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How to cite:
Tseng, Mitchell M., Yue Wang, Roger J. Jiao. (2017) Mass Customization. In: The International Academy for Produ, Laperrière L., Reinhart G. (eds) CIRP Encyclopedia of Production Engineering. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-35950-7_16701-3

Mass Customization

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Synonyms

Personalization

Definition

Mass customization aims to deliver products and services that best meet individual customers' needs with near mass production efficiency (Tseng et al. 1996). In this paradigm, it is critical to provide individually designed products and services by considering every customer as an individual through process agility, flexibility, and integration of product life cycle. A brief summary about the basic properties that make mass customization unique is summarized in Table 1.

Mass customization implies a shift of design and production paradigm from "made-to-stock" to "made-to-order". It challenges the conventional product development and supply chain management, calling for adopting mass production approaches to accommodate "high-variety-low-volume" production. In order to support the paradigm shift derived by the customization process, the enterprise should reconsider the entire value chain to leverage upon three pillars: time-to-market, variety, and economy of scale.

	Mass Customization (MC)
Goal	Delivering affordable goods and services with enough variety and customization that everyone finds nearly exactly what they want
Economics	Economies of scope and customer integration
Focus	Variety and customization through flexibility and responsiveness
Product	Product family and standardized modules assembled based on customer needs
Key Features	▪ Unpredictable demand pattern ▪ Heterogeneous niches ▪ Integrated goods and services ▪ Short product development cycles ▪ Short product life cycles
Organization	Flexible and adaptive
Customer Involvement	In order to meet the customer requirements with efficiency and effectiveness, active customers' involvement though out the product life cycle is essential. Thus, user innovation, co-design, customer configuration and others have become important tools in MC.

Table 1: Properties of mass customization (adapted from Chen et al. 2009)

- Dichotomy of scope and scale

Mass customization was first coined by Stan Davis in Future Perfect (Davis 1987) and later developed by Pine II (1993). It embarks a paradigm shift for the enterprise to offer products and services best catering to individual customer's needs whereas keeping near-mass production efficiency (Tseng et al. 1996). The key feature of mass customization is the capability to integrate the product varieties derived from the individual customer's needs with repetition of modularity and the efficiency of mass production, so that the products are affordable due to low product cost achieved by the scale of economy in production.

Traditional mass production leverages upon economies of scale that emphasizes reducing the average per unit cost of the products and services by increasing the scale of production for a single product type. The key of mass production efficiency is to produce and deliver more of same design of a given product or service by defraying the fixed cost with higher production quantities. In addition to economies of scale, mass customization must achieve economies of scope, which aims to lower the average per unit cost by expanding the number of products and services to be offered. Comparing to economies of scale, economies of scope is a similar but different concept, in that it’s not about making a lot vs. a little of the same product, but about making different but compatible products and services. By using the same facilities, equipment, labor force, technologies, etc., an enterprise can still produce with product diversification to increase revenue. The theory is that offering several different products and services can be done more efficiently than relying on standard products and services, owing to the fulfillment process can distribute the costs over a greater revenue base. What critical to product diversification is to produce and deliver a differentiation or varied products and services by taking advantage of much of existing capabilities of design and production.

Theory and Application

- Design for mass customization

Design for mass customization (DFMC) calls for extensive coordination between many disciplinary emphases. In general, it goes beyond the traditional territory of product design and involves more front-end business and marketing efforts. At the backend, the DF’X’ mindset is extended to take into account downstream production and logistics concerns. Such a complex engineered system requires systematic management throughout customization and personalization decision making. The decision framework of DFMC along the entire spectrum of product realization can be positioned according to axiomatic design (Suh 2001). In a holistic view, DFMC encompasses consecutively five domains, namely the customer, functional, physical, process and logistics domains

(Tseng et al. 2010). Customization and personalization decision making involves a series of "what-how" mappings between these domains.

- o Understanding customer needs

The customer domain is characterized by a set of customer needs (CNs) that are generally categorized as legacy and latent CNs. The CNs are translated into functional requirements (FRs) in the functional domain, in which the specification of a product ecosystem is formulated by taking into account customer and engineering concerns. One crucial step of design for mass customization is to understand individual customer's needs and transform them into functional requirements. The mapping between the customer and functional domains constitutes the front-end issues associated with customization and personalization. As a "co-designer", the customer can directly interact with the producer to express the requirements or even directly design the product, usually through web-based interface.

However, the task of understanding and characterizing customer needs is challenging (Wang and Tseng 2011). Customer needs are subjective. Each individual customer's perceptions to the product depend largely on complicated internal and external factors and differ from person to person. For example, when selecting a cell phone, different customers may have totally different perceptions of aesthetics, comfort and easy-to-use to the same product. The levels of subjective preferences and the corresponding scales may vary significantly across customers. In addition, customer needs and requirements are context-dependent. Customers may vary in their preferences and decision making criteria due to the purchase situation changes. The external factors like mood, emotion or impulsive feeling can also affect their preferences and requirements. Since it has been acknowledged that the key to product success relies on better understanding of the voice of the customer and on better links between the preference of the customers, including artistic appreciation, sensory feedbacks, and value judgment with the capability of the companies, it is imperative to discover new ways to characterize and incorporate customer needs in mass customization practice.

- Modularity and product family architecture

In order to take advantage of economic of scale while trying to serve customers as individuals, product modularity and the underpinning effective product family architecture have been considered as effective approaches to achieve mass customization. Product family design offers a systematic instrument to define product platform, the product architecture, and product families. Product platform is "a set of subsystems and interfaces developed to form a common structure from which a stream of derivative products can be efficiently developed and produced" (Meyer and Lehnerd 1997). Product architecting is mainly concerned with how a product is arranged into physical units and how these units interact (Ulrich and Eppinger 1995). With various adoptions of different product models, Erens and Verhulst (1997) described the architecture of product families. Fujita and Ishii (1997) discussed design for variety in terms of structuring essential tasks and issues associated with variety design. They also tried to optimize the systems structure and the configuration of product families simultaneously (Fujita et al. 1998). However, their work focuses on computational support instead of product architecture planning. Tseng and Jiao (2001) recognized the rationale of a product family architecture with respect to design for mass customization. They addressed an efficient method to tailor different products according to different customers' requirements based on common product family platform. They also observed the difference between customer-perceived variety in terms of functionality and technical variety, which results in different variety design themes.

There are two types of prevailing product family design, scalable product family design and configurational product family design (Jiao et al. 2007, Jiao 2011). Simpson first proposed the scalable approach by using scaling variables at different dimensions to satisfy a variety of customer needs (Simpson 2004). There are two major tasks in scalable product family design. The first one is to determine the appropriate platform. It is followed by the step of optimizing common and distinctive variables' values to better satisfy performance and economics requirements. In a nutshell, the scalable product configuration is to employ scaling variables to shrink or stretch the platform in various dimensions to satisfy diverse customer needs whilst other variables are kept constant. Thus, the important issues are to first decide which variables should take common value in the product family and then determine the optimal value of the common and distinctive variables in terms of customer needs and design requirements. In modular product configuration, the product is designed from adding, substituting and/or removing functional modules.

The other stream of product family design is configurational product family design based on modular product architectures. It is also called module-based product family design (Ulrich, 1995). The modular product configuration takes advantage of modular components. The product module involves a one-to-one mapping from a functional requirement to the physical product feature. The product infrastructure with the specified decoupled interfaces between components allows each module to be changed independently. Various modules can be introduced independently to satisfy customer's heterogeneous needs.

- Configuration

The prevailing practice of DFMC manifests itself through a configure-to-order paradigm, which means to satisfy explicit customer needs and built upon legacy design. Product configuration systems serve as an important enabling toolkit to realize mass customization. Basically, a product configuration system attempts to elicit customer needs and map the needs to design parameters (Piller and Tseng 2010; Wang and Tseng 2014c). A product configurator consists of a set of predefined components or attributes, along with their constraints, to regulate the combination of components. It takes customer needs as input and the output is the desired product variant. Traditional study on product configurations focuses on the reasoning in configurations, modeling of configuration knowledge, the reuse of configuration, etc. One trend in current product configuration research is to incorporate more business intelligence factors into configurators, such as product recommendation (Freuder et al. 2003; Junker and Mailharro 2003; Tiihonen and Felfernig 2010; Wang and Tseng 2013), customer emerging needs detection (Urban and Hauser 2004; Wang and Tseng 2014a and 2014b), and improving efficiency of the choice navigation process of customization (Wang and Tseng 2007 and 2011; Jalali and Leake 2012;). User innovation, data mining and Web learning lend themselves to be the main techniques of customer requirement acquisition and reasoning about user experience (Zhou et al., 2011a). New cyber-physical platforms, such as Web 2.0, cloud computing, P2P and SecondLife, offer great potential for implementing value chain platforms into online personalization engines that can provide recommendations on latent CNs (Zhou et al., 2011b).

- Fulfillment for Mass Customization
    - Flexible manufacturing for mass customization

As the exponentially increased number of process varieties significantly challenges production planning and control of conventional manufacturing process (Tian et al. 2008; Terkaj et al. 2009a), it is critical to have flexible manufacturing process in mass customization. From mass customization perspective, two approaches have been employed to improve the flexibility of a manufacturing process. Manufacturing process family is one important approach. The concept is to comprise a set of similar production process for various products to achieve economy of scale by utilizing the common components and standardized product platform designed within a product family. Thus, the manufacturer is able to configure the production process with quick response to product design change, by exploiting the similarity among the product variety and production process (Colledani et al. 2008).

Manufacturing for mass customization also relies on the availability of flexible manufacturing system. In addition, the system should be incorporated with the advent of modern Information and Computer Technology (ICT) as well as the flexible or reconfigurable manufacturing tools, to reduce the response time from designing a new product to the production ramp-up (Terkaj et al. 2009b). For instance, such system can produce a new last for shoe production within 5 days since the customized shoe order is received. The system enables designers to change the CAD model easily with the limited additional cost. It is equally important that the flexibility in workforce and production management systems are also key to achieve the seemingly conflicting goals of mass customization. With more educated human resource, decision to meet diverse requirements without increasing cost. Likewise, robust production control is essential to achieve on time delivery with complexity of materials management and logistics to realize mass customization.

- Reconfigurable manufacturing system

Product variety can be very high under mass customization regime to cope with the changing product mix and demands. Manufacturing systems for mass customization need to well address the challenges. Reconfigurable manufacturing systems (RMS) were proposed by Koren et al. (1998). An RMS is a system that is designed at the out-set for rapid changes in its structure and control in order to adjust its production capacity and functionality within a part family in response to sudden market changes. Configurations of the manufacturing system play an important role in impacting the performance of the systems. It should be noted that RMS is different with flexible manufacturing system in the sense that RMS attempts to increase the manufacturing's responsiveness to markets and customers and flexible manufacturing system aims at increase the variety of part produced. The flexibility of a RMS is confined within the product family.

- Delaying differentiation

To manage the high uncertainty and variety in manufacturing systems, delayed product differentiation or postponement strategy is widely used in industry. It refers that the manufacturing process makes a generic or family product at the beginning and differentiate into a specific end-product in the later stage when more information about the demand is obtained. Thus the point where the different products take on their unique characteristics is postponed. The processes and assemblies are common up to the point of differentiation. Such delay reduces cost and improves responsiveness of the assembly systems (Lee and Tang, 1997; Ko and Hu, 2008).

Figure 1 illustrates how delayed product differentiation is achieved though process configuration with postponement of variety fulfillment. Multiple end-products can share those common components/modules and the corresponding fulfillment processes at initial stages, leading to a generic product that is indifferent in end-product variety. At a certain point, custom components/modules or specialized processes are enacted to customize the generic product to different end-products. Therefore, mass customization is empowered by architecting product platforms and reengineering the manufacturing processes to delay decisions about specific products as late as possible.

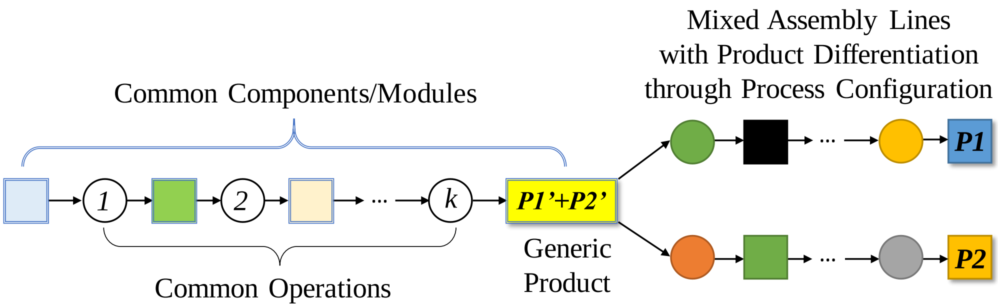

Figure 1. Postponement of variety throughout the fulfillment process

- On-demand manufacturing system

To increase the responsiveness to customer demands, it is critical for manufacturing system to fabricating personalized product features and modules and assembling these modules with other manufacturer supplied modules flexibly. Additive manufacturing has been considered as an enabling technology towards personalization (Srinivasan and Bassan 2012). It can create 3D solid objects directly from a CAD model cost-effectively. In addition, a cost effective on-demand assembly system should be able to configure and reconfigure product in response to customers' personalized designs.

- Cyber-physical systems

Cyber-Physical Systems refer to engineered systems that are built from and depend upon the synergy of computational and physical components (NSF report - Cyber-physical systems 2012). To support the distributed personalization design collaboration and on-demand manufacturing, it is necessary to integrate computational tools with the physical design and manufacturing systems. The development of new user interface methods and tools for personalized production will be critical to support the scalable user experience and collaborative, distributed design approaches. Considering users may share and view the design with likeminded people, we can leverage on existing cyber-social networking infrastructures to support these users. Methodology to identify emerging customer needs will be needed to address the potential business opportunity of new market and new product development.

- Future direction

One of the main streams of MC is to better defining customer requirements. Customer participation in the design process has shown to be the most promising way of getting the requirements efficiently and effectively. Currently the whole process was mainly managed by the designer and the product was finally manufactured and delivered by the producer. However, with the new interactive computing technology, it is possible for consumers to control and dominate the process in virtual environment. Thus, the role of the designer will be shifted to product platforms with sufficient supports to assist the process. It means that the product can be customized at any time when the consumer thinks it is necessary to do so, even after the product has been purchased. Such freedom would offer significant opportunities for consumers to dynamically adapt the product for their new needs as well as reflecting their identity and efficacy through the creative design and modifications, throughout the lifespan of the product. Customers become more connected. Products and services are increasingly knitted to a larger ecosystem of interacting objects. A product ecosystem can be considered as a dynamic unit that consists of all products and users, functioning together with its surrounding ambience, as well as their interactive relations and business processes. Looking at the whole sum of interacting objects and understanding the flow patterns of the ecosystem are for the future of mass customization.

Looking forward, with the entry barrier reduced in both customer requirements acquisition at the front end and product delivery at the back end, we can thus extrapolate mass customization to open customization, along with the similar concepts as open system and open innovation. Open customization, still a working definition, is a paradigm that motivates people to participate, to create, to learn, to acquire, and to recover in providing goods and services to fulfill individual needs, not only products, but also the process of producing, with fair competition.

Finally, the social aspect of product and service platforms in mass customization is emerging as an interesting research area, as a product-service ecosystem is often associated with social networks. Interactive information sharing among customers is becoming fast and convenient over the Internet with the online social networks (e.g., Facebook) or review sections of shopping websites (e.g., Amazon). The increasing availability of data about peer interactions and the popularity of marketing communication techniques based on such interactions have led to even greater interest in understanding the effects of peer influence on customers' choice decisions of product offerings (Iyengar et al. 2010). The extensive reach of the Web and the prevalence of social networking sites have made large amounts of data on social networks easily available, which has recently resulted in their recognition as an important tool for marketing (van den Bulte and Wuyts 2007). Because the market is shifting to the online environment and due to the competitive nature of industries, it is important for firms to benefit from such information with appropriate marketing and product family design strategies (Panchal and Messer 2011). While the effect of peer influence has been well documented in marketing research (Childers and Rao 1992), social network effects have generally been neglected within the product family design process (Günnec 2012). Recent advances in social media that allow better access to social networks of customers have profound technical and economic implications for product and service platform development. A phenomenal trend is emerging towards social commerce (Decker 2007), which makes academia and industries recall the dot-com and e-commerce revolution of the previous decade ago. Abundant research opportunities exist in response to the emerging trend of open architecture product and service platform development that aims to leverage upon systems, humans, cybernetics, and businesses.

Cross References

Modular Design

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