Mass Customization: Where do we go from here?

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Abstract—**Since its inception in the 1980s, mass customization has seen a mixed response both from the industry and researchers alike. In this work, we take a look at the current state of art in research in the area of mass customization. We investigate the possible reasons for the widening gap between research in the field and its implementation in the industry. We conclude by presenting potential directions for future work in this area.**

Keywords: mass customization, manufacturing, product design, flexibility, modularity

1 Introduction

In the beginning, there were craftsmen who made products to order and as per the specifications of the customer. This obviously meant higher lead times and higher costs. Then came Henry Ford who pioneered the concept of mass production and said "Any customer can have a car painted any color that he wants so long as it is black" in his autobiography [13]. Those were the heydays of mass production where customers were happy to buy products that were cheap even if that meant sacrificing on their preferences. Nowadays, customers are not quite satisfied with low costs. They need products that match their preferences albeit at the same low costs as in mass production. In this work, a framework is proposed that classifies the existing literature into different categories based on the scope of the work. Section 2 looks into the basic concepts involved in mass customization. Section 3 discusses the proposed framework for categorizing literature in the realm of mass customization. Section 4 discusses some of the measures to evaluate the effectiveness of implementing mass customization and also looks into some of the issues. Section 5 presents the conclusions and possible directions of future work.

2 Basics

Coined by S. M. Davis [8] and popularized by Joseph B. Pine II[41], mass customization is defined as [41][1] "providing **tremendous variety** and individual customization, at **prices comparable to standard** goods and services...with **enough variety** and customization that

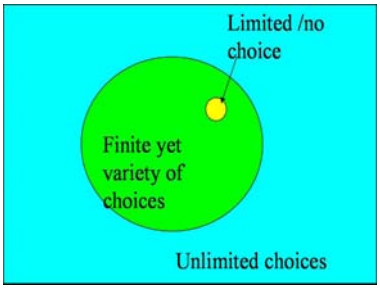

Figure 1: Comparison of product variety

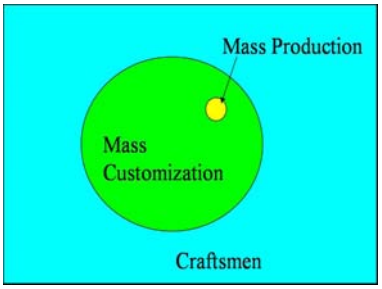

Figure 2: Comparison of 3 Manufacturing Strategies

nearly everyone gets exactly what they want". An alternate definition given by Tseng et al. [48][2] states that mass customization is "the **technologies and systems** to deliver goods and services that meet **individual customers** needs with **near mass production efficiency**..". Joseph B. Pine II has since then redefined mass customization[40] as "Today I define Mass Customization as the low-cost, high volume, efficient production of individually customized offerings". The Venn-diagrams shown in Figures 1 and 2 puts in perspective the product variety available in the aforementioned strategies. It can been seen from Figure 2 that mass customization fits in somewhere in the middle in the spectrum which has *craftsmanship* at one end and *mass production* at the other end. Zipkin [62] defines the three main capabilities of mass customization viz. *elicitation*, *process flexibility* and *logistics*. The basic principles behind *elicitation* is customer co-design [39]. By involving customer early on in the design stages fosters stronger relationship between the customer and the enterprise and lowers the risk involved in introducing new products. It becomes imperative to effectively translate customer preferences

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[1]emphasis added

[2]emphasis added

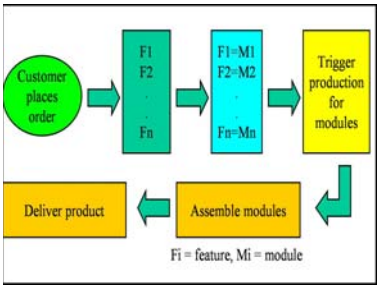

Figure 3: Modularity (modified from [31])

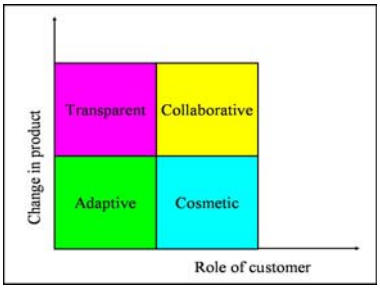

Figure 4: Four Faces of Mass Customization (modified from [16])

into the design and subsequently into the product in order for the product to achieve market success.

Modularity is integral to a successful implementation of mass customization since it forms the vital component of *flexibility*. This involves designing the product to be comprised of multiple modules that can be mixed and matched to yield customized products. Figure 3 has been modified from Kumar [31] and shows how modularity helps in providing highly customized products. Now, the question arises as to how does a company provide a variety of customized products to its customers. Piller [39] identifies three dimensions based on which products may be customized. These include *fit* which refers to the physical characteristics of the product like size and shape, *functionality* indicating the usefulness of the product and *style* implying the aesthetic aspects like appearance.

Gilmore et al. [16] propose a strategy which classifies the extent of mass customization based on the involvement of customer and the variations in the product. Figure 4 shows the four different "faces" of mass customization of which the true and complete form of mass customization is the *collaborative* face which necessitates a high involvement of the customer and also results in significant variations in the product. The *adaptive* approach is the one with least involvement from customer. However, the product may be modified or reconfigured by the customer independently to suit his/her needs. In the *transparent* approach, the company "learns" customer's preferences unbeknownst to the customer by collecting data about the customer's habits and preferences.

3 Framework

In this framework, the existing literature has been categorized into 6 main areas viz. conceptual discussion, product design, manufacturing applications, service applications, software and systems and other areas. The intent is to facilitate quick content analysis and identify future direction of research. Table 1 summarizes the findings of this work.

3.1 Conceptual Discussion

Joseph B. Pine II's pioneering book [42] is by far the most comprehensive description of the concepts of mass customization. Gilmore and Pine serve as editors for the book titled "Markets of One" [15] which is a collection of articles on catering to the increased market diversity. The book also contains the article [16] on the four "faces" of mass customization discussed earlier. MacCarthy et al. [35] compare the different classifications of mass customization approaches and concludes that by far the most easiest and straightforward approach is Gilmore and Pine's approach [16] discussed earlier.

A literature review [54] was conducted in 2001 and future directions which included were proposed. Another state-of-the-art review [39] was conducted in 2004. Piller [40] discusses alternative strategies for implementing mass customization which include personalization [32] and matching services. Kumar et al. [34] perform a statistical analysis of the literature in mass customization since its inception in 1987. The authors also provide a taxonomic framework for classification of literature. Postponement strategy is very commonly used in mass customization. In this strategy, the final assembly of the product (also known as the *point of differentiation*) is delayed as much as possible thus enabling better management of inventories and uncertain demands. Shao et al. [45] evaluate two different postponement strategies using a cost minimization model and conclude that it is not efficient to delay the point of differentiation if the subsequent activities are high-value-added activities.

Oleson [37] focuses on agility and its importance in today's world. The author defines agility as "the ability to respond with ease to unexpected but anticipated events". The author delves into the changes necessary in the different aspects of an enterprise in order to be truly agile. Anderson [3] discusses different approaches to successful implementation of mass customization with special emphasis on product development and related concepts like standardization, modularity, and commonality. Rautenstrauch et al. [43] deals with the information system challenges that are typically encountered while implementing

Table 1: Framework for literature in mass customization

Conceptual	Product Design	Manufacturing
Anderson [3], Gilmore and Pine II [16], Kumar [32], Kumar et al. [34], MacCarthy et al. [35], Oleson [37], Piller [40], Pine II et al. [42], Rautenstrauch et al. [43], Victor and Boynton [52], Wu and Pan [54]	Aldanondo and Vareilles [1], Buyukozkan [5], Chen and Wang [6], Feng et al. [12], Helander and Jiao [19], Hong et al. [21], Jiao and Tseng [23, 24], Jin et al. [25], Jin and Chen [26], Tseng and Jiao [49, 50], Wu and Pan [55], Yu et al. [57]	Alford et al. [2], Anisic and Krsmanovic [4], Dean et al. [10], Feitzinger and Lee [11], Joneja and Lee [27], Mason and Lalwani [36], Tang and Xu [47], Yao and Liu [56], Zhang et al. [59], Zhao et al. [61]
Services	**Software and Systems**	**Others**
Hao et al. [17], Hart [18], Jue et al. [28], Papathanassiou [38]	Dean et al. [9], Karpowitz et al. [29], Shin et al. [46], Verchopoulos [51]	Cui et al. [7], Fu and Qian [14], Helms et al. [20], Huang et al. [22], Kotha [30], Wang and Lin [53], Yu et al. [58], Zhang and Li [60]

mass customization. The authors also provide a list of web-based tools that support mass customization implementation. Victor et al. [52] outline the basic sequence through which an organization would progress towards mass customization viz. craft work → mass production → process enhancement → mass customization. The authors state that it requires deep and thorough understanding of the processes before the company can embark on its journey towards mass customization.

3.2 Product Design

Product design is one of the most important aspects of mass customization. Tseng et al. [49] propose a case-based evolutionary design for implementing mass customization principles. The authors in a related work [50] have also looked into concurrent engineering and how mass customization can be successfully employed in concurrent engineering. Jiao et al [23] propose a methodology for developing product families with high degree of customization. Helander et al. [19] propose a Internet-based product development methodology for mass customization. Jiao et al. propose [24] three categories of product customizability viz. design, process and customer-value. The authors suggest that a customizability analysis helps evaluate the effectiveness of different options available for providing customers with tailored products. Aldanondo et al. [1] break up the configuration process into three categories viz. *product* configuration, *requirements* configuration and *process* configuration. The authors propose a system which permits a smooth flow from the upstream *requirements* configuration to *product* configuration and finally to the downstream *process* configuration systems.

Jin et al. [26] propose a platform-based architecture for designing product families that facilitates better handling of uncertain demands. This architecture minimizes the production costs and reduces inventory levels. Chen et al. [6] develop a two-stage genetic algorithm-based method to identify product families such that the contradicting objectives of maintaining commonality while increasing diversity are both satisfied. Hong et al. [21] propose a graph-based model to represent the variations in product design configurations. Buyukozkan [5] develops a analytical network-based strategy to evaluate the product development process in mass customization.

Yu et al. [57] propose an artificial neural network (ANN)-based algorithm to determine the relationship between product specifications and customer requirements. This helps in identifying the features that are important to the customer thus enabling better product design. Feng et al. [12] develop a representation model that captures relevant information about the product design requirements to assist in the process of product configuration. Jin et al. [25] propose a design-reuse model for small enterprises using ant-colony optimization techniques. Wu et al. [55] provide another design-reuse model to reduce "internal diversity" while increasing the "external diversity" to achieve the benefits of mass customization while limiting the design and configuration issues by making use of modularity and standardization.

3.3 Manufacturing Applications

Manufacturing and services are two important sectors where mass customization can have a major impact. In this section, we look at some of the implications of implementing mass customization in the manufacturing realm. Joneja et al. [27] develop a suite of flexible tools (Modular Parametric, Assembly Tool Set) to improve the through-

put rates in a MC-environment. The authors also develop a computer-aided process planning system that assists in configuring the suite of tools. Alford et al.[2] look into mass customization from the perspective of automobile industry. Feitzinger [11] discusses the concept of power of postponement and how Hewlett-Packard successfully implemented mass customization principles.

Tang et al. [47] propose an ant colony-based algorithm for optimizing the manufacturing chain. Zhao et al. [61] examine the effective design of an overhead traveling crane being used in a manufacturing setup that has implemented mass customization principles. Dean et al. [10] propose a fuzzy systems-based manufacturing resource planning model for better coordination of resources in a mass customization environment. Strojniski et al. [4] propose a method to improve the assembly process for pumps using the Design for Assembly (DFA) methodology with the objective of minimizing part count which can get unwieldy when the pumps are highly customizable. Zhang et al. [59] develop a mixed-integer programming model for effective material purchase decisions that incorporates uncertain demands and vagaries in the supply chain while analyzing the commonality and modularity of products. Yao et al. [56] propose a multi-objective optimization model to solve the scheduling issues in a supply chain when a company has large variety of products as would be the case if the company was implementing mass customization. Mason et al. [36] look into the distribution of products in a mass customization environment.

3.4 Service Applications

Off late, many of the concepts previously applied almost exclusively to manufacturing have found applications in the service sector too. Service sector assumes more importance since there is greater interaction with the customer and hence greater scope for customization. Hart [18] looks into the applications of mass customization in the service industry. Papathanassiou [38] explores the financial services in UK and how Internet and mass customization principles are being employed to provide customers with better services. Jue et al. [28] investigate how IT systems can be decoupled from the actual services rendered in a Chinese restaurant which provides highly customized service. Hao et al. [17] investigate the application of mass customization principles in the tourism industry in an effort to provide better and customized service thus improving the overall experience of its customers.

3.5 Software and Systems

Information systems is one of the two pillars of mass customization (the other being flexibility). Efficient information systems is vital to a successful implementation of mass customization. Internet has become an all-pervasive technology in today's world and holds great promise for the future. Vrechopoulos [51] proposes a business model for management of information to facilitate mass customization in Internet retailing. Karpowitz et al. [29] look into the issues concerning developing web-based software systems for customized automated systems. The authors develop an agent-based system to identify and create web-services for specific tasks. Dean et al. [9] propose an IT-based framework using rule-based systems to automatically generate production orders. This facilitates better management of the wide variety of products. The authors used a company involved in making customized doors and windows as a test case to yield promising results. Shin et al. [46] develop a Finishing Information System (FIS) to assist in customization in the housing industry in Korea.

3.6 Other areas

Besides the aforementioned areas, researchers have focused on some of the other implications that mass customization might have in an enterprise. Zhang et al. [60] use the grey-systems theory that enables accurate prediction based on incomplete or uncertain information to predict the quality issues related to mass customization. Quick Response Ability (QRA) is integral to mass customization and Yu et al. [58] propose a method to evaluate an organization's QRA and provide guidance for improving it. Cui et al. [7] demonstrate a Theory of Constraints (TOC)-based method called the Simplified Drum Rope Buffer(S-DBR) to facilitate rapid response to market changes.Wang et al. [53] propose a Defect Tracking Matrix (DTM) to track the defects in various aspects of the mass customization production process using the concept of House of Quality.

Fu et al. [14] and Kotha [30] look into how mass customization may be tapped for knowledge creation that can be then disseminated company-wide to yield improved processes and efficient systems. Huang et al. [22] develop a knowledge-based view of organizations involved in mass customization. The authors look into the effects of internal and external learning on the implementation of mass customization. Helms et al. [20] posit that Internet-based e-commerce can be effectively used to obtain customer preferences and thus assist in knowledge management in mass customization.

4 Effectiveness of MC Strategies

There is a widening gap between the level of research in the field of mass customization and its implementation in the industry [40]. This may be attributed to multitude of reasons which can be categorized into Zipkin's three capabilities [62] viz. *elicitation*, *process flexibility* and *logistics*. Often times, there is a lacunae in terms of the customers' ability to be able configure the product based on his/her needs. This may be attributed to a multitude

of reasons [31, 39] including non-existence of such a configuration system or lack of knowledge about the product and its various features. Kumar [33] extends his previous work [31] to develop a effectiveness index for both service and manufacturing industries implementing mass customization. Companies often fail to transition from the *cosmetic* or *adaptive* approaches to the *collaborative* [16] approach which promises even greater benefits. It is rather easy to be over-zealous and introduce a wide variety of products leading to "mass confusion" and the customer facing a "tyranny of choices" [44].

More often, companies hastily jump on to the mass customization 'bandwagon' without a full and deep understanding of the concepts and its implications. As illustrated in [52], companies have to follow definite pathways viz. craft work → mass production → process enhancement → mass customization, towards mass customization. They have to have a complete understanding of process enhancement before commencing their journey on the path of mass customization. This would enable them to discover new methods of reconfiguring and recombining processes to facilitate production of customized products. Moreover, companies labor under the impression that they have implemented mass customization principles when they might have focused only on one of the three dimensions outlined by Piller [39] viz. *fit*, *functionality* or *style*.

5 Conclusions and Future Work

In a nutshell, mass customization can be summarized as [39][3] "Mass customization is a vision...to perform company's processes in a truly **customer-centric** manner...resulting in products corresponding to **needs of individual** customer..**without surpluses** associated with customization". Mass customization definitely results in improved market share and reduced inventory levels in a company. It also leads to customer "delight" as opposed to mere customer satisfaction. However, due to certain limitations discussed above, this concept has not yet taken off despite its immense potential. The yawning gap between research in the field and its implementation needs to be addressed. Moreover, it can be seen from the above survey of literature in the field that the bulk of the focus has been on product design and configuration. According to the author, the supply and logistics aspect which forms a vital component of mass customization also needs more focus too.

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[3] emphasis added

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