Koufteros *et al.* 1998), and continuous improvement (Bessant and Francis 1999). Concerning the relationship between AMT and OIP, the result of the study by Zhang *et al.* (2006) indicates that FMC benefits most from AMT if OIP measures are implemented.

The study by Nagarur and Azeem (1999) is mentioned here again. Like the formerly mentioned result that the introduction of component commonality improves the performance of a manufacturing system, the same is valid for the introduction of flexible manufacturing capacity. Particular benefits of commonality include reduced makespan, increased machine utilization, as well as increased factor productivity. Hence, with this increased flexibility of the manufacturing processes, batching of orders to allocate fixed costs on a production lot is no longer a dominant issue, since the economically competitive lot size is significantly reduced. Likewise the earlier mentioned study by Meixell (2005) observed a stabilizing effect of increased machine flexibility on rolling schedules by reducing system nervousness. Given the increased shop floor flexibility, the process of scheduling in a mass customization environment becomes less complex. The process itself will be addressed again in the tactical manufacturing enablers.

Postponement initiatives promise a stabilization of the demand pattern in terms of quantity and timing, because the differentiating parts of the product are required later. It is linked to the product design and allows differentiation of products late in the production process without increasing the value of the semi-finished products. As the concept of modularization is closely linked to postponement, these initiatives can involve only the product, only the process, or (ideally) both. Lee (1996) described how a production process can be changed to allow a later differentiation of a product without changing the design. He also shows the limitations of the economic feasibility of such a manufacturing postponement. Designing a product for modularity – as exemplified in Kamrani and Salhieh (2000), Chapters 2 and 3 – while keeping the goal of postponement in mind, promises wider opportunities to postpone the differentiating production steps. Furthermore, Lee (1996) introduces what is called logistics postponement. Changing the way semi-finished or finished products are distributed and further processed offers cost saving opportunities, as well. Finally, Pagh and Cooper (1998) propose a framework to decide when to strive for a strategy focusing on postponement, on speculation (*i.e.*, building up inventory), or a combination of both.

A white paper by Shen (2005) proposes a framework for developing postponement strategies. He identifies four main driving factors of postponement and outlines a process to formulate and implement a postponement strategy.

10.3.5 Tactical Manufacturing Enablers

Matching demand side with the available production capability is a fundamental issue in MC. Some rather unsubtle approaches to increase responsiveness have been identified in McLaughlin *et al.* (1994). However, as the authors note, these approaches undermine the operational system of a company by deliberately reducing visibility in general, or creating particular blind spots in the company processes. Measures to cope with such dichotomy between lead time expectation and customization are also described in McCutcheon *et al.* (1994). The rise of internet connectivity and the manifold increase in computational power since then opens new paths.

Taylor and Plenert (1999) develop a procedure called finite capacity planning (FCP) to analyze a finite capacity schedule and identify the slack machining capacity. This promises to provide better, more realistic lead time quotations, and protects the production system from over-commitment. Furthermore, by identifying unused machine capacity, sales efforts can focus on products or product configurations that use this capacity.

While FCP promises more visibility in machine utilization, demand reshaping should be employed to utilize the flexibility of customers; furthermore, information from the supply-side should be incorporated as well, to increase due date reliability and corporate revenue. ATP offers this visibility across the customer, manufacturing, and supply domain. Once the supply chain is set up to facilitate product mixes (see section on strategic sales and purchases enablers), it is essential for a competitive firm to gain visibility of its internal and external resources in the order-taking process. ATP serves as a form of integration of production and material planning (Kilger and Meyr 2008). For a discussion of different ATP execution modes and industry cases, refer to Ball *et al.* (2004).

The particular requirements towards the operations management and inventory management systems for an effective ATP system are examined in Pibernik (2005). Only if these are met can ATP contribute to customer satisfaction and corporate success. Xiong *et al.* (2003) present a web-based ATP system with the key feature that it promises to respond faster to customer queries. This is achieved by an open-source architecture and the use of a dynamic bill of materials (dynamic BOM), which make the consideration of component and raw material availability less computationally expensive. Thus, the WebATP promises) to become a feasible scenario planning tool.

A planning model integrating information from supply and demand side for the order commitment process is presented in Zhang and Tseng (2008). This model explicitly and coherently considers the flexibility of the manufacturing system and customer's flexibility regarding his/her specifications, which have both been addressed in earlier sections of this chapter.

A brief discussion of a single-level or two-level hierarchy approach to the scheduling process, the model building, and potential problems when choosing the size of time buckets is presented in Stadtler (2008). Choosing the wrong time bucket size may lead to scheduling excess idle capacity even if a job barely exceeds the remaining capacity of a time bucket. The author also mentions approaches to remedy this problem.

Hutchison and Khumawala (1990) in particular addressed the scheduling of flexible manufacturing systems (FMS). They compare the output and flow time results of real-time and off-line scheduling schemes. They conclude that the off-line scheme yields better performance for little additional computational effort. However, the insights might be outdated because the computational power has increased by several orders of magnitude since the early 1990s.

A literature review on due date management policies is given by Keskinocak and Tayur (2004). They note that lead time reliability/due date reliability is among the most important factors influencing service quality. The effect a due date quotation has on the customer is addressed in Moodie and Bobrowski (1999). They consider trade-offs between price and promised due date with the result that in a simplified setting bargaining over price and due date is beneficial to the company.

This leads to the observation that there is no single best practice of PPC methodology, neither for all manufacturing systems nor all products within the same company. A brief discussion of the aids supporting selection of methods for PPC is presented in Schönsleben (2008). Schönsleben and Wiendahl (2009) introduced the strategic and tactical implications of market changes to production. These, of course, not only involve the facility layout, the machinery and equipment, including AMT, but also the supporting processes OIP. For a thorough discussion of this problem with extended scope towards facility location planning for production, distribution, and service networks as well as strategic procurement, see Schönsleben (2007).

Based on a control theoretic approach, Kim and Duffie (2004) design and analyze closed-loop PPC algorithms for a single workstation. Their results support the implementation of FMC to be able to adjust capacity more often and with less delay. They argue that more responsive capacity control has greater impact on production performance than more sophisticated backlog control algorithms.

A PPC model establishing a relationship between production planning, control, and production performance metrics is presented in detail by Lödding (2008). Based on this model, Nyhuis *et al.* (2009) develop a model founded on control theory. The closed control loop setting allows a constant measuring and steering of production systems. They also present an approach supporting the customization and parameterization of a PPC system for individual companies and their particular production characteristics.

Having discussed the technical side of scheduling, which often focuses entirely on the sequencing, soft factors of scheduling, such as social and organizational aspects, will be introduced in the following.

Wiendahl *et al.* (2005) argue that problems in the PPC configuration are easily recognized but that a technology centered approach cannot solve them. Instead, they demand an approach including the agents and their roles. In their study they identify six aspects for a successful implementation of a scheduling strategy: objectives, processes, objects, functions, responsibilities, and tools. The authors also propose a checklist for decision-makers to use in order to ensure that the PPC system is consistently configured and aligned. In Wiendahl (2008) the approach is discussed in greater detail and supplemented by an industry case.

It should be noted that the functions and responsibilities of schedulers have not been addressed yet. To deepen the understanding of the tasks and roles of schedulers in particular, we refer to Jackson *et al.* (2004). Their study emphasizes the need to take a more holistic approach to scheduling.

Sequencing and scheduling for MC is thus not only limited to using the right models and parameters, but it must also address the role schedulers will have to play. Often, the sequencing part is done entirely by algorithms and computers. Schedulers double-check the generated plans for consistency and also play a major role in foreseeing interruptions in production and develop contingency measures.

The diminishing importance of batching has been addressed in earlier sections, particularly in the context of commonality and FMC. While the former increases the number of copies for a particular component to be produced, the latter *de facto* reduces the economic lot size by reducing the fix cost and set up times.

Similarly, sequencing is facilitated by enablers in other domains. Increasing the process commonality opens more routings for a particular production step. FMC promises to reduce the influence of the production sequence on changeover cost.

Finally, it should be noted that the scope of the term PPC is broadening since the coining of a generally accepted term in the 1970s. Today, it not only involves the internal material management but extends across the firm boundaries to include the entire value chain from the first supplier to the final customer. Schuh *et al.* (2008) noted that the vertical and horizontal integration of relevant information remains a challenge.

10.4 Conclusion

Differing from MP, mass customization encounters the challenges of producing to meet customers' orders with vast product variety and lead time limitation. These challenges translate into operation management in PPC for MC with difficulties in demand forecasting, altered economies of scale, and expectations of shortened delivery lead time. Thus, the requirements of mass customization can best be met by better aligning economies of scale and scope of the entire supply chain, and the product development process. This process may involve the following practices:

1. Appling modularization and commonality in product and process design to higher product hierarchies (such as modules or sub-assemblies) so that tried and proof methodologies in PPC can be deployed at the aggregate levels instead of end product levels.
2. Involving the customer in product design and innovation by using configurators and toolkits, and taking into account the flexibility of the customer by shaping his or her specifications.
3. Creating a coherent process to align the partnership of product design with the competitiveness of order acquisitions and apply best practices in high mix product supply chain to ensure uninterrupted information flow of customer generated demand through the entire value chain from the customer through the manufacturing supply chain and to the delivery supply chain.
4. Preparing the shop floor for the increased variability of demand by using AMT and implementing OIP in order to make manufacturing fixed cost irrelevant. Striving for postponement to create a higher degree of responsiveness to customers' demand by delaying differentiating production steps.
5. Gaining visibility over the upstream value chain to match demand and supply by using ATP, and aligning the order sequencing approach with the organizational setup.

This proposed framework is an attempt to conceptualize the different enabling approaches to PPC in MC from the literature, from which further work can be identified. One possible research direction concerns the parameterization of the enablers. There exist several categorizations for MC along different dimensions, *e.g.*, Gilmore and Pine (1997), Lampel and Mintzberg (1996), and McCarthy *et al.* (2003) to name but a few, and it is likely that different MC categories require different enablers. Hence, further research is required on the effect the degree of customization has on the enablers described in this chapter. Some enablers may not be required; others may have to be adjusted. Also, MC still offers a fertile area for empirical studies to support this framework and other works.

Acknowledgments This work was supported by the Research Grants Council (RGC) of the Hong Kong SAR Government, RGC project number 620308, "An Investigation of Probability-Based Configurator Design".

References

Adler PS (1988) Managing flexible automation. Californian Management Review 30(3):34–56
Anderson DM (2003) Build-to-order & mass customization. Cambria, California
Anisic Z, Cosic I, Lalic B (2005) The choice of the optimal product configuration in mass customization strategy. 16th DAAAM International Symposium, Opatija
Attaran M, Attaran S (2007) Collaborative supply chain management. Business Process Management J 13(3):390–404
Aviv Y (2001) The effect of collaborative forecasting on supply chain performance. Management Science 47(10):1326–1343

Aviv Y (2002) Gaining benefits from joint forecasting and replenishment processes: The case of auto-correlated demand. Manufacturing and Service Operations Management 4(1):55–74
Baker KR (1985) Safety stocks and component commonality. J of Operations Management 6(1):13–22
Balakrishnan A, Xia Y, Zhang B (2005) Shaping demand to match anticipated supply. Northwestern University, Evanston
Balcer Y (1983) Optimal advertising and inventory control in perishable goods. Naval Research Logistics Q 30(4):609–625
Ball MO, Chen CY, Zhao ZY (2004).Available to promise. In: Simchi-Levi D, Wu SD, Shen ZM (eds) Handbook of quantitative supply chain analysis: modeling in the e-business era. Kluwer, Norwell, MA
Bee OY, Khalid HM (2003) Usability of design by customer websites. In: Tseng MM, Piller FT (eds) The customer centric enterprise. Springer, Heidelberg
Bessant J, Francis D (1999) Developing strategic continuous improvement capability. International J of Operations and Production Management 19(11):1106–1119
Bititci U, Turner T, Mackay D, Kearney D, Parung J, Walters D (2007) Managing synergy in collaborative enterprises. Production Planning and Control 18(6):454–465
Blecker T, Abdelkafi N (2006) Complexity and variety in mass customization systems: analysis and recommendations. Management Decision 44(7):908–929
Boyer KK, Ward PT, Leong GK (1996) Approaches to the factory of the future – an empirical taxonomy. J of Operations Management 14(4):297–313
Bramham J, MacCarthy B, Guinery J (2005) Managing product variety in quotation processes. J of Manufacturing Technology Management 16(4):411–431
Cachon GP, Fisher M (2000) Supply chain inventory management and the value of shared information. Management Science 46(8):1032–1048
Chen S (2008) Mechanism design for procuring customized products. Hong Kong University of Science and Technology, Hong Kong
Chen F, Drezner Z, Ryan JK, Simchi-Levi D (2000) Quantifying the bullwhip effect in a simple supply chain: the impact of forecasting, lead times, and information. Management Science 46(3):436–443
Collier DA (1982) Aggregate safety stock levels and component part commonality. Management Science 28(11):1296–1303
Crosby PB (1979) The art of making quality certain. McGraw–Hill, New York
Cunningham JB (1996) Designing flexible logistics systems: A review of some Singaporean examples. Logistics Information Management 9(2):40–48
Da Silveira G, Borenstein D, Fogliatto FS (2001) Mass customization: literature review and research directions. International J of Production Economics 72(1):1–13
Dahan E, Hauser JR (2002) The virtual customer. The J of Product Innovation Management 19(5):332–353
D'Souza DE, Williams FP (2000) Toward a taxonomy of manufacturing flexibility dimensions. J of Operations Management 18(5):577–593
Du J, Jiao YY, Jiao J (2005) Integrated bom and routing generator for variety synchronization in assembly-to-order production. J of Manufacturing Technology Management 16(2):233–243
Du X, Jiao J, Tseng MM (2003) Identifying customer need patterns for customization and personalization. Integrated Manufacturing Systems 14(5):387–396
Er M, MacCarthy B (2006) Managing product variety in multinational corporation supply chains. J of Manufacturing Technology Management 17(8)1117–1138
Ernst R, Kamrad B (2000) Evaluation of supply chain structures through modularization and postponement. European J of Operations Research 124(3):495–510
Ettlie JE, Reifeis, SA (1987) Integrating design and manufacturing to deploy advanced manufacturing technology. Interfaces 17(6):63–74
Eynan A, Fouque T (2003) Capturing the risk-pooling effect through demand reshape. Management Science 49(6):704–717

Eynan A, Rosenblatt MJ (1996) Component commonality effects on inventory cost. IIE Transactions 28(2):93–105

Franke N, Hippel E (2003) Satisfying heterogeneous user needs via innovation toolkits: the case of apache security software. Research Policy 32(7):1199–1215

Gerchak Y, Parlar M (1987) A single period inventory problem with partially controllable demand. Computers and Operations Res 14(1):1–9

Gilmore JH, Pine II BJ (1997) The four faces of mass customization. Harvard Business Review 75(1):91–102

Gunasekaran A, Love PED (1999) A review of multimedia technology in manufacturing. Computers in Industry 38(1):65–76

Hippel E, Katz R (2002) Shifting innovation to users via toolkits. Management Science 48(7):821–833

Holweg M, Pil FK (2004) The second century: reconnecting customer and value chain through build-to-order. MIT Press, Cambridge

Huang GQ, Mak KL (1999) Web-based collaborative conceptual design. J of Engineering Design 10(2):183–194

Huang GQ, Mak KL (2003) Brokering the customer–supplier partnership in product design and realization over the World Wide Web. IIE Transactions 35(4):369–378

Huang GQ, Zhang XY, Liang L (2005) Towards integrated optimal configuration of platform products, manufacturing processes, and supply chains. J of Operations Management 23(3–4):267–290

Hutchison J, Khumawala B (1990) Scheduling random flexible manufacturing systems with dynamic environments. J of Operations Management 9(3):335–351

Hvam L, Malis M (2003) Knowledge based product configuration. In: Mitchell, MT, Piller FT (eds) The customer centric enterprise. Springer, Heidelberg

Jackson S, Wilson JR, MacCarthy BL (2004) A new model of scheduling in manufacturing: tasks, roles, and monitoring. Human Factors 46(3):533–550

Jiao J, Simpson TW, Siddique Z (2007) Product family design and platform-based product development: a state-of-the-art review. J of Intelligent Manufacturing 18(1):5–29

Jiao J, Tseng MM, Ma Q, Zou Y (2000) Generic bill-of-materials-and-operations for high-variety production management. Concurrent Engineering: Research and Applications 8(4):297–321

Jiao J, Zhang L, Prasanna K (2004) Process variety modeling for process configuration in mass customization: an approach based on object-oriented Petri nets with changeable structures. International J of Flexible Manufacturing Systems 16(4):335–361

Jonsson P (2000) An empirical taxonomy of advanced manufacturing technology. International J of Operations & Production Management 20(12):1446–1474

Kamrani AK, Sahlieh S e (2000) Product design for modularity. Kluwer, Norwell, MA

Keskinocak P, Tayur S (2004) Due date management policies. In: Simchi-Levi D, Wu SD, Chen ZM (eds) Handbook of quantitative supply chain analysis: modeling in the e-business era. Kluwer, Boston

Khalid HM, Helander MG (2003) Web-based do-it-yourself product design. In: Mitchell MT, Piller FT (eds) The customer centric enterprise. Springer, Heidelberg

Kilger C, Meyr H (2008) Demand fulfillment and ATP. In: Stadtler H, Kilger C (eds) Supply chain management and advanced planning. Springer, Berlin

Kim JH, Duffie NA (2004) Backlog control design for a closed loop PPC system. CIRP Annals-Manufacturing Technology 53(1):357–360

Kotha S, Swamidass PM (2000) Strategy, advanced manufacturing technology and performance: empirical evidence from U.S. manufacturing firms. J of Operations Management 18(3):257–277

Koufteros XA, Vonderembse MA, Doll WJ (1998) Developing measures of time-based manufacturing. J of Operations Management 16(1):21–41

Lampel J, Mintzberg H (1996) Customizing customization. Sloan Management Rev 38(1):21–31

Lee HL (1996) Effective inventory and service management through product and process redesign. Operations Res 44(1):151–160

Lee HL, So KC, Tang CS (2000) The value of information sharing in a two-level supply chain. Management Science 46(5):626–643

Lei D, Goldhar JD (1991) Computer-integrated manufacturing (CIM): redefining the manufacturing firm into a global service business. International J of Operations and Production Management 11(10):5–18

Lödding H (2008). Ein Modell der Fertigungssteuerung – logistische Ziele systematisch erreichen. In: Nyhuis P (ed) Beiträge zu einer Theorie der Logistic. Springer, Berlin

Matzler K, Waiguny M, Fueller H (2007) Spoiled for choice: consumer confusion in internet-based mass customization. Innovative Marketing 3(3):7–20

McCarthy B, Brabazon PG, Bramham J (2003) Fundamental modes of operation for mass customization. International J of Production Economics 85(3):289–304

McCutcheon DM, Raturi AS, Meredith JR (1994) The customization-responsiveness squeeze. Sloan Management Review 35(2):89–100

McLaughlin CP, Vastag G, Whybark DC (1994) Statistical inventory control in theory and practice. International J of Production Economics 35(1–3):161–169

Meixell MJ (2005) The impact of setup costs, commonality, and capacity on schedule stability: an exploratory study. International J of Production Economics 95(1):95–107

Melnyk SA, Narasimhan R (1992) Computer integrated manufacturing: guidelines and applications from industrial leaders. Business One Irwin, Homewood, IL

Meredith JR (1987) The strategic advantages of the factory of the future. Californian Management Review 29(3):27–41

Mikkola JH, Skjott-Larsen T (2004) Supply-chain integration: implications for mass customization, modularization and postponement strategies. Production Planning and Control 15(4):352–361

Mirchandani P, Mishra AK (2002) Component commonality: models with product-specific service constraints. Production and Operations Management 11(2):199–215

Moodie DR, Bobrowski PM (1999) Due date management: negotiation the trade-off between price and delivery. International J of Production Research 37(5):997–1021

Nagarur N, Azeem A (1999) Impact of commonality and flexibility on manufacturing performance: a simulation study. International J of Production Economics 60:125–134

Nemetz PL, Fry LW (1988) Flexible manufacturing organizations: implications for STRA. The Academy of Management Review 13(4):627–638

Nyhuis P, Kennemann M, Münzberg B (2009) Configuration and regulation of PPC. CIRP Annals – Manufacturing Technology 1

Pagh JD, Cooper MC (1998) Supply chain postponement and speculation strategies: how to choose the right strategy. J of Business Logistics 19(2):13–33

Parthasarthy R, Sethi SP (1992) The impact of flexible automation on business strategy and organizational structure. The Academy of Management Review 17(1):86–111

Petersen KJ, Ragatz GL, Monczka RM (2005) An examination of collaborative planning effectiveness and supply chain performance. J of Supply Chain Management 41(2):12–25

Pibernik R (2005) Advanced available-to-promise: classification, selected methods and requirements for operations and inventory management. International J of Production Economics 94:239–252

Saraph JV, Sebastian RJ (1992) Human resource strategies for effective introduction of advanced manufacturing technologies (AMT). Production and Inventory Management J 33(1):64–70

Schönsleben P (2007) Integral logistics management: operations and supply chain management in comprehensive value-added networks. Auerbach Publications, Boca Raton, FL

Schönsleben P (2008) Zweidimensionale Darstellung für Beziehungen und Auswahl von Methoden der Produktionsplanung und -steuerung. In: Nyhuis P (ed) Beiträge zu einer Theorie der Logistic. Springer, Berlin

Schönsleben P, Wiendahl HP (2009) Changeability of strategic and tactical production concepts. CIRP Annals – Manufacturing Technology 58:5

Schuh G, Stich V, Schmidt C (2008) Produktionsplanung und -steuerung in Logistiknetzwerken. In: Nyhuis P (ed) Beiträge zu einer Theorie der Logistik. Springer, Berlin

Schwarz LB (2005) The state of practice in supply-chain management: a research perspective. In: Geunes J, Akcali E, Pardalos PM, Romeijn HE, Shen ZJM (eds) Applications of supply chain management and e-commerce research. Springer, New York

Sharman G (1984) The rediscovery of logistics. Harvard Business Review 62(5):71–79

Shen T (2005). A framework for developing postponement strategies. MIT Center for Transportation and Logistics

Sherman RJ (1998) Collaborative planning, forecasting and replenishment (CPFR): realizing the promise of efficient consumer response through collaborative technology. J of Marketing Theory and Practice 6(4):4–9

Small MH, Chen IJ (1997) Organizational development and time-based flexibility: an empirical analysis of AMT adoptions. International J of Production Research 35(11):3005–3021

Song JS, Zipkin PH (1996) Inventory control with information about supply conditions. Management Science 42(10):1409–1419

Stadtler H (2008) Production planning and scheduling. In: Stadtler H, Kilger C (eds) Supply chain management and advanced planning. Springer, Heidelberg

Sun H (2000) Current and future patterns of using advanced manufacturing technologies. Technovation 20(11):631–641

Tang C, Tomlin B (2008) The power of flexibility for mitigating supply chain risks. International J of Production Economics 116(1):12–27

Taylor SG, Plenert GJ (1999) Finite capacity promising. Production and Inventory Management J 40(3):50–56

Taylor TA (2002) Supply chain coordination under channel rebates with sales effort effects. Management Science 48(8):992–1007

Thonemann UW, Bradley JR (2002) The effect of product variety on supply chain performance. European J of Operational Research 143(3):546–569

Treleven M, Wacker JG (1987) The sources, measurements, and managerial implications of process commonality. J of Operations Management 7(1–2):11–25

Tseng MM, Du X (1998) Design by customers for mass customization products. CIRP Annals 47(1):103–106

Tseng MM, Jiao J (1996) Design for mass customization. CIRP Annals 45(1):153–156

Wiendahl HH (2008). Stolpersteine der PPS – ein sozio-technischer Ansatz für das industrielle Auftragsmanagement. In: P Nyhuis (ed) Beiträge zu einer theorie der logistic. Springer, Berlin

Wiendahl HH, Cieminski GV, Wiendahl HP (2005) Stumbling blocks of PPC: towards the holistic configuration of PPC systems. Production Planning and Control 16(7):634–651

Womack JP, Jones DT (2004) Lean thinking – Ballast abwerfen, Unternehmensgewinne steigern. Campus Verlag, Frankfurt.

Xiong MH, Tor SB, Khoo LP (2003) WebATP: A web-based flexible available-to-promise computation system. Production Planning and Control 14(7):662–672

Zhang M, Chen YJ, Tseng MM (2005) Distributed knowledge management for product and process variety in mass customization. International J of Computer Applications in Technology 23(1):13–30

Zhang Q, Tseng MM (2008) Modelling and integration of customer flexibility in the order commitment process for high mix low volume production. International J of Production Research 1–20

Zhang Q, Vonderembse MA, Cao M (2006) Achieving flexible manufacturing competence. International J of Operations and Production Management 26(6):580–599