Bottleneck Management in Discrete Batch Production

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Abstract

Today, production planning and scheduling becomes very important part of production management because companies have to react to dynamic market conditions and rising customers´ requirements for shorter delivery times, lower prices and better quality and services. They can use a lot of sophisticated methods and approaches to make their planning processes more efficient and thus meet growing customers´ requirements. However, using these new approaches is not so easy in all types of production systems. This paper deals with production planning and scheduling in discrete batch production that is just an example of very complicated production system. This type of production process is susceptible to demand fluctuation and facility exceptions and this implies bottleneck shifting. Therefore it is quite difficult to implement methods such as Theory of Constraints (TOC) for production planning improvement in the standard way. One part of this paper is a case study wherecurrent production planning and scheduling in real factory is improved just through the use TOC principles.

Key words: bottleneck management, bottleneck shiftiness, production planning, Theory of Constraints, TOC, capacity planning, Drum-Buffer-Rope

1. INTRODUCTION

One of the key activities of production management is manufacturing planning and scheduling that can greatly influence production performance. Mainly today, when changing market environment causes a rise in complexity as well as intensity of production planning, efficient planning system is often a key weapon for remaining competitive.

Already Tomas Bata, who founded the world-famous shoe company on the beginning of 20th century, regarded production planning as one of the most important parts of business management (Trnka&Bejčková, 2010; Zelený, 2010). He was gradually followed by next famous managers who started to deal with production planning problems more frequently as they perceived its importance. One of these persons was also Eliahu M. Goldratt, present personality in the field of business management, who looked at production planning and scheduling matters from the view of limited resources with the framework of his Theory of Constraints (further only TOC).

In the last decades, a lot of various methods and software tools for production planning and scheduling have been evolved but not all of them are suitable for each type of production system. Before starting their implementation, it is absolutely necessary to recognize and properly characterize the type of production process and choose the most suitable method for production planning improvement (Ferenčíková, 2011).

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2. TOC IN DISCRETEBATCH PRODUCTION

According to the TOC, every system has one or more constraints (bottlenecks) which hinder him from unlimited achieving defined goals. In manufacturing process it means that this bottleneck holds down the amount of products that a company can produce. Then we can say that bottlenecks control the throughput of the whole production system (Cox &Schleier, 2010;Bhardwaj, Gupta & Kanda, 2010). When somebody wants to improve such system, it is important to be aware of the fact that any loss of time on the non-bottleneck resources doesn't have to cause any loss of time on the whole system but on the other hand every minute that is lost on the bottleneck resources definitely causes the same loss of time on the whole system (Goldratt, 1990; Liu & Zhou, 2009). Therefore, it is necessary to start with optimization just at points that are bottlenecks and try to remove them or ensure its maximum possible utilization at least (e.g. by using some buffers).

Ray, Sarkar&Sanyal (2010) point to some deficiencies of using traditional TOC model in real world. One of them is dealing with multiple constraint resources. They say that TOC is suitable for simple bottleneck problems but it does not provide the optimal solution for large-scale problems that have several bottlenecks. I agree with their opinion that in very complex production systems, TOC as the only method for optimization does not suffice but it can help to find the best solution for some problem. The example of this statement is given in the case study below where production planning and scheduling process is optimized by using some TOC principles.

Bottleneck identification in discrete batch production is a greatly difficult process because of randomly received production orders. Utilization of individual machines can fluctuate and that is why bottleneck does not have to be stable in these types of production processes.

2.1 Bottleneck shiftiness and its elimination

Today the complexity and dynamics of production processes cause that bottleneck location usually shifts along and makes the whole production system unstable and inefficient (Chen &Shen, 2010). Bottleneck shiftiness can be inflicted by many factors and random events, such as demand fluctuation, order arrival time, material shortage, priority variation etc. Chen&Shen (2010) divide these factors into several groups and suggest some solutions for each of them:

- Setting buffers ahead of the bottleneck machines in case of a low demand fluctuation.
- Paying more attention to control of material release and production scheduling in case of a great demand fluctuation in order to lower the probabilities of shifting bottleneck through the whole production.
- Using Drum-Buffer-Rope technology with three kinds of buffer areas (bottleneck buffer, assembly buffer and consignment buffer) in case of facility exception.

Especially in make-to-order production processes, bottleneck shiftiness can be caused by large variability in technological procedures. It means that production resources are not equally utilized and in different periods, another of them can be a bottleneck.

2.2 TOC based production planning and scheduling

The role of production planning and scheduling is to synchronize production system in order to achieve its objectives in the most efficient way possible. Planning process is one of the most difficult activities of the whole production management because it faces two great problems: complicated synchronizing many different internal variables and high uncertainty (Cox &Schleier, 2010).

Liu, Zhao, Ou`Yang& Yang (2011), who deal with optimization of order planning and scheduling in machine tool production, proposed and described a three-stage order planning and scheduling solution based on TOC concept in their last paper. They say that all constraints must be identified after receiving and analysing all the orders in the first step. Then, some evaluation criteria and their priorities are determined for all orders and products. And finally a multiobjective model, regarding TOC and particle swarm optimization, is set up with a view to minimize bottleneck machines´ makespan and total products´ tardiness.

Production system, which is analysed below in this paper as a case study, had very similar problem with production planning and scheduling. This factory with discrete batch production wrestled with constraints resources and their low utilization as well.Therefore, its production planning and scheduling process has been improved by using TOC principles and bottleneck management which has helped the company to shorten production lead times and reduce stocks as you can see in the next paragraphs.

3. CASE STUDY – USING TOC IN BATCH PRODUCTION

Analysed enterprise is the company producing cardboard and litho-laminated packaging. Production process was monitored without and then with using Theory of Constraints for production planning. By reason of simplification only production facilities and no further resources (workers, tools etc.) are considered.

3.1 Brief description of the production process

Production process begins by printing and continues by laminating (not in all cases), blanking, creasing and gluing and ends by packing (Fig.1 and Tab.1). Company orders sheets in required size so it is not necessary to cut out special format.

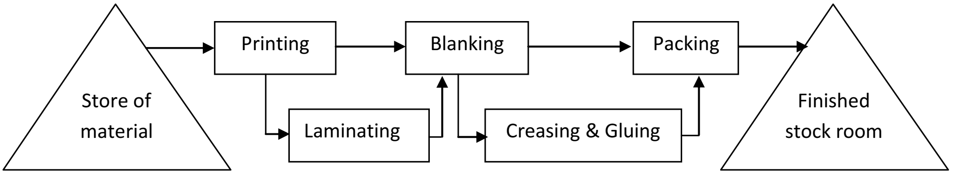

Fig. 1 – Scheme of production process in analysed company. Source: author´s own

Maximum diurnal capacity is determined by difference between availability of the machine during tree working shifts and average time of necessary breaks, servicing and setups per one working day. There is a big variability between sheets sizes therefore we consider one average sheet - sheet weighing about 330 g and the size of about 1 m^2, to be a basic production unit for this example.

Tab. 1 – Individual operations and their specifications. Source: author´s own

Operation	Machine	Machine Specification	performance-sheets/hour	Max. capacity per shift (h)	Max. capacity sheets/1 shift
Printing	P1	black&white print	6 500	7,0	45 500
	P2	black&white print	10 000	6,8	68 000
	P3	colour print	10 000	6,7	67 000
	P4	colour print	7 000	6,5	45 500
Laminating	L1	---	5 000	7	35 000
Blanking	B1	max. 102 x 72 cm	6 300	7,0	44 100
	B2	max. 102 x 72 cm	2 500	6,0	15 000
	B3	max. 130 x 92 cm	6 000	6,5	39 000
	B4	max. 145 x 103 cm	6 300	6,2	39 060
	B5	max. 145 x 103 cm	5 800	6,3	36 540
	B6	max. 145 x 103 cm	6 400	6,0	38 400
Creasing & Gluing	G1	single spot gluing	2 400	7,4	17 760
	G2	1-3 spot gluing	4 600	7,3	33 580
	G3	1-4 spot gluing	2 570	7,2	18 504
	G4	1-4 spot gluing	4 000	7,4	29 600
	G5	1-6 spot gluing	1 950	7,2	14 040
Packing	PK1	---	15 000	7,5	112 500

3.2 Current method of production planning and control vs. TOC – illustrative example

The company schedules individual job orders generally according to delivery time, that means orders with the earliest delivery time are scheduled as the first (see following example and Tab.3). At this type of production control some delays in deliveries are common and additional planning and scheduling of priority orders is very complicated as well.

In the next example, several orders are scheduled - once according to the current planning method and then according to TOC principles. For simplification no other, already scheduled job orders are considered. It is a simulated production schedule that is set into the real production system.

Tab. 2 includes eight simulated job orders for next working week (7 days and 21 shifts). The volume of each order is converted to number of average sheets (1 m2 size) for simplification and better lucidity. All orders have been already received and they are waiting to be scheduled. So that delivery date is calculated from the same date. Withal, supply must be delivered to customer within 5pm in the required day, which means that whole order must be completed and packed before end of the first shift.

Tab. 2 – Simulated orders for production scheduling. Source: author's own

Job number	Number of ordered sheets	Order specification	Time of delivery
Z01	150 000	colour print, 4 spot gluing, size 100 x 100 cm	3 days
Z02	80 000	black&white print, 4 spot gluing, size 100 x 70 cm	4 days
Z03	100 000	black&white print, single spot gluing, size 100 x 70 cm	4 days
Z04	250 000	colour print, 4 spot gluing, size 100 x 100 cm	5 days
Z05	100 000	black&white print, single spot gluing, size 100 x 100 cm	5 days
Z06	50 000	colour print, without gluing, size 130 x 70 cm + laminating	6 days
Z07	180 000	colour print, 4 spot gluing, size 100 x 70 cm	6 days
Z08	80 000	colour print, 6 spot gluing, size 120 x 70 cm	7 days

a) Production scheduling without using TOC principles

Next table (Tab.2) illustrates availability and utilization of all machines at interval of next seven days whereas all three shifts are available every day. Production is scheduled according to the time of delivery in this case – using forward planning.

Tab. 2 – Production schedule without using TOC. Source: author's own

Machine	1st day			2nd day			3rd day			4th day			5th day			6th day			7th day		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
P1		Z03																			
P2	Z02		Z05																		
P3		Z01		Z06		Z07															
P4			Z04				Z08														
L1					Z06																
B1			Z02																		
B2																					
B3				Z03		Z06		Z08													
B4						Z04															
B5				Z05				Z07													
B6				Z01																	
G1						Z03															
G2					Z05																
G3					Z02							Z07									
G4						Z01						Z04									
G5											Z08										
PK1							Z02	Z01		Z03	Z05	Z06		Z08	Z07	Z04		Z07			

Some operations in the same order are generally overlapped because the next activity can start before the previous activity has finished – semi-finished goods are stacked in batches on the palettes which can than continue to the next operation. For simplification we suppose that material is available in the required time and no unexpected failures will turn up.

As we can see from the schedule above, biggest problems with capacity are on the gluing operation that blames for delays in delivery times. Some machines have very low capacity per hour so shifting job orders to another resource does not solve the problem in most cases. For example in the case of job order number Z04, shifting semi-finished goods to the gluing machine G5 (which is free quite earlier) is not helpful because its cycle time is twice longer.

The greatest delay was observed in the order Z04, whole one day. Even though orders Z01 and Z07 were made-up in required day, they were finished on the last shift so it is not possible to deliver goods to customer on time. At the first glance it can be said that production is relatively well scheduled because no dramatic delays were noticed. However remember that our example is only simplification of the real production process and with the real number of unfinished job orders delays occurred much more frequently in the above system of production scheduling.

b) Production scheduling with using TOC principles

Let us now solve the problem using Theory of Constraints and try to schedule the same eight orders otherwise. We have to start with the resources that are bottlenecks, i.e. machines that are able to perform only certain operations or machines with the low capacity in general. Planning process is usually opposite than in the previous case, i.e. backward planning when we start scheduling from the latest allowable delivery date.

Tab. 3 – Production schedule with using TOC. Source: author's own

Machine	1st day			2nd day			3rd day			4th day			5th day			6th day			7th day		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
P1	Z02																				
P2			Z05		Z03																
P3	Z01		Z04						Z06		Z08										
P4		Z01			Z07																
L1											Z06										
B1		Z02					Z07														
B2																					
B3							Z03					Z08									
B4		Z01					Z04														
B5			Z01										Z06								
B6					Z05																
G1								Z05													
G2								Z03													
G3			Z01								Z07										
G4			Z01						Z04												
G5					Z02										Z08						
PK1						Z01			Z02	Z03	Z05	Z04		Z06	Z07			Z08			

As we can see from the table above (Tab. 3), all orders should be delivered on time. The only problem may arise with the order Z01 because this order is scheduled without any time reserve and some operations are split into two or more workplaces. I am pointing out that this example is not comprehensive because no working cost and no other conditions that can influence the production process are considered. The real production system of this company is also more complicated as well as the number of received orders waiting to be scheduled. The aim of this example is only to point out the benefit of using TOC principles in production processes with technological layout and bigger variability in produced goods.

3.3 Some measurable benefits of using TOC principles for production planning

a) Better reliability in delivery dates

In the table below (Tab.4) we can see that delivery time was exceeded in two cases using standard planning method - orders number Z01 and Z04. Albeit order Z01 was finished in the third day (required day) however it couldn´t be despatched up to 17 o clock because it was finished at the third shift. Using TOC principles for production scheduling no excess should appear in the ideal case. The most endangered order is order number Z01 that has no time reserve and moreover some operations had to be divided into two or more identical machines because of the long process time.

Tab. 4 – Comparing reliability in delivery dates. Source: author's own

Job number	Number of ordered sheets	Required time of delivery	Real time of delivery	
			Standard planning	TOC planning
Z01	150 000	3 days	4th day !!!	3rd day
Z02	80 000	4 days	3rd day	4th day
Z03	100 000	4 days	4th day	4th day
Z04	250 000	5 days	7th day !!!	5th day
Z05	100 000	5 days	5th day	5th day
Z06	50 000	6 days	5th day	6th day
Z07	180 000	6 days	6th day	6th day
Z08	80 000	7 days	6th day	7th day

b) Shortening of the production lead time

For simplification the production schedule was done only for shifts not for individual hours or smaller time units. Therefore shortening of the production lead time can be quite miniscule at the first glance. However the main purpose is to point out haw respecting of TOC principles can help to shorten production lead times (Tab.5) and reduce stocks of input and semi-finished products as well (Tab.6).

Tab. 5 – Comparing production lead times. Source: author's own

Job number	Number of ordered sheets	Production lead time	
		Standard planning	TOC planning
Z01	150 000	9 shifts	7 shifts
Z02	80 000	7 shifts	9 shifts
Z03	100 000	10 shifts	6,5 shifts
Z04	250 000	17 shifts	12 shifts
Z05	100 000	9,5 shifts	9 shifts
Z06	50 000	9 shifts	6 shifts
Z07	180 000	14 shifts	13 shifts
Z08	80 000	8,5 shifts	8,5 shifts

c) Reducing stocks and bounded finances

Material is always ordered to be available one shift before the planned productions begin at least. Purchasers order required number of sheets + 10 % reserve for defects. For our example, we can monitor input and also inter-operational stocks in average sheets because they are in the same form during the whole production process (that means that they are not assembled together).

Tab. 6 – Comparing stocks. Source: author's own

Day	Shift	Standard planning			TOC planning		
		Inputs	Semi-products	Total	Inputs	Semi-products	Total
1st	1st	100 000	580 000	680 000	250 000	230 000	480 000
	2nd	-	680 000	680 000	100 000	480 000	580 000
	3rd	50 000	680 000	730 000	280 000	580 000	860 000
2nd	1st	180 000	730 000	910 000	-	860 000	860 000
	2nd	80 000	910 000	990 000	-	860 000	860 000
	3rd	-	990 000	990 000	-	860 000	860 000
3rd	1st	-	990 000	990 000	-	860 000	860 000
	2nd	-	910 000	910 000	50 000	710 000	760 000
	3rd	-	910 000	910 000	-	760 000	760 000
4th	1st	-	760 000	760 000	80 000	680 000	760 000
	2nd	-	660 000	660 000	-	660 000	660 000
	3rd	-	660 000	660 000	-	660 000	660 000
5th	1st	-	510 000	510 000	-	560 000	560 000
	2nd	-	510 000	510 000	-	310 000	310 000
	3rd	-	510 000	510 000	-	310 000	310 000
6th	1st	-	250 000	250 000	-	260 000	260 000
	2nd	-	250 000	250 000	-	80 000	80 000
	3rd	-	250 000	250 000	-	80 000	80 000
7th	1st	-	-	-	-	80 000	80 000
	2nd	-	-	-	-	-	-
	3rd	-	-	-	-	-	-
Ø stock		58 570/ day	1 677 140/ day	1 735 710/ day	108 570/ day	1 411 430/ day	1 520 000/ day

As we can see from the table above (Tab. 6) the total stocks dropped by more than 12 % a day. It means that company would have daily about 12 % of the financial resources more and it can use them for purchasing other things, material or for investment. Furthermore, the stocks reduction can appear also in output stocks because in the first case (standard planning) some orders were finished in advance and customer probably will not take them earlier.

4. DISCUSSION

Firstly, it was processed the short analysis of other research works in the field of Theory of Constraints based production planning and bottleneck management where authors describe some difficulties with production planning in discrete batch production. Consequently, it was presented the concrete example which confirms the previous statements. In this example, scheduling problem in the real company was solved by using TOC principles. It was proven that Theory of Constraints can help to solve major problems with capacity planning in discrete batch production and reduce stocks and number of delayed orders (Tab. 7).

Tab. 7 – Reached results from the case study (see chapter 3). Source: author´s own

Indicators	Standard planning	TOC planning	Improvement
Number of delayed orders	2	0	100%
Average production lead time (weighted by number of ordered sheets)	11,9	9,7	18%
Average daily stock	1 735 710	1 520 000	12%

On the other hand, implementing TOC principles for production planning and control can bring also some costs and negatives. Our case study is only the very simplified example of this problem and it describes only the short period and small number of production orders. However, companies often face problems with changing priorities of production orders, machine failures, maintenances etc. These factors seriously influence the production planning process and disrupt the production schedule. Theory of Constraints is very simple method that can help to make production planning more efficient but in many cases it is not possible to use it without any software support that incurs significant costs. However the payback period of such an investment can be rather short if it brings the benefits described above.

5. CONCLUSIONS

Today, production planning and scheduling is one of the most important parts of production management because it influences all three critical factors of competitiveness, i.e. time, quality and price. Complexity of production planning is increasing with range of products and complexity of production systems and its importance is intensified by constant customers´ calling for shorter delivery times. A lot of planning algorithms of information systems supporting production planning and control are based on Theory of Constraints in these times. The main principles of this method are usable also for production planning and control, mainly in companies depressed by the capacity problems.

In this paper, the benefits of using TOC for production planning and scheduling were presented on the very simplified example because of the paper volume. However a lot of examples from practice prove that this very simple method can help to solve a lot of production problems and sometimes also greatly reduces stocks and lead times. As you can see in the case study, discrete batch production is really very complicated for production planning and scheduling because of great variability in orders´ specification. Individual machines are irregularly utilized in different periods what causes that bottleneck is not the same location each time. Therefore, it is really difficult to clearly identify, exploit, subordinate and elevate constraints according to the TOC Five Focusing Steps (Cox & Schleier, 2010) in this type of production systems. However, TOC can greatly help with optimization of production planning and scheduling if current bottlenecks are considered when production schedule is being made. It is important to start scheduling process on bottlenecks and try to provide their maximum utilization. The main results of this approach are shorten lead times, better reliability in delivery dates and lower stocks.

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