Multi-assortment rhythmic production planning and control

B Skolud\textsuperscript{1}, D Krenczyk\textsuperscript{1} and M Zemczak\textsuperscript{2}
\textsuperscript{1}Silesian University of Technology, Faculty of Mechanical Engineering, Konarskiego 18A, 44-100 Gliwice, Poland
\textsuperscript{2}University of Bielsko-Biała, Department of Production Engineering, Willowa 2, 43-309 Bielsko-Biała, Poland

E-mail: bozena.skolud@polsl.pl

Abstract. A method for production planning in a repetitive manufacturing system which allows for estimating the possibility of processing work orders in due time is presented. The difference between two approaches are presented; the first one one-piece flow elaborated in Toyota and the second one elaborated by authors that consists in defining sufficient conditions to filter all solutions and providing a set of admissible solutions for both the client and the producer. In the paper attention is focused on the buffer allocation. Illustrative examples are presented.

1. Introduction

Formulating Nowadays, two tendencies are observed in the industry, the first one: manufacturing of small quantity but in many varieties and the second one: manufacturing of small variety but in different quantity [1, 2, 3].

Both cases are characterized by small batches, what result with the need to shortening of the planning horizon.

It is not possible to elaborate a universal planning strategy suitable for every manufacturing condition. New approaches compete with each other in the context of the minimization of loses (lean manufacturing), which are related to the low level of resources utilization, minimization of production stock and storage costs. They reflect the producer’s aim to increase profits and not to assure the satisfaction of manufacturing as such.

In this situation the most important thing is to be competitive. It means to assure lower price and precise time of production order completion then competitors. Because of that negotiation with clients about prices is impossible. To be better means to be cheaper. Costs of manufacturing decide about the profit [4, 5]. If the first estimating of production costs and terms of production order realization is not precise enough, then the profit is perceptible only in the phase of gaining of clients. In longer perspective it causes loose of the customer confidence as well as possibility of new orders gaining.

In the planning process the organizational variants, accomplishing limitations or subsetting the alternative solutions are determined, and then, the best variant is chosen basing on the additional criteria. Most cases of production planning and scheduling belong to a class of NP-hard problems. Many methods such as mathematical programming, computer simulation, application of artificial intelligence, are applied for solving these problems. A combinatorial explosion of possible variants makes it impossible to use an optimal solution in practice. Firstly, the feasible solution does not have
to be an optimal one and the set of feasible solutions does not have to contain all the possible solutions.

The method presented in the paper guarantees meeting of the customer’s demands. The constraint propagation technique is used. This approach proposes the creation of the sufficient conditions for filtering all solutions and it gives a set of admissible solutions for both the customer and the producer. The approach is presented with comparison to one piece flow philosophy proposed by Toyota.

2. Continuous flow

The methodology of continuous flow boils down to selection of products for simultaneous realization in the manufacturing system [6]. According to this idea product are classified into 4 groups. Products which are similar each other and characterized by high demand belong to the first group. In the contrary the 4th group contains products of low demand from the market and which are extremely different from others (in design, size and technology). Products which are classified into the last (4th) group should not be allowed to perform in the considered system because of their big diversity and also because of time-consuming and expensive setup. Those elements should be commissioned in order to perform to another production cell or line or should be outsourced under cooperation to another company. In those systems an application of (Single Minute Exchange of Die) SMED techniques is recommended, in particular requalification of internal changeovers into external ones that are performed outside of the workstation, what, in practice, eliminated preset times.

With regard to products manufactured in the same system concurrently, one should be aware that their number does not have to be identical.

This approach is presented as an idea of the flow, but never is explained on the operational level. It is easy to imagine how it is carried out when one operational processes are analyzed. The problem appears when the process is multi operational and when processes have different production routes.

![Figure 1. Production flow; a) batch production and b) one-piece flow [5].](image)

In the figure 1 production flow is presented on the Gantt chart. It is visible how the flow is created starting from the longer period and batch production (figure 1a) and approaching to the single element flow (figure 1b).

2.1. Illustrative example

Below an example of the production flow on the operational level is presented. Given are processes described by matrices (1). First row of the matrix contains resources number from the production route, second one contains operations time respectively for these resources. Elements are manufactured one after one. Interoperations buffers are not provided in the system.
\[ \begin{bmatrix} 1 & 2 & 3 \\ 4 & 3 & 3 \end{bmatrix} ; \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 2 \end{bmatrix} ; \begin{bmatrix} 1 & 2 & 3 \\ 2 & 3 & 3 \end{bmatrix} \] (1)

The efficiency of resources utilisation in the repetitive period is calculated and is \( \eta = 0.74 \).

Let us assumed that between resources interoperalional buffers are allocated. The production flow is presented in figure 3.

The efficiency of the resources utilisation in the repetitive period is calculated and is \( \eta = 0.89 \) however this result can be obtained only if between resources buffers are allocated. This allows transfer the item to the buffer despite the fact that next machine in the route is busy. Interesting observations on buffers are presented in [7, 8].

3. Problem formulation

The production system is given and the set of production orders as well. Each production order is described by process with its route. Processes are concurrent, which means that before one finishes another process is already beginning. Each process can characterise different route with different number of operations and different flow direction.

The problem is: how to organise production flow to provide the best resources utilisation and order completion in due date (according to customer expectation)?

The method bases on the synthesis of constraints. Theory of constraints (TOC) is applied in this approach. Constraints are used for creation the sequence of sufficient conditions that should be accomplish for a new production order acceptance for realisation in the given system. In the paper most of constraints are only mentioned. Authors of this paper concentrate mainly on constraints relating to the buffers capacity.

4. Buffers allocation in the context of the constraints propagation approach

The Buffers allocation and they capacities are one from list of constraints which should be satisfied in order to ensure deadlock free and starvation free functioning of the system and to ensure bottleneck utilisation according to theory of constraints (TOC) investigated and described by Goldratt.
Constraints in the production system are divided into two groups: producers' constraints and customers' constraints.

One of the producer’s constraints that are taken into account is the productivity of the system and limits of the possibility of the production order acceptance for realisation in the system, and permissible largest batch size, which may be processed by the system.

Other producer’s constraints are buffers capacities that are available for realised processes. These constraints limit the batch sizes that may be processed in the given system. Sufficient conditions based on the producer’s constraints are given in a form of theorems [9, 10, 11].

Accomplishing the producer demands assures that the system functions without deadlock and starvation. This fact does not guarantee the realisation of the production order in the time expected by the client. That is why other constrains like the time limit of the production order completion, should be taken into consideration.

If the production order cannot be realised in the expected time than the shortest possible realisation time is calculated.

The following question appears: what allocation of buffers capacity, for given batch production of order $Z_{n+1}$, providing the production orders $(Z_1, Z_2, \ldots, Z_n)$ realisation without disturbance?

The answer for this question is possible when the sufficient condition, determining buffers capacities, are known. Elements, executed in one cycle, are waiting for realisation in the next period. It causes that buffers capacity should be bigger than that one allocated for one batch production. This knowledge allows us to establish the condition for the synthesis of the system.

### 4.1. Illustrative example

Let’s take the process P1 running by the M1 and M2 with times $t_1=1$ and $t_2=4$. The batch consists of $p=3$ elements.

![Buffers capacity allocation in the system](image)

Figure 4. Buffers capacity allocation in the system.

Figure 5 present running processes and the capacity of the buffer indispensable for system functioning without disturbances. According to (2) required buffer capacity is 5 (figure 4).

### 4.2. Theorem

The system S is given. If the condition (3) concerning buffers capacity allocation holds, then realisation of the batch production, which consists of K elements, is possible without disturbance of production.

$$Cs(M_k, M_p) = 2*K-1$$ (2)

where: $Cs(M_k, M_p)$ - the capacity of the buffer allocated between k-th and p-th resource; $K$ – the batch size.

Accomplishing of the condition from theorem assures completion of the batch of K elements.
If the realisation of two operations has place in the same period \( T \), then sufficient buffer capacity allocated for this process between two neighbouring resources is equal to \( K \)?

In the system possible is a situation when one operation is executed in one period, and succeeding operation in the next one. In this situation buffer with capacity \( 2K-1 \) assures realisation of the production without disturbances.

5. **Different flow direction**

As was mentioned before, one-piece flow is always presented on the example of one- operational processes. The approach elaborated by authors of the paper allows for any production flow direction. The example presents multidirectional system of processes and also desired capacity of buffers which satisfied defined constraints.

5.1. **Illustrative example**

Let’s assume a system of 4 resources \( M_1, M_2, M_3, M_4 \). The following orders \( Z_1, Z_2, Z_3 \) are waiting for realization in the system. The routes of processes are presented in Fig. 5 and described by matrixes \( P_1, P_2, P_3 \). The first row of the matrix contains successive numbers of resources, the second row contains operations times on those resources, the third row contains pre-set time.

![Figure 5. Flow of processes P1, P2, P3 in the system composed of 4 resources, a scheme of the flow and Gantt chart.](image)

The coefficient of the resource utilisation is: \( \eta = 0.821 \). The required capacity of central storage is: \( C_s = 6 \) (or 1 place in each interoperation buffer), according to (2). As was presented in the example the approach allows the analysis of the processes that have different routes.

6. **Constraints sequencing**

The constraints used for the synthesis of the system should be applied not randomly but in a precisely determined succession. To determine due time order completion (customer’s demand), one should know the number of elements in one batch. This information is important only if it is possible to execute at least one element during one cycle. The qualitative functioning of the system means deadlock-free and starvation-free behaviour of the system. Considering these criteria it is possible to conduct the quality validation. This solution may not be the best one. It is very probable that the set of solutions does not contain an optimal one therefore the obtained solution is the best solution in a given sense of searching.

The conditions of qualitative system functioning determine the subset of admissible process realisations. Basing on this subset the satisfaction problem is formulated. This condition guarantees, the steady-state behaviour of the system and is a base of the analytical determination of the following parameters:

- the cycle time (repetitiveness);
- number of critical resources;
- capacity of storage system.
These parameters are the base of the determination of the solution which meets the elements that are definitely quantitative coefficient oriented (dedicated) to the producer or to the client.

7. Conclusion
In the paper the approach to the rhythmic production planning in the contrast of one-piece flow elaborated by Toyota is presented. Authors concentrate on constraints First of all the buffers allocation and its capacity was discuss as elements allowing critical resource creation according to TOC. Moreover it was presented an example which shows that this approach also relate to the system where processes are characterized by different flow directions.

The procedure of the synthesis can be applied in a computer system that aids decision-making. It can be used for assisting an engineer to give a quick answer to the question: Is it possible to realise the expected production order? And another question: Can the production order be executed in the time expected by the client? Presented approach was applied in the The presented methodology constitutes for the “System of Production Order Validation” application. The system aids an engineer in decision making, allocating the dispatching rule, which co-ordinates the production flow.

References
[1] Banaszak Z, Skolud B and Zaremba M 2003 Computer-aided prototyping of production flows for a virtual enterprise Journal of Intelligent Manufacturing 14 Issue 1 pp 83-106
[2] Bocewicz G, Wójcik R and Banaszak Z 2014 Cyclic scheduling of multimodal concurrently flowing processes Advances in Intelligent Systems and Computing 240 pp 587-598
[3] Zemczak M and Krenczyk D 2014 A new procedure of production orders sequencing in mixed-model production systems Advanced Materials Research 1036 pp 864-868
[4] Hemmati S, Ebadian M and Nahvi A 2012 A new decision making structure for managing arriving orders in MTO environments Expert Systems with Applications 39 (3) pp 2669-2676
[5] Skolud B 2014 Market oriented approach to the production management on the operational level Advanced Materials Research 837 pp 663-668
[6] Pool A, Wijngaard J and Van Der Zee D-J 2011 Lean planning in the semi-process industry, a case study International Journal of Production Economics 131(1) pp 194-203
[7] Bahroun Z and Campagne J-P 2010 Medium Term Production Management for Cyclic Deliveries Journal of Mathematical Modelling and Algorithms 9 Issue 4 pp 311-342
[8] Bahroun Z, Campagne J-P and Moalla M 2006 Flow-shop cyclic scheduling for cyclic deliveries 12th IFAC Symposium on Information Control Problems in Manufacturing (St Etienne: France) 3 pp 81-86
[9] Krenczyk D and Skolud D 2011 Production Preparation and Order Verification Systems Integration Using Method Based on Data Transformation and Data Mapping Hybrid Artificial Intelligent Systems, Lecture Notes in Computer Science 6679 pp 397–404
[10] Krenczyk D and Skolud B 2014 Transient states of cyclic production planning and control Applied Mechanics and Materials 657 pp 961-965
[11] Skolud B 2008 Approaches to the production flow scheduling and control. Intelligent manufacturing for industrial business process Journal of Machine Engineering 8/2 pp 5-13