Applied Computer Science, vol. 13, no. 4, pp. 35–44
doi: 10.23743/acs-2017-27

Submitted: 2017-10-25
Revised: 2017-11-13
Accepted: 2017-12-06

mass customization, computer aided planning, TOC

Janusz MLECZKO[*], Paweł BOBIŃSKI[**]

PRODUCTION PLANNING IN CONDITIONS OF MASS CUSTOMIZATION BASED ONTHEORY OF CONSTRAINTS

Abstract

In accordance with the requirements of the modern market, small and medium-sized enterprises (SMEs) need to offer a wide range of products tailored to the specific and individual requirements. The success of many enterprises, which work in mass production system and use economic effect of scale production slowly is a thing of the past. There are many enterprises, generally small and medium manufacturing in unit and small batch production, for which it is necessary to develop optimal methods of production planning, taking into account the flexible production requirements, matched to the time-varying customer's demand. The article presents the production planning based on TOC in conditions of mass customization. Presented solutions are used in modern practice.

1. INTRODUCTION

Companies operating on today's market have been forced to offer a wide range of products for a long time. What is more, realization time does not increase because of this. Clients became more demanding and they want products which meet their individual needs. Instead of mass production, SME's must comply with mass customization (Tien, 2011). For many companies, it means the necessity to use the unit production in many variations. Mass customization forces a change in the approach to product design and implementation of flexible tools for manufacturing

[*]University of Bielsko-Biała, Department of Industrial EngineeringWillowa 2,
43-309 Bielsko-Biała, Poland,phone: +48 33827253, e-mail: jmleczko@ath.bielsko.pl
[**]LiuGong Dressta Machinery, Stalowa Wola, Poland

process. Mass customization forces also a change in business processes in many aspects. The standard approach assumes unified mass production of semi-finished products and manufacturing of product families based on already finished semi-finished products. However, there are product families, for which this approach is not possible. They demand using unit production. The adaptation of production system to the changing needs of the customer seems to be necessary to maintain a competitive advantage in many industries. During manufacturing in such conditions, the role of production planning becomes very important. Increasing the flexibility of organizational production preparation is often a key element of the whole process. The problem that was addressed in this paper concerns the analysis of alternative methods for planning the production of products with short production cycles in conditions of mass customization. The issue of mass customization is widely presented in the literature. The summary of this issue was shown in (Da Silveira, Borenstein & Fogliatto, 2001) and then in 2012, extension (Fogliatto, Da Silveira & Borenstein, 2012) was released. It contained an overview of the literature of the subsequent years. The implementation of mass-customization without the appropriate class of software is virtually impossible (Luo, Tu, Tang & Kwong, 2008; Peng & Heim, 2011). Because of the fact, that above problem, to a large extent, applies to small and medium-sized enterprises, it is particularly important to use adequately simple and low-cost solutions. The implementation of ERP applications for this purpose is largely insufficient. This refers to both: cost area and the need to adapt the ERP application to product families management requirements. Applications to efficient management of configurable products manufacturing in small and medium-sized enterprises are rather known only in theory than in practice (Kumar, 2007).The general trend in recent years is moving away from mass production to mass customization (Kumar, 2007; Tien, 2011). The be-ginning of this methodology was engineered or the order strategy (Haug, Ladeby & Edwards, 2009).

2. PROBLEM FORMULATION

The problem discussed in this work concerns the manufacturing of high-variety products. To solve this problem the point is to find answers to the following questions:

- What data and what algorithms are necessary for the automatic process of gene-rating production plan for high-variety products?
- What knowledge bases to extend the ERP system for the production of high-variety products is necessary?
- Does the change of the planning method have a major impact on the organization of the manufacturing process in conditions of mass customization?

3. METHODS USED FOR THE CREATION OF PRODUCTION PLANS

The problem of the production flow of machine elements in conditions of unit and small batch production can be presented in a mathematical form. The solution to this task is a working schedule of individual production workstations. To define a model of the manufacturing process the following definitions, designations and assumptions were assumed (Mleczko, 2014).

An order – involves execution of the actions called operations, each of which requires the involvement of specific resources. An order can be a production process of set of elements in machine industry, an assembly process or processing batch of material for process production. The order is characterized by the following attributes:

- planned start date,
- demanded completion date,
- route of the manufacturing process (with the possibility of the multivariate route of manufacturing process).

$Zl = \{Zl_1, Zl_2, \dots, Zl_l, \dots., Zl_L\}$ means set of orders, where $L -$ means number of orders, l – means order identifier.

Each Zl_l order consists of a set of J_k jobs represented by $Po_{l,k}$, manufacturing processes

$$Zl_l = \{Po_{l,1}, Po_{l,2}, , \dots, Po_{l,i}, \dots, Po_{l,k,}, \dots, Po_{L,K}\} \quad (1)$$

where: K– means number of jobs for the Zl_l order,
i, k – indicates identifiers of jobs for Zl_l order.

Besides this, for each J_k job and corresponding to it manufacturing processes $Po_{l,i}$, $Po_{l,k}$ from the Zl_l order, a sequential relation is defined:

$$\forall_{i,k \in \{1,\dots,K\}} Po_{l,i} \prec Po_{l,k} \quad (2)$$

Likewise, as the product consists of the elements, such an order is made up of jobs. Jobs are semi-orders for the realization of the element of the product. The set of jobs was marked as *J*. Jobs have a hierarchical structure. To make a job, it is necessary to follow the sequence of operations of the manufacturing process. It is assumed that the realization of the jobs means the realization of the manufacturing process for the product component. The operations are carried out in a sequential system.

Each $Po_{l,k}$ manufacturing processconsists of a set of $O_k$operations. The operations in the job have to be done in the following order (technological order), i.e. every *n* operation has to be done after *n–1*, and before *n+1*. To simplify the notation set of operations of $Po_{j,k}$ process is denoted by O_k.

$$O_k = \{O_k^1, O_k^2, \dots, O_k^n, , \dots, O_k^N\} \tag{3}$$

A resource– resources are equipment, staff, materials, machines, capital or energy raw materials needed to carry out the operations of the manufacturing process. In the case of resources their three basic categories are taken into consideration:

- reusable (employee, machine, robot),
- consumable (raw materials),
- double-limited (energy, money).

$$M = \{M^1, M^2, \dots, M^a, \dots, M^A\} \tag{4}$$

means a set of resource types (homogeneous in terms of the feasibility of the operation of the manufacturing process), where A – number of resource types (group of workstations), a – resource type identifier.

On each of the workstations operations assigned to the group of workstations can be done.

Reusable resources have limited availability, consumable resources – have limited quantity, and the double-limited – both kinds of limitation.

Among the many important features of reusable resources the most frequently mentioned are:

- availability,
- quantity,
- cost.

The above attributes can be written as

$$M^a = (Ca^a, g^a, K^a) \tag{5}$$

where: Ca^a – calendar of working time of a type of resource specifying availability,
g^a – number of a workstation types,
K^a – labour cost of a resource type.

Using iterative methods to solve scheduling problems guarantees receiving all possible trajectories of decision, leading to receiving the set of schedules, from which we must choose one – fitting the best to our optimization criteria. The process of generating all the possible solutions to this task – due to the high computational complexity – may not be possible in conditions of unit and small batch production and even more in mass customization. The main barrier, which makes it impossible to carry out a full course of calculations, is most of all the time, which is dependent on the used computer equipment and on the algorithms. In the case of generating a list of solutions using multi-stage programming, there is a possibility to reduce the number of generated solutions, efficiently at the stages prior to the final. This greatly reduces the time of searching for optimal solutions and enables real implementation of the given model under variable manufacturing conditions.

The problem of finding the solution of optimal plan was an issue repeatedly taken into consideration by researchers. It should also be noted – that solution requires high computational power and defining parameters e.g. operations and times, which are challenging to achieve in conditions of mass customization. There are two main reasons for this situation: a very big amount of potential products and defined routes of production process.

For these reasons an alternative solution has been sought. This solution should be good enough, requiring significantly less data and realized in production practice.

4. ASSUMPTIONS OF PRODUCTION PLANNING BASED ON TOC

For the manufacturing system in conditions of high-variety, TOC was used in the production planning process. Following the 5 steps of concentration in the TOC, underlying assumptions were presented.

4.1. Identification of constraints

There are constrains of 2 types in manufacturing enterprises – internal constraints (appearing inside the organization) and external constrains (appearing in the environment of the system and at the market – this constraint is usually a customer demand).

In the case of production in conditions of mass customization, in many cases internal constraints will apply to two areas: the design area and manufacturing area.

According to the theory of constraints, the flow is determined by constrain "bottleneck". The production system was built in such a way that:

1. Given product family (or set of them) was limited by one bottleneck.
2. Due to the simplification of the management system, the bottleneck was located on the last operations in the process (usually assembly operations).
3. Bottlenecks accounted for disjoint set.
4. Bottlenecks were stable – they did not move under the operation of one product family.

Bottlenecks $C_S = \{1, \ldots, S\}$ were definied from the process. Due to the variability of resource availability in time (schedule, shift system) it was defined for individual units of time (taken as a basic planning parameter). In the analysed in the further part of this paper example, because of the short manufacturing time in the bottleneck, 1 day was taken as a time unit.

The correlation between the consumption time in bottleneck onproduct family design should also be defined. In many cases product family's options have significant influence on consumption time in bottleneck. It means that dependence between options in a product family and manufacturing time in the bottleneck should also be defined. From the above assumptions results also ability to assign to the product family to one bottleneck, determining the manufacturing process.

The method of production planning assumes multi-level scheme:

1. The division of the manufacturing process into stages:
   a. Production of semi-finished products – separate planning method of the level of semi-finished products – as outlined in chapter 3.
   b. Production of the finished product – planning of assembly manufacturing of finished products and components with high variability resulting from the configuration, that storage in the processed form is pointless, e.g. components dependent on the dimensions.
2. Verification of the availability of raw material.
3. Production planning of the finished product – based on the algorithm of automatic planning and visualization – allowing correction of the plan by the planner in emergency situations.
4. Distribution planning of the finished product.

The multistage planning method assumes sequence of actions 1 to 4, herein in the forward planning method first point 3 is carried out, then point 4. In backward scheduling first point 4 is carried out, next point 3.

Visualization of the process of bottleneck occupation time will enhance the decision making process concerning the deadline for taking orders from customers.

	T1	T2	T3	...	Tn
Cs1	89	67			89
Cs2	35	5			6
Cs3	4	60			4
Cs4	65	6			6
Cs5	56	77			56
...					6
Csn	12	33			12

Fig.1. Example matrix of bottleneck availability

Fig. 1. shows an example of matrix of bottleneck's availability which is crucial for the planning process.

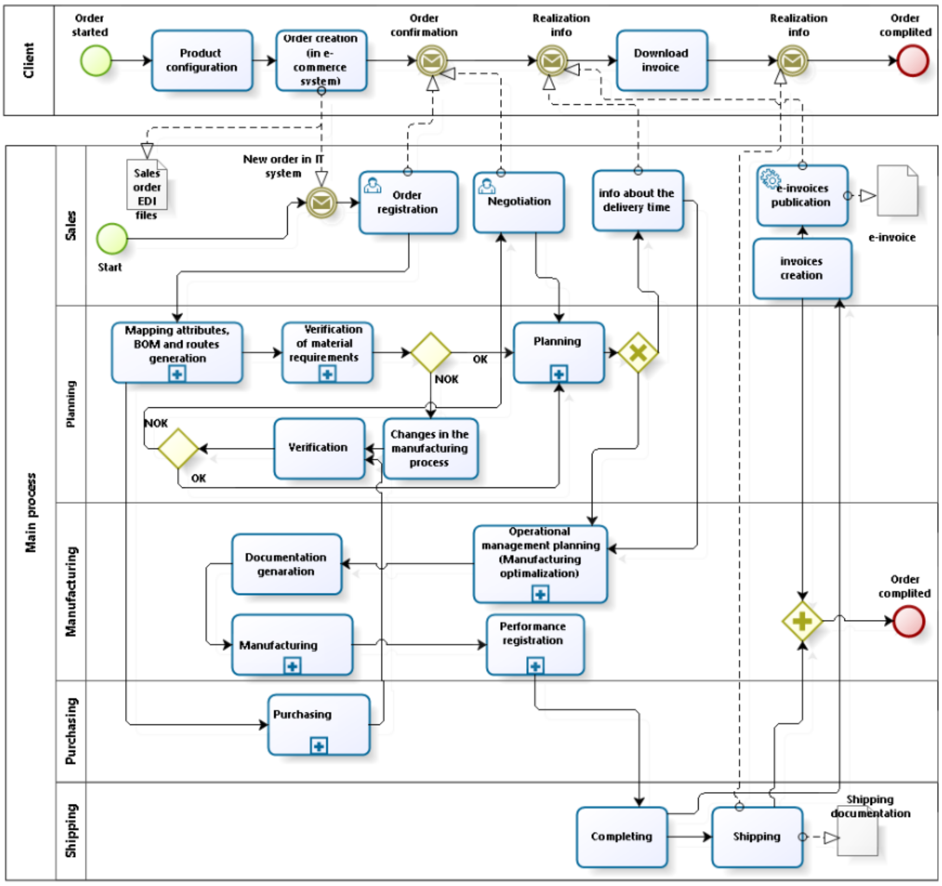

Fig. 2. The main process of production planning

The main process is shown below (Fig. 2.). Further simplification of the planning process results from the adopted assumptions. Since semi-finished products at the level of finished products were separated from manufacturing order, the order takes the form of only one job (subset of order) (Zl_{PR})

$Zl_{PR} = \{Po_{PR}\}$,in manufacturing process Po_{PR}, the operation passing through the bottleneck was separated.

$$O_{PR} = \{O^1_{PR}, O^2_{PR}, \ldots, \boldsymbol{O^{WG}_{PR}}, , \ldots., O^N_{PR}\} \tag{6}$$

where O^{WG}_{PR}, means the operation of bottleneck.

The parameters of flow through the bottleneck can also be given in a simplified way:

$$Zl_{PR} = (C_S, O_S^{PR}, \gamma) \tag{7}$$

where: C_S – specified element of the set of bottlenecks in the process, s – bottleneck identifier,
O_S^{PR},– operation on S bottleneck for process of PR finished product,
γ – occupancy of bottleneck expressed by the accepted unit (eg. time) for proces of PR finished product.

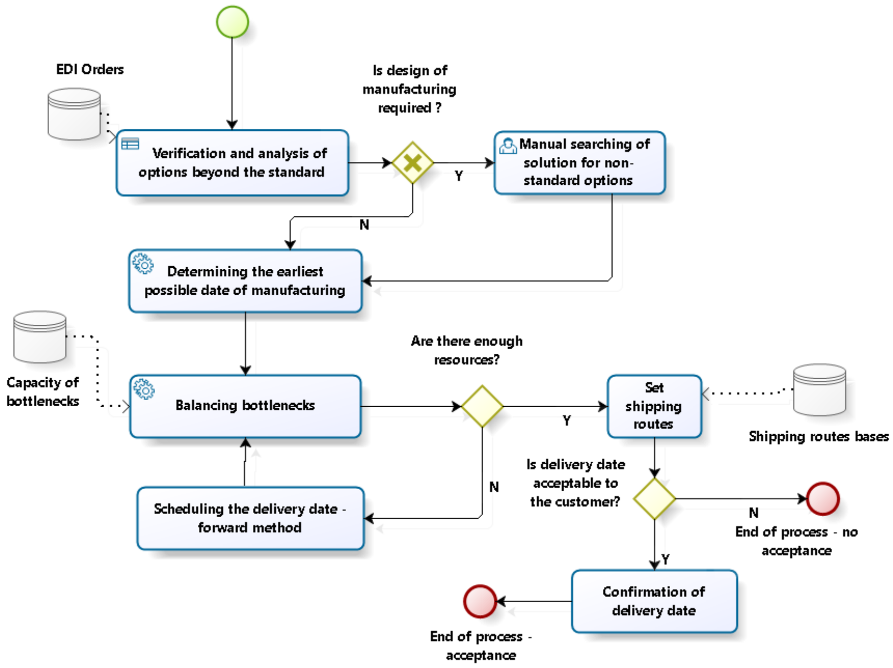

Fig. 3. Process of production planning – „forward" method

4.2. Production planning using forward method

In determining the order of realization of the tasks two strategies for scheduling are basically used – "backward" and "forward" strategies. In some practical solutions mixed method, which is a unique combination of these two strategies, is also used.

Forward scheduling (Fig. 3) answers the question: When manufacturing of the product will be completed, if you know the date of commencement of the associated manufacturing process?

"Forward" scheduling involves making the following algorithm:

– start of production of the product components, as the earliest possible,
– "forward" calculation of the deadlines for the products searching for empty places in the production plan,
– calculation of availability time and quantity of planned to buy materials.

This procedure of forward scheduling enables determination of the earliest date of products availability.

The time needed to manufacture the batch of products, parts or subassemblies is calculated with the using the available data of the operation of the manufacturing process (the time of the task working on the manufacturing resource) for every operation on a specific machine or line.

4.3. Visualization of the production plan

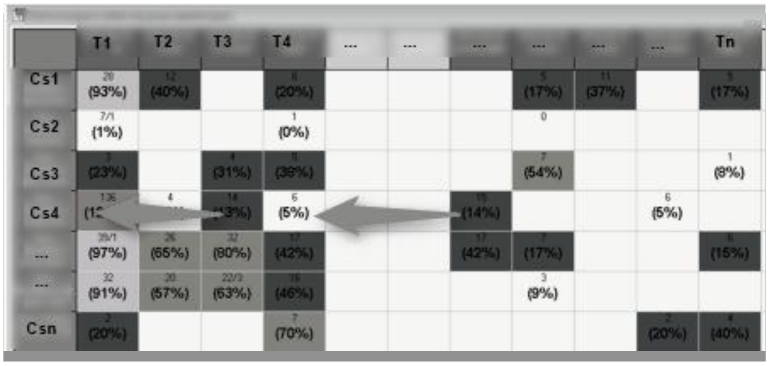

Fig. 4. Visualization of production planning – „forward" method

Fig. 4 showed the result of automatic planning procedures. It is possible to tune the plan by manually moving jobs. In practice, manual tuning is rare and it is used only in exceptional situations. Postponing of the production date results from the prioritization of the delayed or pledged orders.

5. CONCLUSIONS

The change of the planning method has a major impact on the organization of the manufacturing process. In forward planning method, the solution is always found by the system. By moving the completion dates forward, sooner or later the company will find a period of time, in which there are spare capacities for the fulfilment of customer orders. Of course, the date may be unacceptable for the customer and then the company loses the order. However, it does not have an impact on the increase of the demand for capacities. Unfortunately, in this method we do not really know how much the company loses due to not taking orders because of too distant dates. Moreover, we do not have a major influence on this. In the forward method, a real market demand for capacity in specific bottlenecks was not entirely transparent. Nevertheless, using this method it is possible to significantly automate planning and also reliably and immediately respond to the customer's question about the delivery time. The method was verified for a production, where about 2000 different orders were produced every day. Both studies and production practice have proven utilitarianism of the proposed solutions. After applying this method, studies on the implementation of a more demanding method (backward scheduling) were also carried out.

REFERENCES

Da Silveira, G., Borenstein, D., & Fogliatto, F. S. (2001). Mass customization: Literature review and research directions. *Int. J. Production Economics, 72*, 1–13. doi: http://dx.doi.org/10.1016/ S0925-5273(00)00079-7

Fogliatto, F., Da Silveira, G. & Borenstein. D. (2012). The mass customization decade: An updated review of the literature. *International Journal of Production Economics, 138*, 14–25. doi:http://dx.doi.org/10.1016/ j.ijpe.2012.03.002

Haug, A., Ladeby, K., & Edwards, K. (2009). From engineer- to- order to mass customization. *Management Research News*, *32*(7), 633–644. doi: 10.1108/01409170910965233

Kumar, A., (2007). Mass customization: manufacturing issues and taxonomic analyses. *Int. J. Flex. Manuf. Syst., 19*, 625–629. doi: 10.1007/s10696-008-9049-5

Luo, X., Tu, Y., Tang, J., & Kwong, C. K., (2008). Optimizing customer's selection for configurable product in B2C e-commerce application. *Computers in Industry*, *59*, 767–776. doi:http://dx.doi.org/10.1016/j.compind.2008.03.003

Mleczko, J., (2014). *Manufacturing processes creating with use of dynamic classification in conditions of unit and small-batch production*. Bielsko-Biała: Publishing House of University of Bielsko-Biała.

Peng, D. G., Heim, G. (2011). Impacts of information technology on mass customization capability of manufacturing plants. *International Journal of Operations& Production Management*, *31*(10), 1022–1047.doi: 10.1108/01443571111182173

Tien, J. M., (2011). Manufacturing and services: From mass production to mass customization. *Journal of Systems Science and Systems Engineering*, *20*(2), 129-154.doi: 10.1007/s11518-011-5166-x