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# COMPLEXITY MANAGEMENT IN TERMS OF MASS CUSTOMIZED MANUFACTURING

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**Abstract**: Mass customized production is the type of production using a combination of knowledge of craft production and mass production to achieve this goal. One of important managerial problems of manufacturing companies is an increasing complexity of product structure, which results from a wide variety of products needed to satisfy customer requirements. From economic point of view, this type of production is profitable and has many benefits such as reduction of inventory. This paper presents an overview and definition of mass customized manufacturing, development stages, decisive approaches to mass customized manufacturing and main problems resulting from this type of manufacturing. Finally, an overview of approaches to complexity measures and complexity management are provided.

**Key words:** mass customization, manufacturing, product, complexity

## Introduction

Mass customized manufacturing (MCM) is a relatively old concept that many people don´t know, but can be seen in our everyday life. People are choosing equipment in the car according to their requirements and ideas which enables so called mass customization (MC). It is not just the automotive industry, but mass customization affects every area of production which can be customized. However, it is necessary to have sufficient technology. This type of production allows companies to fulfil customer´s needs faster and to deliver customized products with near mass production efficiency. There are many definitions of MCM because the concept is multidisciplinary. David and Anderson (2004) explain what mass customization really is. They describe mass customization as manufacturing custom products (not just assembly modules) quickly and efficiently to achieve higher customer satisfaction. Many authors focus on MCM and they present different definitions of the mass customization in literature. Kull (2015) divided mass customization into two types: configuration and parameterized type of MCM. Customers can configure selected parts of computer to customize their own computer to satisfy their individual needs – this is the configuration type. Parameterized type allows customers to change the visual aspect of the product (e.g. example size or shape of a window). Companies usually offer customers a wide range of mass customized products and services. This fact brings new possibilities and benefits that are different from the standard production.

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On the other hand this strategy requires well-coordinated cooperation between companies within supply chains (Modrak, 2007; Bednar and Modrak, 2014). Moreover, Modrak et al. (2012), in this context pointed out that mass customization brings other sources of uncertainty that affect an operational complexity of manufacturing processes.
In this paper it is intended to explore mass customized manufacturing from viewpoint of its development stages and to analyse managerial complexity issues arising when number of product variants grows using own methodology.

**Literature Review**

In centuries, people have already met with the concept of customization. For example, armour of the knights was customized to fit knights' body and its shape. Experienced and skilled craftsmen were responsible for the production of armour. This type of production was called craft production. Armour and all the necessary equipment had to be tailor-made. But today, in business industry, we use the term "custom-made" or made to fit the needs, requirements of a particular person. A. Wheeler (2010) claim, that customization was probably the best sales tactic in the history of free enterprise. An evolution of manufacturing technology started with craft production in 1850, where customers got exactly what they want; later products were heterogeneous and for higher price. A comprehensive review on the evolution of manufacturing systems from craftsmanship to mass customization is presented in the book of Modrak and Semanco (2014).
In the coming years people prefer mass production for the industry. Good advantage of using mass production was a great price for average people who couldn't buy a product or service, while products were homogenous. So mass production recorded an increase and popularity in 50s, where customers got low-cost products, but they didn't get what they want.
In the 21st century, mass production has taken on entirely new capabilities for customers and also for industry. New trend in 1980 - mass customization, provided to customer low-cost products now and exactly products they want. Blecker et al. (2006) pointed out that MCM includes from managerial viewpoint two different business practices: mass production and craft production to produce customized products and services for customers. On the one hand, industries can mass-produce customized products and services and on the other hand consumers have to choose from many product variations – products are heterogeneous. Customers can use internet and choose or design what they want. They can customize cars, clothes, design rooms, houses, create their own websites, shoes and etc. Schonberger (2010) was the first one to describe formally the concept of mass customization. Brunoe et al. (2014) describes MCM like a strategy to help to a greater variety of products and individualization. The main goal of MCM is to produce and deliver rapidly customized products while keeping costs at the mass-production level. Every evolution stage of manufacturing production uses another business model. Pull strategy dominates in pull strategy, which means: sell – design – make –

assemble. Push strategy dominates in mass production, which means: design – make – assemble – sell. In mass customization dominates "push and pull" strategy, which means: design – sell – make – assemble.

## The Four Approaches of MCM

According to Gilmore and Pine (1997) mass customization may appear as: a) Collaborative customization, b) Adaptive customization, c) Transparent customization, or d) Cosmetic customization.

*Collaborative customization* means that company and customer are in a partnership to produce individual goods and services to satisfy the customer the best (see Fig. 1).

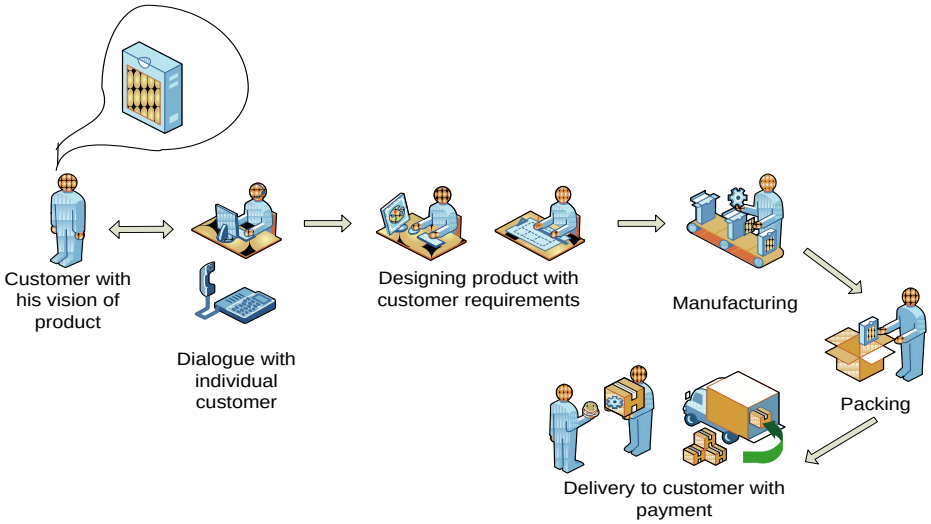


**Figure 1. An example of collaborative customization**

The companies help customers to choose what they need from a wide range of options. The best way to satisfy the customer needs is dialogue with individual customers. Dialogue between individual customer and company's product managers help manufacturers to produce precise product with precise fulfilment of customer requirements (Pine and Gilmore, 2011).

Example: The best example for approach of collaborative customization is in the shoe industry. Customers can customize their own products online.

*Adaptive customization* means when company produces products and services, which are standardized, but with a few customized options. Product can be customized by final customer. It can be easy tailored, modified or reconfigured to satisfy customer needs without any direct interaction with the company's managers.

The following Figure 2 describes the principle of adaptive customization. Example: Microsoft© offers a package of software designed to run all activities of small businesses so that the final customer may add more functions into a package.

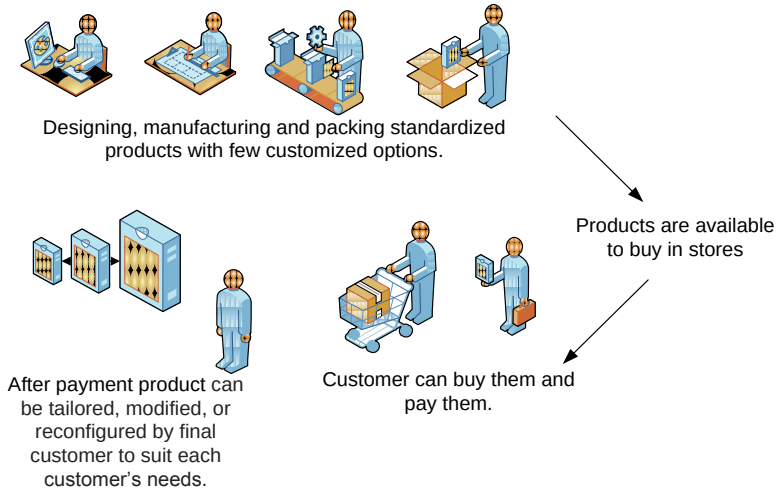


**Figure 2. An example of adaptive customization**

*Transparent customization* means that a company, which produces standardized products differently for different groups of customers (without overtly stating the products are customized) (Kindersley, 2015). Transparent customizers observe behaviours over time and they are looking for predictable preferences (Rautenstrauch et al., 2012). Products in standard package have customized features or components without telling customers that the products are produced and customized for them, as seen in Figure 3. Transparent customization is the precise opposite of cosmetic customization. For example approach of transparent customization is used within the hotels. Employees in hotels already know about regular customers, which room the customer wants and what are its requirements, when they visit the hotel.

Hotel employees store information about customers in the hotel database to predict their needs. Other example of this approach can be seen on websites of online shopping portals, which providing a book of recommendations based on the information about your past purchases.
*Cosmetic customization* means that company produces products, which are standardized, but market offers the products in different ways to different customers. It is opposite of transparent customization.

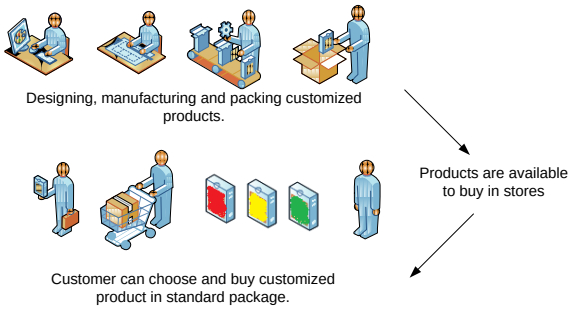


**Figure 3. An example of transparent customization**

According to (Pollard et al., 2008) the nature of business using this managerial strategy is that the product life cycle is very short. A product comes through different stages of its life from introduction, growing, maturity, and then decline (customers will stop buying them). Therefore, changing the representation of product is a good way to attract these customers, as seen in Figure 4.

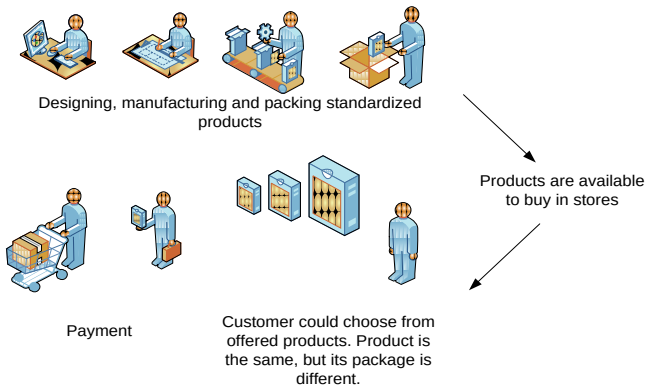


**Figure 4. An example of cosmetic customization**

For example: different size of packages: planters packages it peanuts and mixed nuts in a variety of containers on the basis of specific needs of its retailing customers such as Wal-Mart®, 7-Eleven®, and Safeway®. It is even possible to combine multiple approaches. Many companies combine two or more approaches in order to satisfy specific customers´ needs.

## Benefits and Challenges of MCM

MCM is a business strategy with lots of benefits used by companies to outpace competitors. Customers want a wide range of product variety and these forces companies to using a modern technology and sophisticated manufacturing

processes. Among others, MCM brings number of benefits and challenges with it (Boër et al., 2013). Fulfilment of a specific need of a customer is the core benefit of the strategy but this in turn, the challenge here is increasing price of the product. Higher level of customers´ needs has huge impact on increasing complexity in production. Complexity is also related to increasing level of product variety and increasing number of product components. MCM is changing the way consumers are making decisions about their needs and wants. MCM determines how companies make products. To provide the mass customized products while keeping the prices competitive, adaptive flexible manufacturing methodologies have to be developed (Qiao et al., 2015).

**Discussion on Complexity in MCM**

Today companies want to achieve flexibility and product variety in their production. There are many reasons leading companies to manufacture a wide variety of products. Abdelfaki (2008) appoints that there are some reasons leading to product variety: introduce new product variations by companies, because market deregulation compels them, retailers are putting more pressure on suppliers to differentiate their offers, companies must to conquer niche markets for serving specific needs of smaller customer due to market saturation and customers want more choice from the product range – they want product variety. The product variety is continuously increasing. Some producers can provide a huge number of product variants to the marker. For example, Mercedes offers far more variations in its S-class and E-class models than the company could ever sell in its entire existence (Holweg and Pil, 2005). Higher variety of products is usually associated with higher managerial complexity. Some authors claims that MC cannot be successful in the practice because the complexity has negative impacts on costs and other business indicators (Krus, 2015).
Why complexity is increasing due to MCM? Customers prefer to use online configuration systems made by manufacturers to express their needs. If a product variety is too high, customers can have difficulties. Anderson (1972) brought an interesting finding that the real customer prefers to spend minimum time and effort when specifying or buying product. When the purchasing activity becomes time consuming and even difficult, buyers may turn to another offer or product category (Babin et al. 1994).They are overwhelmed by the configuration task. This aspect is known as a configuration complexity. Piller et al. (2003) claim that configuration process can take a long time, because customers are overloaded with information due to a wide range of variants. Blecker et al. (2004) point out that an immediate effect of mass customization is high product variety that triggers high production program complexity that brings to production managers more awareness and new tasks. The production of a large variety can be efficiently realized by using the flexible manufacturing systems, which can improve manufacturing performance, they increase planning and scheduling complexity, but flexible manufacturing systems reduce setup times and manufacturing lead

times. On the one hand MC is a business strategy that increases complexity, but on the other hand it gives manufacturers a competitive advantage such as - it is not necessary to hold final products in inventory. Products are manufactured when customer wants and sends his order – what is called as "customer pull strategy" that helps to reduce work in process and lead manufacturing times.

In a context with mentioned shortcomings, production managers have to cope with related complexity problems. It means that they need to identify suitable approaches and methods to measure and manage complexity. There are various complexity measures and approaches and thus managers may have a problem which of them are suitable and could be effectively used for the given purpose.

Accordingly, in the next section we offer an overview of selected pertinent methodological approaches and variety induced complexity types and metrics. The following Table 1 shows selected methods to measure complexity with its characteristics including classification of complexity measures due to the methodology used to develop the measure.

**Table 1. Review of complexity methods and measures**

| Author | Year | Complexity type | Characteristics | |
|---|---|---|---|---|
| | | | Theory | Complexity |
| **C. E. Shannon** | 1939 | Shannon's entropy rate | A | a |
| **Kolmogorov** | 1955 | Kolmogorov complexity | B | a |
| **Vapnik, Chervonenkis** | 1971 | VC dimension | C | b |
| **Packard, Crutchfield** | 1982 | Excess entropy | A | b |
| **Bennet** | 1986 | Logical depth | B | b |
| **Lloyd, Pagels** | 1988 | Thermodynamic depth | A | a |
| **Rissanen** | 1989 | Rissanen complexity | B | a |
| **Suh** | 1990 | Complexity in AD | B | b |
| **Meyer, Foley Curley** | 1993 | Management of software development | A | b |
| **Gell-Mann** | 1995 | Effective complexity | A, B | - |
| **Wolpert, Mcready** | 1997 | Self – dissimilarity | A | b |
| **Deshmukh** | 1998 | Analysis of static complexity | A | b |
| **Mattsson, Gullander, Davidsson** | 2001 | Complexity index | A | b |
| **Frizzelle, Woodcock** | 2001 | Complexity entropy model | A | b |
| **ElMaraghy, Urbanic** | 2006 | Information diversity | A | b |
| **Isik** | 2010 | Quantitative measures, of SC complexity | A | a |
| **Modrak, Marton** | 2013 | Vertex degree index I | A | a |

| | | | | |
|---|---|---|---|---|
| **Marton, Bednar** | 2013 | Vertex degree index II | A | a |
| **Budde, Nagler, Friedli** | 2015 | Complexity index methodology | B | b |
| **Where:**<br>**A: Information theory; B: Computation theory; C: Computation learning theory**<br>**a: Deterministic complexity; b: Statistical complexity** | | | | |

The categorization in the Table 1 is based on methodological background of the measures. As it can be anticipated, managers may have a problem to select the most suitable approach or method from available portfolio measures.
Based on previously performed computational experiments and empirical knowledge (by e.g. Czajkowska and Minda, 2014 or Modrak and Bednar, 2015), we assume as preferable methods those which are based on information theory. For so called product complexity, we assume to apply combinatorial rules to express complexity through available number of product alternatives due to growing number of product components.
Currently, out research is based on calculation of all possible configurations as a result of increasing number of components. In the concept, components are divided into three groups: (a) stable components *i*, (b) voluntary components *j*, and (c) compulsory optional components *k*. Amount of possible configurations for one stable component when *i = 1*) can be calculated simply applying combinatorial rules as follows:

$$\sum Conf = 2^j - 1 \quad . \tag{1}$$

The amount of possible configurations for two and more stable components (when *i = 2, 3, 4 ... n*) can be calculated as:

$$\sum Conf = 2^j \quad . \tag{2}$$

In order to present the method on simple product composition, we took a case where *i*=2, *j*=2.
The following Figure 5 shows a scheme of such product and its possible combinations/configurations.

Using Equation 2, one may enumerate number of alternative products assembled from only two optional components as follows:

$$\sum Conf = 2^j = 2^2 = 4 \quad . \tag{3}$$

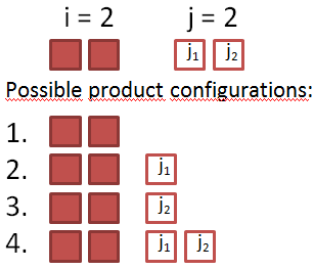


**Figure 5. Product consisting of 2 stable and 2 alternative modules**

The result is four possible configurations for this type of product. Applying the above mentioned rules for calculation of product configurations, managers obtain information on variety offered to customer (so called variety induced complexity). It is only logical, that the higher number of optional and compulsory optional components in any customized offer returns product variety which is much higher, that the company could ever sell during its active existence.

## Conclusion

The main objectives of this paper was to study the concept of mass customized manufacturing with the associated complexity and reveal complexity methods to measure structural designs in MCM. Authors claim that mass customized manufacturing causes increasing complexity of manufacturing systems and because of this, complexity management cannot be successfully implemented without theoretical knowledge and experimental testing (Dima et al., 2010). Authors argue that the solution is in the optimum variety of the specific production portfolio. Such analysis can be performed using demand records of the selected product. Our future research will focus on the reduction of variety induced complexity using proposed entropy-based methods to validate such approach on a realistic model.

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## ZARZĄDZANIE ZŁOŻONOŚCIĄ W KATEGORIACH MASOWO ZINDYWIDUALIZOWANEJ PRODUKCJI

**Streszczenie:** Masowo zindywidualizowana produkcja jest rodzajem produkcji, który do osiągnięcia celu wykorzystuje kombinację wiedzy z zakresu produkcji rzemieślniczej i produkcji masowej. Jednym z ważnych problemów zarządczych firm produkcyjnych jest coraz większa złożoność struktury produktu, co wynika z szerokiej gamy produktów niezbędnych do spełnienia wymagań klientów. Z ekonomicznego punktu widzenia ten typ produkcji jest opłacalny i daje wiele korzyści, jak na przykład zmniejszenie zapasów. Artykuł prezentuje przegląd oraz definicję masowo zindywidualizowanej produkcji, etapy rozwoju, decydujące podejścia do masowo zindywidualizowanej produkcji, a także główne problemy wynikające z tego typu produkcji. Na końcu zaprezentowany został przegląd podejść do środków złożoności oraz zarządzania złożonością.

**Słowa kluczowe:** masowa indywidualizacja, produkcja, produkt, kompleksowość

## 複雜性管理在批量定制製造方面

**摘要：**大規模定制生產是生產使用工藝生產，大規模生產的知識的組合，以實現這一目標的類型。之一的製造企業的重要管理問題是一個遞增的產品結構，這導致從各種各樣的，以滿足客戶的需求所需的產品的複雜性。從經濟角度來看，這種類型的生產是有利可圖的，有許多好處，如減少庫存。本文提出了大規模定制生產，開發階段，決定性的方法來大規模定制生產，並從這種類型的生產而導致的主要問題的概述和定義。最後，提供的方法的複雜性措施和複雜性管理的概述。

**關鍵詞：**大規模定制，製造，產品，複雜性