LEAD TIME REDUCTION METHODS

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This paper describes methods for reducing the lead time in manufacturing systems. In general, there are many methods for reduction of lead time, various methods are described in this article. For many manufacturing enterprises is shortening the lead time the difference between being part of the market and be in the first place in the production and sales of a specific product. It follows that this methodology can provide the company a competitive advantage in the form of the primacy of the market and what is equally important, the customers can see that company as a firm leader in the market. It is therefore also in the article an example of the reduction of lead time in the production of the company. The result of this process is the recommendation for the managers of the company, which includes the specific changes that reduce the lead time for production and subsequently increase the production rate.

Keywords
Production rate, lead time, manufacturing system, WIP, flow time

1. Introduction

This article is focused on the description of the methods for reduction of the lead time in the production systems. Lead time can be seen from two perspectives. At first the lead time is a period of time, which starts from the first request to the product. This requirement may be an award from a customer, initiation of the production of an entirely new product, or an upgrade of existing product. This includes access to the lead time as well as all activities involved in the pre-production phase and the preparation of production, such as marketing, purchase of raw materials, accounting, etc. The end of the period of lead time is to divert the product to the customer. This type of lead time is called lead time of the product. In addition to the lead time of product there is also an ongoing production time. This differs from the previous that its origin is defined first by the statement on the resource, which may be the machine (group of machines) or an operator (group of operators). The end of the production lead time is analogous to the last command, which is needed for the processing of the product. Shorten the lead time production has radical importance on the issue of streamlining key performance indicators of the production.

The main methodology to shorten the lead time for production, whose components are defined and discussed in this article, is to use the planning and scheduling method. Planning and scheduling rank among the decision-making processes that are common in many industrial processes and in the tertiary sector. These forms of decision-making play an important role in the supply and production, transport and distribution, and in the information processes and communication. Planning and scheduling function in the company consist of mathematical techniques and heuristic methods, which are used to allocate limited resources activities, which are to be ensured. This allocation of resources must be realized in such a way as to optimize their business goals and achieved them. The resource may be the machines in the factory, the runway at the airport, work crews on building sites or processors (computers) in the computing environment. Activities may be occurring on construction sites, take-offs and landings at airports, the phase of the construction project, or a computer program, which is to be performed. Each activity can have a priority, the earliest possible time of beginning and completion date. Objectives may have multiple different forms, such as minimizing the time needed to complete all the activities, minimizing the number of activities, which are completed after the authentic completion date, etc.

In today's turbulent time, the competitive environment is important for each manufacturing plant, to be able to market and increase profitability. One of the ways how to achieve this is to shorten the lead time for production and an increase in the production rate through planning and scheduling.

2. Lead time reduction methods

As already mentioned earlier in this article, there are multiple methods for reducing the production lead time. One of these is the planning and scheduling. This methodology defines several approaches, which are used to achieve the objective of reducing the lead time: Reduction of the WIP (Work In Progress), synchronization of production, ensuring the continuity in the flow of work, elimination of variability, etc. For the purposes of this article is the most important "Reduction of the WIP", therefore it is described in more detail.

There is not a production company, which would not reduce the amount of stocks of work-in-progress. WIP inventory reduction seems to be a very popular tool to improve the overall performance of the enterprise in order to reduce the lead time for production, increase flexibility, reduce costs and increase quality.

Suzaki stated: „Excessive inventory is the root of all evil" [Suzaki]. However, according to the Goldratt access, that the significance of inventory is „to protect the bottlenecks" [Goldratt]. These two approaches show that the greater quantity of stocks in the bottleneck cannot be considered excessive, if it is necessary to maintain throughput. For the understanding of the relationship between stores and the time it is important to recognize that the flow of time and inventories are not interdependent, and that for the concrete production rate are related. In any case, plus stocks and a larger flow of time, depending on this example are in relation mentioned below:

added inventory = production rate x added flow time (1)

This expression is known as „Little law" and is widely applicable to almost any resource, which generates the queue. For example, if the assembly is often delayed, because some parts are not available, the supply of required parts will be equal to production rate multiplied by the average waiting time for parts. Therefore, any activity for the reduction of lead time will reduce inventories.

Figure 1 shows an example of two densities of flows time with the same meaning and different standard deviation. We can see that 99% of the work orders completed with the flow time (lead time), which is not longer than 15 days, where is a greater standard deviation, requires 27 days for the same level of services. Also, note that the most likely time for smaller standard deviation is 11 days. Therefore, work with the delivery period of 15 days will end most likely about 4
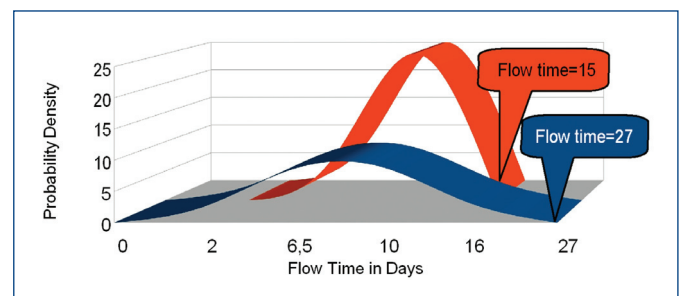

Figure 1. *Two densities of flow time with unequal variance*

days earlier. This implies that stocks, which will wait 4 days on-hand inventory, reduce production (Little law). In the second case is most likely lead time of 8 days, which means 19 days holding on-hand inventory. Although this extreme case, shows that as of the delivery period and held stocks, depends on the variability associated with continuous time and not only with an average lead time.

3. Simulation example

3.1. Manufacturing system

The following text describes a practical example of the use of methods for reducing production lead time. For the particular production system the simulation model is created with the implemented algorithms for the reduction of the length of queues for resources, reducing the lead time on the processing of all production orders, etc. In order to achieve the objective of reducing production lead time are used the following steps: 1. development of simulation model of production system, 2. planning (scheduling)-production simulation of different alternatives, 3. analysis of the bottlenecks of the production 4. analysis Gantt charts of different alternatives and additional assessment of capacity constraints, 5. design, validation and evaluation of various alternatives, 6. processing recommendations for managers of production. The company does not wish to be published, it is therefore also in the text appointed as the company „M".

A manufacturing system is primarily focussed on machining of titanium products. The products are intended for surgical operations in human medicine. This production system consists of six halls. The main products which are part of the simulation model can be divided into 3 groups: Screws, plates and bars from titanium. Those products have their technological procedures. Since there are separate products, bills of materials are not included in the model. The system layout contains all of the machines, which are listed in the technological procedures. This layout is a schematic and does not match the real deployment of machines, because the simulation model does not take into account the transport work-in-progress. This simplification is selected on the basis of available data, which do not contain information on the transport of materials and items. However, transport times are included in the procedural times, but only as the average value. This limitation affects the accuracy of the simulation model. The layout contains the intermediate storage for each machine or group of machines. Machines and the buffers are inserted into each production halls, as shown in the following figure.
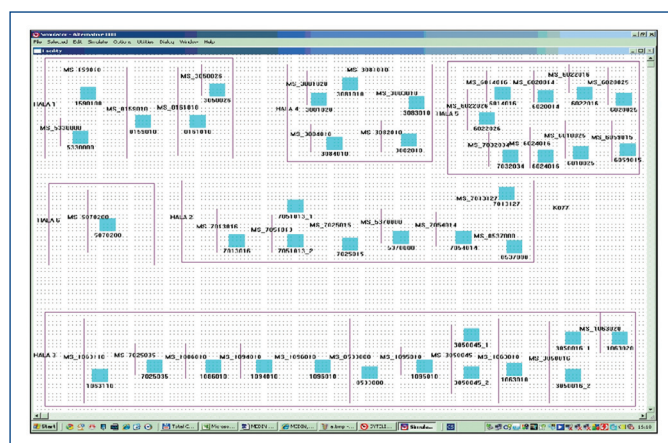

Figure 2. *Layout of the simulation model*

3.2 Verification and validation of the model

A verification process includes verification of correctness and functionality of the simulation model without having to have the results compared with the actual production system. During the process of verification syntax and content errors were corrected. The validation process is carried out with regard to the relationship of the

simulation model to real production. However, this does not mean that the simulation model behaves exactly like a real production system. The simulation model includes future changes in production, production control, other algorithms, etc. Verification and validation of simulation model was made for the use of Resource Gantt chart and Order Gantt chart (see Fig. 3).
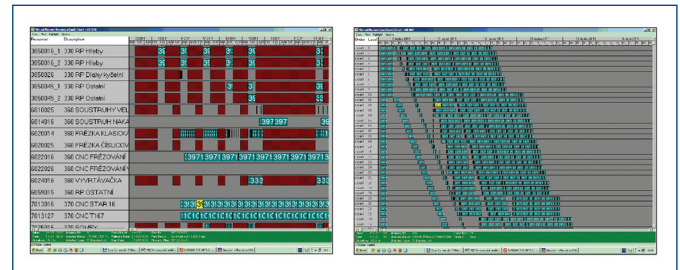

Figure 3. *Resource Gantt chart, Order Gantt chart*

3.3. Analysis of the initial state of the basic simulation model
(basic alternative = initial state)

The following text describes the initial state of the system, which were obtained from the analysis of simulation model for the use of two analytical instruments such as the APS (Advanced Planning and scheduling): Virtual Planner and Simplan. The aim was to identify bottlenecks and optimize production. Using of the APS system were obtained the following results:

- The total number of manufactured products – 38520 PCs.
- Production rate – 14.77 PCs/HR.
- The average lead time of the order – 1784.964 (HR).
- The average number of outstanding batches – 96.682 PCs.
- The average number of batches to resource – 32.767 PCs.

The following chart is one of the outputs used for the definition of the bottlenecks of the system. The bottleneck is a group of machines 3050016 and machine 3050026, because they are the biggest percentage use during work shifts.
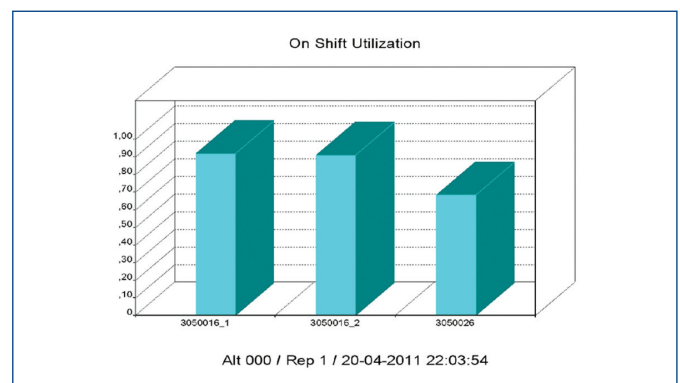

Figure 4. *On shift utilization of machines*

3.4. Results

The following text describes the proposal for a solution to eliminate the bottlenecks including investment costs and an evaluation of alternatives. On the simulation model of company, M does not change the configuration of production, but gradually increases capacity by adding work shifts and then adding the resources. Capacities shall be carried out according to the bottlenecks in the production. The aim is to increase production throughput. Alternative 001 models the initial state. In the course of the optimization of production in order to eliminate bottlenecks and increasing production rate the following alternatives were elaborated:

Alt	Production Rate [PCs/HR]	% improvement compared to Alt001	Change/investment costs to changes in CZK million	The total investment cost of the changes in CZK million
001	22.995	100	3050016 -4 operators	
002	31.085	135.18	3050016 -4 operators 3050026 –10 operators	
003	32.982	143.43	3050016 –10 operators 3050026 –10 operators	
004	32.982	143.43	3050016 –10 operators 3050026 –10 operators 3050045 –10 operators	
005	32.923	143.18	Alt004 + 6020014_1 -3 work shifts	
006	38.442	167.18	Alt004 + 6020014_1 -3 work shifts 6020014–2 machines – 2 500 000 CZK 7013127–2 machines – 5 000 000 CZK	7 500 000 CZK
007	42.648	185.47	Alt006+ 6022016–2 machines – 3 000 000 CZK 7025015–2 work shifts 7025035–2 machines – 2 000 000 CZK 7032034–2 work shifts	12 500 000 CZK
008	43.710	190.09	Alt007+ 6022016-3 machines – 3 000 000 CZK 7025015-3 work shifts 6020025-3 work shifts 7013016–2 machines – 4 500 000 CZK 7051013–2 machines – 2 000 000 CZK	22 000 000 CZK

Table 1. *Summation of alternatives of simulation model*

Figure no.5 shows an increase of the production rate introduction of further changes. For alternative no.8 the increase of production rate was 90% compared to the initial option, i.e.. that produces nearly twice more products.
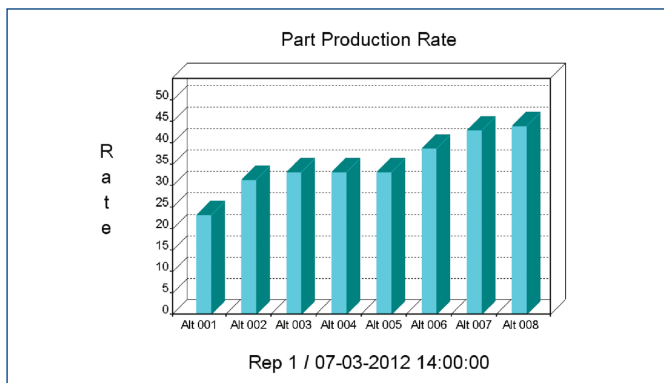

Figure 5. *Part production rate of alternatives of simulation model*

Investment costs for the acquisition of new resources are included as the costs of change. The increase in wage costs for workers is not considered, since the staff necessary for the new changes of alternatives will be moved from other workstations.

4. Conclusions

This paper has described the methods for reducing the lead time in manufacturing systems. The practical example mentioned has dealt with the use of the methods for reducing production lead time. For the analysis and optimization, a simulation model was created of the system using the APS systems belonging to the category of FCP (Finite Capacity Planning). After the simulation of various alternatives for the layout of the production the best option has been evaluated and recommended for application to a production system. The analysis of the bottlenecks of the production being carried out according to the percentage use of resources, analysis of queues resulting from production in the forward planning and analysis of Gantt charts.

In order to increase the production rate two approaches are used. The first approach increases just any shift and the number of operators without added new resources. The second approach follows up to expand the capacity of the bottlenecks added new machines at the expense of increasing investment costs.

For the first approach has been generated and compared various alternatives (0 to 5). The best production rate has an alternative 3 (19.356 PCs/HR), but there is a reduction in the use of key resources 3050016. For alternatives no. 3 is reached the shortest simulation time of processing all the batches and the largest hourly production rate [PCs/HR]. For application in the production company was recommended an alternative number 3. It means to add second and third shift for the resource no. 3050026 and to add third shift for the resource no. 6020025. Capacity expansion is carried out in full shifts at the request of the management of the company.

For the second approach has been gradually increased capacity by adding work shifts and then adding the resources. It was divided 8 alternatives. Capacities shall be carried out according to the bottlenecks in the production. For each of the alternatives are listed the investment costs. The decision on the suitability of alternatives will be carried out by the management of the company on the basis of demand forecasting and investment costs.

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