Mass Customization and Footwear

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Abstract:

This paper provides a roadmap of how mass customization can be applied to footware design. Particularly, the following questions are to be considered: What shoes are being customized in the market? Can you give more examples? What is the difference between a pair of “tailor-made” shoes with a mass customized one? What is the value derived from the footwear customization? What is the additional cost incurred in the footwear customization? What are the key dimensions of the footwear customization? How do they influence the footwear design? What is the role of a customer playing in a footwear customization process? How can a customer influence the attributes of the customized shoes? How should a conventional design process be changed to realize the mass customization strategy for footwear?

Keywords: Mass customization, footware, customer preferences

1. Introduction – Mass Customization and Footwear

In this new millennium, two critical driving factors are identified that may dominate the footwear business and initialize a paradigm shift (Boër and Dulio 2007). First, there is an increasing competitive pressure from low labor cost producers, especially from China and the Far East. Those competitors are capable of delivering products of a similar quality, but at a better price. In order to reduce the production cost, major shoe companies are forced to split the production processes, outsource several production steps to the areas with lower labor costs and organize global production and supply chain network. The low cost competition also results in a market push towards further diversification and demands for increasingly higher quality products. Secondly, there is a trend that the footwear industry is increasingly integrated into the fashion industry, driven by a few multi-product oligopolies. Consumers now expect shoes not only to offer comfort but also reflect their personal identities. Thus, higher fashion consciousness and personalized shoes have been identified in the footwear consumer market (Piller and Muller 2004). Facing two driving factors of paradigm shift, all shoe providers should develop new business strategies and look for innovative business models in order to maintain a competitive advantage. Shoe producers should spend more effort on product quality improvement, innovation in design and materials, quick response to dynamic fashion trends, and more importantly, the individual consumer's personalized needs and relative supporting service rather than simply offering goods.

Mass customization regards heterogeneous demand among different customers not as a threat, but as a new opportunity for profits. A working definition of mass customization is adopted as "*the technologies and systems to deliver goods and services that meet individual customers' needs with near mass production efficiency*" (Tseng and Jiao 2001). This definition implies two major goals of mass customization: achieving products of high quality which was defined as satisfying consumers' individual needs and in the meantime keeping the cost as low as close to mass production. In other words, mass customization recognizes each customer as an individual and provides attractive "tailor-made" features which could only have been offered in the pre-industrial craft era, while customers can now afford this kind of product due to the low production cost from modern mass production efficiency and high flexibility. The elicitation of an individual's consumer needs relies on active interactions with the consumer, and the specific information about the consumer's desires are translated into a concrete product or service specification (Zipkin 2001). With an interaction and configuration toolkit, customers are able to express their product requirements and carry out the product configuration process by mapping the requirements into the physical domain of the product, so that customers are considered as "co-designers" (Von Hippel 1998; Chen et al., 2007). On the other hand, the competitive advantage of mass customization is its capability to combine the efficiency of mass production with the diverse varieties derived from individual consumers' needs and desires, so that the production of mass customized products can still achieve the scale of economy. However, current practices of mass customization in many industries have shown that customers are usually willing to pay a price premium for customization, as the satisfaction of individual needs increase the perceived value of the product (Tseng and Piller 2003; Franke and Schreier 2010; Tseng et al. 2010). Thus, the adopter of mass customization may be able to enjoy a higher profit margin. Therefore, because of the main features in providing customers with more personalized and more profitable products without increasing production costs, mass customization strategy is a good fit to the paradigm shift of the footwear industry.

Mass customization can be a win-win strategy to both the footwear producer and the consumer. With mass customization, customers can have a much larger product range from which to select, and it is easier for them to have shoes which can reflect their individuality. In order to meet the goals, from the producer's perspective, mass customization requires the company to be customer-centric, to be able to respond quickly to market, and efficiently manage production and supply chain.

A. Customer Centric Mass customization integrates the consumer into the company's value-creation activities. In a traditional footwear business, after a pair of shoes is sold to a consumer, the product life is over from the perspective of the footwear producer, as no further value is generated and returns to the company during the product in-use. However, in this new strategy, the consumer takes part in many activities which used to be the domain of the company, such as concept design and product development, which become the resource for future design. The customer's requirements and feedbacks are the company's initiation points of the activities in the value chain, and a long-term relationship of mutual trust is developed between the customer and the company. In many practices, customers are even considered as the "co-designer" more than simply "consumers". The customer can directly interact with the shoe producer to express the requirements or even directly design the shoes themselves (Tseng and Piller 2003). Meanwhile, the company is also able to learn more about the customer's personal preference and serve her needs more accurately than competitors. Thus, the customer centric company can not only improve customer satisfaction on the product with better fitting to an individual's needs, but also create customers' loyalty so that the customer is more willing to come back in the future to maintain the mutually beneficial relationship with the shoe producer.

B. Quick Response to Market With direct communication with the customer and immediate feedback, the shoe providers can respond to the dynamic market more quickly with a mass customization strategy. The knowledge collected from the consumer's co-design can better assist the company to assess and predict the customer's rapidly changing needs, which are the key for next season's new products. In addition, with the customer's online account which is established during online customization, the providers can better employ one-to-one marketing, promoting and collecting feedback from individual consumers. Thus, analytical knowledge management combined with quick feedback collection can enable the shoe providers to become more reactive to the changes in the shoe market (Boër and Dulio 2007).

C. Inventory and Supply Chain Management Efficiency As mass customization is a make-to-order process, the shoes are only made when the purchase order is placed. Thus, the shift from “made-to-stock” to “made-to-order” can significantly improve the production and supply scheduling and reduce the inventory cost and the risks of investment in materials and product development that will not encounter the preference of consumers. Furthermore, mass customization can be conducted online in some cases, so that many providers even sell shoes completely online without any physical stores, such as Zappos. This strategy can further reduce the operation and rental costs by online direct channel sales and increase the profit margin rate (Tseng et al. 2003). Even for those providers still with physical stores, they no longer have to show a full inventory of selection in all stores.

2. Dimensions in Customized Footwear

Setting the right extent of mass customization is of importance in footwear customization. According to current prevailing practices, mass customization in the footwear business can be divided in three different dimensions, including style customization, comfort customization, and function customization (Boër and Dulio 2007).

2.1 Style Customization

Style customization in shoes aims at satisfying customers’ diverse demands on shoe aesthetics and self-identity reflected by the shoes. Shoe styles have been strongly considered as expressing the wearer's personality and having the capability of transforming them into more handsome, beautiful and confident people. Even for adolescents and young adults, shoes are usually a key signifier of their identities, individualism, ethnicity and personality, and it also happens that their desired shoe styles conflict with what their parents regard as appropriate (Belk 2003). Current trends include antiquated, vintage, and contemporary designs with burnished or tumbled leathers. Causal and formal styles are usually combined and woven leathers are abundant. In addition, graffiti motifs and checkered patterns are increasingly popular in sneakers, and more super-lightweight, air-breathable, waterproof and abrasion-resistant materials are used in sports shoes (Cantor-Stephens 2007). In style customization, based on the standard lasts and sizes, the customer can choose from diverse style options, including colors, fabrics, leather, and other accessories, within the constraints set by the provider (Piller and Muller 2004).

Style customization should integrate customers' personal preference and current fashion trend. It offers customers the freedom to configure shoes by selecting favorite options among a list of possible variants based the standard shoe design (Boër and Dulio 2007). This strategy has been widely adopted by many large shoe producers, because it requires less effort from both producers and customers. Although style customization involves high costs in design sales, it has little effect on manufacturing and production costs.

The style customization is usually conducted online, and it is a shoe configuration process that is controlled by the customer. Large shoe producers, such as Nike, Adidas, Timberland, and Selve, have different features in style customization, but the basic process for customer participation is common. Customers customize the style through a computer configuration toolkit, usually at the website of the company or sometimes at a computer in a physical retail store. With the toolkit, customers can create their own version of shoes by changing colors or materials on specific parts of the shoes. For instance, a typical configuration toolkit is shown in Figure 1, and is developed by Selve, a Munich and London based provider of customized footwear. Although customers are limited to a pre-defined design freedom, they can totally control the configuration process without interception by the producer. However, on the other hand, this strategy also requires that customers know the size of shoes they wear and provide this information during the configuration, as there is no foot measurement in this process. After the customer finishes the configuration and feels satisfied with the customized shoes, a purchase order can be made online, which is then transmitted to the manufacturers and initializes a production order. Usually, the style customized shoes can be delivered to the customer's address within one or two weeks, or a little bit longer for luxury-class hand-made customized shoes. Currently, many shoe providers are trying to reduce the delivery lead time.

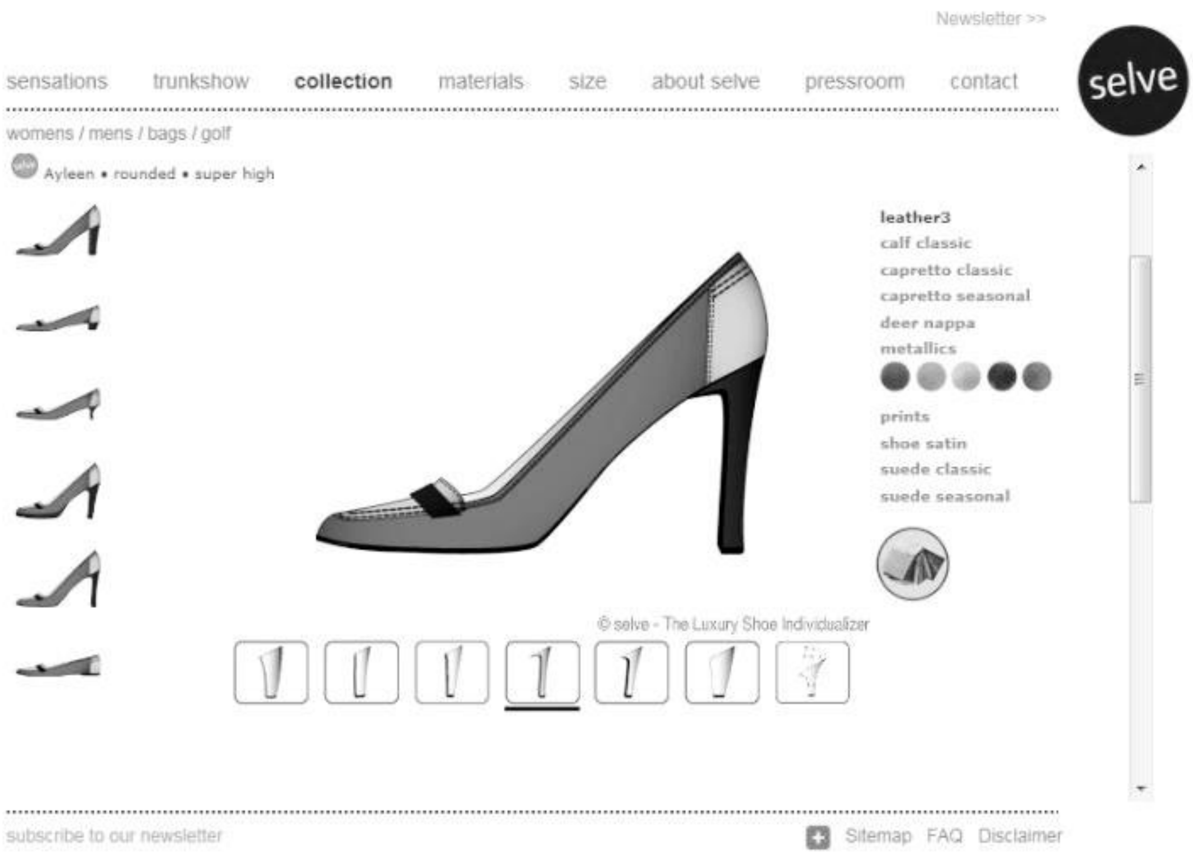

Fig. 1 Selve style customization toolkit (courtesy of Selve)

2.2 Comfort Customization

Comfort customization is to configure a pair of shoes in order to make the consumer feel comfortable and well fit , which is based on the fit of shoes with the foot measurement of the customer (Boër and Dulio 2007). There are two types of approaches for measuring foot shape in order to make the wearer feel comfortable. One is the measurement of static foot shape, including lengths, widths heights and girths of feet, which can be measured by laser scanner technologies. The measurement data should match with those of shoes, including the shoe last , the design of the upper, lining, toe shape, insole, outsole etching, and the materials used in fabrication (Witana et al.

2006). Besides the static measurement, it is also important to measure the dynamic shape of the feet in motion, because the foot deforms while walking or running. A popular approach is to analyze the foot motion in the stance phase of the gait cycle, because the nonconformity between the shoe and the foot shape happens during the stance phase (Kimura et al. 2011).

Comfort customization can be addressed by two approaches, custom fit and best-match fit (Boër and Dulio 2007). Custom fit is to exactly and strictly tailor a last and a shoe on the dimensions and morphological data of the consumer’s foot. During craftsmen and cobbler times, most shoes were made with a custom fit for each individual customer by carefully measuring the feet of the customer and manually constructing the shoes. A few luxury shoe producers are still working this way, but most ordinary customers cannot afford the expensive price. Best-matched fit is to choose a best-matching last to aim at the privileging comfort, in order to avoid the production of tailor made, individually adjusted lasts. Different from custom fit, the last and all shoe components are pre-defined in best-matched fit. After measuring a customer’s feet parameters, the system selects the one last which is closest to the dimension of measurement. Thus, no individually new last model is produced in best-matched. With advanced foot scan technology and sufficient knowledge about foot fit, best-matched fit achieves a compromise between the comfort perceived by the customer and the increased cost in design, sale, and manufacturing. The consumer may not be able to really differentiate the comfort of shoes made by best-match fit and custom fit. As long as the range of the pre-defined dimensions is large enough, it is believed that no difference is perceived in comfort from a custom fit shoe to a best-matched one. Actually, these two approaches are theoretically the same, as they are both based on optimal approximation, in which best-matched fit approximates to an existing last, while custom fit to a mathematical limit to the real feet.

Comfort customization usually focuses on formal shoes. As this kind of shoes can reflect the owners' identity, people are usually willing to spend more time and money purchasing the fittest ones, just like customized business suits. Large shoe producers who have started comfort customization include the American Otabo, Finnish LeftFoot, and the German Selve. In most practices, customized shoes for comfort fit are sold through real stores, instead of online stores. Sales people use foot scanners to take customer's feet dimensions, store the data, and identify some foot problems, such as different sizes in left and right feet. Then, customers try on the sample shoes selected with best match between customer's foot measurement and the database. In addition, customers can also select different models, outsoles and heel, which may be classified as style customization. After customers finish the configuration and feel satisfied with both the style and comfort, a purchase order is placed in the store and customers may wait for product delivery to their home.

2.3 Function Customization

Function customization is to make a shoe for each individual consumer by "optimizing" its dimensional parameters, techniques and materials in order to match the use the consumer will make of their shoes (Boër and Dulio 2007). It specifically focuses on the functionality or interfaces of the product, such as selecting speed, precision, power, cushioning and output devices (Piller and Muller 2004). Due to the intricate and specialized nature, function customization is currently employed by sports shoes manufacturers, such as Adidas, Nike and ErtlRenz sport shoes. The shoes for many professional sporting stars are made in this way, and they are usually hand-made individually for each one of them. Designers capture the star's running behaviors and apply specific techniques to protect stars' ankles or improve the sporting performance. In the consumer market, sports shoes have been categorized into different groups according to their diverse functions, such as soccer, running, tennis, golf, etc. The purpose is to maximize the usage utility of the shoes, and provide the best foot protection to customers during sports. However, function customization in the footwear industry should not be limited to sports shoes, and it can be designed for any people who require special functions, such as elderly people. For instance, functional customized shoes may have a huge potential in the foot orthoses and personal health market. It is found that wearing customized shoes can be included in the physical therapy for postsurgical rehabilitation of patients with severe rheumatoid arthritis (Shrader and Siegel 1997). In addition, "Dr Foot" in the UK offers special insoles to provide extra longitudinal support and cushioning. Therefore, more shoe providers will extend the focus to offer personalized foot health functions through their footwear products.

Most current prevailing sales practices of functional customization are similar to comfort customization. Customers can purchase customized shoes from both online stores and real stores. In online stores, customers usually do not have much freedom, and sometimes they can only select from existing shoe libraries according to purchase navigation. For instance, for Adidas running shoes, customers can only choose shoes based on different running behaviors, including underpronation, normal, and overpronation. However, such a simple process is reasonable as customers usually do not have much knowledge of technical functionalities. If faced with a complex configuration process, they would rather choose to leave. On the other hand, in the real store, a customer will be invited to a dynamic measurement device, such as the Footscan stage in the Adidas Flagship store, and run on the device to elicit the main features of her running behavior for detailed product configuration. Specific models can be selected for precise sports and uses, such as running, soccer, basketball and tennis. In addition, customers can also configure the style of the shoes. After a purchase order is placed, the product will be delivered to customer's home in several weeks.

2.4 Combined Strategy and Challenges

The prevailing practices of shoe customization show that different dimensions of customization strategies are not necessarily mutually exclusive. Instead, companies are taking a combination of these areas to offer the best value within the customer's budget with a combination of different emphases. Thus, the nature of shoe customization is addictive (Boër and Dulio 2007). Style customization has become a popular option provided by many shoe producers, and it is usually employed simultaneously with comfort customization or function customization in one shoe product.

Meanwhile, however, the three dimensions of shoe customization also result in more challenging requirements that a shoe provider should satisfy in order to adopt the paradigm of mass customization successfully. Customer participation in the product configuration process and the resulting large amount of product variants requires for more efficient customer-oriented and product variants management. In addition, a high variety of the products also challenges providers' ability to take advantage of flexible manufacturing and supply management to achieve the economics of scale in order to reduce the production cost. Thus, the shoe providers should apply diverse technical approaches to the each step of the value chain in order to address those new challenges.

3. Technical Approaches in Shoe Customization

From the customer's perspective, the whole shoe customization process can be broken down into four steps: search for favorite "basic" shoes, co-design and configure the shoes, make an order to purchase the customized shoes, and receive the shoes delivered to home soon. To support the customization process, the producer should reconsider the whole value chain from the front-end, including product portfolio management, customer interface design and product configurator, to the back-end including flexible manufacturing and supply chain management, as shown in Figure 2.

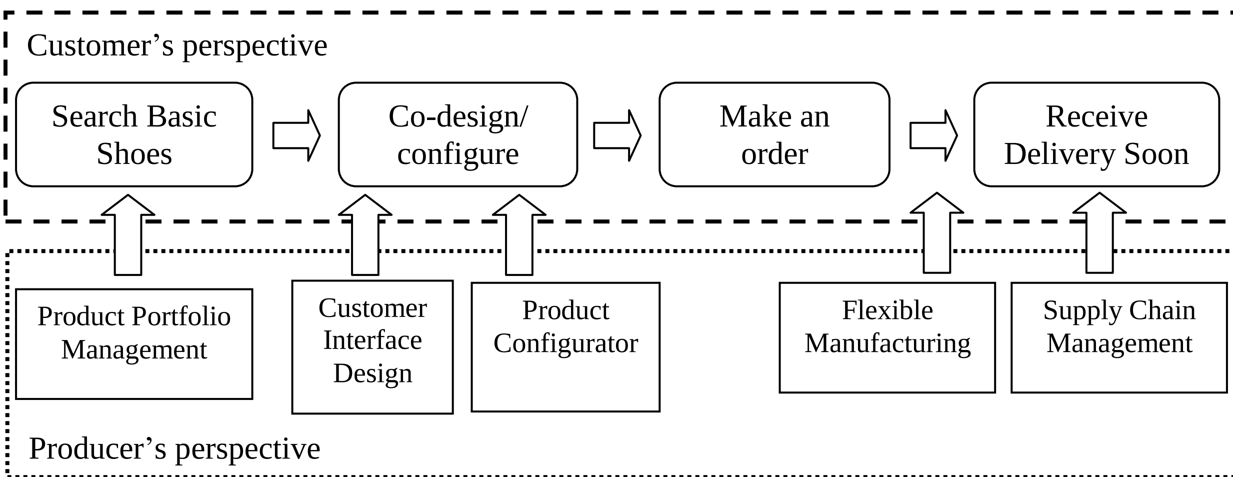

Fig. 2 Technical approaches to support shoes customization

3.1 Product Portfolio Management

Product portfolio management is especially important for style customization, which derives a huge amount of product variety from customer's customization. Customers are provided with a "basic" shoe to customize and a variety of style options and accessories. Thus, how many varieties should the shoe provider offer to the customer? In the original mindset of mass customization, designers make a large variety of products available and let customers choose from the shelf, but it has been found as unnecessarily wasteful and expensive, which may also lead to mass confusion and constrain customer satisfaction (Huffman and Kahn 1998). Thus, designers must leverage from marketing studies to identify the shoe features preferred by the customer and market segments with higher profit potential. The essential question of the product portfolio is to decide how to offer the right product variety to the right target market (Jiao et al. 2007).

Feasible product portfolios are usually developed with emphasis on portfolio optimization based on measuring customer preference in terms of expected utilities (Jiao and Zhang 2005), in which the objective is to maximize sale profit and market share. Conjoint analysis has been widely employed as an effective means to estimate consumer preference, such as part-worths, importance weights and ideal points associated with individual product attributes (Green and Srivivasan 1978). Considering substantial amount of diverse variations in consumer preference, conjoint analysis is usually conducted at the individual level, and the basic steps are introduced as follows (Green and Srinivasan 1990). The first step of conjoint analysis is to select one preference model, such as vector model, ideal point model, or part-worth function model. The mixed model can be developed by allowing some attributes to be treated as the part-worth function model while others follow vector or ideal point models. The second step is to select a data collection method. A popular one is a full-profile method, which describes each option on all of the attributes and measures overall preference judgments directly by behaviorally oriented constructs such as willingness to pay (WTP) and chances of switching to a new brand, usually conducted through online surveys. The third step is to construct a stimulus set, such as fractional factorial design, random sampling from a multivariate distribution, and Pareto-optimal designs. Then the fourth step is to develop a stimulus presentation method, including verbal description, paragraph description, pictorial or 3D model presentation and physical products. In addition to rating and ranking scales, the paired comparison is also widely used as measurement scale for the dependent variable, which is the fifth step. Since conjoint analysis is based on regression estimate procedures, its last step is to determine an estimation method to deal with instability of estimated parameters facing various sources of error variance. With the development of information technology, adaptive conjoint analysis is also proposed, which starts with a simple self-explication task through which the respondent's more important attributes are identified (Green and Srinivasan 1990). It is dynamic and the respondent's previous answers are used at each step to generate the next paired comparison questions so that most information can be elicited. In the study of "Design by Customer" (Tseng and Du 1998), adaptive conjoint analysis is applied so that customers can navigate through product families, define their preferences, and then design the products in the sense that they may map their own functional requirements into a physical domain on their own. The technical challenge is at preparation and presentation of product portfolios so that the customers can make the best informed decisions to select a desired one to fulfill their needs.

The other challenge in generating a product portfolio is to tackle the optimal selection of promising products by maximizing the surplus – the margin between the customer-perceived utility and the price of the product, the objective of achieving best profit performance. Green and Krieger (Green and Krieger 1985) first consider a buyer's problem in which a product line is selected to maximize customers' utilities. They also propose a seller's problem in which the product line is chosen to maximize sellers' return, constrained by each buyer's choice of the most preferred item from the product line. Jiao and Zhang (Jiao and Zhang 2005) propose a portfolio selection approach with the goal of maximizing an expected surplus from both the customer and engineering perspectives, in which the manufacturer must determine what combinations of attributes and their levels should be introduced to offer the potential products or be discarded from consideration of product offerings. Such models can integrate marketing analysis inputs with the cost information associated with product development and manufacturing process, and capture the tradeoff between the profits derived from offering varieties to the market and cost savings realized by product portfolios that can be produced efficiently within the current company's manufacturing capacities.

3.2 Customer Interface Design

Customer's participation is the key to successful mass customization strategy. In style customization, the customer should input their preference to configure the shoe they like; in comfort and function customization, customers should measure their feet and walking behavior on the foot scanner to capture their foot parameters. When the product is delivered to the customer, another interaction opportunity happens. However, among all of interactions, the customer's participation in co-designing their own shoe style through a "co-design interface" provided by the producer may be the most important one for the shoe producer, because the customer can easily leave the product without any cost and concerns if she is not satisfied with the process (Franke and Schreier 2010; Franke et al. 2010). How to design the customer interface in order to make the customer interested in shoe customization and enjoy the process is a crucial question.

Web-based mass customization has been employed in most practices of shoe mass customization, which not only allows companies to enhance their interaction with customers, but also increases customers' confidence and educates them about the product they are ordering, which will enhance customers' satisfaction as well (Siddique and Boddu 2004; Franke et al. 2010; Wang and Tseng 2007 and 2011). The success of web-based mass customization depends on customers' co-design interface, an ability to allow for learning by doing, to stimulate customers' satisfaction and positive experience, and its integration into the brand concept, as well as its technological capabilities (Franke and Piller 2003). The interface should enable customers to express their requirements and carry out the product development process by mapping the requirements to the physical domain of the product without complexity and confusion (Huffman and Kahn 1998; Tseng and Du 1998; Chen and Wang 2010).

The customer co-design interface should first assist the customer to explore the whole solution space, clearly delineating what will be offered and what will not (Salvador et al. 2009). Conventional design approaches assume that customers know what they want, which, unfortunately, is not true (Tseng et al. 2010). Instead, customers' needs will be clarified or identified through the configuration process, by trying different possibilities, learning from errors, and comparing different solutions, which is an iterative and time-consuming learning process (Salvador et al. 2009). In this process, it is crucial to provide customers with immediate feedback via virtual prototype creation, usually a 3D shoe CAD model, which the customer is able to evaluate and compare with the ideal product in mind.

The customer co-design interface should also balance customers' effort and perceived complexity, to avoid "mass confusion" (Huffman and Kahn 1998). Currently, even a simple product configuration system can provide endless possibilities (Franke and Schreier 2008). It is found that customers can be overwhelmed by the excess variety and external complexity during product configuration (Huffman and Kahn 1998), which is termed "mass confusion". In such cases, customers would postpone buying decisions and consider the product as difficult and undesirable (Salvador et al. 2009). In order to address this problem, it is suggested that the company can provide choice navigation to simplify the ways in which people explore desired product offerings, such as product recommendations based on customers' profile or trial-and-error. The recommendation is generated as the optimal solution based on customers' given information, which would be a good reference for them to further identify and explore their options (Wang and Tseng 2011; Wang and Tseng 2011). In addition, an ecosystem design concept is proposed (Tseng et al. 2010; Zhou et al. 2011), in which customers are invited into a virtual reality environment embedded with an affective-related recommendation system supported by the affective-related knowledge database and configuration database. Different from existing personalization recommendation, such systems allow customers to freely configure and experience with the product in a simulated but close-to-practice context and focuses more on customers' needs reflected by the user experience, which may be much closer to customers' real needs.

On the other hand, customer co-design interface should also satisfy customer's hedonic needs as a "creator". Empirically, it is observed that people seem to derive an intrinsic benefit from "doing it themselves", which is also called pride of authorship (Schreier 2006). It describes the output-oriented benefit of having done it oneself, and the positive outcome of such processes constitutes positive feedback, which gives the individual a strong feeling of pride. Unlike satisfaction in high product utility and fit, it indicates a value increment a customer ascribes to a self-designed product, arising purely from the fact that she feels like the originator of the product (Franke et al. 2010; Wang and Tseng 2011). Due to this psychological effect, customers may overvalue their (often poorly made) creations (Norton 2009), in which case a customer may be willing to accept a lower-quality self-design product even at the same cost of expert design (Ulrich 2011). In other words, customers may appreciate the value not from product utility, but from their participation in the product design process. In order to enhance this psychological effect, customers should invest a large amount of effort in designing the product, or it may not truly make the customer feel she is the product's "originator". Therefore, it may be more challenging to develop a customer co-design interface for such psychological effect than that for high product utility.

To design such an interface, some suggestions are proposed in (Franke et al. 2010). First of all, customers can be offered a great deal of design freedom to enable high preference fit and a large degree of decisional control over the process to make the customer feel like they are "the cause" of the outcome of customized shoes. Second, immediate positive feedback can be provided on successful performance during the process. Third, affirmative feedback such as labels and certificates can be provided to the customer to emphasize their role as creator. Thus, designers may actually design customers' enjoyable experience in the shoes' self-design process, rather than just the pair of the shoes alone.

3.3 Shoe Configurator

It is the shoe configurator that translates customers' design or feet measurement data into a 3D detail model of the shoes. The information generated by the product configurator is essential for shoe production as well as 3D model generation shown to the customer in the co-design interface. To take advantage of economic scale, the configurator generates all customized shoes from a product family with some common structures and product technologies, which form the platform of the family (Erens and Verhulst 1997). In general, a product platform has three aspects: the product architecture, the interfaces, and the standards that provide design rules to which the modules must conform (Baldwin and Clark 2000). It defines the way in which the product elements are arranged into physical components and the way in which components interact, and each function is mapped to the modular component, while standardization and decoupling of the interface are integrated between components (Ulrich and Eppinger 1995).

There are two popular platform-based product configuration approaches based on different product platforms. One common approach is scalable product configuration, in which scaling variables are employed to shrink or stretch the platform in one or more dimensions to satisfy diverse customer needs. This approach is effective in comfort and function customization, in which the lasts can be easily adjusted according to each individual’s foot measurement. The other approach is called modular product configuration, from which each product is derived from adding, substituting, and/or removing one or more functional modules (Du et al. 2001). Obviously, this approach is effective in style customization and function customization, in which each changeable component or accessory can be designed as a module. The change of one module does not influence the other parts or the whole design, so that the design cost can be significantly reduced.

In scalable product configuration, the first task is to determine which design parameters take common values, and the second task is to determine the optimal values of common and distinctive variables by satisfying performance and economic requirements (Simpson 2004). Shoe designers can study the foot measurement database to find out which last parameter is usually constant among most customers. The modular product configuration is based on a modular product architecture, which involves one-to-one mappings from functional elements to the physical components of a product. With specified decoupled interfaces between components, each functional element of the product can be changed independently by changing only the corresponding component (Ulrich 1995).

The configurator has become the major approach to link with customers' orders and the components, which organizes the logics of component relationships and essential product parameters. Knowledge management and AI techniques have been widely employed and have shown great promise for automatic product configurations (Simpson 2004; Shooter et al. 2005). A computer-based product platform concept model is introduced in (Johannesson and Claesson 2005) to capture both functional behavior and embodiment of design solution, as well as the operative component structure in a configurable system product. This model includes documentation of the design history capturing design motives, decisions and results, embodiment definition of a selected set of design parameters from a function-means-tree, and parameterization of the selections of the design parameters which allow the design solution to appear as different design variants. Unified Modeling Language, UML, has been employed for modeling configuration knowledge bases (Felfernig et al. 2001). The configuration model includes the component model and a set of corresponding functional architectures defining which requirements can be imposed on the product. The configuration model reduces the development time and effort because it can be automatically translated into executable logic representations. In addition, the graph grammar is thought of as an effective method to model the logical organization of product family elements, as well as the mechanism of product variant derivation to satisfy individual customer needs. The advantages of graph grammar include visual representation, formal definition, ease of computational implementation and extensibility (Du et al. 2002). A graph rewriting system is proposed in (Du et al. 2002) to support product family design, in which the family graphs performs as the starting graphs for a series of graph operations, and variant graphs are derived by executing pre-defined rewriting rules in terms of appropriate control structures. It is demonstrated that the graph-based product family design system can provide an interactive environment for customers to make choices among product variants, and negotiations among sales, design and manufacturing.

3.4 Flexible Manufacturing Process

One consequence of mass customization in manufacturing is observed as an exponentially increased number of process varieties, including diverse machines, tools, fixtures, setups, cycle times, and labor (Wortmann et al. 1997), and such process varieties would introduce significant constraints to product planning and control (Kolisch 2000). Thus, a flexible manufacturing process is important to reduce the cost of producing more product variants. From the mass customization perspective, there are two approaches which can be implemented to improve the flexibility of the manufacturing process.

One approach is to implement a manufacturing process family idea. The common components and standardized basic product structure designed for a product family enable similarity in the production process and make process family possible, which comprises a set of similar production processes sharing a common process structure (Martinez et al. 2000). The platform idea can be expanded from product to production process, which implies a focus on commonality of production tools, machines, and assembly lines (Meyer and Lehnerd 1997). In addition, some researchers also present the concept of process configuration which combines the principles of product configuration and process planning, as the commonality across the product variety leads to a number of same or similar productions and operations among process variants (Schierholt 2001). Thus, it is suggested that companies can configure existing operations and manufacturing processes by exploiting similarity among product and process families in order to take advantage of repetitions (Schierholt 2001).

Flexible manufacturing should also rely on the availability of agile manufacturing systems such as a new CAD/CAM manufacturing technology to reduce the response time. It is claimed that the next generation of manufacturing systems must be able to support high levels of flexibility, reconfigurability and intelligence to allow them to adapt for diverse product variety (Molina et al. 2005). Such manufacturing systems must be rapidly designed, able to convert quickly to new productions, able to adjust capacity quickly, and able to produce increased product varieties in unpredictable quantities (Mehrabi et al. 2000). In order to achieve these objectives, the manufacturing system can be created by incorporating basic process modules which can be rearranged or replaced quickly and reliably. In addition, reconfiguration should allow adding, removing, or modifying specific process capabilities, control and operation structure to adjust production capacity to respond to diverse product configurations (Mehrabi et al. 2000). For instance, the SoleCAD system developed by HKUST integrates a prototype sole module design and manufacturing system for shoe industry, as shown in Figure 3. With the SoleCAD/CAM manufacturing system, the response time from receiving personalized shoe orders to producing a last for shoe production can be reduced to around 5 days. The flexibility of the system also enables designers to easily change the CAD model to produce another personalized last with limited additional cost.

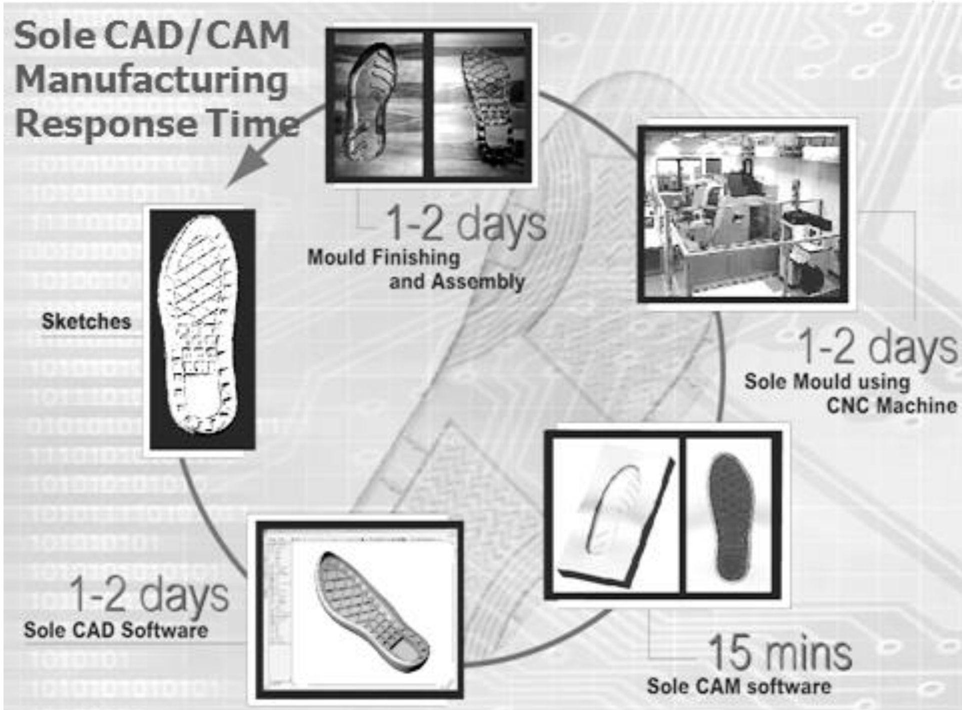

Fig. 3 SoleCAD/CAM Manufacturing System (courtesy of HKUST)

3.5 Supply chain management

In the background of mass customization with the shortened product lifecycle and proliferation of product variety, there has been found a tremendous opportunity to enhance supply chain management by including product design as an integral part of supply chain (Tseng et al. 2003). Suppliers can be seen as an extended manufacturing capability. Thus, the company's supply chain should be configured to address customers' requirements for flexibility, agility, cost efficiency and product variety, and focus more on collaboration with external suppliers or partners (Salvador et al. 2002). For instance, "Earlier Supplier Involvement (ESI)" is proposed as a form of vertical co-operation in which the manufacturer involves suppliers at an early stage of the product development process (Tseng et al. 2003).

Mass customization has challenged the traditional supply chain of many shoe producers. In the traditional supply chain, raw material providers sell to footwear manufacturers who sell to final assembly manufacturers. Then the products are distributed through wholesalers, distributors, and retailers to the final customers. However, mass customization in the Business-to-Customer (B2C) commerce background results in an entirely new direct channel opportunity, a process of disintermediation (Tseng et al. 2003). In the direct channel, shoe producers can sell the products directly to the customer, bypassing the traditional intermediaries. It is the electronic commerce that serves as a disintermediator replacing the intermediary links in the traditional supply chain with a direct channel to the customer. The disintermediation of the supply chain leads to better inventory management and production planning by taking advantage of better signals regarding demand levels from consumers directly (Warkentin et al. 2000).

In terms of the EUROShoE project (Boër and Dulio 2007), currently most footwear producers have outsourced the production process to the developing countries, such as China, where the labor cost is much lower than that in Western countries. In addition, in this era of globalization, a shoe is made by the materials collected and human labor from all over the world. Then, a global production network should be carefully designed and planned by the shoe providers. There are four major location strategies for global production networks that have been identified (Rodrigue et al. 2009). In centralized global production, the production is completed only in one region and then exported to the global market in order to take advantage of economies of scale and address the difficulties in relocation and reproduction. In regional production, the product is manufactured in each region with the size of the production system related to the size of the region market. Such strategy relies more on regional accessibility than economies of scale to reduce high distribution costs. In regional specification, the production is divided into various regions in terms of specific comparative advantages. The manufacture in each region can specialize in producing a specific product and import from other regions what it requires. In vertical transportation integration, different stages of the production are placed at the locations that offer the best comparative advantages. For instance, raw materials can be extracted from the most accessible location, and the manufacturing and assembly can be performed in regions with low labor costs or high levels of expertise. Therefore, shoe providers can select different strategies according to their own production capability and market.

4 Conclusion

Mass customization can be a competitive factor to help footwear firms face the current competitive global market. Cost pressure and customer preference on product personalization force footwear firms to adopt new strategies, such as mass customization, to increase the level of satisfaction for the customer and manage the cost and complexity in the design and production process. However, is mass customization the panacea to the footwear industry? The answer depends on how the provider restructures the business model and takes advantage of a global production network to reduce the cost. To most shoe providers, individuality is clearly a global trend, so it would be better to consider new strategies as soon as possible in order to survive in this rapidly changing market.

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