# THE ANALYSIS OF PRODUCTION LINES BOTTLENECKS – IDENTIFICATION AND WAYS OF MANAGEMENT

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***Abstract***

Insufficient and limited production capability is a common problem faced by production enterprises nowadays. The production processes management is continuously improving. Theory of Constraints (TOC) is an interesting concept of planning and controlling production. TOC is a simple and most importantly, a very effective technique of production systems management.

The aim of this article is to present the possibilities offered by the application of TOC in practice. The first step in investigating the production system under analysis was identifying bottlenecks in two production lines. Improvement proposals were presented for each line.

The subject of the study is an existing automotive enterprise producing a variety of components. This article analyses two production lines. LP01 – a production line which produces only one product and LP02 which produces many different products. The authors' research method was employed - based on the analysis of i.e.: tact time, productivity and the level of machine exploitation, profit margin.

The explorations of the authors do not exhaust all the other possible variants of improvement in production systems managed with TOC logic. The presented ways of proceeding are designated to support production managers in decision-making processes. Reducing the impact of bottlenecks to a minimum entails independence from constraints. Due to such operations production processes will be much more productive.

**Key words:** production line, theory of constraints (TOC), bottleneck, productivity, automotive industry

## 1. INTRODUCTION

According to the theory of constraints (TOC), the central task of effective production management is to find and eliminate the impact of a bottleneck in a company. A bottleneck is an element of resources (e.g. a job position) with the lowest potential (production capacity). It marks the capacity of the entire production system. Production system capacity is a crucial element of manufacturing companies competitive advantage. It has an influence on company's costs and ecological issues (Kolinski, 2017, pp. 161-177).

Taking the occurrence of bottlenecks into account, production management may be divided into (Koliński & Tomkowiak, 2010, pp. 16-17):
- management in a situation with no bottlenecks in the production process,
- management in a situation with one bottleneck in the production process,
- management in a situation with many bottlenecks in the production process,

The absence of bottlenecks in the production process means that the production productivity is enough to achieve forecast sales. If one bottleneck occurs, it needs to be determined whether there is only one production process or whether alternative production processes are possible. Contribution margin analysis for individual combinations of products and processes is a useful tool in this case. If it turns out that there are several parallel bottlenecks in the production process, the decision becomes more complex. In such an event, solutions to these problems should be seeked with the use of linear programming methods.

## 2. THE THEORY OF CONSTRAINTS AS AN EFFECTIVE TOOL OF ANALYSING BOTTLENECKS IN THE PRODUCTION PROCESS

The theory of constraints was formulated by Dr. Eliyahu M. Goldratt, an Israeli physician. He applied the methods of exact sciences to improve the functioning of business companies. The theory of constraints was created in the 1970s. Its concept has been developing through the years. It initially focused only on selected functional areas of companies, such as production, whereas presently it is used for the purpose of managing an entire company, or an entire supply chain. Described above trend is strictly connected with integration of supply chain (Cyplik et al, 2014, pp. 4465-4470; Hadas et al, 2015, pp. 225-239).

In 1984, E. M. Goldratt published a book describing the DBR (Drum-Buffer-Rope) method – one of the tools used by the theory of constraints (Goldratt & Cox, 1984). An example of implementation of TOC in production area was described in paper (Cyplik et al, 2009, pp. 1-12). In his new book, published in 1990, Goldratt extended the theory of constraints with the possibility to make measurements in selected production processes (Goldratt, 1990). In 1994, the second part of his best-selling book "The Goal", which presented the possibilities of applying the TOC concept in other areas of company operations at the strategic level (Goldratt, 1994), was published. 1997 marked the publication of Goldratt's next book, "Critical Chain", showing the use of tools of the theory of constraints in the area of project management (Goldratt, 1997). In 2004, G. I. Kendall's book, describing practical application of the theory of constraints in an entire company, was published (Kendall, 2004).

The basic assumptions of TOC are as follows (Hadaś et al, 2012, p. 93):
- each system has a goal,
- a system is expected to improve its achievements (related to the goal),
- achievements of every system are limited with constraints.

Thus, the theory of TOC assumes that every system has at least one constraint. According to these assumptions, smoother delivery of a system's goal depends on the removal of the constraint which prevents its achievement. Efforts should therefore be focused on the constraint, defined as every factor which prevents the system from achieving better results, such as profit.

TOC defines a set of tools which may be used to control and manage constraints and, consequently, increase profit. One of the basic tools is the five focusing steps method. Its essence lies in continuous perfection of the system. In relation to the fact that TOC sees a production system as a chain whose strength depends on the strength of its weakest link, the method assumes focusing attention on the point where maximum effect may be achieved, namely on the system's constraint.

As part of step 1 (identify), the constraint must be identified. In a production company, there is always at least one resource that will constrain maximum productivity. Inside the company, there may be one or more work stations forming a constraint (the so-called critical resource). Identification of a bottleneck in a production process is not a difficult task – as early as at the stage of planning (balancing of loads) it is possible to indicate positions with the highest load (close to 100% or above it), which may represent a constraint. Identifying a constraint marks the start of actions aiming at improving the situation.

As part of step 2 (exploit), a decision on how to exploit the constraint must be made. Everything that causes the waste of time of this resource's work, i.e. disrupts the continuity of its work, should be eliminated. At this stage, streamlining the work of the critical resource is of organisational nature, e.g. adapting employees' breaks so that they do not cause a break in the constraint's work, without incurring any extra costs. An important rule should be taken into account: an hour lost in a bottleneck is an hour lost in the entire system.

Step 3 (subordinate) concerns subjecting all decisions to work and the constraint's productive. It should be borne in mind that effectiveness of the production process depends on undisturbed work of the bottleneck. It results in the planning of all activities ensuring the continuity of the constraint's work. All the resources should therefore work according to the rhythm of the critical resource, while their production volume should not be higher than the constraint which limits throughput.

Step 4 (elevate) focuses on improving the bottleneck's work productivity, as it is the only activity which influences the growth of productivity of the entire production process. There is a number of ways to achieve this goal: purchase of additional resources performing operations which form a constraint; change of technology, which will result in lowering the load of the critical resource; outsourcing. The step usually forces an organisation to incur additional costs.

As part of step 5 ("go back to step one"), which is the last step, an analysis if the constraint has been eliminated is carried out. If it has, step 1 should be taken again to identify a new constraint. The purpose of the last step is to continually strive to improve the system (Hadaś et al, 2012, pp. 94-96; Woeppel, 2009, pp. 14-20). The five focusing steps method will be applied in practice in sections 4-7 of the article.

## 3. CHARACTERISTICS OF THE OBJECT OF RESEARCH – A SELECTED PRODUCTION COMPANY

The company is one of the world's leading manufacturers. It applies different types of solutions used in numerous car brands produced all over the world, such as Volkswagen, Honda, Ferrari, Fiat, Toyota, Chevrolet, Mazda, General Motors, Lexus and many more. Its product portfolio includes shock absorbers, batteries, radiators, condensers, evaporators and air-conditioning systems.

The company has its branches in 36 countries. It owns 159 production plants and 41 joint-venture production plants. In also operates 53 customer service centres and 33 technical inspection centres.

The company started its operations in Poland in 1994. It already has 4 factories located in Gdańsk, Błonie, Jeleśnia and Kraków. The company's technical centre is located in Kraków. Until recently, the company also had a branch in Ostrów Wielkopolski, which has been closed. Study results are based on data from this location.

## 4. ANALYSIS OF THE PRODUCTION PROCESS DEDICATED TO THE PRODUCTION OF ONE TYPE OF PRODUCT

The analysed production line LP01 consists of 12 work stations. Due to the fact that the line is dedicated to the manufacture of one product type (product A), in the production process a part of employees performs more than one operation. The layout of LP01 is therefore U-shaped.

In the analysed production company, operational data are defined as follows:
- ta – nominally available working time during one shift (480 min.),
- tc – cycle time, i.e. time of performing one operation for one item,
- ts – set-up time, i.e. time spent on preparing the station before starting work and on cleaning it up after ending work,
- tu – machine's unproductive time, providing for production downtimes (such as planned breaks, failures etc.)

The analysed production line manufactures product A during each of the three shifts in the form of mass production. Table 1 presents operational data concerning time for individual work stations.

**Table 1.** Data of individual operations for production line LP01

| Operation related to production | Work stations | Operational data | |
|---|---|---|---|
| | | Time | Value |
| OP01 | ST1 | tc [min] | 2 |
| | | ts [min] | 30 |
| | | tu [min] | 50 |
| OP02 | ST1 | tc [min] | 5 |
| | | ts [min] | 30 |

| | | | |
|---|---|---|---|
| | | tu [min] | 35 |
| | ST2 | tc [min] | 6 |
| | | ts [min] | 50 |
| | | tu [min] | 40 |
| OP03 | ST1 | tc [min] | 3 |
| | | ts [min] | 10 |
| | | tu [min] | 20 |
| OP04 | ST1 | tc [min] | 5 |
| | | ts [min] | 15 |
| | | tu [min] | 10 |
| | ST2 | tc [min] | 3 |
| | | ts [min] | 30 |
| | | tu [min] | 20 |
| OP05 | ST1 | tc [min] | 2 |
| | | ts [min] | 15 |
| | | tu [min] | 22 |
| OP06 | ST1 | tc [min] | 1 |
| | | ts [min] | 7 |
| | | tu [min] | 40 |
| OP07 | ST1 | tc [min] | 2 |
| | | ts [min] | 14 |
| | | tu [min] | 32 |
| OP08 | ST1 | tc [min] | 3 |
| | | ts [min] | 20 |
| | | tu [min] | 15 |
| OP09 | ST1 | tc [min] | 3 |
| | | ts [min] | 15 |
| | | tu [min] | 40 |
| OP10 | ST1 | tc [min] | 2 |
| | | ts [min] | 15 |
| | | tu [min] | 15 |
| OP11 | ST1 | tc [min] | 1 |
| | | ts [min] | 10 |
| | | tu [min] | 10 |
| OP12 | ST1 | tc [min] | 2 |
| | | ts [min] | 2 |
| | | tu [min] | 0 |

Source: materials obtained from the company

Operations OP02 and OP04 re performed on two work stations. The productivity of these two operations should therefore be determined as a sum of productivity of individual work stations. Other operations as part of LP01 are performed by single work stations, which is why the productivity of these work stations is at the same time the productivity of particular operations.

The first step in analysing the bottlenecks of LP01 is to determine the productivity of particular operations. In the case of the first operation (OP01), there is one work station performing it. To determine the productivity of operation OP01, productivity of the work station should be calculated with the use of the following formula (description of parameters – bullets at the beginning of the section):

$$P_{EO} = \frac{t_{d_i} - t_{pz_i} - t_{b_i}}{t_{j_i}}$$

The productivity of operation OP01 is therefore:

$$P_{EO_{OP1}} = \frac{480 - 30 - 50}{2} = 200 \ [szt]$$

In the case of operation OP02, we have two work stations, thus to determine the productivity of OP02, productivity of these two work stations should be summed up:

$$P_{EO_{OP2}} = \frac{480 - 30 - 35}{5} + \frac{480 - 50 - 40}{6} = 83 + 65 = 148 \ [szt]$$

Productivity for the remaining stations is determined in a similar way. Table 2 presents a list of productivity of individual operation of production line LP01.

**Table 2.** Productivity of individual operations of production line LP01

<table>
<tr><th>Operation<br>related to production</th><th>Work stations</th><th colspan="2">Station productivity [pcs/shift]</th></tr>
<tr><td>OP01</td><td>ST1</td><td colspan="2">200</td></tr>
<tr><td rowspan="2">OP02</td><td>ST1</td><td>83</td><td rowspan="2">148</td></tr>
<tr><td>ST2</td><td>65</td></tr>
<tr><td>OP03</td><td>ST1</td><td colspan="2">150</td></tr>
<tr><td rowspan="2">OP04</td><td>ST1</td><td>91</td><td rowspan="2">234</td></tr>
<tr><td>ST2</td><td>143</td></tr>
<tr><td>OP05</td><td>ST1</td><td colspan="2">222</td></tr>
<tr><td>OP06</td><td>ST1</td><td colspan="2">433</td></tr>
<tr><td>OP07</td><td>ST1</td><td colspan="2">217</td></tr>
<tr><td>OP08</td><td>ST1</td><td colspan="2">148</td></tr>
<tr><td>OP09</td><td>ST1</td><td colspan="2">142</td></tr>
<tr><td>OP10</td><td>ST1</td><td colspan="2">225</td></tr>
<tr><td>OP11</td><td>ST1</td><td colspan="2">460</td></tr>
<tr><td>OP12</td><td>ST1</td><td colspan="2">239</td></tr>
</table>

Source: own study

Analysing the productivity of individual operations and bearing in mind the basic assumption of the theory of constraints which states that the productivity of the entire production process is equal to the productivity of the weakest link, it should be stated that the productivity of production line LP01 is 142 pieces during one shift. Thus, it is reasonable for all of the operations to work in accordance with the bottleneck's productivity. As a result, most of the work stations will not have maximum load.

The degree of using particular operations is determined by the quotient of productivity of the whole production line (142 pieces) against the productivity of individual operations. For OP01, usage indicator is:

$$P_{OP01} = \frac{142}{200} = 70{,}83\%$$

For the remaining stations, the indicator is calculated in a similar way. Table 3 presents the degree of using individual work stations in production line LP01.

**Table 3.** Degree of using individual stations of production line LP01

| Operation related to production | Productivity of the station | Usage of the station |
|---|---|---|
| OP01 | 200 | 70.83% |
| OP02 | 148 | 95.95% |
| OP03 | 150 | 94.67% |
| OP04 | 234 | 60.68% |
| OP05 | 222 | 63.96% |
| OP06 | 433 | 32.79% |
| OP07 | 217 | 65.44% |
| OP08 | 148 | 95.95% |
| **OP09** | **142** | **100.00%** |
| OP10 | 225 | 63.11% |
| OP11 | 460 | 30.87% |
| OP12 | 239 | 59.41% |

Source: own study

A 100% usage of a work station which performs operation OP09 comes as no surprise, as it is an identified bottleneck of production line LP01, which should use its production capacity to the maximum. Despite unsatisfactory value of the production capacity usage indicator for individual operations (e.g. OP06), it should be borne in mind that increasing the degree of their usage may cause the generation of excessive stock (applies to all the operations located before the bottleneck), resulting in higher production cost. Lower usage of stations performing operations after the bottleneck (e.g. OP11) is caused by a much lower production capacity of the weakest link (the critical resource).

## 5. ANALYSIS OF THE PRODUCTION PROCESS DEDICATED TO THE PRODUCTION OF MANY TYPES OF PRODUCTS

Production line LP02 manufactures products characterised by a high degree of technological similarity. As a rule, all of the products manufactured on this type of production line are ordered by the same customer. Specific nature of the industry in which the analysed company operates and specific nature of products manufactured has a fundamental influence on production technology. As in the case of production line LP01, LP02 also consists of 12 operations, in accordance with specific features presented in Table 1. Due to the variability of products, each employee is assigned to one work station, and the production process is classically shaped. Production line LP02 manufactures 4 products which are technologically similar: product B1, product B2, product B3 and product B4. Forecast number of customer's orders for individual products is provided on a daily basis and does not change throughout the year. Operational data concerning the volume of weekly orders, margin of particular products and cycle times have been presented in Table 4.

**Table 4.** Operational data for production line LP02

| | Product B1 | Product B2 | Product B3 | Product B4 |
|---|---|---|---|---|
| Forecast number of orders | 70 | 110 | 60 | 100 |
| Margin | 100 | 200 | 150 | 75 |
| OP01 [min] | 2 | 3 | 1 | 2 |
| OP02 [min] | 3 | 2 | 2 | 3 |
| OP03 [min] | 2 | 1 | 2 | 1 |
| OP04 [min] | 5 | 4 | 4 | 5 |
| OP05 [min] | 2 | 3 | 2 | 3 |
| OP06 [min] | 1 | 2 | 1 | 2 |
| OP07 [min] | 2 | 2 | 2 | 2 |
| OP08 [min] | 3 | 4 | 3 | 3 |
| OP09 [min] | 3 | 2 | 2 | 3 |
| OP10 [min] | 2 | 3 | 3 | 2 |
| OP11 [min] | 1 | 2 | 2 | 1 |
| OP12 [min] | 1 | 2 | 1 | 1 |

Source: materials obtained from the company

The first step of analysing bottlenecks for this type of a production line consists in checking if the production line is capable of executing all of the orders in full. Cycle time for individual operations should therefore be multiplied by the volume of orders for particular products. Assuming 3-shift production (8h x 3 x 60 min = 1440 min), it should be checked if all of the operations are able to deliver production in accordance with available time.

Daily OP01 usage time is:

$$OP01=70 \times 2 + 110 \times 3 + 60 \times 1 + 100 \times 2 = 730 \text{ min}$$

For the remaining stations, the indicator is calculated in a similar way. Table 5 presents summary results for the identification of bottlenecks in production line LP02.

**Table 5.** Identification of bottlenecks

| | Product B1 | Product B2 | Product B3 | Product B4 | Total |
|---|---|---|---|---|---|
| Forecast number of orders | 70 | 110 | 60 | 100 | 340 |
| Margin | 100 | 200 | 150 | 75 | - |
| OP01 [min] | 140 | 330 | 60 | 200 | 730 |
| OP02 [min] | 210 | 220 | 120 | 300 | 850 |
| OP03 [min] | 140 | 110 | 120 | 100 | 470 |
| **OP04 [min]** | **350** | **440** | **240** | **500** | **1530** |
| OP05 [min] | 140 | 330 | 120 | 300 | 890 |
| OP06 [min] | 70 | 220 | 60 | 200 | 550 |
| OP07 [min] | 140 | 220 | 120 | 200 | 680 |
| OP08 [min] | 210 | 440 | 180 | 300 | 1130 |
| OP09 [min] | 210 | 220 | 120 | 300 | 850 |
| OP10 [min] | 140 | 330 | 180 | 200 | 850 |
| OP11 [min] | 70 | 220 | 120 | 100 | 510 |
| OP12 [min] | 70 | 220 | 60 | 100 | 450 |

Source: own study

Table 5 allows concluding that operation OP04 exceeds available time (1440 min) on one working day. It means it is not capable of manufacturing products meeting daily demand for individual products. Thus, the next step of analysing bottlenecks will consist in reducing the number of manufactured products in order to make maximum use of the weakest link. To this end, relative contribution margin must be determined:

$$\text{relative contribution margin (RCM)} = \frac{\text{contribution margin per piece}}{\text{time of bottleneck usage}}$$

The value of relative contribution margin (RCM) presents the level of profitability of a given product. As a rule, the higher the value of this indicator, the more cost-efficient the production of the particular product. The relative contribution margin (RCM) indicator for B1 is:

$$RCM_{B1} = \frac{100}{5} = 20$$

For the remaining products, the indicator is calculated in a similar way. Table 6 presents the RCM indicator for individual products.

**Table 6.** Relative contribution margin for individual products

| | Product B1 | Product B2 | Product B3 | Product B4 |
|---|---|---|---|---|
| Forecast number of orders | 70 | 110 | 60 | 100 |
| Margin | 100 | 200 | 150 | 75 |
| OP04 [min] | 5 | 4 | 4 | 5 |
| **RCM** | **20** | **50** | **37.5** | **15** |

Source: own study

Table 6 leads us to a conclusion that product B2 is most cost-effective, while B4 is least economic. Therefore, if it is obligatory to resign from a part of production, the least cost-effective part of production should be given up. According to the theory of constraints, with a defined bottleneck we focus on its work exclusively.

Thus, to reduce time spent on performing operation OP04, time of manufacturing product B4 should be decreased by 90 minutes (1530-1440=90). According to Table 5, 500 minutes a day is required to manufacture the entire order for product B4. Considering the need to decrease working time by 90 minutes, OP04 operation usage time should be reduced to 410 minutes. As Table 4 shows that the time of manufacturing one product B4 on operation OP04 is 5 minutes, with 410 minutes we may produce 82 pieces of B4 (410/5=82). In the present situation, the best solution will be:

- production of B2 in maximum order volume (110 pcs)
- production of B3 in maximum order volume (60 pcs)
- production of B1 in maximum order volume (70 pcs)
- production of B4 in the amount of 82 pcs.

Knowing the volume of orders for individual products, it is possible to calculate revenue:

$$P = 70 \times 100 + 110 \times 200 + 60 \times 150 + 82 \times 75 = 44150 \ [zł]$$

## 6. IMPROVEMENTS IN PRODUCTION LINE LP01

Taking the specific nature of production line LP01 into account, first of all work stations should be evenly loaded (for an operation performed by more than one work

station), providing for the degree of operation usage. Only two operations from production line LP01 were performed by more than one work station. They were:
- OP02,
- OP04.

Table 3 allows concluding that production capacities of OP02 are used in over 95%, whereas in the case of OP04 it is hardly 60%. It should be borne in mind, however, that the productivity of operation OP02 (148 pcs/shift) is close to the productivity of the bottleneck (142 pcs/shift), which makes it more probable that the operation may in the near future become a potential constraint. Table 7 presents a suggestion of even load put on both work stations performing operation OP02.

**Table 7.** Suggestion of even load put on both work stations performing operation OP02

| Operation related to production | Work stations | Manufactured quantity | Degree of station usage |
|---|---|---|---|
| OP02 | ST1 | 80 | 96.39% |
| | ST2 | 62 | 95.38% |

Source: own study

In the case of operation OP04, we are dealing with an insufficient degree to which production capacities of individual work stations are used. Table 8 presents a suggestion of even load put on both work stations performing operation OP04, providing for the current status of the machinery park.

**Table 8.** Suggestion of even load put on both work stations performing operation OP04

| Operation related to production | Work stations | Manufactured quantity | Degree of station usage |
|---|---|---|---|
| OP04 | ST1 | 55 | 60.44% |
| | ST2 | 87 | 60.70% |

Source: own study

The degree to which both work stations performing operation OP04 are used may be considered insufficient. Accepting an assumption that production for stock is not cost-effective, the only way to improve the situation is to reduce the usage of work stations to one machine. In should be borne in mind, however, that in this specific case using station ST2 to produce 142 pieces will result in a nearly maximum (142/143=98.84%) usage of this work station's production capacity. It may create a risk of forming another bottleneck in production line LP01.

In the case of other operations, which are performed by one work station, the only suggested improvement was to take additional orders for performing this operation in collaboration with partners in the supply chain. In the case of operation OP12, i.e. product quality control, one may suggest to allocate the remaining time of employees (unused in accordance with product A controlling scheme) to other activities aiming at streamlining production in production line LP01 (e.g. by the monitoring and control of machines manufacturing product A).

## 7. IMPROVEMENTS FOR PRODUCTION LINE LP02

In the case of production lines dedicated to manufacture a larger amount of products, improvements should be analysed in a different way. Considering the fact that the company's management decided not to buy new machines, the only suggested improvements are those of technological nature, which shorten the time spent on performing operations for individual products. The present section analyses the profitability of introducing technological changes suggested by company employees, according to the assumptions of the theory of constraints.

The planned undertaking assumed shortening the time spent on performing operation OP04 by 1 minute for product B1 (other data of the remaining operations have stayed the same – Table 4). Table 9 presents operational data for production line LP02 providing for the suggested change.

**Table 9.** Operational data for production line LP02 - suggested improvements

| | Product B1 | Product B2 | Product B3 | Product B4 |
|---|---|---|---|---|
| Forecast number of orders | 70 | 110 | 60 | 100 |
| Margin | 100 | 200 | 150 | 75 |
| OP04 [min] | **4** | 4 | 4 | 5 |

Source: own study

Analysis of the data above allows brings us to a conclusion that the situation related to production will change only in the case of OP04. The use of working time of other operations against the situation preceding the improvements has not changed (the results have remained the same as in Table 5). Table 10 shows a suggested situation related to production following the introduction of improvements.

**Table 10.** Identification of bottlenecks in production line LP02 - suggested improvements

| | Product B1 | Product B2 | Product B3 | Product B4 | Total |
|---|---|---|---|---|---|
| Forecast number of orders | 70 | 110 | 60 | 100 | 340 |
| Margin | 100 | 200 | 150 | 75 | - |
| **OP04 [min]** | **280** | **440** | **240** | **500** | **1460** |

Source: own study

Despite introduced improvements, the constraint in operation OP04 is still present. However, attention should be drawn to the fact that the shortage of time to fully execute orders dropped to 20 minutes (formerly it was 90 minutes). It allows us to conclude that we will be able to manufacture more products, which will result in higher revenues.

According to the theory of constraints, a step aiming at determining relative contribution margin should be repeated. In the case of products B2, B3 and B4, it will be the same as before (Table 6). In the case of product B1, the relative contribution margin indicator is:

$$RCM_{B1} = \frac{70}{4} = 25$$

Table 11 present current values of the RCM indicator after the improvements.

**Table 11.** Relative contribution margin for individual products - suggested improvements

| | Product B1 | Product B2 | Product B3 | Product B4 |
|---|---|---|---|---|
| Forecast number of orders | 70 | 110 | 60 | 100 |
| Margin | 100 | 200 | 150 | 75 |
| OP04 [min] | **4** | 4 | 4 | 5 |
| **RCM** | **25** | **50** | **37.5** | **15** |

Source: own study

Analysis of Table 11 allows concluding that the hierarchy of the profitability of individual products has not changed. B4 is still the least cost-effective product. To reduce the time spent on performing operation OP04, the time spent on manufacturing product B4 should be shortened by 20 minutes (1460-1440=20). According to Table 11, 500 minutes a day is still required to manufacture the entire order for product B4. Considering the need to decrease working time by 20 minutes, OP04 operation usage time should be reduced to 480 minutes. As Table 9 shows that the time of manufacturing one product B4 on operation OP04 is 5 minutes, with 480 minutes we may produce 96 pieces of B4 (480/5=96). In the present situation, the best solution will be:

- production of B2 in maximum order volume (110 pcs),
- production of B3 in maximum order volume (60 pcs),
- production of B1 in maximum order volume (70 pcs),
- production of B4 in the amount of 96 pcs.

The last step of the analysis of bottlenecks is to compare the result of revenues generated before and after introducing the improvement (Table 12).

**Table 12.** Comparison of revenues before and after improvements of production line LP02

| | Product B1 | Product B2 | Product B3 | Product B4 | Total |
|---|---|---|---|---|---|
| Before the improvement | 7000 | 22000 | 9000 | **6150** | **44150** |
| After the improvement | 7000 | 22000 | 9000 | **7200** | **45200** |

Source: own study

The suggested improvement, aiming at shortening the time spent on performing operation OP04 by 1 minute, will cause the growth of revenues by PLN 1050 a day. On this basis it needs to be stated that the improvement is cost-effective, because the production system meets daily demand for products to a greater degree, and, consequently, generates higher revenues.

## 8. CONCLUSION

A bottleneck may be a reason for a number of unfavourable situations at a company, leading to significant financial losses. The entire production process should therefore be carefully monitored. It allows early identification of a bottleneck and reduction of its impact to a minimum level.

The theory of constraints focuses on increased throughput of a constraint, which, consequently, allows the increase in the throughput of the entire production system. Thus, the most important element of TOC is the throughput, i.e. the speed at which a company manufactures and sells its products and services, receiving cash in exchange. The practice of applying the theory of constraints shows that one's attention should be focused not on what should be limited, but on what should be increased. Thus, companies should absolutely concentrate on activities increasing throughput ("throughput thinking").

The authors of the article presented ways to identify bottlenecks and suggestions of various streamlining activities upon their identification in a production line manufacturing products of varied characteristics. The suggested solutions are chiefly of an organisational (costless) nature, according to the accepted criterion of choice. Future research will be directed to developing more detailed variants of calculations of relative contribution margin in the production system.

The solutions do not exclude the possibility to take advantage of other innovative options. The study may be an inspiration particularly for practitioners who apply the theory of constraints at their companies.

## 9. ACKNOWLEDGMENTS

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