APPROACHES TO THE ANALYSIS AND IDENTIFICATION OF FLOATING CAPACITY BOTTLENECKS

Radim Lenort

VŠB – Technical University of Ostrava

Abstract: Theory of Constraints (TOC) is considered a promising approach to material flow control. Successful applications are implemented in companies where production includes fixed capacity bottlenecks. However, key limitations in many production companies are the floating capacity bottlenecks, i.e. the workplaces or devices that tend to become bottlenecks depending on the portfolio of products processed. These bottlenecks significantly complicate applying the relatively simple TOC principles and tools. Putting them into practice is limited especially by the lack of knowledge and of systematic procedures for analysis and identification of floating bottlenecks. The paper presents possible ways to elimination of mentioned problem based on capacity calculations and computer simulation.

Keywords: Theory of Constraints, floating capacity bottleneck, capacity calculation, simulation

1. Introduction

The contemporary development in material flow control in production companies leads to a vehement search for new control methods. The Theory of Constraints (TOC) elaborated by E. M. Goldratt [1] is increasingly more often considered a promising approach in this field.
Applying TOC in production control starts from an assumption that no production system will be so well balanced as not to contain a bottleneck. The bottleneck is the weakest element that determines the production system output. Any production element that disrupts the continuity of material flows in any way or limits the capacity utilization of other production elements may be regarded as a bottleneck [2]. That is why not only a device, but also a worker, missing material, energy, or lack of demand can be a bottleneck.
Capacity bottlenecks are regarded as the basic limitations in many production companies. In general they can be defined as specific resources that disrupt the continuous flow of products through the production process [3] because of an apparent lack of available capacity.
The principles and tools of the Theory of Constraints have already found their practical application in various branches. This is evidenced, among other things, by the conclusions of a detailed study conducted by the American organization IMA Foundation for Applied Research based on a research in 21 American and European companies [4]. A characteristic of 7 production companies that managed to implement the TOC tools with the success is a part of the study.
The object of successful solution of the companies mentioned in the study was fixed bottlenecks. The fact that the positions of the said places in the production system do not

vary, guarantees faultless control of all production operations and therefore the relatively easy application of the TOC tools.
But the key limitations in many production companies are the floating capacity bottlenecks, i.e. the workplaces or devices that tend to become bottlenecks depending on the portfolio of products processed.
The mentioned character of bottlenecks significantly complicates applying the relatively simple TOC principles and tools in production control. Putting them into practice is limited these days especially by the lack of knowledge and of systematic procedures for analysis and identification of floating bottlenecks.

2. Basic approaches to the analysis and identification of capacity bottlenecks

According to [5] the following procedures for identification and analysis of capacity bottlenecks can be used in practice:

1. Observation and experience – wherever the bottlenecks are constant and products and processes are simple, the bottlenecks are usually known immediately. In more complex processes, will the presence of a bottleneck be indicated by the fact that stocks of unfinished production are repeatedly cumulated behind a certain workplace, or certain operations are always delayed.
2. Capacity calculations – these consist in determining the capacity requirements of the considered plan alternative and in comparing them with available capacity of individual workplaces. This capacity balance will allow determining the level of equilibrium and the capacity overload or under loading spots.
3. Computer simulation – simulation of the passage of the portfolio under consideration through the production system turns out to be a universal and efficient tool for finding out the capacity bottlenecks, especially the floating ones. The influence of various plan alternatives on production throughput, fulfilling the deadlines, or the costs can be simulated.

Based on the author's experience from analysis and identification of specific capacity bottlenecks in production companies, the statement can be made that the first of the said options in itself can be utilized only to a limited extent. The bottleneck character nearly always requires the use of capacity calculations.
But the gross capacity calculations based on aggregated data (overall labour standards, general final product volumes etc.) only provide a reference view. They do not reflect the production sequence, batch size, or the need for reconstructions and adjustments. They are usually carried out for groups of workplaces and not for individual workplaces. So, especially in case of the floating capacity bottlenecks, they can be misleading.
It turned out to be a good practice to utilize detailed capacity calculations based on determining the available capacities of individual workplaces in the form of their hourly output depending on the production portfolio.
Performing a detailed analysis of organization and activity of individual workplaces is a necessary condition of completing the detailed capacity calculations. Such procedure is sufficient in cases where individual workplaces are:

- Organized as a simple chain of serially arrayed workplaces
- Free from significant random influences (fluctuations of the processing time, device failures, and the like).

In the opposite case it is suitable, or eventually necessary, to supplement the detailed capacity calculations by applying a simulation. Composing a model of the production system and filling it in with data is an essential part of the simulation. In most cases it is possible to start from information obtained from an analysis of organization and activity of separate workplaces carried out in advance.

3. Output analysis of floating capacity bottlenecks

Carrying out the detailed capacity calculations requires obtaining and processing a relatively large amount of information and data. Unfortunately the information systems used in many production companies often fail to provide the necessary data, or their usability is difficult. That is why a series of partial analyses is necessary.
Based on the experience of the author from the analysis and identification of specific floating capacity bottlenecks in production companies, the following procedure may be recommended for analysis of their output:

1. An input analysis of individual production process factors
2. An analysis of production process organization on the floating bottlenecks
3. Time studies of the floating bottlenecks
4. An analysis of the floating bottleneck activity in time
5. Determining the hourly output of the floating bottlenecks.

The procedure proposed is suitable for cyclic production processes where individual operations are regularly repeated at constant time intervals, i.e. rhythmically.

3.1. An input analysis of individual production process factors

The basic aim of the input analysis of individual production process factors of the analysed production process is the determination of the potential floating capacity bottlenecks, which will become the object of further inquiry, as well as obtaining the initial information and data for the subsequent determination of their output depending on the portfolio processed.
Identifying and determining the intensity of all essential factors influencing the production capabilities of the investigated process is an initial condition for any capacity computations. Of all the factors, the areas of production facilities, production object, technology, and production organization [6] must be considered in the first place.

3.2. Production process organization analysis in floating capacity bottlenecks

The aim of analysing the floating bottleneck process is to obtain an overview of the course of the production process from the entering of materials or intermediate products (working object) to the bottleneck, to their output in the form of a ready product, either intermediate or completed. Specifically, the determination of individual operations and production levels, of mutual relations between the operations and the levels, and of the passage of the working object through the workplace, are involved.
To visualize the mutual relations between the operations and the production levels, a flow chart can be used. To draw the path passed by the working object during the course of its processing on the workplace and to determine the transport distances, a circulation chart can be used [7].

3.3. Time studies of floating capacity bottlenecks

The aim of the time studies performed on floating bottlenecks is the determination of the average duration of individual production operations or their elements. If the operation

durations depend on the processed portfolio, it is necessary to determine the appropriate functional dependencies.
In practice, operation snapshot (also called a time study) is used for these purposes [7]. To evaluate the results obtained, statistical data analysis is used, and in the case of operations whose duration depends on the processed portfolio, regression and correlation analysis are also used [8].

3.4. Analysis of the floating capacity bottleneck activity in time

The aim of analysis of the floating bottleneck activity in time is to determine the rhythm (also called pace) of production on the analysed workplace. Because floating capacity bottlenecks are involved, the pace value will be expressed by means of a certain dependence on the portfolio processed.
The production pace is defined as the time interval between the beginning of two consecutive production cycles [9]. To determine its value, an analysis of the production cycle and of the organization form of the cyclic production process needs to be carried out.

3.5. Determining the hourly output of the floating capacity bottlenecks

The last stage of the proposed procedure for analysing the output of floating capacity bottlenecks is the actual determination of their output. The aim is to deduce a formula for computing the hourly output of the workplace depending on the processed portfolio.
For the output *P* of cyclic processes for the duration of time *T*, the following general formula applies [9]:

$$P = \frac{T - t_p}{t} G \cdot k \qquad (1)$$

where

- G - mass of the working object processed in one cycle
- k - production yield
- t - production process pace
- t_p - idle time of all the breaks occurring during the period *T* (time on repairs, device adjustments, and the like)

Considering that the aim of the analysis performed is to determine the hourly output of the floating bottleneck, it is possible to convert the formula to the following form (the time of breaks t_p is not considered while determining the output for a short time *T*):

$$P = \frac{60}{t} G \cdot k \qquad (2)$$

where production pace is expressed in minutes.
More information about procedure for output analysis of floating capacity bottlenecks was published in [10], and an example of its utilization in [11].

4. Simulation as effective tool for analysis and identification of floating capacity bottlenecks

The detailed capacity calculations in analysis and identification of floating capacity bottlenecks are often limited just for use in production units with relatively stable and simple technological and organizational links among individual workplaces. If there are for example in parallel operating or mutually fungible workplaces, a service equipment servicing several

workplaces in one time or significant stochastic effects in the observed production system then it is suitable or necessary to complete the detailed capacity calculations by simulation models which combine the experimenting sort of "trial and mistake" with a mathematical model for the purpose of description and evaluation of a real system behaviour.
Simulations provide relatively cheaply and quickly conceptions about systems' behaviour under various conditions and give basic data for choice of the best variant. Simulation experiments can be repeated and their results can be statistically processed and interpreted.
Simulation is a descriptive rather than a normative toll; there is no automatic search for an optimal solution. Instead, a simulation describes or predicts the characteristics of a given system under different circumstances. Once these characteristics are known, the best policy can be selected. Simulation has become a universal tool not only for analysis and identification of floating capacity bottlenecks but also for searching and evaluation of different measures for their better utilization or a substantial capacity increase.
In real use of simulation in frame of analysis and identification of floating capacity bottlenecks it is necessary to determine:

1. The methodology of simulation, i.e. procedure of designing and conducting the experiments
2. Possible advantages from its utilization
3. Type of simulation suitable for analysis and identification of floating capacity bottlenecks.

4.1. The methodology of simulation

Simulation involves setting up a model of a real system and conducting repetitive experiments on it. The methodology consists of a number of steps [12]:

- Problem definition – the real-world problem is examined and classified. We should specify why simulation I necessary. The system's boundaries and other such aspects of problem clarification are attended to here.
- Construction of the simulation model – this step involves gathering the necessary data. In many cases, a flowchart is used to describe the process.
- Testing and validating the model – the simulation model must properly imitate the system under study. This requires validation.
- Design of the experiment – once the model has been proven valid, the experiment is designed. Included in this step is determining how long to run the simulation and whether to consider all the data or to ignore the transient start-up data. This step thus deals with two important and contradictory objectives: accuracy and cost.
- Conducting the experiments – there are several types of simulation where this step is different.
- Evaluating the results – the final step, prior to implementation, is the evaluation of the results. At this stage, we may even change the model and repeat the experiment.
- Implementation – the implementation of simulation results involves the same issues as any other implementation. However, the chances of implementation are better since the manager is usually more involved in the simulation process than with analytical models and these simulation models are closer to reality.

4.2. Advantages of simulation

Simulation belongs to methods whose practical application becomes more and more important:

- Simulation theory is relatively straightforward.

- The simulation model is the aggregate of many elementary relationships and interdependencies.
- Simulation allows asking what-if type questions, experimenting with various policies and searching a suitable solution.
- The model is built from the practice perspective and corresponds with real-life decision making process.
- Simulation is universal tool, which can handle a wide variation of problems.
- Simulation allows for inclusion of the real-life complexities of problems; simplifications are not necessary.
- Due to the nature of simulation, a great amount of time compression can be attained, which allows to find out the long-term effects of various policies in a matter of minutes.
- The experimentation is done with a model rather than by interfering with the system, which allows searching for a solution at a relatively low cost.

This all continue to emphasize the massive development of IT support as well as the availability of the high-quality and user friendly simulation software which enables to solve also relatively complicated problems. In the case of less difficult tasks a spreadsheet is enough.

4.3. Type of simulation

There are several various types of simulation approaches. In practice probabilistic simulation is used the most often for analysis and identification of floating capacity bottlenecks. This type of simulation is oriented to study and solving of complex dynamic problems where one or more of the independent variables is probabilistic. The simulation results in a statistical estimation of monitored parameters and its exactness increases with a number of repeated trials. Therefore it is usually necessary to carry out the trials on a computer in order to obtain representative results. Probabilistic simulation is conducted with the aid of a technique called Monte Carlo.
Examples of simulation applications in field of analysis and identification of floating capacity bottlenecks were published in [13].

5. Conclusion

In order to realize the analysis and identification of floating capacity bottlenecks in a metallurgical production it was necessary to propose and develop procedures based on:

1. Analysis of bottlenecks output depending on the production portfolio
2. Simulation.

Based on the experience of the author from application given approaches in practice, it is possible to come to the conclusion that:

- Carrying out the detailed capacity calculations requires obtaining and processing a relatively large amount of information and data. Unfortunately the information systems used in many production companies often fail to provide the necessary data, or their usability is difficult.
- Data required for determining of the hourly output of a floating capacity bottleneck can be obtained in form of partial analyses – an input analysis of individual production process factors, production process organization analysis, time study and analysis of activity in time.

- The final procedure proves good especially in production units with relatively stable and simple technological and organizational links among individual workplaces. In other cases it is necessary to add a simulation process.
- Simulation is a universal tool not only for analysis and identification of floating bottlenecks but also for their solution and optimization.
- A "classical" methodology based on problem definition, construction of the simulation model, testing and validation the model, designing and conducting the experiments, and evaluating the results has proved good for the simulation use.
- The probability simulation seems to be the most suitable tool for the solved problem.

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