Mass Customization as a Collaborative Engineering Effort

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Abstract:

Mass customization aims to deliver customized products with near mass production efficiency. To achieve this seemingly self-contradictory goal, manufacturers need to effectively integrate customers into the value creation process and resolve the associated preferential conflicts. From collaborative engineering perspective, mass customization can be viewed as collaborative efforts between customers and manufacturers, who have different sets of priorities and need to jointly search for solutions that best match customers' individual specific needs with manufacturers' customization capabilities. Viewing mass customization from such a perspective offers a new angle to advance mass customization research and implementation; reciprocally, the vested interests of different players in mass customization offers a realistic and promising test bed for developing collaborative engineering theories, technologies, and tools. This paper explores the synergies between these two fields of study, sketches out the scenarios of applying collaborative engineering in mass customization, and points out directions for future research.

Key Words: Mass Customization, Collaborative Engineering, Synergy

1. Introduction

Mass customization aims to deliver products and services that best meet individual customers' needs with near mass production efficiency (Tseng and Jiao 1996). It's a production paradigm that tries to combine the benefits of craft production of pre-industrial economies and mass production of the industrial economies. The paradigm shift to mass customization is made an imperative for many companies to survive in an increasingly diversified, fragmented, and competitive marketplace; and it's made possible by the revolutionary progress in technologies like information technology, flexible manufacturing systems, fast prototyping etc (Pine et al. 1993; Pine 1993; Kotha 1995).

Mass customization has attracted enormous attention from both academia and industry in the last two decades (Silveria et al. 2001; Tseng and Piller 2003), and has been widely recognized as a viable strategy for companies to gain competitive advantage. Bain & Company, a management consulting powerhouse, has included mass customization in its annual survey of management tools and trends that have strategic importance (Bain & Company, 2005). Currently, the focus of research in mass customization is shifting from its strategic viability to operational feasibility, i.e. from *what* and *why* to *how* (McCarthy 2004). Many firms like Dell, Motorola, Hewlett-Packard, and Adidas are experimenting or implementing mass customization. According to Selladurai (2004), mass customization is no longer an *oxymoron* but a *reality*.

Despite its advances in academia and industry, mass customization continues to be challenged by critics as well as reality from different aspects. Companies implementing mass customization often find themselves mired in a net of conflicts both strategically and operationally, e.g. the conflict between manufacturing cost and customization

(Squire et al. 2006), between responsiveness and customization (McCutcheon et al. 1994) etc. Agrawal et al. (2001) and Zipkin (2001) assert that mass customization is only viable for a very limited range of applications. Spring and Dalrymple (2000) conclude similarly that mass customization has limited novelty and restricted applicability.

Essentially, these challenges and conflicts can be traced to information asymmetry and preferential conflicts between customers and manufactures in customization. According to Hippel (2005), customers and manufacturers are asymmetrically endowed with *need information* and *solution information* respectively, both of which are 'sticky' in the sense that they are difficult to be acquired, transferred, and used in a different location. Innovative tactics and technologies like differentiation postponement (Feitzinger and Lee 1997), product family design (Tseng and Jiao1996), and product configuration systems (Salvador and Forza 2004) have greatly mitigated the severity of these challenges. But the ever-escalating market competition and customer expectation keep pushing firms to the edge and there's a genuine need for more effective means for customer-manufacturer collaboration in general and conflict resolution in particular to move mass customization forward.

Emerging research in collaborative engineering, particularly Engineering Collaboration via Negotiation (ECN) paradigm (Lu 2003), promises great potential to tame many of the challenges that are currently constraining many mass customization programs. From a collaborative engineering perspective, mass customization can be viewed as a series of activities, many of which are of engineering nature, where customers and manufacturers with different preferences engage in interactive problem solving and joint conflict resolution to create artefacts that best satisfy individual customers' needs while simultaneously meet manufacturers' economic objectives. Viewing mass customization from collaborative engineering perspective offers a new angle to advance mass customization research and implementation; reciprocally, the vested interests of different players in mass customization offers a realistic and promising test bed for developing collaborative engineering theories, technologies, and tools.

This paper aims to explore the synergies between mass customization and collaborative engineering. The first part introduces mass customization concept, its historical development, and then examines the challenges and conflicts that are currently constraining its implementation. In the second part, research in collaborative engineering is introduced as a potential conceptual framework to address the challenges and conflicts associated with mass customization. In the third part, a generic framework of mass customization is introduced. Based on the framework, potential scenarios of applying collaborative engineering in mass customization are characterized and the potential use of mass customization as a test bed for collaborative engineering research is also discussed.

2. Mass Customization as a New Production Paradigm

2.1. Mass Customization Concept

The concept of mass customization was first expressed in Toffler's book *Future Shock*, in which he predicted that future manufacturing enabled by information technology would be able to provide customized products in a large scale with little or no extra cost (Toffler 1970). The term 'mass customization' was first coined by Davis (1987) in his book *Future Perfect*, in which he described a trend where companies sought to micro-segment markets and offer unique products and services to customers. It's Pine *et al.*'s Harvard *Business Review* article (Pine et al. 1993) and Pine's book (Pine 1993) that popularized the concept of mass customization and ignited a wave of academic research and industrial experimentation. In their work, mass customization was defined as the ability to provide individually designed products and services to every customer through high process agility, flexibility, and integration.

Many authors propose more practical definitions by describing mass customization as a system that uses information technology, flexible processes, and organizational structures to deliver a wide range of products and services that meet specific needs of individual customers at a cost near that of mass-produced items (e.g. Hart 1995; Tseng and Jiao 1996; Silveria et al. 2001). In general, mass customization can be described as a production paradigm that tries to combine the benefits of craft production of pre-industrial economies and mass production of the industrial economies, aiming to deliver products and services that best meet individual customers' needs with near mass production efficiency.

It's worth noting that mass customization is NOT mass production with batch size of one. Mass customization is fundamentally different from mass production and requires different values and roles, systems, learning methods, and ways of relating to customers (Pine et al. 1993; Pine 1993; Kotha 1995; Piller et al. 2004). One essential feature that differentiates mass customization from mass production is that customers are actively involved in the value creation process in mass customization (Duray 2002; Piller et al. 2004). In mass production, customers are subjects to be observed, their demand is to be forecast, and their attention and purchasing decisions are to be studied, influenced or even manipulated as manufacturers strive to push their products into the market. In mass customization, customers are no longer passive recipients of products or services that are designed and produced for a nominal customer. Instead, each customer has his/her individual identity and provides key inputs to design, produce, and deliver the product or service based on his/her individual preferences. Table 1 summarizes the differences between mass customization and mass production.

Table 1: Mass Customization vs. Mass Production

	Mass Production	**Mass Customization**
Goal	Delivering goods and services at prices low enough that nearly everyone can afford them	Delivering affordable goods and services with enough variety and customization that nearly everyone finds exactly what they want
Economics	Economies of scale	Economies of scope and customer integration
Focus	Efficiency through stability and control	Variety and customization through flexibility and responsiveness
Product	Standardized products built to inventory	Standardized modules assembled based on customer needs
Key Features	▪Stable demand ▪Large homogeneous markets ▪Low-cost, consistent quality, standardized goods and services ▪Long product development cycles ▪Long product life cycles	▪Fragmented demand ▪Heterogeneous niches ▪Low-cost, high-quality, customized goods and services ▪Short product development cycles ▪Short product life cycles
Organization	Mechanistic and hierarchical	Organic and flexible
Customer Involvement	Customers are passively involved in the value chain.	Customers are actively integrated into the value chain.

2.2. Development of Mass Customization

The concept of mass customization originated in a historical context where mass production as the predominant production paradigm since Henry Ford ran into crisis in a new market reality and technology landscape. The paradigm shift to mass customization is mainly propelled by three forces. The first is market demand. An increasingly affluent society and diversifying demographic characteristics demand products and services that are tailored to individual customers' specific needs. Kotler (1989) claims that '*the mass market is dead and segmentation has progressed to the era of mass customization*'. He argues that there's an increasing demand for product variety and customization, and even segmented markets are too broad as they no longer permit developing niche strategies.

The second force is market competition. As customers become increasingly empowered and globalization gains momentum, companies across many industries are faced with local rivals as well as competition from abroad. Product variety is exploding while product life cycle is shortening. As a result, many companies operating under the mass production doctrine of *economies of scale* find it increasingly difficult to amass enough volume, effectively differentiate from competition, accurately forecast demand or plan production.

The third is technological revolutions, which enable new ways of organizing production activities and doing business in general. Flexible manufacturing systems allow manufacturers to quickly adapt to changes in product variety, volume, and delivery schedule without incurring high penalty in terms of cost and lead time. Information technologies like Internet and telecommunication systems establish efficient channels for companies to interact directly with individual customers.

Since the birth of the mass customization concept, many companies and entrepreneurs have been striving to implement mass customization for competitive advantage. Some of these initiatives were very successful. One of the most cited cases is Dell Computer, which is able to deliver customized personal computers and notebooks within one week with prices lower than its mass producing competitors. By adopting mass customization, Dell Computer has gained the so-called first-mover advantage and maintained high profitability and growth in a hyper-competitive industry for a long period (Magretta 1998). Other prominent cases include Motorola's customized pagers, Adidas Mi customized shoes, Hewlett Packard's printers etc. (Feitzinger and Lee 1997; Selladurai 2004).

2.3. Mass Customization Economics

From a customer's point of view, the economic justification of mass customization lies in the availability of more choices that potentially can best fulfil his/her specific needs with slightly or no extra payment. However, there're some mediating factors. First, choice itself does not mean value but only a potential. Choices are associated with tradeoffs, which may not be a pleasant experience to customers and could result in dissatisfaction or even distress (Schwartz 2004). Huffman (1998) points out that there's a thin line between mass customization and *mass confusion*. Second, customers may not know what they really want. Need is a term with contextual connotations. It's subject to influences of the social environment, human emotions, and other factors that are difficult to be captured. Customers are often unable to articulate their needs for a customized product. Third, there's an asymmetry between customers and manufacturers in terms of information and knowledge. Customers may fail to understand or appreciate manufacturers' offerings; even the customized offer fulfils their articulated preferences (Simonson 2005).

From manufacturers' point of view, the economic justification lies in the notion of "*economies of integration*". According to Piller et al. (2004), with customers integrated into the value creation process, companies gain access to more accurate information about market demand and can postpone some activities until an order is placed. As a result, manufacturers can reduce, if not eliminate, expensive inventory of finished goods. Also, by producing in response to real market demand, manufacturers can avoid using costly marketing techniques like sales discounts to clear unpopular products. In a highly competitive and volatile marketplace, the cost of inaccurate forecast could be very significant. Furthermore, customer loyalty can be enhanced via customization because companies are able to interact with each individual customer directly. The information gained through customer interaction also provides valuable insight into customers' latent needs and can guide future product development (Kotha 1996; Piller et al. 2005).

In general, the key issue in mass customization from an economic perspective is how to leverage *economies of integration* to compensate potential loss of *economies of scale* and provide individual customers choices that can best satisfy their specific needs with superior experiences. More specifically, this translates into finding an effective means to best match customers' individual specific needs with manufacturers' customization capabilities.

2.4. Conflicts in Mass Customization

Despite the maturity of theory and enabling technologies, it's still a daunting task for companies to successfully implement mass customization. Many mass customization programs were folded and large amounts of investment had to be written off. Levi's Strauss closed its custom jeans program (Original Spin) in 2003; P&G closed its custom cosmetics program (Reflect.com) in 2005. Toyota learned the hard way that mass customization requires very different organizational structures, values, management roles and systems, and customer relations, which Toyota, the most successful car manufacture in the world, was not ready yet. In general, mass customization is not the natural next-stage of mass production via incremental change. Instead, it's a system-wise overhaul of traditional paradigm of organizing production and doing business. It challenges the traditional taboo of combining *mass* with *customization*, while in the meantime it submerges itself into a flood of conflicts that need to be carefully and innovatively handled for its own salvation.

Strategically, there's an inherent conflict within mass customization as its name suggests and as many critics rightly claim: *Mass* implies aggregation and repetition, while *customization* means individual and *one-of-a-kind*. Traditionally, companies compete either on *mass* via high efficiency and low cost, or on *customization* by offering differentiated solutions and charging monopoly premiums. Combining *mass* and *customization* into a single strategy risks saddling the company in a dilemma where competitive advantage gets lost on both ends.

Operationally, there're conflicts between different performance objectives in mass customization. Under the customer-centric philosophy, individual customers' *pull* is the driving force for mass customization to function (Tseng and Piller 2003). However, customers' needs are usually diverse and irregular. The diversity of customer needs requires manufactures to offer high product variety, which often leads to high component variety, large numbers of suppliers, and high administrative complexity. The irregularity of individual customers' needs means demand unpredictability and instability. As a result, production planning becomes very difficult and ineffective, leading to either resource under-utilization or shortage and eventually drives up cost. Furthermore, as the value chain in mass customization is driven by customers' *pull* instead of manufacturers' *push*, delivery lead time becomes part of customers' waiting time. Customers' increasing demand for responsiveness and time-based competition further aggravate the difficulty to achieve high efficiency and high quality customization simultaneously.

Although conflicts abound and usually assume different forms, ultimately they can be accounted for by the diverging preferences between manufacturers and individual customers, both of whom have to make tradeoffs in seek of superior value propositions. With customers actively integrated into the value chain, tradeoffs making needs to be done in a collaborative way so that customers' needs could be well matched with manufacturers' capabilities. One of the central questions in mass customization is how manufacturers and individual customers could work collaboratively and resolve conflicts effectively for mutual benefits.

3. Collaborative Engineering as a Tool for Conflict Resolution

To collaborate means '*to work jointly with others or together especially in an intellectual endeavour*' (Merriam-Webster dictionary). How to collaborate effectively has been a subject of research since the birth of human beings. Recent development in information technology like Internet and telecommunications has enabled people to engage in collaboration 'virtually' across temporal and geographical boundaries. To date, researchers from various disciplines including optimization, group decision making, business research, information and computer science etc. have employed different theories and techniques to study the general subject of collaboration and collaborative engineering in particular (Lu 2003).

According to Monplaisir and Salhieh (2002), collaborative engineering can be viewed as a process in which *people* working in teams according to *engineering methodologies* and supported by *technical tools* can share resources and knowledge to achieve common goals. *People* are the main body of collaborative engineering, since all enterprises and organizations are made up of people no matter they are physically co-located or virtually co-located. *Engineering methodologies* include methodologies like Quality Function

Deployment (QFD), Design for X (DFX), Concurrent Engineering etc, which basically prescribe a systematic framework and process to conduct collaboration activities. The *technical tools* mean systems that can be utilized to support teams and enhance the process.

A key issue in collaborative engineering is how to resolve conflicts, since participants' preferences are often not fully aligned and there's uncertainty involved. Recently, Lu (2003) proposes Engineering Collaboration via Negotiation (ECN) as a new paradigm for collaborative engineering. ECN is defined as *"a socio-technical decision making activity where a team of stakeholders with different expertise and mixed motives engage in interactive and joint conflict resolutions to co-construct consensual agreements of some engineering matter"*. The ECN framework treats collaborative engineering as a socially-mediated technical activity which concerns more about human behaviour and its impact on technical decisions. It also treats the collaborative engineering as a dynamical system in which each participant's views may change and be influenced by others' perspectives, basically a process of negotiation.

4. Mass Customization in Collaborative Engineering Perspective

4.1. Conceptual Synthesis

Viewed from collaborative engineering perspective, mass customization is essentially a production paradigm under which customers and manufacturers collaboratively create an artefact (either a product or a service) to best meet individual customers' needs in the most efficient and economical way. The process of creating the artefact is essentially of engineering nature but also has a social bearing because of the interactions among engineers, sales, marketing etc., which usually have different information, expertise, motives, preferences, and agendas. Conceptually, mass customization can be taken as a collaborative engineering activity, where customers and manufacturers with asymmetric information and different preferences engage in interactive and joint conflict resolutions to co-create an artefact. How such collaboration can be carried out effectively and efficiently is an ideal research topic for collaborative engineering, and it also holds a key to advance mass customization research and implementation. In general, there're synergies between these two fields of study. On one hand, collaborative engineering research results can be applied to address various collaboration issues in mass customization; on the other hand, mass customization offers a fertile test bed to develop new collaborative engineering theories, techniques, and tools.

4.2. Applying Collaborative Engineering in Mass Customization

Firms pursue mass customization following different routes; customers get involved at different points along the value chain and they are involved in different ways subject to factors like industry structure, product nature, market conditions etc. Different operation modes of mass customization will involve different people and require different approaches and methodologies for collaboration. This section refers to a generic mass customization framework to discuss *where* and *how* collaborative engineering could be applied in mass customization.

In discussing product customization in a broad manufacturing strategy context, Spring et al. (2000) propose a generic model of product customization, which includes 3 stages, namely *problem solving, design specification,* and *transfer* (Figure 1). The *problem solving* stage can be further decomposed to *problem definition* and *solution realization*. During the problem solving stage, the product customization concept and design scheme are determined and agreed between customers and manufacturers. *Design specification* follows *problem solving* and it's the stage where a particular customization type or product configuration is determined based on the product architecture. The *design specification* and the process by which it is achieved will determine the firm's performance on some of the operational objectives, e.g. quality, service and cost. The *transfer stage* is to convert design specifications into actual products.

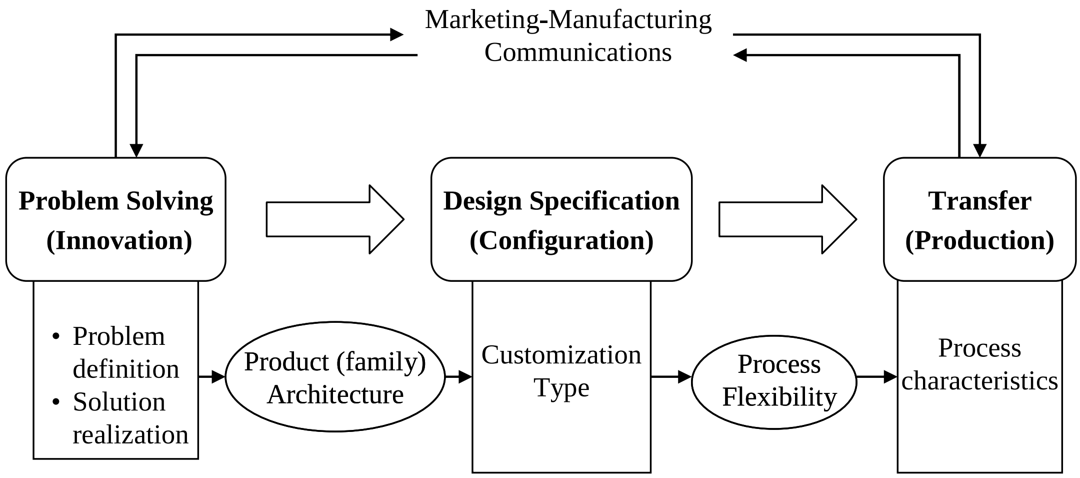

Figure 1: A Model of Product Customization (Adapted from Spring et al. 2002)

The 3-stage model provides a generic and compact framework to conceptually approach mass customization. A limitation is that customer – manufacturer interaction is confined to the *problem solving* stage only. This paper extends this model to allow customer integration in *design specification* and *transfer* stages as well and uses the extended model as a framework to discuss the application scenarios of collaborative engineering in mass customization. In correspondence to the 3 stages of customization, these general scenarios are termed as *co-innovation*, *co-configuration*, and *co-production* respectively. Relevant research is reviewed and discussed in more detail according to *people/team*, *engineering methodologies*, and *tools* within a collaborative engineering perspective (Figure 2).

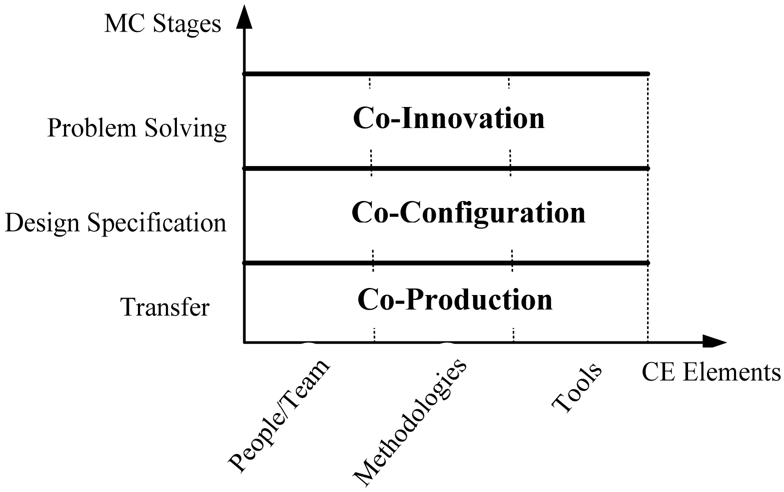

Figure 2: Application Scenarios of Collaborative Engineering in Mass Customization

4.2.1. Scenario I: Co-Innovation

Mass customization is a very dynamic system in the sense that both customers' needs and manufacturers' capabilities are constantly evolving. Given the diversity, irregularity, and unpredictability of customers' needs, it often happens that customers with needs may not find a satisfactory configuration out of the manufacturer's current offerings. As a result, companies implementing mass customization are often faced with new problems and challenged to design and develop new solutions, i.e. to innovate. The ability to innovate and innovate at a rate that matches or exceeds customers' changing tastes and expectations is critical for any mass customization program to survive and sustain.

How problems can be effectively solved or *where* innovations come from is a question that is subject to hot debate. The manufacturer-centric view holds that innovations result from intentional research, e.g. the design and development work in a company's R&D centre. The user-centric (or customer-centric) view contents that many innovations actually come from users, particularly the *lead users*, whose present strong needs will become general in a marketplace in the future (Hippel 2005). One common foundation between these two different views is that (customer) *need information* and (manufacturer) *solution information* need to be brought together for innovation to take place. As a result, *problem solving* in mass customization is collaborative in nature and designated as *collaborative innovation (co-innovation)* in this paper.

In a typically organizational setting, co-innovation usually takes place between customers and product and/or process design engineers, intermediated by sales, application engineers, marketing etc. Customers could be individual consumers or business customers. If it's the latter, they are usually from the purchasing and sometimes engineering department. Among customers, the so-called *lead-users* deserve special attention. According to Hippel (2005), lead users are those users (or customers) who are ahead of the majority of users in their populations with respect to an important market trend.

As engineering methodology is concerned, the joint problem solving in mass customization is essentially a collaborative design activity. Family Architecture (PFA) provides a compact and structured way to represent and organize design knowledge from multiple views (Tseng and Jiao 1996, Jiao 1998). Under PFA, customers, product engineers, and process engineers can work under a unified framework with their interdependent relationships explicitly mapped out. As a result, PFA could serve as a framework for co-innovation. Given the preferential differences between customers and manufacturers, conflict resolution mechanism is a key issue in co-innovation. The ECN paradigm (Lu 2003) provides a promising methodology to address this issue.

For technical tools, engineering design tools like Computer Supported Collaborative Work (CSCW) systems (Monplaisir and Salhieh 2002) can be used to support the co-innovation process. In the context of mass customization, Hippel (2005) proposes user toolkits to facilitate user innovation. With built in design knowledge, customers are able to innovate on their own and design products or services according to their individual specific needs while within the manufacturer's capabilities. Reversely, by providing user-friendly design tools to customers, manufacturers can economize upon the cost of eliciting customers' 'sticky' need information. Future research is needed to understand customers' decision making behaviour and the source of innovation during customer-manufacturer collaboration, develop new mechanisms and processes for co-innovation (e.g. collaboration via negotiation), design and develop new technical tools (e.g. interactive user toolkits) to facilitate the process of co-innovation.

4.2.2. Scenario II: Co-Configuration

Configuration is the stage where customers and manufacturers come to agree upon the specifications of a specific product offering or customization type. It corresponds to the *design specification* stage (Figure 1). Configuration is essentially a special form of product design with the product family architecture already defined and the solution space determined. In other words, configuration is a process of searching from a large pool of alternatives to locate a specific product variant that is mutually satisfactory to the customer and the manufacturer.

The quality of configuration is critical to customer satisfaction because it will determine how well individual needs will be satisfied, and it also determines to a large extent on manufacturers' performance on several dimensions like cost, delivery lead time etc. However, high quality configurations are usually difficult to achieve, particularly when the products to be customized are complex. It requires good understanding of customers' needs and manufacturers' offerings plus the ability to effectively link these two. However, good sales persons with deep technical knowledge are almost always a scarce resource, particularly in an environment characterized by fast pace of technological change.

One approach of configuration is to shift the task of configuration to customers via product configuration systems, e.g. Dell's online PC configurator. Using configurators can streamline and automate the configuration process, reduce configuration errors, and enhance flexibility and responsiveness (Sabin and Weigel 1998). However, shifting configuration to customers has its downside. When products are complex and customers are unclear about what they really want, they could get overwhelmed by the choices offered and the tradeoffs to be made. They may find the configuration process unpleasant or even stressful (Huffman and Kahn 1998; Schwartz 2004).

Salvador and Forza (2004) did an extensive survey on the application of configurators for product customization. Their findings indicate that: although many companies tend to rely on product configuration systems to customize their products, they are faced with difficulties like inadequate product information supply to the sales office, excess of repetitive activities within the technical office, and high rate of configuration errors in production etc. Ironically, many of these difficulties are what product configuration systems have been designed to resolve.

The difficulties faced by many product configurators can be accounted by the partisan approach they take, i.e. they view configuration either from the manufacturer's or the customer's point of view while the collaborative nature of configuration in mass customization is neglected. As a result, these configurators perform well in environment where manufacturers are able to effectively convey what they can provide or customers know precisely what they want. There's a need to treat configuration from a collaboration perspective to deal with the customer diversity and product complexity in mass customization. We name the scenario of applying collaborative engineering in the *design specification* stage of mass customization as collaborative configuration (co-configuration).

In a typical organization setting, co-configuration often involves customers and sales engineers (sometimes design engineers). Up to date, there have been no engineering methodologies developed specifically for co-configuration. Existing configuration design methodologies can be generally classified into rule-based, case-based, and model-based, depending on the reasoning techniques used (Sabin and Weigel 1998). In a rule-based system, design knowledge is codified as configuration rules or constraints; in a model-based system, design knowledge is contained in a system *model*, which consists of decomposable entities and interactions between their elements; in a case-based system, new configurations are adapted from previous, similar configurations (or *cases*). Extending traditional configuration methods, Guttman and Maes (1999) propose Distributed Constraint Satisfaction as a new mechanism to support integrative negotiation.

Besides product configuration systems, personal recommendation systems (Stolze and Strobel 2004) are proposed to facilitate customers in product configuration. Enabled by techniques like data mining, recommendation systems are able to suggest product variants based on customers' historical purchasing behaviours. However, this approach requires customers' needs and preferences to be relatively stable so that the preferences revealed in the past can have predictive power for future preferences. Further research is needed to better understand the dynamics within the co-configuration process, to develop engineering methodologies specifically for co-configuration. In the meantime, technical tools need to be developed to enrich the functionalities of existing product configurators and recommendation systems by enabling interactivity.

4.2.3. Scenario III: Co-Production

Production here corresponds to the *transfer* stage (Spring et al. 2000) by including material conversion, material transportation, shop floor control, procurement, inventory management etc. To many manufacturers, production still remains a bottleneck to pursue mass customization strategy. The simultaneous need for high variety, efficiency, responsiveness, and flexibility simply outstrips many manufacturers' financial resources or technical capabilities. Collaborating with supply chain partners or end customers promises great potential to further increase production efficiency, improve responsiveness, and reduce cost so as to overcome the barrier to move into mass customization. We name the collaboration between customers and manufacturers in production functions of mass customization as collaborative production (co-production).

The people/team involved in co-production usually include customers, supply chain managers, and production engineers etc. By sharing demand and supply information, supply chain partners can better utilize production resources in response to volatile market demand. Many methodologies have been proposed for co-production from different perspectives. Cachon (2003) applies game theory to mathematically analyze different collaboration scenarios in a supply chain and design contracting schemes accordingly. The Voluntary Inter-industry Commerce Standards (VICS) group promotes Collaborative Planning, Forecasting and Replenishment (CPFR) as a roadmap to cope with mutual reconciliation of activities in supply chain collaboration (VICS 2002). Advanced Planning Systems (APS) begin to incorporate collaborative planning as an important functionality (Kilger and Reuter 2005).

Up to now, the scope of research on co-production has been focused at the supply chain level with business customers, and attention has been primarily placed on the value of information sharing. Primary methodologies are game theory and optimization. Participants of collaboration are usually assumed to be profit-maximizing *economic men*, who are deprived of social identities. To cater to a mass customization environment, there's a need to extend the research scope to investigate how manufactures and a large number of individual customers can collaboratively arrange production activities. The actual process of collaboration among participants with different agenda and local incentives also needs to be studied. Existing tools need to be interconnected, to enable interoperability and effective conflict resolution.

Table 2. summarizes the application scenarios of collaborative engineering in mass customization. It's worth noting that the list in the table is not meant to be exhaustive or definitive but assumes a typical setting and serves as examples. Also, the boundaries between these general scenarios of applying collaborative engineering in mass customization are not clear-cut. The decisions made during co-innovation will have their impact felt in co-configuration and co-production, and vice versa. So, it's important to apply collaborative thinking from the overall system perspective.

Table 2, Application Scenarios of CE in MC

CE Elements / MC Stages	**People/Team**	**Methodologies**	**Tools**
Co-Innovation	▪ Lead users ▪ Design engineers ▪ Process engineers	▪ User innovation ▪ Product Family Architecture ▪ ECN	▪ Design toolkits ▪ CSCW
Co-Configuration	▪ Customers ▪ Sales engineers	▪ Rule-, model-, case-based reasoning ▪ Distributed constraint satisfaction	▪ Configurators ▪ Recommendation systems
Co-Production	▪ Customers ▪ Supply chain managers ▪ Production engineers	▪ CPFR ▪ Contracting (game theory)	▪ Advanced Planning Systems

4.3. Advancing Collaborative Engineering via Mass Customization

Based on the discussion in previous sections, collaborative engineering has wide applications in mass customization. Reciprocally, the vested interests of different players in mass customization offer a realistic and promising test bed for developing new collaborative engineering theories, technologies, and tools. On one hand, there's strong need in mass customization for more effective means of collaboration; on the other hand, there're problem solving methodologies within collaborative engineering research.

There is great need for more effective means of collaboration in mass customization. More specifically, individual customers are actively integrated into the value chain in customization, but there's a gap between customers and manufacturers in terms of domain knowledge and product-specific information, which will create barriers for communication and joint problem solving. Furthermore, during the customization process, customers' preferences are often not fully aligned with manufacturers' preferences. The diversity, irregularity, and unpredictability of individual customers' needs and preferences pose great challenges for effective conflict resolution. Last but not the least, the simultaneous need for high variety, efficiency, responsiveness, and flexibility in mass customization creates enormous tensions between different performance objectives and further aggravates the challenges for effective collaboration in mass customization.

The move towards mass customization challenges existing methodologies and techniques in collaborative engineering. Generally speaking, existing research in collaborative engineering tends to focus on the *technical* aspects and the *integrative* part of collaboration, i.e. how to share and aggregate information and optimize from an overall perspective. Future research is needed to pay more attention to the *social* aspects and the *distributive* side of collaboration, i.e. how collaboration is conducted in a social context and how conflicts could be jointly resolved. The emerging research in ECN (Lu 2003) as a new paradigm of collaborative engineering is a promising research direction for further investigation. As an exploratory study in this direction, Chen and Tseng (2005) propose a negotiation support system based on multi-attribute negotiation to facilitate collaborative product specification definition in mass customization.

5. Conclusion

Mass customization defies the contradiction between *mass* and *customization* and aims to deliver products and services that best meet individual customers' needs with near mass production efficiency. A novel and ambitious concept as it is, mass customization is also exposed to various conflicts, both strategically and operationally. Ultimately, these challenges and conflicts can be traced to the asymmetry of information and the diverging preferences between manufacturers and individual customers, who need to work collaboratively for creating new alternatives that are not in the conventional offerings. Thus, economic value is created by offering the additional customer satisfaction without significant sacrifice of efficiency in design and production etc. The innovation of developing new options is primarily a collaborative effort among participants of diverse sets of self interests. Therefore, it is important that all parties concerned can engage in collaboration with sufficient trust where we believe collaborative engineering can play a significant role. Collaborative engineering can be essential for customers, manufacturers and suppliers with different information, expertise, motives, preferences, and agendas to engage in interactive and joint conflict resolution.

This paper explores the synergies between mass customization and collaborative engineering. General scenarios of applying collaborative engineering in mass customization (*co-innovation*, *co-configuration*, and *co-production*) are proposed based on a generic mass customization framework and discussed in collaborative engineering perspective in terms of *people/team*, *engineering methodologies*, *technical tools*. Reciprocally, the potential use of mass customization as a test bed for advancing collaborative engineering research is also discussed and future direction of research is pointed out.

Based on these scenarios, this paper reviews relevant works across a wide spectrum of interdisciplinary research topics. It appears that there is a mutually reinforcing linkage between mass customization and collaborative engineering, although both of which are disciplines of research on their own right. There’s great potential for creating new knowledge for advancing both subjects. This paper serves as initial identification of possibilities and hopes to attract attention for future research in this potentially rich field of study.

Acknowledgement:

This research is supported by National Natural Science Foundation of China (NSFC: No.70418013) and Hong Kong Research Grants Council (RGC: N_HKUST625/04).

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