Complexity Management and Its Impact on Economy

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Abstract **– The purpose of this article is to describe how complexity impacts on economy. Firstly, the paper introduces and defines the term mass customization and related definitions of a supply and demand function. Subsequently, two domains, market equilibrium and complexity are presented and the complexity impact on economy is studied by changing modularity. Finally, modularity demonstration is shown on the selected examples and enumerated by proposed approaches.**

Keywords **– Mass customization, Complexity management, Cost, Demand, Production.**

1. Introduction

Economic development and constant competition for customers bring new ideas to all, production, trade and consumption [1, 2]. Manufacturers are trying to attract the interest of their customers. By the production and business strategy they want to satisfy the needs of a broader group of consumers. In order to meet the individual needs of customers, a new marketing strategy called mass customization (MC) appears in the 90s. Such custom-made products are directly tailored to meet specific wishes of the wide range of customers. However, this production is effectively applied in a one-piece-flow batch rather than for batch production or mass production [3]. Currently, manufacturers worldwide in all areas of industry and services are trying to adapt to consumers at much higher rate and at the same efficiency and competitive prices.

The aim of this paper is to review the literature dealing with the interpretation of mass customization and its impact on the economic aspect of manufacturing. It is important to know what proposals can be applied within a manufacturing plant with regards to financial management - costs for the implementation of mass customization into existing business strategy. Determination of the mass customization's costs is one of the most important efforts of corporate governance having direct impact on market balance. With regards to the scope of this paper, the following research questions can be stated: 1. Does mass customization have an impact on market equilibrium?, and 2. Is there a point of economy-based utility relating to optimum variety of products/processes?, and if yes, what are the implications of choosing higher/lower variety of products for a company?

2. Mass Customization

The term mass customization was for the first time mentioned by Davis [4]. This term is defined as a way to produce products based on consumers' specifications regardless of the product economy. Author [5] defined such customization as a capability to design and manufacture customized products at almost the same speed and efficiency as the manufacturing process of mass production. MC companies provide number of „tailored“ product variants through flexibility and rapid response of the production management. Every customer finds exactly what he needs but without considering the higher price.

However, the definition of mass customization is still not clear and lacks conceptual boundaries [6]. Some authors consider it as a complexity of management, localization strategy and adaptability

DOI: 10.18421/TEM72-13
https://dx.doi.org/10.18421/TEM72-13

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Received: 16 January 2018.
Accepted: 11 April 2018.
Published: 25 May 2018.

[7], or just as an own adaptation of products [8]. According to [9], MC is a form of goods and services' production intended for (relatively) large sales market satisfying individual requirements of each customer and at a cost that roughly corresponds to the cost of standard products [10].

Methods of customization give consumers the opportunity to directly influence certain specific design or functions of end products, extend the number of products offered and increase the degree of satisfaction of customers' needs through wide choice finished goods. Among the various ways of customization, the following ones are the most common [5]:

- creation of individualized products and services,
- individualization service for standardized products,
- modularisation of components to meet individual requirements,
- achieve a rapid response in the value chain.

Figure 1. shows percentage distribution of companies within eleven categories applying MC.

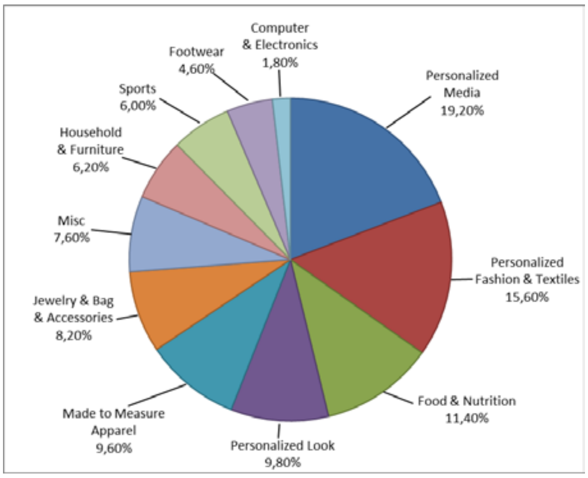

Figure 1. State-of-the-art of Mass Customization dominating categories [11].

Using the methods of customization aimed when meeting the individual needs of customers result in businesses with commercial success. This success is not caused only by the mere/pure customization of products but also through the fact that when purchasing the finished product, the customer decides on the basis of a subjective assessment of the product, making the growth in the added value of the product possible. Consumers prefer always the product - the newer product, if the difference between the added value of customized and original product is greater than the difference in price of the two products. This phenomenon can be seen in Figure 2. (a), where the difference between the traditional mass product and the customized product is significant, in the form of additional added value generated by the implementation of the customization strategy. As a consequence of higher product variability, managers have to be aware of the increased production and product complexity related to acceptable level of customer satisfaction or utility, as can be seen in Figure 2. (b).

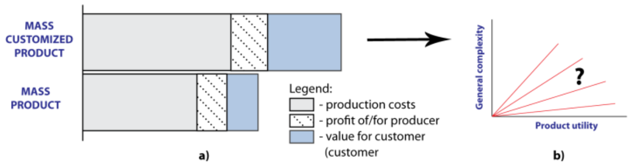

Figure 2. a) Value created and consumed increases with mass customization; b) product complexity vs. utility for producers

Mass customization is the reaction of the business community on the development of the global market, where through the same changes on the demand side and the supply side, raise new horizons for businesses.

A function of supply

The supply or offer represents the interests of manufacturers for trade goods and services. It interprets appropriate discretion of the amount of production where the producer is willing and able to sell at a given price. It expresses the functional relationship between the amount and the cost of production. From the manufacturer's perspective, it is an economic entity which decides on how much to produce and sell and how to make and sell. The manufacturer is rational, thus it seeks to maximize its profit at minimum cost. Supply factors are agents that cause a rise or decrease in supply and the most important factors of supply include the price of a particular good (P_x), production costs (C), prices of alternative goods (P_y), changes in production conditions (B), organization of market (O).

By the supply factors, a function can be derived indicating the quantity of goods offered depending on various factors. The function has the following form:

$$S_x = f(P_x, C, P_y, B, O). \quad (1)$$

A supply curve can be constructed from the function which shows the decisions of the manufacturer or the dependence of the offered quantity of goods from its price.

In Figure 3. we can see the rising supply curve S and simultaneously the shift of the total supply curve ($S_1 \rightarrow S_2$). The shift of the supply curve occurs under the influence of factors, another than the price of the estate. A shift in the supply curve from S_1 to S_2 may be e.g., the case of obtaining additional resources or the introduction of new technologies. Following the introduction of new technologies into the production process, the manufacturer is able to come to a market with a wider range of products, thus, increasing its variability while the selling price of the final product is constant (shifting the supply curve to the right).

Offer and special shape supply curve are affected in particular time. The time factor is particularly important for the manufacturer with respect to its ability to change some inputs in time. In a very short period of time (days, weeks), a manufacturer can increase/decrease the only variable inputs – number of employees, materials, raw materials, energy, etc. While the number of fixed inputs – buildings, facilities, production sites, etc., cannot be changed anyhow. This requires longer time periods (months, years) as such change requires adequate preparation, purchase of additional resources, as well as changes in work organization and production and other related activities.

A demand function

Under the term consumer demand, one can understand a sensible decision on the quantity of goods that a user is ready and able to buy according to its price. It expresses a functional relationship among the two variables, quantity and price. Consumers are perceived as a single economic entity which is rational and has a choice. Customers pursue their goal – maximizing utility with minimum expense.

A number of factors influence the demand and its size: the price of a particular good (P_x), consumer revenue (I), the number of consumer households (X), the price of other goods that can be substituted (complemented) (P_y), subjective preferences (T), other factors (F).

Change of each of the factors may differently affect the demand and its size. For example, increasing the consumer's income (ceteris paribus) will lead to an increase in demand and consumption of an estate. Assumption of ceteris paribus means that only the factor of income consumers will change, while all other factors stay fixed. Such an assumption is possible only in theory because in actual practice and especially in the longer term, there is a simultaneous change and the impact of various factors.

The demand factors may be entered as a function of demand, reflecting functional dependence of the required quantity of goods (L) on each factor:

$$D_x = f(P_x, I, X, P_y, T, F). \quad (2)$$

Demand curve is downward (Figure 3.), reflecting the law of falling demand. Moving along the demand curved line, the total demand curve shifts to the left or to the right ($D_1 \rightarrow D_2$). A movement of the total demand curve takes place under the influence of other factors in addition to the price of the estate. In the analysis of demand, an important role is given to the preferences, their habits, but also the time factor. Based on the preferences of consumers to meet their needs and based on the substitution and complementary relationship, shifting the demand curve to the right means that the consumer prefers services with more variety for the same and constant selling price.

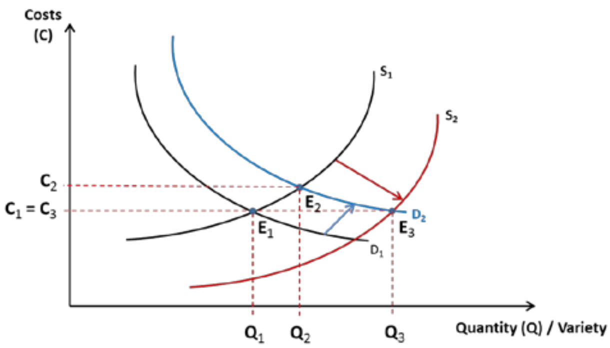

Figure 3. Impact of mass customization on variety and market equilibrium

3. Market equilibrium and complexity

Market equilibrium exists when the demand meets supply. Market equilibrium occurs when the price and the quantity/variety on the market conforms to the buyer and the seller. This means that the market offers as many goods as customers are willing and able to buy and at the same time the market price of such a form, in which producers are willing to produce and consume that amount.

Market equilibrium point – *E* is the point at which the demand and supply curved lines interfere. This point is a point of the equilibrium quantity and the equilibrium price [12].

In the context of potential for the implementation of MC strategy into a batch production process, as a secondary effect, one should consider the market balance, or the equilibrium, after all the changes in the market occurred [13]. As outlined by e.g. [14,15], making the phenomenon of equilibrium possible for the same selling price, a manufacturer can produce more but with increase in variety while the consumer is willing and able to buy the product for the same selling price but choosing from a larger product variety. However, this situation and the decision of light or heavy customization within market equilibrium must be done by industrial engineers and company management to build a production system capable of such customization. This should be decided on the basis of the appropriate ratio of flexibility and productivity of such company and its production facility. Big part of production management tools aims their scope to solve this conflict, e.g. [16,17]. On the other hand, MC brings enormous problems to production environment and management as a consequence of higher product and process variability, respectively. This fact is called complexity and is considered as purely negative aspect of MC. On the other hand, modularization as an enabler of customization is obligatory for the success of MC where set-up costs are critical and it can be seen from an engineering perspective as a form to make complexity manageable [18]. It is due to the decomposition, which is often found when dealing with a complex task. It means that modularity can be defined as subdivision of a complex object into simpler objects. The subdivision is determined either by the structure or function of the object and its subparts. The complex system and its modular design has "tolerant of uncertainty" and it "welcomes experimentation" in the modules.

Tiihonen et al. [19] claim that the complexity of production is directly related to the degree of product modularity. So, how modularity is changing due to different layout types, it is proposed and shown in the Fig. 4. on the two layout design types of the manufacturing system. For this purpose, two indicators will be used, namely, *Module Independence* (MI) and *Singular Value Modularity Index* (SMI).

Module Independence

Blackenfelt [20] proposed this indicator for measure product modularity and it is calculated using the equation:

$$MI = \frac{the\ sum\ of\ relations\ inside\ all\ modules}{the\ sum\ of\ all\ relations}. \qquad (3)$$

The above presented index is evaluated from 0 to 1. The highest value of modularity equals 1 (MI=1).

Singular Value Modularity Index

It measures the modularity degree of internal structure of the product by the following equation [21]:

$$SMI = 1 - \frac{1}{N \cdot \sigma_1} \sum_{i=1}^{N-1} \sigma_i (\sigma_i - \sigma_{i+1}), \qquad (4)$$

where:
N – is the number of components of the system
σ_i– represents singular values, $i=1,2,\ldots, N$ ordered in decreasing magnitude.

The presented indicator SMI is measured from 0 to 1. If SMI=1, then modularity has the highest value - the highest degree of modularity.

To demonstrate the increasing modularity and subsequently complexity, the two layout types are compared. First layout type presenting standard production contains 9 processes producing part consisting of one component type (see Figure 4a) and the second layout design of manufacturing system presents production of mass customized products has 9 processes, which are divided into 4 modules producing 7 types of parts and three component types. The second manufacturing system produces higher number of part types (Figure 4b).

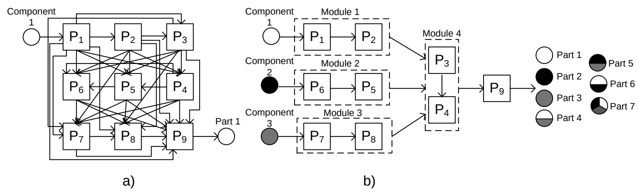

Figure 4. a) manufacturing system layout design 1 b) manufacturing system layout design 2.

The above mentioned indicators are used to enumerate the modularity values according to the equations (3) and (4) for layout 1 and 2. To enumerate the SMI values it is needed to create the binary design structure matrices for both layout types.

$$DSM_1 = \begin{bmatrix} 0&1&1&1&1&1&1&1&1 \\ 1&0&1&1&1&1&1&1&1 \\ 1&1&0&1&1&1&1&1&1 \\ 1&1&1&0&1&1&1&1&1 \\ 1&1&1&1&0&1&1&1&1 \\ 1&1&1&1&1&0&1&1&1 \\ 1&1&1&1&1&1&0&1&1 \\ 1&1&1&1&1&1&1&0&1 \\ 1&1&1&1&1&1&1&1&0 \end{bmatrix}$$

$$DSM_2 = \begin{bmatrix} 0&1&0&0&0&0&0&0&0 \\ 1&0&1&0&0&0&0&0&0 \\ 0&1&0&0&1&0&0&1&0 \\ 0&0&0&0&0&0&0&0&1 \\ 0&0&1&0&0&1&0&0&0 \\ 0&0&0&0&1&0&1&0&0 \\ 0&0&0&0&0&0&0&1&0 \\ 0&0&1&0&0&0&1&0&0 \\ 0&0&0&1&0&0&0&0&0 \end{bmatrix}$$

Then, the obtained results are shown in the following table:

Table 1. Obtained modularity values for both layout types.

	Manufacturing system layout designs	
Modularity indicators	Layout 1	Layout 2
MI	0	4/8=0,5
SMI	0,21	0,83

As can be seen from the previous table, it is possible to state that Layout 2 has higher modularity than Layout 1 according to both indicators. So, layout type presenting mass customized production has also higher complexity than layout presenting standard production. Thus, mass customization allows the benefits of mass production with high production flexibility but also with higher operating cost of such production facility. It combines the economy of scale and the economy of opportunities [22].

4. Discussion

Several forms of MC have been successfully applied in companies so far. As, it was presented on the mass customization and standard production, where in case of mass customized production modularity and complexity is higher due to the higher process variability. The selling price of such customized product is legitimately higher than the price of a standard product as flexible production implies, among others, higher number of components and process options, higher number of mistakes, longer technological preparation period, input material and component diversity, and more expensive supply chain, etc.

The aim of this paper was to outline the mechanism of economy on the market equilibrium. It is clear that the Customization approaches can be taken as examples of changes in market conditions. These changes are conditioned by changes in scientific and technical knowledge, the introduction of new technologies into production, but also social change, the increasing differentiation of consumers, changes in market segmentation, creating new lifestyles and so on. Changes greatly influenced the decision about the product. On one hand the possibility of applying mass customization creates a competitive advantage, on the other side it must be integrated into all business decisions. Usually, it also requires changes in the organization of production, product development, and in the overall system management organization.

5. Conclusions

With regards to the research questions stated in this paper, the following implications can be stated:

1. In the short term, MC as a strategy moves equilibrium into a position in which both, product and process variability grows together with production costs. However, in the long term, equilibrium is shifted to a level where production costs are falling and will return to the level of costs before the implementation of MC while variability keeps growing.
2. In the long term, it is also the result of the manufacturers' adaptation of the MC strategy and elimination of its negative impacts (i.e. product and process complexity). These aspects can be eliminated only in the longer term. Simply put, the customer is willing to pay for this added (non-financial) value of the product. Then, a manufacturer is also satisfied because after a certain time, manufacturing costs for the production of such customized product portfolio will decrease. Any such manufacturer is then able to extend own product portfolio potential as any customer is only satisfied when buying a product that meets his specific needs even at higher acquisition costs, which represent its added value.

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