SIMULATION AS EFFECTIVE TOOL FOR ANALYSIS OF FLOATING CAPACITY BOTTLENECKS IN METALLURGICAL PRODUCTION

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SIMULACE JAKO EFEKTIVNÍ NÁSTROJ PRO ANALÝZU PLOVOUCÍCH ÚZKÝCH MÍST V HUTNÍ VÝROBĚ

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Abstrakt

Hutní výroba je charakteristická výskytem tzv. plovoucích kapacitních úzkých míst, tj. pracovišť nebo zařízení, která se mohou stát úzkým místem v závislosti na struktuře zpracovávaného sortimentu. K efektivnímu plánování a řízení hutních procesů je nezbytné hledat nové nástroje pro analýzu plovoucích kapacitních úzkých míst. Jako univerzální nástroj může být k tomuto účelu použita simulace, která kombinuje metodu pokusů a omylů s matematickým modelem s cílem popsat a vyhodnotit chování reálného systému. Tento článek představuje metodologii simulace založenou na definování problému, vytvoření simulačního modelu, testování a verifikaci modelu, návrhu a realizaci experimentů a vyhodnocení výsledků a doporučuje tzv. pravděpodobností simulaci jako vhodný typ simulace pro analýzu plovoucích kapacitních úzkých míst. Tato zjištění jsou dokumentována na příkladu aplikace simulace k analýze konkrétního plovoucího kapacitního úzkého místa v hutní výrobě – linky pro dělení tyčí válcovaných za tepla, která je součástí válcovenského provozu hutní společnosti. Vytvořený simulační model poskytuje relativně levně a rychle představu o propustnosti této dělící linky. Simulace různé struktury zakázek umožňuje určit zda se dělící linka stane kapacitním úzkým místem, jestliže se sníží minimální množství ve výrobních zakázkách, zvýší podíl zakázek s malým množstvím nebo sníží podíl zakázek větších průměrů. Navíc simulační model umožňuje vyhodnocení dopadů rozhodnutí ke zvýšení výkonu dělící linky. V závěru je uvedeno srovnání využití kapacitních propočtů a simulace k analýze plovoucích kapacitních úzkých míst. Na rozdíl od kapacitních propočtů, může být simulace použita pro analýzu komplexnějších hutních procesů s výskytem významných stochastických vlivů.

Abstract

Metallurgical production is characteristic by occurrence of so called floating capacity bottlenecks, i.e. the workplaces or devices that tend to become bottlenecks depending on the portfolio of products processed. It is necessary to search new tools for analysis of floating capacity bottlenecks to effective plan and control metallurgical processes. As universal tool can be used simulation for this purpose, which combine the “trial-and-error method” with a mathematical model with the aim of description and evaluation of a real system behaviour. The paper presents the methodology of simulation based on problem definition, construction of the simulation model, testing and validation the model, designing and conducting the experiments, and evaluating the results and recommends so called probability simulation as a suitable type of simulation for analysis of floating capacity bottlenecks. These findings are documented on example of simulation application for analysis of particular floating capacity bottleneck in metallurgical production – the line for the cutting of hot rolled bars, which is part of rolling mill plant in a metallurgical company. Constructed simulation model provides relatively cheaply and quickly conceptions about permeability of the cutting line. Simulation of various order structures enables to determine whether the cutting line is the capacity bottleneck in case decrease of minimum order quantity, increasing of the share of orders with low quantity or decrease of the share of orders with higher diameters. In addition, the simulation model allows evaluation of impacts of decisions for increasing the cutting line output. In conclusion there is comparison of capacity calculations and simulation application for the purpose of analysis of floating capacity bottlenecks. Contrary to the capacity calculations simulation can be used for analysis of more complex metallurgical processes with occurrence of significant stochastic influences.

Keywords: floating capacity bottleneck, simulation, cutting line, hot rolled bars, analysis of metallurgical processes

1. Introduction

Any production system will not be so balanced in changing conditions to avoid any bottleneck. Bottleneck is the slightest link that determines production system output. Any production element may be possibly considered to be bottleneck that „obstructs“ fluency of material flows or keeps down the usage of other production elements capacity in any way. That is why bottleneck must not be only production equipment but also worker, missing material, energy, lack of orders and so on [1]. So called capacitive bottlenecks are object of interest of paper author. These ones may be defined as specific resources that disrupt the continuous flow of products through the production process because of an apparent lack of available capacity [2].

Bottlenecks in production may have dual character - permanent bottlenecks (longtime) or floating bottlenecks (marked also as movable, dynamic or variable), whose position changes according to momentary set-up of production assortment. Metallurgical production is characteristic especially by occurrence of floating bottlenecks that are in addition characterized by:

1. Processing of considerable range of production assortment.
2. Outstanding differences in output depending on production assortment.
3. Non-existence of simple dependence of assortment structure and their output.
4. The line for the cutting of hot rolled bars may be an example of such a bottleneck:
5. The production portfolio is a combination of bar diameters, trade lengths and ordered quantities, which represents tens of thousands portfolio items.
6. Depending on the production portfolio, the cutting line output may vary from a range of approximately 5 to 240 tons/hour.
7. Even in the case of cutting a very similar portfolio, a significant change in the line output can occur (for example changing the trade length by 0,5 m can mean a change of line output reaching up to 100% in some cases).

According to [3] the following procedures for analysis of capacity bottlenecks can be used in practice:

- Observation and experience – wherever the bottlenecks are permanent.

- Capacity calculations – these consist in determining the capacity requirements of the considered plan alternative and in comparing them with available capacity of individual workplaces.
- Simulation – the influence of various plan alternatives on production throughput, fulfilling the deadlines, or the costs can be simulated.

In practice capacitive calculation are used for the first, rough identification of assortment items that lead to „movement“ of bottlenecks. Simulations are used for more exact determination.

2. Simulation

Simulation models combine the “trial-and-error method” 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 tool; 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.

In real use of simulation in frame of analysis of floating capacity bottlenecks it is necessary to determine the methodology of simulation (i.e. procedure of designing and conducting the experiments) and type of simulation suitable for analysis of floating capacity bottlenecks.

2.1 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 [4]:

1. Problem definition – the real-world problem is examined and classified. We should specify why simulation is necessary. The system’s boundaries and other such aspects of problem clarification are attended to here.
2. Construction of the simulation model – this step involves gathering the necessary data. In many cases, a flowchart is used to describe the process.
3. Testing and validating the model – the simulation model must properly imitate the system under study. This requires validation.
4. 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.
5. Conducting the experiments – there are several types of simulation where this step is different.
6. 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.
7. 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.

2.2 Type of simulation

There are several various types of simulation approaches. In practice probabilistic simulation is used the most often for analysis 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.

3. Simulation of the line for the cutting of hot rolled bars

The following example came into existence during the solving process of a real problem which was, in its original form, so complicated and extensive that its complete description would exceed the scope of that paper. Nevertheless, the basic logic and the terms of solution were kept.

3.1 Problem definition

The practical application is focused on the analysis of operation of the hot rolled bars cutting line. The cutting line is part of rolling mill plant in a metallurgical company. The line performance to a great extend depends on the assortment structure processed on the line. With regards to the increasing requirements from the customers, we can expect that the structure of orders will gradually shift particularly towards the lower order quantities thus reducing the cutting line performance. The line could therefore become the floating capacity bottleneck which would decrease the performance of the whole rolling mill.

The simulation objective can be defined as examination of the influence of the rolling mill orders structure on the cutting line permeability.

3.2 Construction of the simulation model

It was necessary to carry out the following operations within the frame of cutting line simulation model construction:

a) Analysis of the structure of existing orders.
b) Analysis of the production process organization.
c) Time study.
d) Derivation of relation for calculating the processing time of a single order.
e) Composition of the simulation table.
f) Defining the method of simulation experiments evaluation.

a) Analysis of the structure of existing orders (in the last quarter)

Production order in the examined rolling mill plant consists of three parameters:

1. Bar diameter – we are considering a range from 16 – 32 mm for the sake of our example and the discrete probability distribution from figure 1.
2. Order quantity – let's presuppose the range from 4 – 24 t and the probability distribution from figure 2.
3. Trade length – we will use only one trade length for the purpose of simplification.

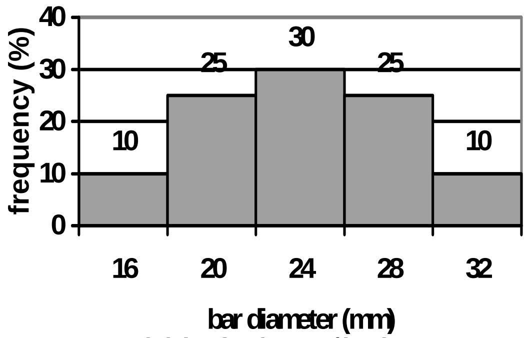

Fig.1 Probability distribution of bar diameter

Fig.2 Probability distribution of order quantity

b) Analysis of the production process organization

Two serial operating grinding machines are the cutting line basic technological devices. The manipulation with the bars is secured by means of platform lorries, the transfer is done by chain conveyor. The line consists of two production stages:

- Ist stage – includes operations carried out by an operator in the 1st grinding machine control room,
- IInd stage – includes operations carried out by an operator in the 2nd grinding machine and transfer of bars control room,

The app. 100 m long rolled bars, which are divided into layers corresponding to the platform lorries width, represent the input of the cutting line. The rolled production order can therefore consist of several so called full layers and one incomplete layer of the remaining bars which don't fill up the cutting line platform lorries. Each layer is subsequently cut on the 1st grinding machine into double of the trade length and after that it is cut on the 2nd grinding machine to the final trade length. The bars are then transferred and tied according to customer's request.

Permeability of the cutting line is determined by the slower IInd production stage during which the operator not only cuts the bars but also provides their transfer.

c) Time study

In the next step, it was necessary to define the time of those operations of the IInd production stage which indicate the total processing time of the individual layers of bars (they set the rhythm of the cutting line). 6 basic operations were defined for these purposes and they were put through chronometric measuring.

The monitored operations were initially divided by means of correlative analysis into operations the duration of which doesn't depend on the assortment structure and operations the duration of which depends on the assortment structure.

In case of the first group, the statistic analysis of the data was made in order to eliminate the deviating measures and to define the average operation times. This group included manipulation operations and transfer of bars carried out within a scope of a single layer cut on the 2nd grinding machine. Let's set their total time in the amount of $t_1 = 1{,}083$ min.

Only the actual cutting on the 2nd grinding machine was included in the second group. A regressive analysis was carried out for this operation. It also eliminated the deviating measures and the corresponding regressive model was determined. The average time of a single cut on the 2nd grinding machine t_2 (min.) is given by a linear regressive model where the cutting area $S_{ř}$ (mm^2) is the arbitrary variable. We take into account the following function in the example:

$$t_2 = 0{,}133 + 0{,}0000167 \cdot S_{ř} \tag{1}$$

It is possible to determine the relation for calculating the processing time of a single bar layer T_v (min.) on the basis of the presented information:

$$T_v = (t_1 + t_2) p_{ř1} \tag{2}$$

where $p_{ř1}$ is number of cuts in a single layer – for the given trade length $p_{ř1} = 8$ cuts. After substitution and editing it is:

$$T_v = 9{,}728 + 0{,}0001336 \cdot S_{ř} \tag{3}$$

d) Derivation of relation for calculating the processing time of a single order

The input variables of the model are bar diameter d (mm) and order quantity m (t). The following form for calculating the processing time of a single order T_z (min.) results from the analysis of the production process organization:

$$T_z = T_{vp} \cdot p_{vp} + T_{vn} \tag{4}$$

where T_{vp} is processing time of a single complete layer of a given order (min.), p_{vp} is number of complete layers in the order and T_{vn} is processing time of an incomplete layer of the given order (min.). On the basis of time study results the following will apply:

$$T_{vp} = 9{,}728 + 0{,}0001336 \cdot S_{řp} \tag{5}$$

$$T_{vn} = 9{,}728 + 0{,}0001336 \cdot S_{řn} \tag{6}$$

The relations for calculating the number of complete layers in an order p_{vp} and the cutting area of complete and incomplete layer in the given order ($S_{řp}$, $S_{řn}$) were derived on the basis of information from the area of rolling and cutting the bar steel technology used in the given plant. They will not be further discussed thanks to their complexity.

e) Composition of the simulation table

The model takes into account neither any idle time of the cutting line caused by the previous or following production stages (rolling mill and dispatching sector), nor any idle time arising in the scope of the cutting line which would lead to extension of the operations governing the cutting rhythm (breakdowns, changing the cutting discs…). Subsequently, the problem being solved can be modelled using the simulation table from table 1.

Table 1 Simulation table

Input variables		Auxiliary variables					Output variables		
d (mm)	m (t)	p_{vp}	$S_{řp}$ (mm^2)	$S_{řn}$ (mm^2)	T_{vp} (min.)	T_{vn} (min.)	T_z (min.)	$T_{z,kum}$ (min.)	m_{kum} (t)

The basic parameters of the order represent the model input variables, i.e. bar diameter d (mm) and order quantity m (t), which are generated by means of Monte – Carlo method from discrete probability distributions. The auxiliary variables serving for the calculation of processing time of the generated orders are: p_{vp} – number of complete layers in an order, $S_{řp}$ – cutting area of a complete layer in the given order (mm2), $S_{řn}$ – cutting area of an incomplete layer in the given order (mm2), T_{vp} – processing time of a single complete layer in the given order (min.) and T_{vn} – processing time of an incomplete layer in the given order (min.). The order processing time T_z (min.) represents the basic input variable. The remaining two variables are used for evaluation of the conducted experiments: $T_{z,kum}$ – accumulated order processing time (min.) and m_{kum} – accumulated order quantity (t).

f) Defining the method of simulation experiments evaluation

The production orders in the model are generated up to the total planned quantity which should be achieved in the simulated period of time. The total production time of the orders can be derived from the processing times of the individual production orders. This time is subsequently compared to the net (usable) processing time of the cutting line in the simulated period of time.

In case the time necessary for processing the generated production orders is longer than the net processing time, it is possible to reach the conclusion that the given production orders structure won't allow achieving the target production quantity and vice versa. At the same time, it is possible to evaluate the achieved degree of target production quantity.

3.3 Testing and validating the model

A simulation of cutting line operation from discrete probability distribution determined on the basis of existing orders structure in the last quarter was carried out for the purpose of model verification. The production orders were generated only for the real production quantity which was achieved in the given quarter. The order processing time acquired from the simulation was subsequently compared to the real operational time of the cutting line. That verification evidenced sufficient conformity between the model and the real system.

3.4 Design of the experiment

The compiled model enables to execute the following simulation experiments:

1. Simulation for various order structures which enable finding answers to questions like „What will happen to the permeability of the cutting line when“:

- It will reduce the minimum volume in production orders from 4 to 2 t.
- It will either increase or decrease the share of orders with low quantity.
- It will increase or decrease the share of orders with higher diameters etc.

2. Simulation of impacts of decisions for increasing the cutting line output on its permeability with various order structures.

3.5 Conducting the experiments

As an example, there will be introduced analysis of cutting line permeability with a 10% decrease in the share of large ordered quantities in favour of small order quantities in the original orders structure. The probability distribution of order quantity will therefore have the form from figure 3.

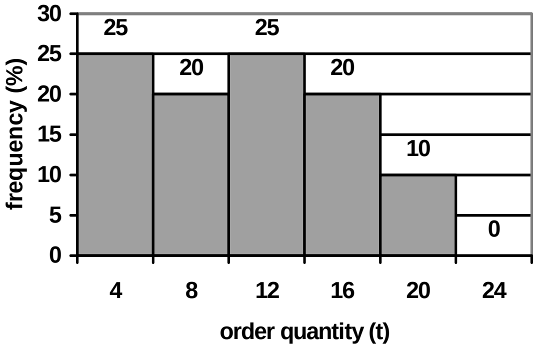

Fig.3 Modified probability distribution of order quantity

The other starting conditions are:

- Probability distribution of bars diameters from figure 1.
- The total target production volume in the amount of 50 kt per quarter.
- Net (usable) quarterly operational time 1 400 hours.

If we use spreadsheet program MS Excel and its pseudo-random numbers generator for the realization of the simulation experiments, the simulation table will have the form from table 2.

Table 2 Simulating the decrease in the share of large order quantities

Input variables		Auxiliary variables					Output variables		
d (mm)	m (t)	p_{vp}	$S_{řp}$ (mm^2)	$S_{řn}$ (mm^2)	T_{vp} (min.)	T_{vn} (min.)	T_z (min.)	$T_{z,kum}$ (min.)	m_{kum} (t)
16	20	2	13069	2011	11,47	10,00	32,94	32,94	20
24	8	0	-	12667	-	11,42	11,42	44,36	28
20	8	0	-	11310	-	11,24	11,24	55,60	36
28	12	0	-	18473	-	12,20	12,20	67,80	48
:	:	:	:	:	:	:	:	:	:
20	8	0	-	11310	-	11,24	11,24	72633,85	49964
16	12	1	13069	3820	11,47	10,24	21,71	72655,57	49976
28	4	0	-	6158	-	10,55	10,55	72666,12	49980
24	20	1	19453	12215	12,33	11,36	23,69	72689,80	50000

Processing 50 kt of bars on the cutting line will, in this case, require 72 690 min., i.e. 1 211,5 hours.

3.6 Evaluating the results

The result of the experiment implies that a 10 % decrease in share of large order quantities in favour of small order quantities, with net (usable) quarterly operational time of 1 400 hours, will mean cutting line capacity reserve in the amount of 13,46 %. Under these conditions, the cutting line won't be the capacity bottleneck and it will make processing of the total amount of rolled bars possible.

4. Conclusion

Based on the author's experience from analysis of specific floating capacity bottlenecks in metallurgical companies, the statement can be made that the 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.

Thus, capacity calculations in analysis 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 capacity calculations by simulation models which enable description and evaluation of a real system behaviour.

Simulation is a universal tool not only for analysis 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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