TECHNICAL ASPECTS OF MASS CUSTOMIZATION IN THE LEAN PRODUCTION SYSTEM

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ABSTRACT

The manufacturing industry is facing the particular challenge of quick response to changing customer needs. Market requires more and more diversified products as well as lower cost. The era of economy of scale, the main competitive weapon of mass production, is irreversibly finished. Typical mass producers have to change their ways of doing business or go to bankruptcy. Today's enterprises seek for more "lean" methods, tools and management systems for operating in high-mix, low-volume (HMLV) manner. Lean production and mass customization are two philosophies of serving customers exactly with what they want, in the desired quantity, quality, and features and exactly when they want it. They do not compete but rather supplement each other.
This paper presents technical aspects of mass-customizing products in the lean production systems. Both lean and mass customization concepts are briefly described as well as relationships between them. Explanation of technical requirements for achieving ultimate goal of lean production – to deliver pure value to the customer – is given. Value stream mapping and its role in matching production processes with market demand is characterized and brief discussion of ensuring capability, availability, adequacy, flexibility, and minimal variability of lean mass customization system follows.

KEYWORDS

lean production, mass customization,

1. INTRODUCTION

Enterprises worldwide act in more and more difficult environments, both macro-and microeconomic. Intensifying competition as well as continuous growth of the customers' requirements causes that companies face new challenges in order to keep their positions. Under these conditions, undertaking the actions to lowering of enterprises internal costs and increasing quality of realized actions seems necessary. But low costs are not enough to gain competitive advantage. Another big issue that companies should offer to customers is diversity of products. There are two strategies which can provide customers with both low cost and variety. These are lean production and mass customization. Lean is often mistakenly considered as not suitable for high-mix, low-volume manufacturing therefore mass customization is indicated as a panacea for ensuring choice to customers. However the most frequent cited author of papers on mass customization, B. Joseph Pine II stated *"customers […] do not want more choice. They want exactly what they want – when, where, and how they want it…"* (Pine II et al., 1995). This statement is exactly in line with lean and just-in-time approaches' ultimate goal of producing the required items, at the required quality and in the required quantities, at the precise time they are required (Brown et. al., 1998)
This paper shows that lean production and mass customization are supplementary philosophies and that lean producers seek proper ways to mass customize their products. Following section of this paper describes lean production concept, its origin and principles as well as main concepts of mass

customization and its relationship with lean. Then Value Stream Mapping method is described in the context of matching production processes with market demand. Some technical requirements for implementing mass customization into the lean production system are discussed.

2. LEAN PRODUCTION - HAND IN HAND WITH MASS CUSTOMIZATION

Lean Production is based on the best Japanese (Toyota Production System) as well as American (Ford) practices. In recent years it begun applying with success in enterprises in Poland (for example: Thomson, Sauer Danfoss, Delco Remy Elmot). The word "lean" represents adaptation and fitness in reference to humans figure. In the case of production systems, "lean" means "slimming" or "losing all the unwanted fat" of production (and all other enterprise' activities) in regard to necessary resources, finished goods and work-in-process inventories as well as space used for production. The term Lean Production describes production systems which are much more "slim" in relation to traditional, existing in predominant number of enterprises, mass production systems (Martyniak, 1998). As Womack, Jones and Roos pointed out in their book *The Machine That Changed the World*, Lean Production "*uses less of everything compared with mass production – half the human effort in the factory, half the manufacturing space, half the investment in tools, half the engineering hours, to develop a new product in half the time. Also it requires keeping far less than half the needed inventory on site [and] results in ... fewer defects...*" (Womack et al., 1991).

2.1 Origins of lean production

Although lean was popularized in last decade thanks to researchers from MIT, fundamental principles, which it is based on, are whole decades older, well-known and described good. The Toyota Production System (TPS) is pioneering lean system and the benchmark in the automobile industry for high quality and low cost (Pine II et. al., 1993). It was developed by Toyota Motor Corporation to provide best quality, lowest costs, and shortest lead time through the elimination of all waste. TPS is built on two pillars, Just-in-Time and jidoka, and is often illustrated with the "house" shown in Figure 1. TPS is maintained and improved through iterations of standardized work and kaizen as well as scientific methods (Shook, Marchwinski, 2003).

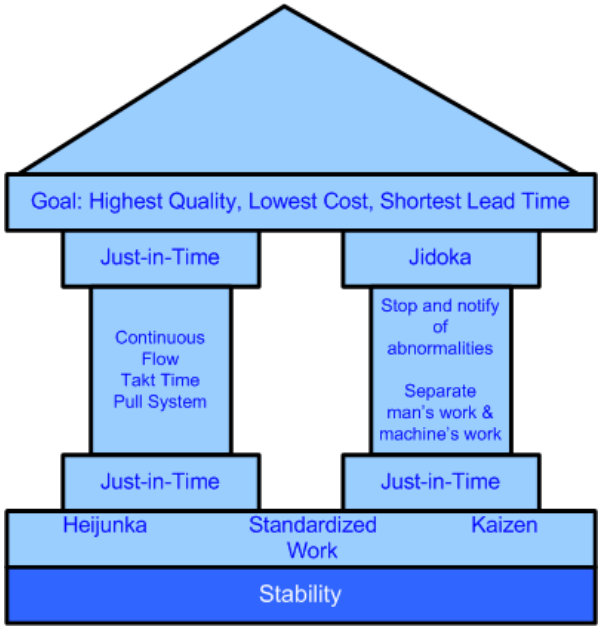

Figure 1. Toyota Production System "House" (Shook, Marchwinski, 2003)

The concepts of Just-in-Time (JIT) and jidoka have their roots in the pre- war period. Sakichi Toyoda, founder of Toyota group, invented the concept of jidoka in the early 20th Century by incorporating a

device on his automatic looms that would stop the loom from operating whenever a thread broke (Shook, Marchwinski, 2003). Jidoka enabled high quality and freed people up to do more value creating work than simply monitoring machines for quality.

Kiichiro Toyoda, son of Sakichi and founder of the Toyota automobile business, developed the concept of Just-in-Time in the 1930s. He ordered that Toyota operations should remove excess inventory and that Toyota would strive to work in partnership with suppliers to level production. Under leadership of Toyota's executive, Taiichi Ohno, JIT developed into a unique system of material and information flows to control overproduction (Shook, Marchwinski, 2003).

Developers of TPS widely drew from Ford's accomplishments of continuous flow and scientific methods. In the Spring of 1950, a young Japanese engineer named Eiji Toyoda visited Ford's vast Rouge plant in Detroit. Eiji Toyoda studied every corner of the Rouge, the world's biggest and most efficient manufacturing complex. Upon his return to Japan, Eiji and his production genius, Taiichi Ohno concluded that mass production would not work in Japan. They also concluded, famously, that "there were some possibilities to improve the system" (Dennis, 2001). Ohno and Toyoda strived for applying continuous flow in high-mix low-volume environment, totally different from Ford's "only black" mass production.

2.2 Customer comes first - five principles of Lean Thinking

After "The Machine that Changed The World" was launched and term "lean production" or "lean manufacturing" became popular in the West, many managers wanted to implement lean but didn't know how to do it. In the response of their needs Womack and Jones launched in 1996 new book *Lean Thinking: Banish waste and create wealth in your corporation*, where authors describe in detail principles of Lean Manufacturing. Womack and Jones summarize LM as five main principles (Womack, Jones, 2003):

1. Precisely specify value of specific product,
2. Identify the value stream for each product,
3. Make value flow without interruptions,
4. Let the customer pull value from the producer, and
5. Pursue perfection.

Above sequence is also an order in which companies should implement lean in their operations. As Figure 2 shows this is never-ending sequence – enterprises should repeat these steps again and again for every product to pursue perfection.

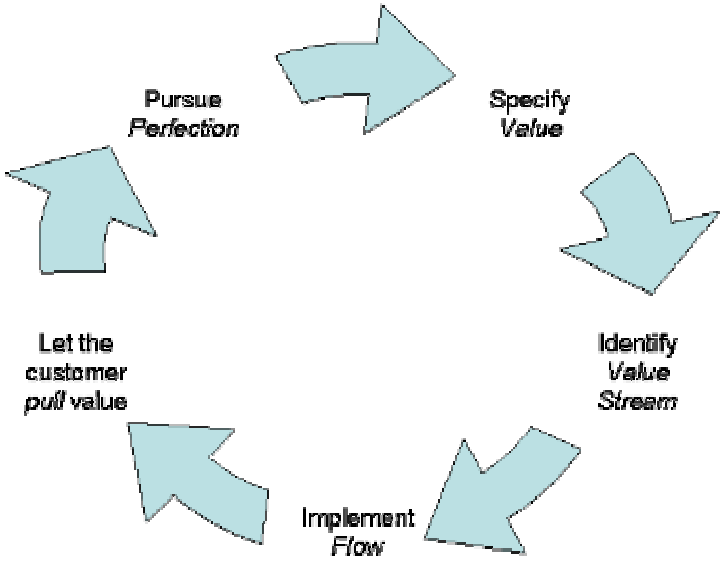

Figure 2. Never-ending loop of continuous improvement

The value is starting point for Lean Thinking. It can be defined only by customer, which can be both internal and external (final customer, next process or next firm in supply chain). Value must be specified for particular product (good, service or both at the same time), which satisfy the needs of particular customer, at the acceptable price in specific place and given time. It's necessary to correctly identify value stream (all the activities necessary to make a product, both value added and non-value added, along value stream from raw material to finished good) and create continuous flow of product, which is stimulated by customer who pulls goods from manufacturer. Enterprises should continuously strive for perfection. Continuous changes and process improvements are inherent part of Lean philosophy.

2.3 Mass customization – required quality, quantity and features when needed for every customer

In his book "*Mass Customization: The New Frontier in Business Competition*" B. Joseph Pine II defines mass customization as a process by which firms, in different industries, apply technology and management methods to provide variety and customization through flexibility and quick responsiveness (Kotha, 1994). Pine lays out the basic approaches to mass customization which include (Pine II, 1993):

- customizing services around standardized products,
- creating customized products and services,
- providing point of delivery customization,
- providing quick response throughout the value chain, and
- using modularized components to customize end products and services.

Some authors (e.g. Michel Baudin, 2000 and SMThacker & Associates, 2000) extend above list with other strategies among which *postponement* plays vital role. Baudin presents interesting approach for technical implementation of mass customization in the customer-driven manufacturing. He describes eight strategies which are useful in many circumstances (Baudin, 2000):

1. analyze the structure of the demand
2. standardized components
3. make a catalog with a discrete set of sizes
4. postpone customization to the end of the process
5. identify a common process
6. maintain a database of past designs
7. design your custom manufacturing process
8. set up a simple production system.

Above strategies consist of set of techniques, which include creating product families and product cells, establishing simple material control mechanisms (e.g. Kanban, FIFO), standardizing components and modularizing products which all are strongly in line with lean production philosophy. Furthermore Gilmore and Pine presents four approaches of mass customization which are more or less used in lean production systems (Gilmore, 1997):

1. *Collaborative customization* is conducting a dialog with individual customers to help them articulate their needs, to identify the precise proposal that fulfills those needs, and to make customized products for them,
2. *Adaptive customization* consist in offering one standard, but customizable, product that is designed so that users can change it themselves,
3. *Cosmetic customization* is presenting a standard product differently to different customers.
4. *Transparent customization* consist in providing individual customers with unique goods or services without letting them know explicitly that those products and services have bees customized for them.

First approach is most often associated with the term mass customization and is appropriate for businesses whose customers cannot easily articulate what they want. This strategy is also used by lean producers who wants to keep in good relationships with their customers and continuously scan customer needs and convert them into technical specification e.g. through Quality Function Deployment method.

Enterprises which strive to be lean often apply also second approach – adaptive customization. They use such strategy as modular design of their products thus each product can be customized through adding particular modules to standard.

Cosmetic customization is really a standard in today's manufacturing. Each producer face demands of different customers to ship or pack, or present the same product differently.

Fourth approach – *transparent customization* – is also connected, however indirectly, with lean or more general, world class manufacturing. This class of producers seeks to meet anticipated needs of their customers and through innovations and quick introduction of new products they can satisfy them. Of course it require very good product development process and short lead time, but as 3M and Toyota show it is possible.
Above examples as well as several analysis (e.g. Jina et al., 1997) confirm that mass customization can be considered to espouse lean production rules and principles. The paramount importance of customer orientation and fast response attached to lean manufacturing is thus shared by mass customization (Jina et al., 1997).

3. TECHNICAL ASPECTS OF LEAN MASS CUSTOMIZATION

To become lean producer and mass customizer, what is equivalent to providing customer with pure value, enterprise have to know how to match customer demand with internal processes and what are technical requirements of that. Value Stream Mapping is excellent tool for designing lean value stream and pointing out areas which need improvement to fulfill technical requirements of mass customization.

3.1 Value Stream Mapping – tool for building customer requirements into manufacturing processes

A value stream is all the activities (both value added and non-value added) currently required to bring a product through the main flows essential to every product:

- the production flow from raw material into the arms of the customer
- the design flow from concept to launch.

Taking a value stream perspective means working on the big picture, not just individual processes, and improving the whole, not just optimizing the parts.

Value Stream Mapping (VSM) was popularized by American Lean Enterprise Institute, founded by James P. Womack. VSM methodology is simple: choose product family, draw current-state map, draw future-state map and make implementation plan. With current state map made for chosen product family, we can identify sources of waste which have to be eliminated in order to achieve world class manufacturing (Shook, 1999). With future-state drawing we create implementation plan for LM. Hypothetical current-state map is shown in figure 3.

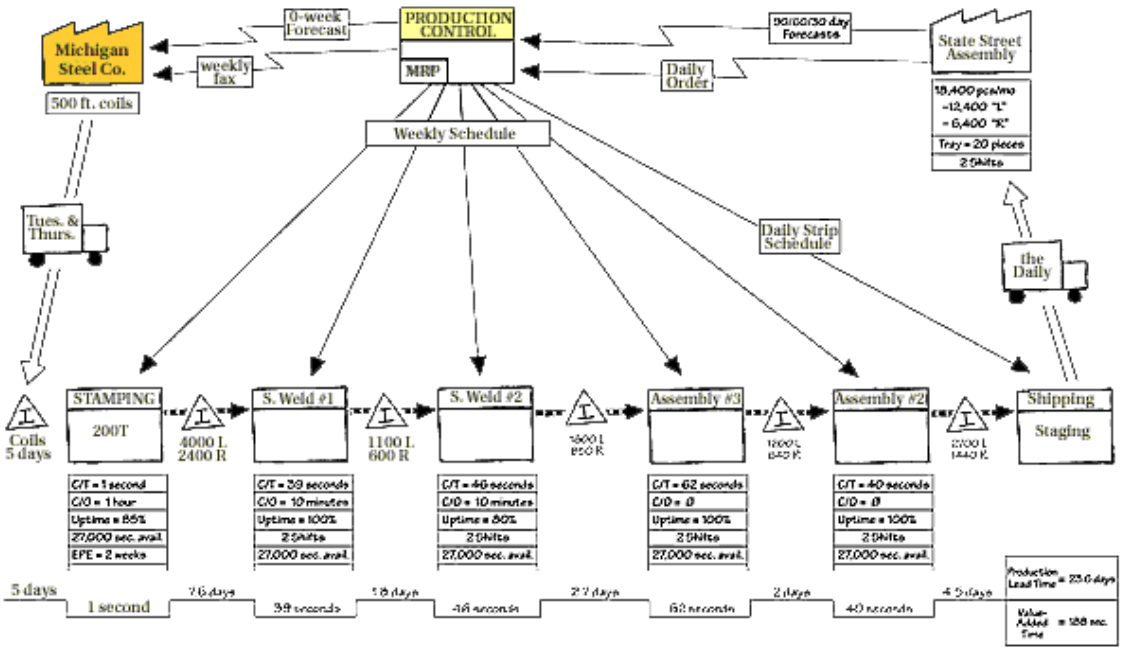

Figure 3. Current State Map (Shook, 1999)

We can see problematic areas on the basis of following data:
1. EPEI refers to the "every-part-every-interval", which is a measure of production batch size – the bigger EPEI, the bigger batch size what is exactly opposite to what is lean and mass customization looking for,
2. C/O – setup time. Big value of C/O points at processes which require setup time reductionThis is essential for effective LM implementation and quick response to changing customer requirement,
3. Uptime – equipment availability – lower uptime points that enterprise is subject to disruptions due to machine failures,
4. Lead Time / Value Added Time - high value of lead time in relation to value added time shows that flow is very inefficient. In cases such of that there is a tendency to inventory accumulation, what can be seen at the figure 3.

On the basis of current-state map, future-state map is created, which is blueprint for required changes (Figure 4). It also integrates lean tools and techniques in order to eliminate all the disruptions, which are barriers for Lean Manufacturing.

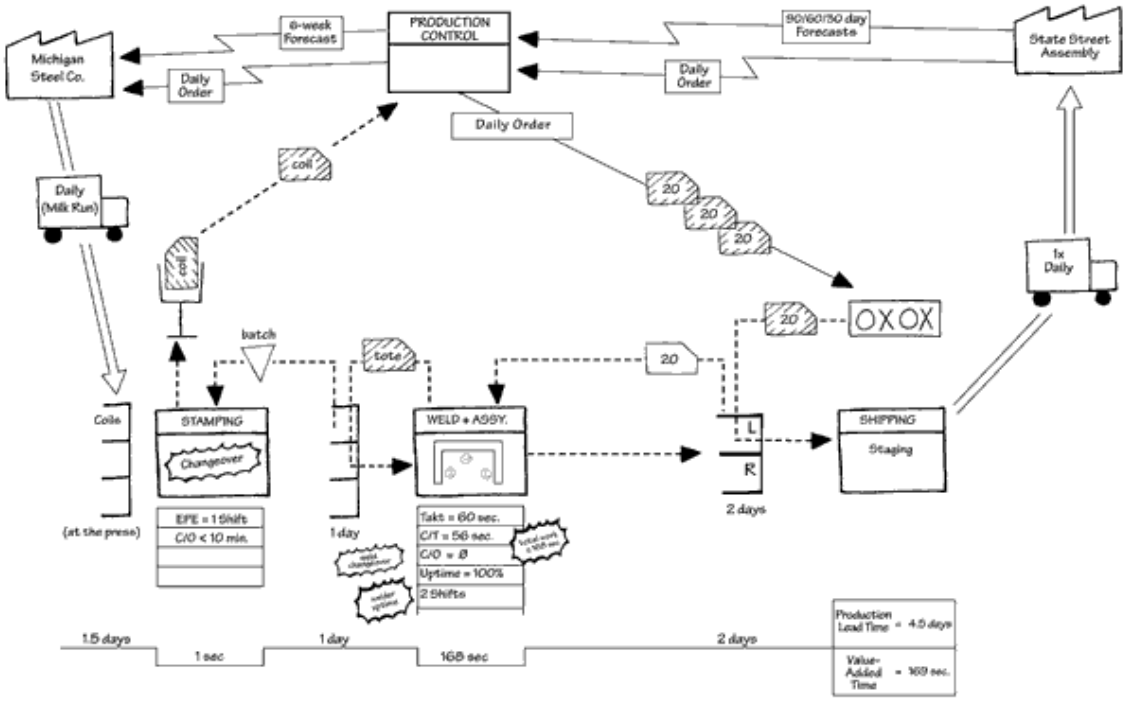

Figure 4. Future State Map (Shook, 1999)

Future state map shows only these processes which fulfill some technical requirements to create lean system. They have to be capable, available, adequate and flexible (Womack, 2003). To achieve future state which would allow being lean mass customizer, company also has to eliminate variability in its internal processes

3.2 Capability

Process is capable when it can be conducted with the exact same result every time. Lean producers strive for 100% capability through the combination of source inspection (which detects errors before they become defects) and mistake-proofing (or poka yoke) devices (which remove defects before they're passed down the production line) that eliminates the need for statistical quality control. Shigeo Shingo, the father of Poka Yoke demonstrates how this proven system for reducing defects to zero turns out the highest quality products in the shortest period of time (Shingo, 1986). Common examples of mistake-proofing include (Shook, Marchwinski, 2003):

- product design with physical shapes which make it impossible to install parts in any but the correct orientation,
- complex parts monitoring system with photocells, which make sure the right combination of parts was selected for the specific product being assembled,

and many more.
Poka Yoke system is most desired in HMLV environment especially when standard product is being customized in the last phase of production. Lean producers when aim to be mass customizers have to make their processes brilliant, 100 percent capable because only with brilliant processes they will be able to gain competitive advantage.

3.3 Availability

Availability of the process (or machine) is a percentage of time when it can perform when it is needed. When process is subject to breakdowns its availability is low. It is strongly unwanted because the supplier has to be sure that he will be able to respond quickly to customer requirements. To raise availability of internal processes lean producers implement Total Productive Maintenance. It is a set of techniques, originally pioneered by Denso in the Toyota Group in Japan, to ensure that every machine in production process is always able to perform its required tasks. Its most significant contribution is the reduction and elimination of the 6 big losses presented in Table 1 (*TPM*).

Table 1. Six big losses in TPM

Loss	Description
Breakdowns	Long interruptions, expensive repairs
Setup and Changeover	Taking much longer than needed
Idling and Minor Stoppages	Hard to quantify, add up to big losses
Reduced Speed	Equipment cycle times have gradually deteriorated
Defects and Rework	Quality losses and unhappy customers
Startup Losses	Too long to get to steady state after a change

TPM approach is termed total in three senses. First, it requires the total participation of all employees, not only maintenance personnel. Second, it seeks total productivity of equipment by focusing on all of the six major loses (Table 1). Third, it addresses the total life cycle of equipment to revise maintenance practices, activities and improvements in relation to where equipment is in its life cycle (Shook, Marchwinski, 2003).

3.4 Adequacy

Each company have to secure enough capacity to produce goods with short lead time. In the current era of big, automated machines, producers often have to much capacity. It of course allows quick response, but is very expensive. Lean producers do not like big, automated machines (they call them "monuments") because they cannot be easily changed over to produce different products. They rather look for "right-sized tools", which are highly capable, easy to maintain (and therefore available to produce whenever needed), quick to changeover, easy to move and designed to be installed in small increments of capacity (Shook, Marchwinski, 2003). Adding (or subtracting) capacity in small increments is very important because doing this producer can achieve capital linearity (the amount of capital needed per part produced can be very nearly level (linear)).

3.5 Flexibility

Flexibility if one of the most desired characteristics of production system. It is strongly connected with time – time from order to delivery. As George Stalk Jr., pioneer of time-based competition, stated: "*today, time is on the cutting edge*" (Stalk, 1988). When company is able to respond quickly to customer demand, it can be competitive. Overall lead time consists of set-up time, processing time, transport time and queue time (Browne et al., 1988). Lean producers aim to achieve ideal goal of "zero lead time" through a set of techniques that shorten every component of lead time. They are briefly described in Table 2.

Table 2. Techniques for shortening lead time

Technique of shortening lead time	Description
One- piece flow and small batches	Minimizes processing time and queue time
Cellular layout	Minimizes distances thus transport time
Single Minute Exchange of Dies	Minimizes set-up time
Line balancing	Minimizes queue time
Small transport lots	Minimizes queue time when production have to be perform in batches

Another facets of flexibility is ability to handle changing demand and producing different products with the same staff and equipment. It is called labor and equipment flexibility. Labor flexibility is accomplished through educating people so they can handle many machines (multi-machine handling) or many processes (multi-process handling). Multi-skilled people can be relocated to different work centers when demand for particular product changes. Flexibility of equipment can be achieved through designing simple machines which can be easy changed to produce different products. Specialized machines used in mass production are not suitable for mass customization because they are not supporting production of variety of goods.

3.6 Elimination of variability

In every production system management faces hard task of elimination of existing variability in both process (because of rework, scrap, breakdowns etc.) and flow (e.g. arrival rates). In mass customization and lean systems it is much more problematic than in for example mass production, because these systems usually uses less inventory, capacity and time so they have less buffers to compensate variability. Only solution for lean mass customizers is to reduce variability at every opportunity. In particular (Kornicki, Koch, 2003):

1. *Demand variability.* Limiting the number of options of goods produced. Postponement of customization (even dealer-installed options). Small fluctuation in demand can be reduced by supermarket pull system.
2. *Manufacturing variability.* By focusing on setup reduction, standardizing work practices, total quality management, error proofing, total productive maintenance, and other flow-smoothing techniques, lean producers can do much to eliminate variability inside its factories.
3. *Supplier variability.* Reducing number of suppliers and helping suppliers reduce variability in their operations

Variability is a very broad concept so above is only simple examples of reducing it. At the moment Six Sigma strategy, which aims to reduce variability with more sophisticated methods, is strongly developing. It is also applied by lean producers and even “lean sigma” term was coined for integration of this two philosophies.

4. CONCLUSIONS

Lean manufacturing and mass customization seemed to be relatives in term of perceiving meeting customer requirements as their ultimate goal. Achieving this goal is a big challenge in terms of matching production process, its technology and resources up with the market demands. It was shown however that plenty of lean production techniques exist that can help with creating adequate, capable, available and flexible lean production system supporting mass customization.

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