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IMPROVEMENT OF PRODUCTION PROCESSES BY SEARCHING AND INCREASING OF THE PRODUCTION SYSTEM CONSTRAINTS WITH UTILIZATION OF THE MODELLING AND SIMULATION METHOD

Abstract

There is presented the practical application example of the theory of constraints, in the paper. In all enterprises from engineering industry, the main problem connected with realization of production orders are the constraint existing in every production system. Searching and increasing of the bottleneck (constraint) should be the first step in situation, when exist necessity to increase production. There are described principles and stages of the production system improvement, which are based on the mentioned above theory.

In the paper, there is demonstrated that the computer simulation is very useful aiding tool for finding constraints and facilitating the analysis of different proposed changes in production systems.

1. INTRODUCTION

At production planning, it is not enough to determine how, what and when we should produce something but also to determine what, where and for whom we should produce it. Production planning is realized by starting with long-term tasks and short-term tasks planning and ending with the planning realization of the operation tasks. The planning of production can be understood as a creation of conditions for fluent and effective run of the production processes coming into existence. We should remember here about costs and realization time, which should be made broadly optimal [1,7].

Development of the system aiding control of production resulted from the targets, which were to be fulfilled by the created systems. These targets were often quite different but if they were the same, they differed from each other with the assigned priorities. To the most important targets of the system aiding planning and managing of the production, belong:

- satisfying customers needs,
- keeping the fixed time-terms,
- realization of technological requirements,
- maximum utilization of workplaces,

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- minimization of the realization time of production orders,
- decreasing of production costs,
- correct settlement of the batch size,
- minimization of the storage time,
- minimization of shortcomings,
- minimization of storages.

The activities of a company in the conditions of a free market economy make managers undertake increasingly complex tasks. The consequence of this is the necessity for the synchronisation of increasing quantities of technological factors. This leads to more effective methods of controlling the production processes. Control of production planning is one of the most important tasks of a company. The target of these activities is to manufacture the products at the planned time. Furthermore, they have to fulfil qualitative requirements, and their manufacturing costs should be as low as possible.

New tendencies within a company's organisational field, which also have an influence on computer systems, have a meaningful influence on the development of production planning and control. Among them, the most important are: Material Requirements Planning (MRP I), Manufacturing Resource Planning (MRP II), Enterprise Requirements Planning (ERP or MRP III), Just in Time (JIT), and Kanban and Optimised Production Technology (OPT). Furthermore, modelling and simulation become a more substantial method to aid production management.

2. COMPUTER MODELLING AND SIMULATION

Several stages of development of the computer simulation method can be distinguished. They are connected with development of programming languages and development of data processing techniques. The development of both software and equipment, caused that the method of modelling and computer simulation has been more wider used. The stages of the mentioned above development are presented in table 1.

Presently on the market are available different simulating systems from the simplest created on the basis of mathematical models, to the most complex, with environment for creating animation, 3D graphics, virtual reality and the possibility for integration with the company computer system - Fig. 1.

Simulation systems such as ARENA and QUEST offer a comprehensive set of advanced information solutions designed to analyse the processes of production enterprises [10]. They are used in various branches of industry, for example in machine, electrotechnical, electronics industry, arm, aviation, in the production of ships, consumptive goods, in assembly, and in automation. The range of uses cover the whole manufacturing process, from planning to assembly of final products. This allows the ability for the complete design and analysis of actual manufacturing processes

The simulation of production systems becomes the recognized tool used in designing, planning and controlling of systems. From beginnings, when this method was used in space and military researches, we can observe the gradual expansion, especially in last years, in direction of varied branches of industry. Except mentioned above applications, the simulation finds use on all levels of enterprise management. Not only in the manufacturing area, but also on the lowest level of management, in range of storing, inter-department and workplace transport, through tactical tasks realized on average management level, to strategic tasks realized on the highest level of the management enterprise [2, 5, 6, 8].

Tab.1. Generation of software for simulation [9]

Generation	Time	Features	Examples
1	50s	General programming languages - no special support for simulation	FORTRAN, ALGOL ASSEMBLER
2	60s	Special programming languages, support for random numbers, statistics, execution, etc.	GPSS, SIMSCRIPT GASP II, SIMULA
3	70s	Discreet – events, continuous and combined simulation	GASP IV, ACSL
4	80s	Special problem concentrated simulators, use of animation, simulation as a project	SIMAN/CINEMA, SIMFACTORY, SEEWHY
5	85s	Artificial intelligence and expert systems in simulation	SIMKIT, SIMULATION CRAFT
6	90s	Object oriented simulation systems	SIMPLE++, ARENA
7	2000	3D modelling	QUEST, ARENA, DELMIA

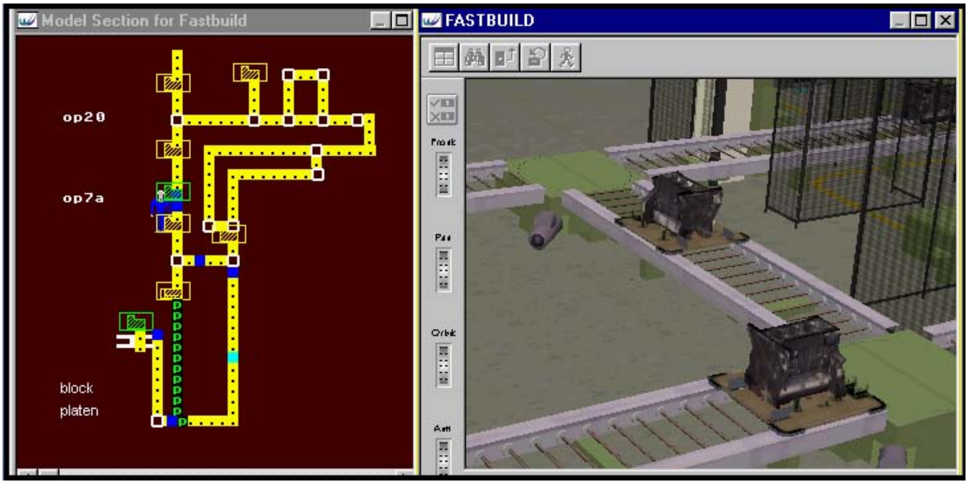

Fig.1. 2D and 3D simulation model [10]

Creating of a simulation model consists in selecting and locating different component elements in the defined space of the simulated system. At the same time with defining of logical connections among the component elements of the modelled system, the main parameters to present the animation to collect data for statistical analysis are specified – Fig. 2. Defined parameters of the graphic model can be edited and modified if necessary.

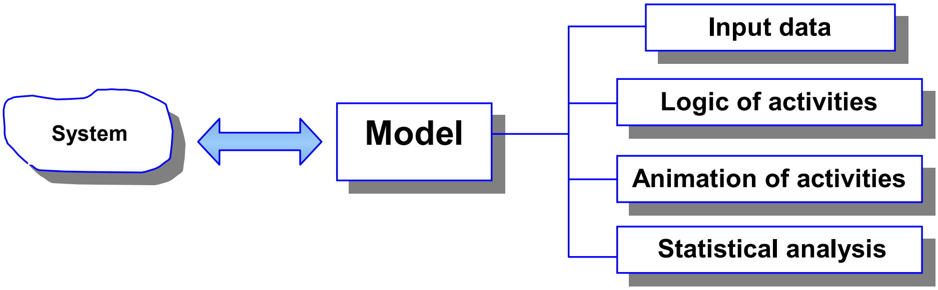

Fig.2. Elements of the model of production system

Creating of a model is only a part of the simulation project. Each project begins with defining the problem and collecting data suitable for execution a representative simulation – Fig. 3.

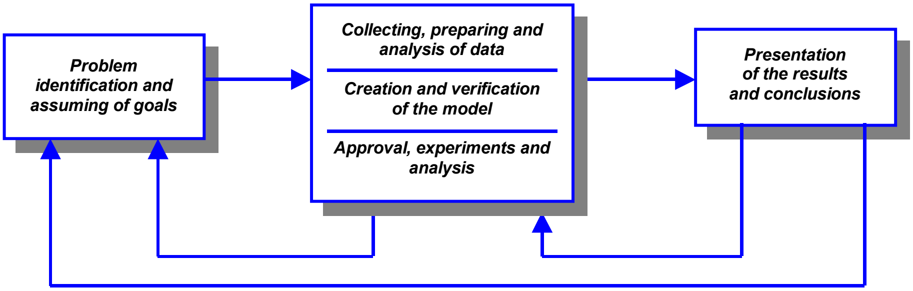

Fig.3. Stages of the simulation project

The model of manufacturing process can be considered as the system consisting from inputs, outputs and realized processes. The inputs are mainly raw materials and on other side the outputs are final products. The manufacturing process is the series of following operations, for which the exit of previous operation is the piece of entry next. The input material possesses already imposed qualitative characteristics from previous operation, which have on realization of analysed operation essential influence.

After that, when the model is ready, it should be verified, whether it works correctly and then the obtained output data should be analysed. Through the analysis of these data, critical areas of the modelled system can be determined. We can also drawn out main conclusions and required modifications of the system, which are necessary for efficient realization of the defined goals.

Using the tools for modelling and simulation one should take into account the following rules [8]:

a) Profits obtained by the use of modelling and simulation have to be bigger than the expenditures, which are necessary for realisation of simulation and for improvement of the production system. The main criterion, at undertaking the decision about the utilisation of simulation in practice, are the benefits resulting from its utilization. These advantages can be divided into quantitative and qualitative ones. In many cases, a target of modelling and simulation is not to achieve a precise economic result, but e.g. to improve the functionality, effectiveness, or reliability of the system run – [5].
b) To get the best effect from the simulation, it must be conducted in the right time, i.e. at initial phase of working out the project because then, at the beginning, it is possible to determine suitable parameters of the system being designed. Additionally, the costs of realisation of changes proposed on the basis of conducted simulation, at the beginning of project realisation, are the lowest. Later, it is more difficult to introduce changes and also additional costs, which exceed expected profits, appear (Fig. 4) – [5, 8],

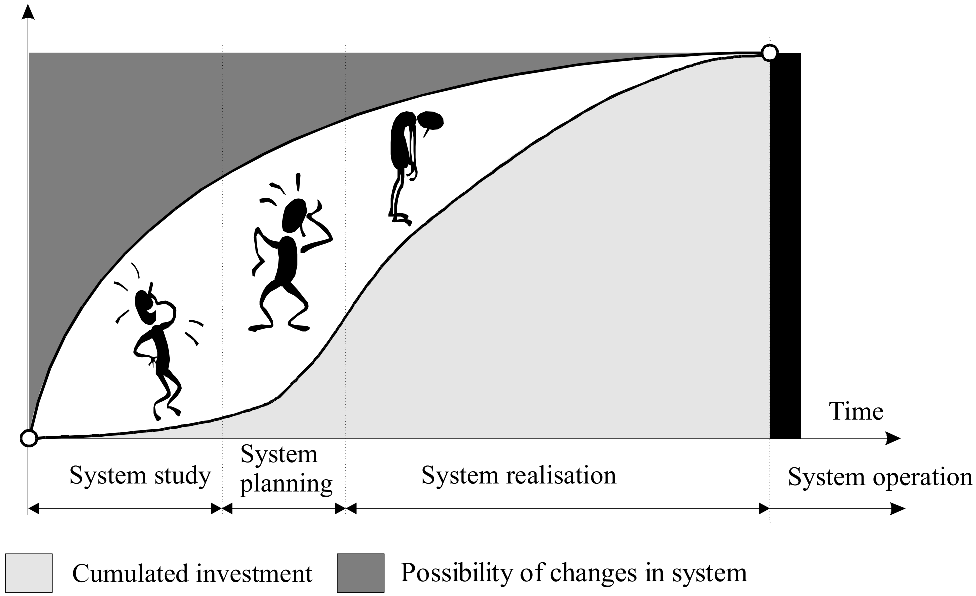

Fig.4. Possibilities of changes and costs of investment at different stages of project's realisation [5]

c) System for modelling and simulation of the production processes should be integrated with information system of the company (Fig. 5). Company's databases should be a direct source of data for simulation. In the modelled production system one can easily and quickly change the production plan, check both different variants of production schedules and possibilities of realisation of different production orders [2].

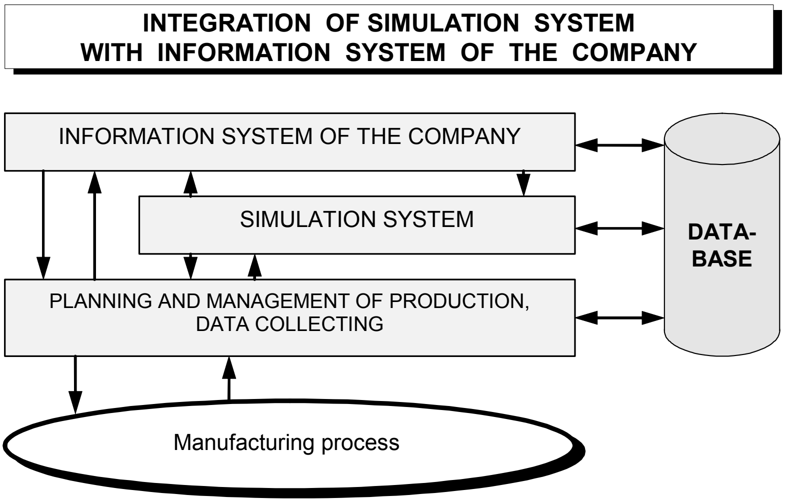

Fig.5. Information system of the company as a data source for modelling and simulation [2]

3. THEORY OF CONSTRAINTS (TOC)

3.1. Modelling and simulation in theory of constraints

The Theory of Constrains (TOC) is the philosophy of management, which directs the main attention on a bottle-neck of production system, that is the part, which decides about efficiency of the whole system – Fig. 6. Improvement of the bottle-neck gives the largest progress in process of company development [3, 4, 11, 12].

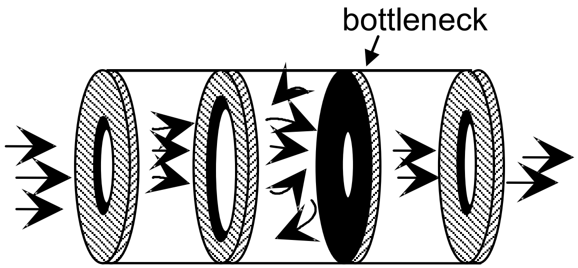

Fig.6. Bottleneck as the main element deciding about productivity of the whole production system

A large majority of persons from high and medium management try to increase the efficiency of only chosen fragments of the production process, especially own departments. They don't look at the whole production system. The basis of such approach often is an assumption, that if every unit of the system will be improved, then the efficiency of the whole enterprise will increase too.

Such assumption doesn't take into account connections between particular departments and particular production processes. The improvement of particular sections very often doesn't lead to improvement of the firm efficiency. The optimum of the system is not a sum of local optimums. The improvement of efficiency in a one part of the organization doesn't guarantee the improvement of the whole.

According to Theory of Constraints every activity in each part of organization has to be estimated from the point of view of their influence on the whole organization. All organizations has to be treated as the system of joined processes – chains of activities [3].

All systems have "the weak link", which is the constraint and which determines the efficiency of the whole organization. Strengthening of other links, beyond the weakest, will not strengthen the chain of processes.

The modelling and simulation method is the perfect tool, which enables finding of this weak link [6]. It is often this workplace, which is maximally loaded and before which comes into being the largest queue of pieces waiting on processing. The bottleneck of a production system it is possible to find through analysing information included in the report from simulation, and also through observation of animation from computer simulation.

With the help of simulation it is possible to realize next activities leading to the system improvement and connected with the Theory of Constraints – checking possibilities of the bottleneck from the point of view of maximum utilization, checking possibilities for his strengthening, adaptation of the supply and manufacturing schedule to the possibilities of the bottleneck.

3.2. Process of changes in the theory of constraints

Production process is the chain of activities, which are realized on mutually related resources and only several units (constraints) in this system have influence on the achieved result [7]. Understanding of this dependence makes possible to find solution also even very complicated problems [3,4].

The theory of constraints and the modelling and simulation method are connected directly with changes [11, 12]. The Goldratt's theory of constraints gives us answer for three questions:

- What to change?
- In what to change?
- How to cause changes?

The theory of constraints makes reorientation on the system approach, which is indispensable for determining of the constrained area. Next activities already concentrate only on this area (on the bottleneck of the system).

The theory of constraints in production management means orientation on critical points of the system (the critical chain), what assures the maximization results of the system. The improvement of achieved results, it should can reach introducing different improvements in cyclic way in 5 following stages [4, 12]:

1. identifying of the constraint (bottleneck) of the system,
2. maximum exploitation of the present possibilities of the bottleneck,
3. subordination of all to the maximum utilization (exploitation) of the bottleneck,
4. elevation of the bottleneck possibility (throughput),
5. return to the stage 1.

ad. 1. Identifying of the constraint (bottleneck) of the system

In different companies, there exist following kinds of constraints:

- physical constraints – they concern maximum production capacity of machines, departments or individual men's,
- political constraints - the most often they are connected with principles, plans, procedures, ways of measurement, and they decides about our success or defeat.

Another constraints' division:

- internal constraints – they exist, when demand is large then supply, that is when possessed production means are not able to satisfy all needs of market,
- external constraints – they exist, when supply is large then demand, that is when possessed means make possible the production of larger quantity of products than the company is able to sell.

ad. 2. Maximum exploitation of the present possibilities of the bottleneck

Increasing of the bottleneck efficiency means higher utilization without additional investments. It can reach by maximizing of the working time of bottleneck (worker, machine, department), by implementation of continuous work (without breaks).

ad. 3. Subordination of all to the maximum utilization (exploitation) of the bottleneck

When the bottleneck works on maximum, all other activities have to be subordinated him. All non-constrained means should support constraints and improve their exploitation.

ad. 4. Elevation of the bottleneck possibility (throughput)

On this stage we should execute investment enlarging possibilities (capacity) of the bottleneck, for example the purchase of a new machine, enlargement of the office space, trainings, employment of a new worker, hire of consultant.

ad. 5. Return to the stage 1

Because all systems have some constrained factor, after his finding and elimination there will appear next. The work connected with improvement of activities' efficiency never ends. The Theory of Constraints is the philosophy of continuous improvement of the working efficiency.

On every stage, there is possible to use simulation, for example for identifying the system limitation, for checking the present bottleneck possibilities and to planning properly uncritical tasks practically. All unlimited resources (uncritical) should support constraints and improve their exploitation.

Through the simulation we can execute the analysis of different investments enlarging possibilities (throughput) of the bottleneck, for example the purchase of new machines, modernization of existing machines and devices, enlarge employment.

In next point of this paper, there is presented an example of the project realized according to above-mentioned stages.

4. EXAMPLE OF IMPROVEMENT OF THE SHAFT TREATING CELL

4.1. Characterization of the analysed production system

The firm producing electric motors intends to enlarge production. The constraint was outside the firm - firm possesses means of production, which are not used maximally. Production abilities are higher than existing sale. However planned large sale crosses production abilities (about several percentage). The aim of introduced below analyses was the check of different possibilities for improvement of the present system.

After preliminary analysis of the manufacturing process of electric motors it turned out, that the shaft treating cell is the limitation of the whole system. The process of working of shafts is the main process in the analysed firm, and one workplace in this cell is the bottleneck of the whole production system. Therefore, there was executed more detailed analysis of this cell using the method of modelling and simulation.

The standard production process of shafts for electric motors is presented in the table 2. The particular types of shafts differ from each other only in times of realization of operations. The difference mainly is connected with different size of worked shafts.

On account of large quantity of different types of shafts (~70 types per month) and connected with this large labour-consuming of the model building, they were divided into groups according to the criterion of constructional similarity. For each group there was additionally defined a representative, for which the simulation was realised. Thanks to this, there were limited quantity of defined production processes in the simulation model to five processes. Having for example the SYSKLASS software packet, it is possible to take direct advantage of a classifier for manufactured parts.

Tab.2. The shaft treating cell – manufacture process, machines and their quantity

Op.	Name of operation	Workplace (quantity of machines)
1	Cutting on length	Band-saw (2)
2	Facing on length and centring	Mill-centring machine (1)
3	Turning	Turning machine DFS 450 NC (2)
4	Grinding	Centre-type grinder (4)
5	Slot milling	Sequence milling machine (3)
6	Grease conservation	Manual workplace

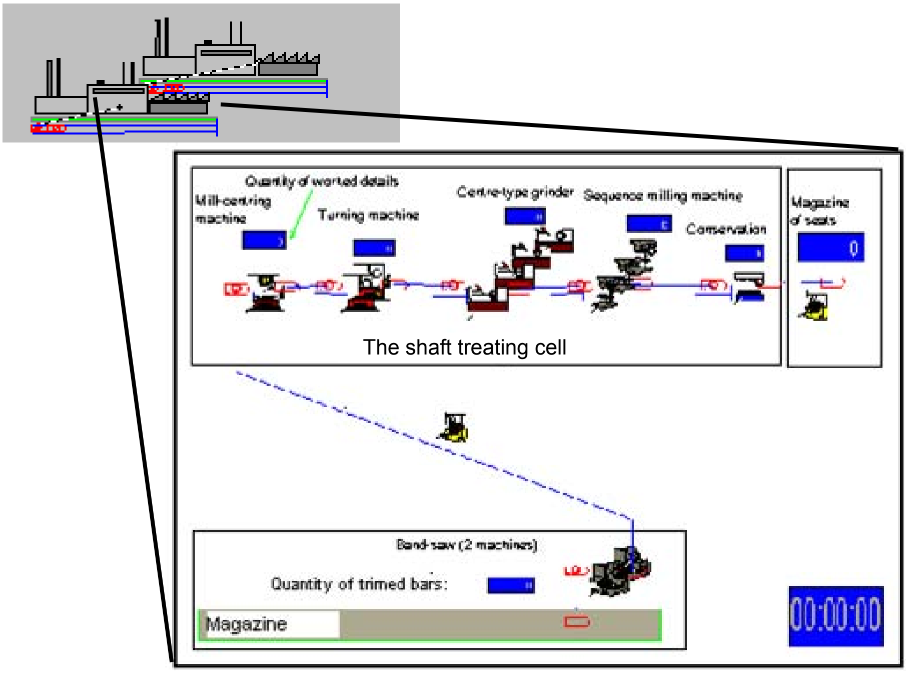

Fig.7. Simulation model of the shaft treating cell – animation

On next figures are presented the simulation model of the analysed treating cell: animation part (Fig. 7), block diagram of the production process (Fig. 8) and example of the application window presenting main parameters of the simulated processes and simulation (Fig. 9).

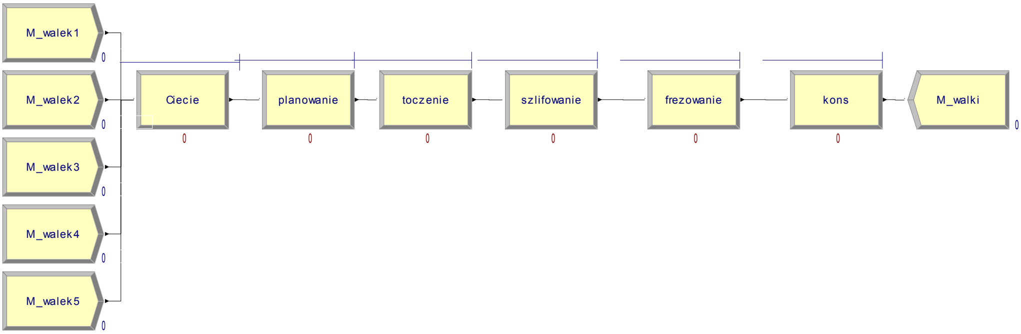

Fig.8. Simulation model of the shaft treating cell – the block diagram of the manufacturing process

The presented, on above figures, model of the shaft treating cell was prepared in the ARENA software package [9, 10]. In the table 3 is presented an example of the report from simulation (1st variant presenting present state).

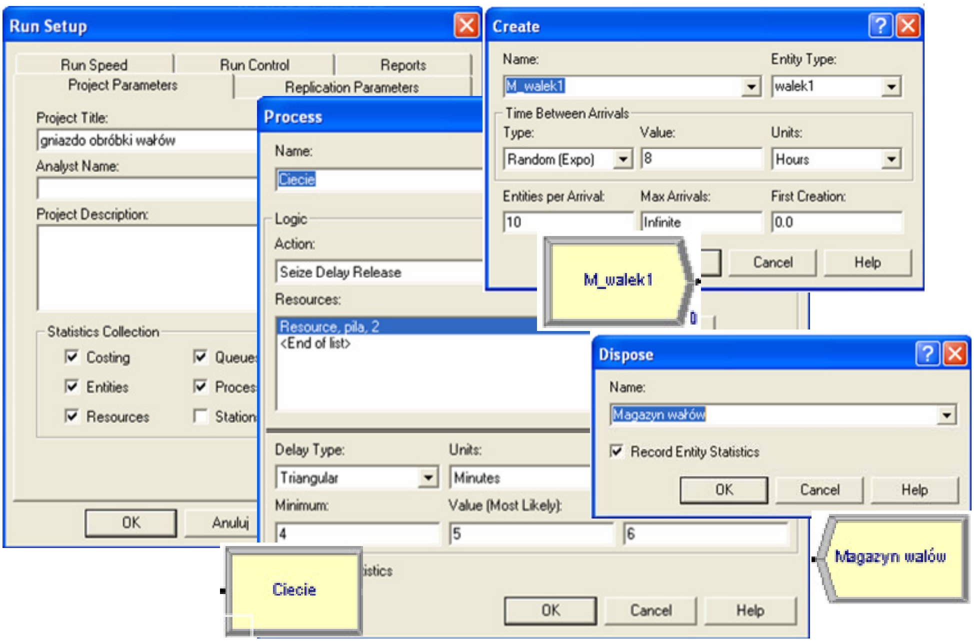

Fig.9. Examples of windows for defining of different parameters in the simulation model

Tab. 3. The report from first simulation

REPORT FROM SIMULATION		
Volume of production 1355 pieces.		
Utilization of workplaces (simulation time:168 hours)		
Workplace (quantity of machines)	**Work time [hours]**	**Duty of machines [%]**
Band-saw (2)	103.87	61,83
Mill-centring machine (1)	167.66	99,80
Turning machine (2)	167.09	99,46
Centre-type grinder (4)	160.29	95,41
Sequence milling machine (3)	150.46	89,56
Conservation (1)	125.45	74,67

4.2. Identifying of the constraint

After modelling of the shaft treating cell and simulation of monthly production there was got information about duty of workplaces, about size of queues before workplaces and the time of realization of planned production. The example results are in table 3. It made possible identifying of the bottle-neck.

The bottleneck of the analysed working cell is the milling-centring machine characterizing by the largest duty (Fig. 10) and the largest number of waiting pieces in the queue (Fig. 11). Now this workplace is modernized. It will allows to achieve shorter process time of realized here operations, average about 10% for every part. This activity is a typical example of realization of the fourth step in TOC (elevation of the bottleneck possibility)..

Usage

Instantaneous Utilization	Average	Half Width	Minimum Value	Maximum Value
Milling machine	0.8956	(Correlated)	0.00	1.0000
Mill-centring machine	0.9980	(Insufficient)	0.00	1.0000
Conservation	0.7467	0,107884531	0.00	1.0000
Band-saw	0.6183	(Insufficient)	0.00	1.0000
Centre-type grinder	0.9541	(Correlated)	0.00	1.0000
Turning machine	0.9946	(Insufficient)	0.00	1.0000

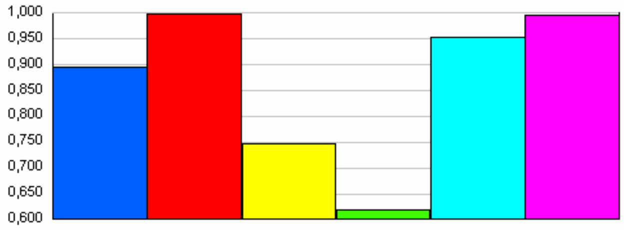

Fig.10. The example of results from simulation – usage of workplaces

Queue

Other

Number Waiting	Average	Half Width	Minimum Value	Maximum Value
Cutting on length	5.5601	(Insufficient)	0.00	29.0000
Slot milling	0.00117190	(Insufficient)	0.00	1.0000
Grease conservation	3.0674	(Correlated)	0.00	14.0000
and control	0.1281	(Insufficient)	0.00	2.0000
Facing	33.5984	(Correlated)	0.00	65.0000
Grinding	0.00743920	(Insufficient)	0.00	1.0000
Turning	7.9896	(Correlated)	0.00	17.0000

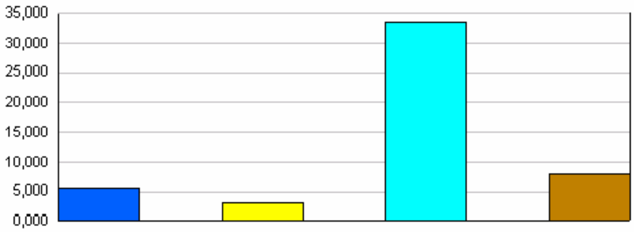

Fig.11. The example of results from simulation – quantity of pieces in the queue

Conclusions from the first simulation:
- workplaces with the highest duty are two turning machines – there is the bottle-neck of the modelled seat;
- workplaces with the least duty are two band-saws and workplace for conservation.

4.3. Maximum exploitation of the present possibilities of turning machines

To enlarge the efficiency of turning machines there were proposed organizational changes. The creation of conditions for continuous production on these workplaces was the effect of these changes. There were established different hours of breaks on both turning workplaces. There always will be worked the least one operator. The turners' work will be supported additionally by the operator of neighbouring mill-centring machine.

Above mentioned changes were introduced in the second simulation model. Additionally the operation of conservation will be realized on the milling workplace. From the conducted simulation there were drawn out following conclusions:
- duty of all workplaces of the analysed cell grew up - average about 2%. The bottleneck was loaded almost 100%;
- the volume of production grew up similarly - from 1355 to 1380 pieces (about 2%).

4.4. Subordination of all to exploitation of the bottleneck

This principle was realized by the proper scheduling of production orders. In first simulation the size of batches of material was established on the level of 400 parts per week. How it turned out from simulation, we are not able to process such quantity of material. In effect, this guided to enlarging queues before turning workplaces. On the basis of results from simulation, there was established, that 370 pieces will be the suitable size of week's batch of production. With such level of production the average week's size of the queue before bottle-neck will be constant.

4. 5. Elevation of the bottleneck throughput

The possibility of turning workplaces should be enlarged by purchase of a new machine. This solution was rejected - too large costs of investment. The next proposed solution was the modernization, which makes possible shortening of the necessary time for handling shafts. There is possible shortening of the operation time from 15 to 12 minutes. This change was taken into account in next simulation model. To check the possibility of the cell after such improvement, there was defined the same size of batches identically like in first simulations (400 pieces).

From simulation there was turned out, that only after such changes we will be able to execute whole orders accepted for realization. The achieved volume of production carries out 1430 pieces. The duty of workplaces was increased average about 6%. The centre-type grinder are the bottleneck now - their duty carries out almost 100%, what means that we should return to the beginning of analysis, that is to the improving of a new constraint of the analysed production system.

4.6. Examples of others analysis

With help of computer simulation we can realize additionally different cost analyses. In the ARENA software package for every operation or workplace we can attribute the activity cost, the machine-hour cost and waiting cost. After conducted simulation in the final report we will find different compositions of costs: for individual workplaces the cost of work (Fig. 12) and the cost of standstill (Fig. 13), the accumulated costs for operations (Fig. 14) and the unit cost (Fig. 15) and also the manufacturing costs for different types of shafts (Fig. 16).

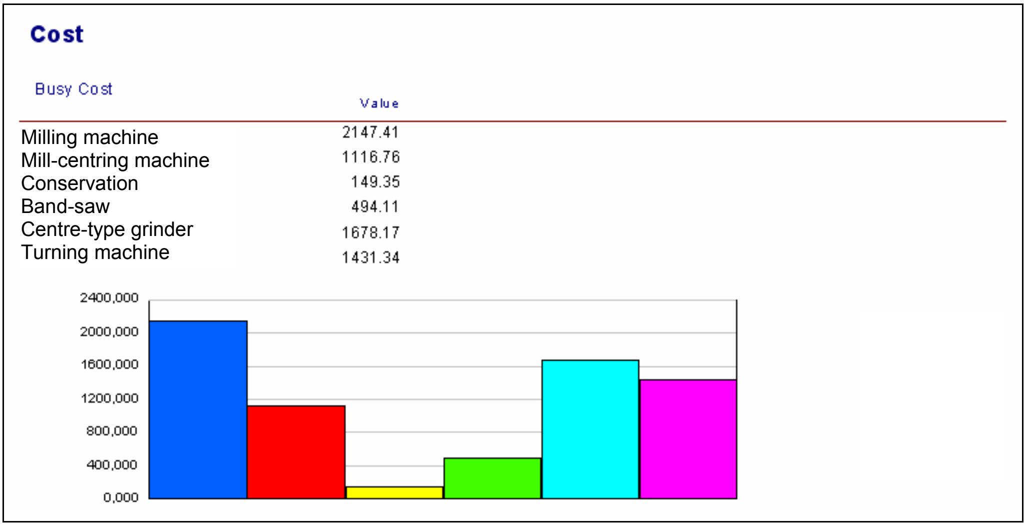

Fig.12. The example of results from simulation – the cost of work

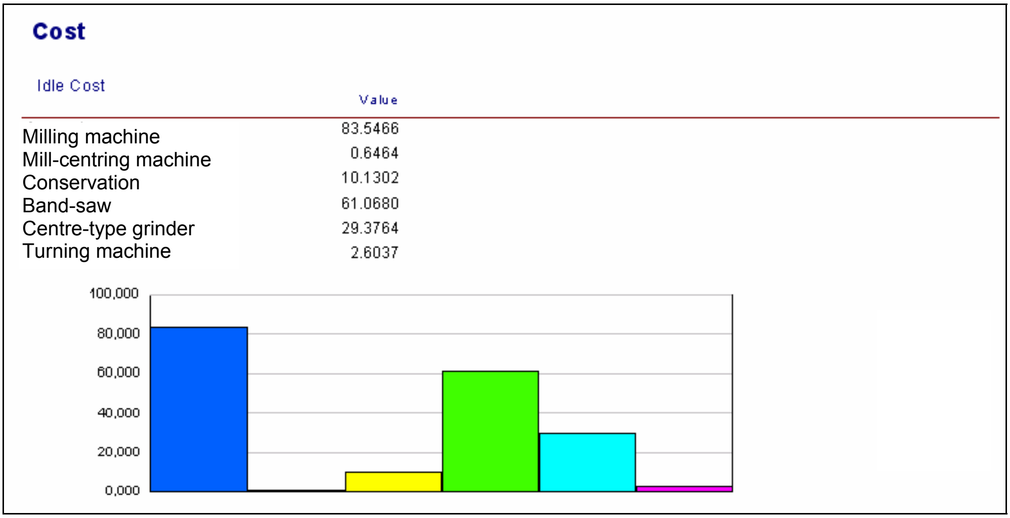

Fig.13. The example of results from simulation – the cost of standstill (waiting for parts)

Accumulated Cost

Accum VA Cost	Value
Cutting on length	1141.09
Slot milling	2750.39
Grease conservation	31.0308
Facing	1767.59
Grinding	2288.30
Turning	2046.81

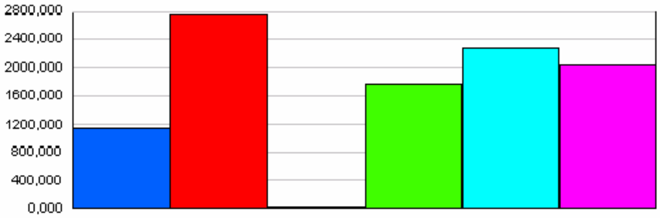

Fig.14. The example of results from simulation – the accumulated costs for operations

Cost per Entity

VA Cost Per Entity	Average	Half Width	Minimum Value	Maximum Value
Cutting on length	3.8420	(Insufficient)	3.4937	4.2627
Slot milling	10.4578	(Insufficient)	9.6770	11.2443
Grease conservation	0.1180	(Insufficient)	0.06133378	0.1946
Facing	6.2680	(Insufficient)	5.9124	6.6204
Grinding	8.6678	(Insufficient)	8.1747	9.3960
Turning	7.7238	(Insufficient)	7.3239	8.1112

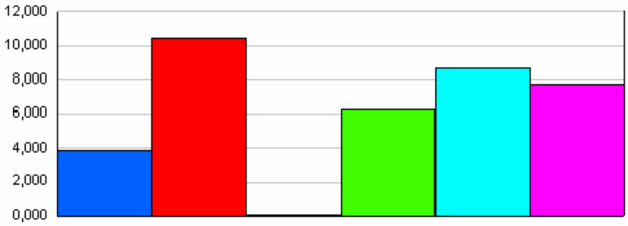

Fig.15. The example of results from simulation – the unit cost per operation (per 1 shaft)

Cost

VA Cost	Average	Half Width	Minimum Value	Maximum Value
Shaft 1	86.3693	(Insufficient)	85.4353	87.3947
Shaft 2	96.6497	(Insufficient)	95.8223	97.9683
Shaft 3	107.01	(Insufficient)	105.86	108.06
Shaft 4	117.20	(Insufficient)	116.25	118.31
Shaft 5	127.67	(Insufficient)	126.75	128.75

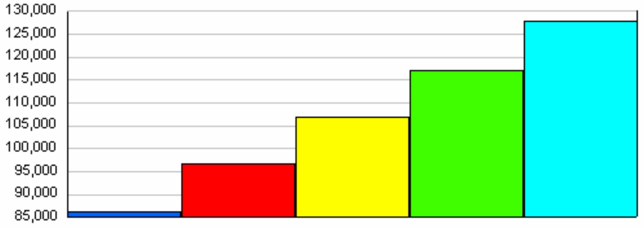

Fig.16. The example of results from simulation – the unit cost for different types of shafts

The next analysis, which we can realize, are the analysis of the waiting times in queue before workplaces (Fig. 17) and the production cycles for particular parts – types of shafts (Fig. 18). There is possible the analysis of different production orders, their possibility of realization from point of view of the realization time or for checking different variants of the production plan differing for example in quantity of parts for particular types. There is possible the estimation of influence of the orders sequence on their realization time also.

Time

Wait Time	Average	Half Width	Minimum Value	Maximum Value
Shaft 1	1.9728	(Insufficient)	0.00	3.1572
Shaft 2	7.3037	(Insufficient)	2.1392	12.1364
Shaft 3	6.8217	(Insufficient)	2.7768	9.5205
Shaft 4	7.7663	(Insufficient)	3.5170	11.6993
Shaft 5	8.0636	(Insufficient)	4.2749	10.9684

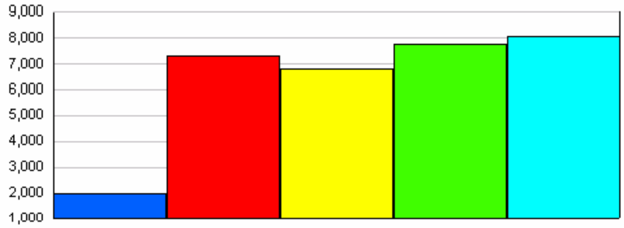

Fig.17. The example of results from simulation – average waiting time for different shafts

Time

Total Time	Average	Half Width	Minimum Value	Maximum Value
Shaft 1	2.7668	(Insufficient)	0.6761	4.6713
Shaft 2	8.1110	(Insufficient)	2.8233	12.7924
Shaft 3	7.5415	(Insufficient)	3.4572	10.2134
Shaft 4	8.5348	(Insufficient)	5.0954	12.3737
Shaft 5	8.8240	(Insufficient)	4.9372	11.6502

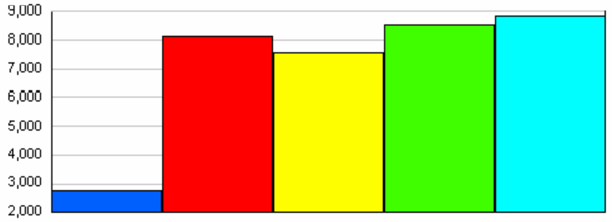

Fig.18. The example of results from simulation – average working time for different types of shafts

5. CONCLUSIONS

If it will turn out, that another workplace after improvement (realization of changes in the production system) will be the bottleneck, we should back to stage 1. In the last stage of the presented analysis it turned out, that the grinding machine became the bottleneck now, and this workplace we should strengthen in the next step of improvements. Thanks to simulation, after each change we see its influence on the constrain and also on the other elements of the analysed system.

All improvements of the bottleneck give the advantage for the enterprise, but they the most often are short-lived. Projects of improvements we should not realize "once on some time", but they should be the basis of the continuous improvement of the production system – Fig. 19. All enterprises should realize the improving projects, if they want to stay on competitive market.

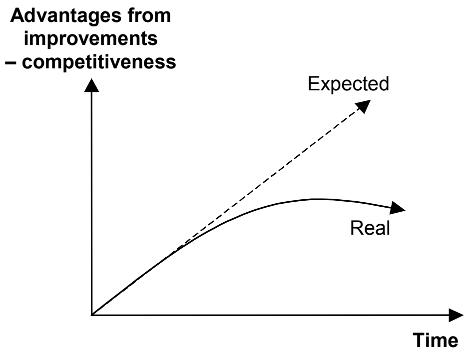

Fig.19. The need for continuous improvements

In the described analysis were presented only examples of simulating variants. In practice, there are more variants. They are more detailed and they take into account more aspects of the analysed production systems.

The disadvantage of the modelling and simulation is labour-consuming of building models. Having it (the first model), we can comparatively easily change its parameters and create next models taking into account other variants of different improvements of the identified constraint. We can, in continuous way, manage constrains – identify, plan loading and check possibility for improving.

The introduced example confirms, that modelling and simulation of production processes becomes more and more important aiding technique, not only for designing of new production systems, but also for continuous improving of already functioning production systems.

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