SPECIFICITY OF BOTTLENECKS IN CONDITIONS OF UNIT AND SMALL-BATCH PRODUCTION

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Abstract:

The manufacturing industry has evolved over the past several decades in response to changing customer needs. Customers have become more demanding and want products that can meet their specific individual requirements. The standard products previously produced in large batches are not sufficient to meet this variety demanded. Given the increased competition, both locally and globally, companies must also now respond faster to get and keep customers. Enterprises were forced to unit and small-batch production. Currently, advanced planning systems are coming into use, however their cost exceeds the possibilities of small and medium enterprises and algorithms used often require great customization to industries' needs and conditions of unit and small-batch production. The paper has been drawn on the basis of research on overloads of moving bottlenecks in conditions of unit and small batch production in real conditions having a big number of resources and tasks. The methods used so far are not capable of finding the global optimum of such big data ranges.

The author took on building a heuristic algorithm, which could find solution good enough and based on TOC (Theory of Constraints) assumptions and verification of assumptions using tests in real production systems. The above method found application to the industrial scale, as extension of the ERP class system.

Keywords: *Theory of Constraints, job shop scheduling, moving bottlenecks, heuristic algorithm.*

1. Introduction

The guarantee of success on contemporary, more and more competence-driven and changeable market is fast and flexible implementation of production processes, which also assures immediate adjustment of production to changes both of the environment and more and more demanding customers. If the 70's were the times of costs reduction, the characteristic of the 80's was quality improvement, the 90's were focused on flexible production, the beginning of the 21st century is characterized by focus on customer's satisfaction This trend translates into production of articles adapted to customer's needs and to shortening the availability of products very often below the production cycle. Today, manufacturers in many industries are faced with very high product variety and much smaller batches, which can approach one unit.

To implement the tasks connected with controlling the production in such conditions it is necessary to construct operational plans determining the order of production tasks performance by individual production sections. For the plans no to be a chance set of tasks it is necessary to order them properly and to optimize the route of processes.

Since the production is aimed at fulfilling specific needs of demanding customers and not at filling warehouses, the production volume should reflect the volume of orders. In times of fight for the client every order has to be performed on time. What is more, in times of fight for shortening the delivery cycle, meeting safe deadlines, that is distant in time, is not enough. Companies are forced to meet short deadlines with keeping the product price competitiveness condition. It is hardly possible without a proper, APS (Advanced Planning System) class, advanced planning support system. Currently, advanced planning systems are coming into use, however their cost exceeds the possibilities of small and medium enterprises and algorithms used often require great customization to industries' needs and conditions of unit and small-batch production.

2. Formal description of the issue

This paper contains some propositions regarding optimization of production plan (ordering tasks, orders) of real businesses and a description of problems related to this issue in real conditions narrowed to abovementioned conditions. Particular attention was given to issues of uncertainty and verification of algorithm assumptions using positive feedback in the plan. They are the key to obtaining a model, which properly reflects the reality in which we often encounter vague or even incomplete information.

Given is a finished set n of tasks $\{J_i\}_{i=1}^{n}$, which have to be performed by finished m of machines from the finished set $\{M_j\}_{j=1}^{m}$. Each task J_i is a sequence $n(i)$ of operations $\{w_{ik}\}_{k=1}^{n(i)}$, whose arrangement (order) is determined by a set of limitations usually described with a graph. Each operation is performed by only one, specific machine in the specified period of time [7].

To find the solution of arranging task, measurements connected with the rate of utilization of machine job fund (Z_j) were used:

$$Z_j = \frac{(H_j - \mathcal{J}_j)}{w_j H_j}, \qquad (2.1)$$

where:

$\mathcal{J}_j$ - means the sum of jobs' process time on the machine j,
H_j - standard working time of the machine j,
w_j - rate of carry out the standard of the operation for the machine j.

If $H_j < \mathcal{J}_j$ then machine j is overloaded.

The criterion of the optimization was formulated as

$$\sum_{j=1}^{m} -Z_j = \sum_{j=1}^{m} \frac{-(H_j - \mathcal{J}_j)}{w_j H_j} \rightarrow min$$

for every j where $H_j < \mathcal{J}_j$. (2.2)

It is hardly possible to determine "a priori" fulfillment of the condition $H_j < \mathcal{J}_j$ so dp_aps_1 procedure is committing preliminary selection of machines.

3. Alternatives of the manufacturing process

The abovementioned assumption should be supplemented with additional ones, which will bring the issue closer to real conditions.

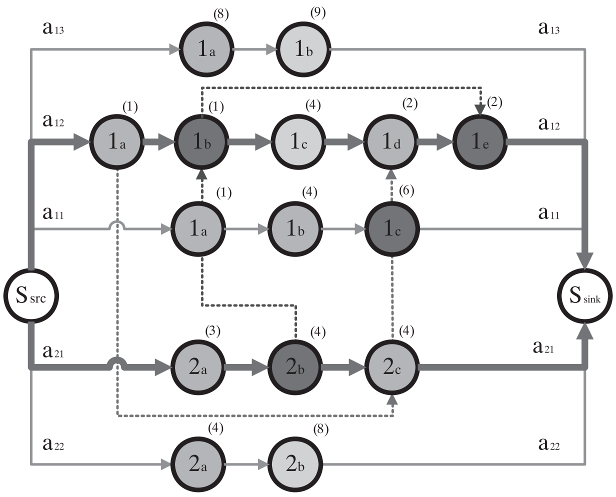

Fig. 1. Graph of the model solution for scheduling with alternatives of the manufacturing process.

The first assumption relates to alternatives of the manufacturing process. For some products and elements we possess a database of alternative itineraries. The itinerary of production process can basically be presented in the form of a graph. Every type of scheduling issue can be presented in the form of a disjunctive weighted graph in nodes. Let $G = \{N, A \cup E\}$ be such a graph. N – set of apexes, A – set of conjunctive arcs (edges), E – set of disjunctive arcs. Every operation w_{xy} represented by the apex of a graph is performed by a given machine within the period of time defined by the weight of the apex by which it is represented. Additionally two apparent apexes (operations) were introduced: the source - S_{src} - direct predecessor of the first operation of every task and the outlet $S_{\sin k}$ - direct follower of the last operation of every task, whose weight equal zero. Order limitations between operations are represented by conjunctive arcs from set A. Numbers in brackets by the apexes represent the duration of the operation. For every operation there is an arc leading from it directly to the subsequent operation.

For every operation w_{ik} there is an arc leading from it directly to the subsequent operation $w_{i(k+1)}$. Additionally there also exist conjunctive arcs leading from the apparent operation of the source - S_{src} to the first operations of every task. The operation arc w_{ab} to operations w_{cd} represents the requirement of the operation to be finished before starting operation w_{cd}. From the practical point of view the abovementioned issue was broadened by alternatives of production process. Each task J_i is possible to be performed in alternative production processes. Task J_{ia} is a sequence $an(i)$ of operations $\{w_{ik}\}_{k=1}^{an(i)}$, for alternative $a(l)$, whose arrangement (order) is defined by a set of limitations usually described using a graph. Single performance of a task J_i in alternative a is enough for the task J_i to be performed. In the example (see Fig. 1) for the task J_i there are 3 variants a_{11}, a_{12}, a_{13} of the production process and for the task J_2 there are 2 variants a_{21}, a_{22}. The number of possible solutions of scheduling is growing dramatically. Model solution (see Fig. 1) is based on choosing the alternative a_{12} for task J_1 and a_{21} for task J_2. The schedule for the machines' tasks is as follows:

$M1 : \{1a \longrightarrow 2c \longrightarrow 1d\}'$ $M2 : \{2a\}'$
$M3 : \{2b \longrightarrow 1b \longrightarrow 1e\}'$ $M4 : \{1c\}^{\cdot}$

Practically the number of alternatives is unlimited. In principle we can define the optimal variant in statistical terms (e.g. – without taking into account the availability of machines or the influence of this variant on other processes). The criterion of choice of this variant in statistical sense is usually costly but a large-area analysis can also be conducted. The main variant – optimal in the statistical sense, will play crucial part in searching for a global optimal solution. The phrase “searching for” is the key one here since finding such a solution in case of N^P hard problem is rather a chance event.

4. Solutions already used

There exist many algorithms used to solve problems of arranging tasks (scheduling), which can be divided into two main groups: optimizing (accurate) and approximating (rough) [8]. The first group is algorithms guaranteeing finding an optimal solution. Practically speaking, while solving problems of bigger scale only approximating techniques are used, which do not guarantee finding an optimum but they require fewer resources and are faster. The main problem in approximating algorithms is “being stuck” in one of local extremes. The basic strength of this type of algorithms is finding acceptable, „good enough” solution. One of the main problems to be solved is the starting point determining the pace of reaching the aim function and the possibility of avoiding “being stuck” in the local extreme. The algorithm presented below can be also counted among approximating methods. This article is based on model of automated data collection for simulation [6] from ERP system [3]. This kind of problems is also solved using methods of engineering optimization [5].

5. Solution algorithm

The solution in the method above is based on assumptions of the Theory of Constraints formulated by dr Eliyahu M. Goldratt in business novel [2]. In the solution we will use those elements of the Theory of Constraints, which refer to a bottleneck [4]. Since the flow of material stream is limited by the flow in the bottleneck, the profit of a company directly correlates with this flow. The theory, simple in its essence, will be strengthened by mathematical device and computer data container of ERP-class data system.

Creating the algorithm (see Fig. 2) we focused on the bottleneck's work. The problem is however the fact that the bottleneck is moving, it appears periodically at some machines, while very seldom or never at others. In the first step of the algorithm we make standard backwards scheduling using the method without resources limitations. For production orders the work tasks have been originally generated in the variant described as the major one. It is usually the statistically optimal variant of the process. Assigning the reverse scheduling function to so prepared tasks allows us to perform tasks as late as possible. Limitless scheduling allows for identifying overloads of particular resources in specific periods of time. Additionally, the above method of scheduling enables calculating the normative length of the cycle - $\mathcal{F}_i^*$ and the sum of lengths of cycles being the basis for calculating – $\sum_{i=1}^{n} \mathcal{F}_i^*$, the rates $\mathcal{V}_i$ of the lengthening of production cycle calculated according to $\mathcal{V}_i = \frac{\mathcal{F}_i}{\mathcal{F}_i^*} \geq 1$, V_{max} – maximum of the lengthening of production cycle calculated according to $V_{max} = \max_{0 \leq i \leq n} \mathcal{V}_i$, $\bar{V}$ medium of the lengthening of production cycle calculated according to $\bar{V} = \frac{\sum_{i=1}^{n} \mathcal{F}_i}{\sum_{i=1}^{n} \mathcal{F}_i^*}$.

Since we only focus on critical resources of the whole range of tasks and from the resources we only pick up those for which the sum of tasks $\sum \mathcal{J}_k$ is greater than the accepted norm $\sum H_k$. The multiple overloads will remain under the relation (2.3). The problem to be solved is still the density of time axis division. Generally, we dispose of daily density, weekly density or monthly density. Assuming monthly density is burdened with too great an error. In the sum of a month there may not be any excess; there can however appear heaps in particular days and weeks. On the other hand, assuming daily accuracy seems to be exaggerated.

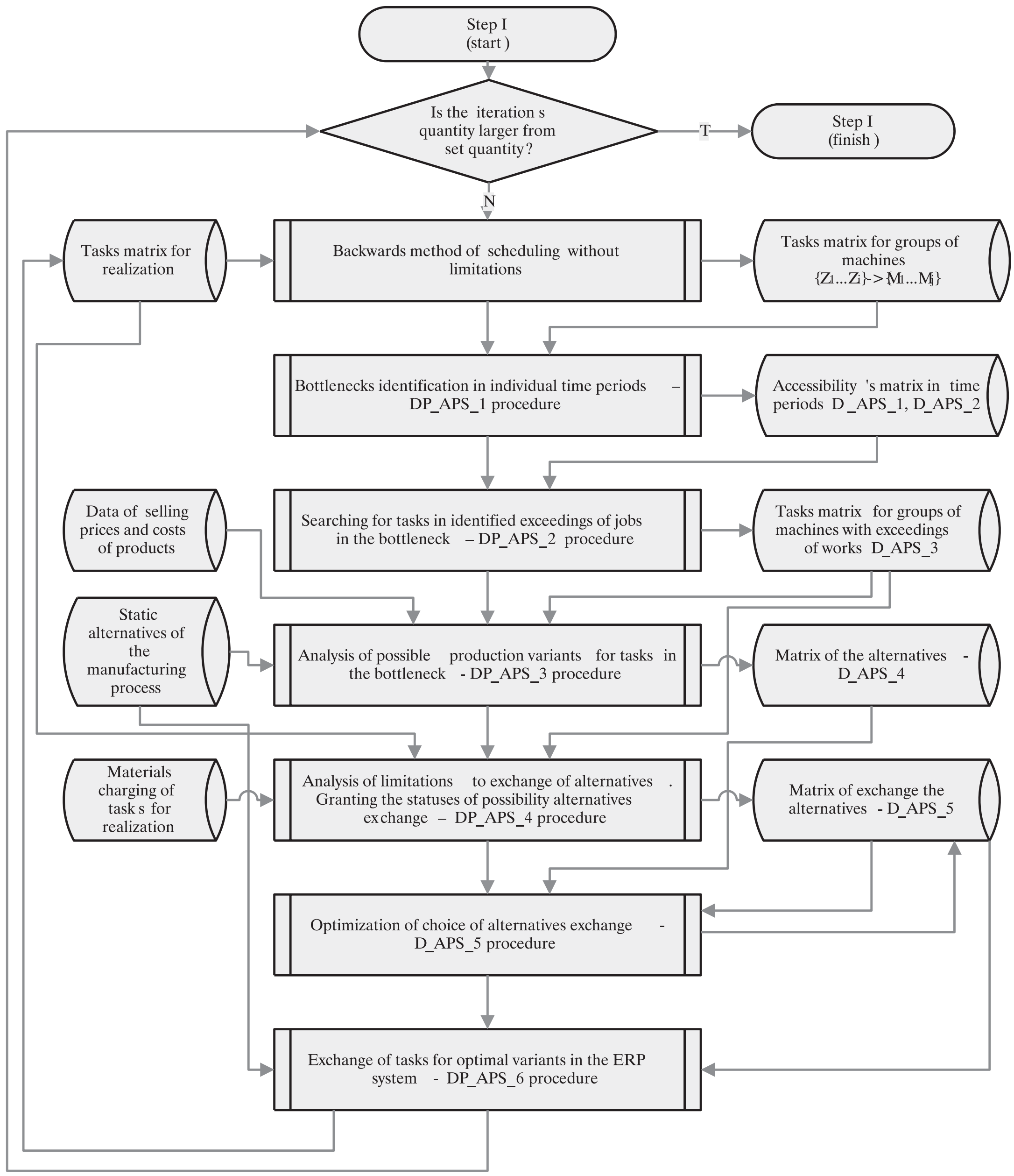

Fig. 2. General scheme of the optimization algorithm.

Optimization within daily plans should be left to solving in the next optimization phases. The above assumptions have been verified by production practice.

5.1. Bottlenecks identification – DP_APS_1 procedure

The operation of the procedure for bottleneck identification DP_APS_1 consists in assigning aggregated overloads to weekly ranges and groups of workstations. In the first step the availability of workstations is calculated on the basis of data of class ERP system. In class ERP system the availability of workstations, in other words job time fund follows from 3 basic attributes of workstations group: the number of workstations (machines), work calendar (working days, non-working days – planned renovations, failures, holidays etc.) and regulations of work scheme (1-shift, 2-shift, continuous work etc.). The aim of this step is to create the matrix H_{kt} of job fund H:{1,2,…n}x{1,2,…m} aggregated to particular weeks of job fund, where {1,2,…n} is a set of machines groups and {1,2,…m} is a set of numbers of week of the year. In the next step what is investigated is the sum $\sum \mathcal{J}_k$, of job intensity of particular terms ranges, in addition to which the terms of tasks performance follow directly from previously implemented scheduling function. In the next step we calculate the matrix of overloads PC while the element of matrix $pc_{kt} = (j_{kt} - h_{kt})$, where j_{kt} is the element of tasks matrix and a h_{kt} is the element of job fund matrix. The PC matrix is presented in D_APS_1 table. If $pc_{kt} > 0$ in order to speed up calculations the outcomes are written into a supporting table D_APS_2. In order to depict the functioning of the procedure, the achieved outcomes have been presented below (see Fig.3).

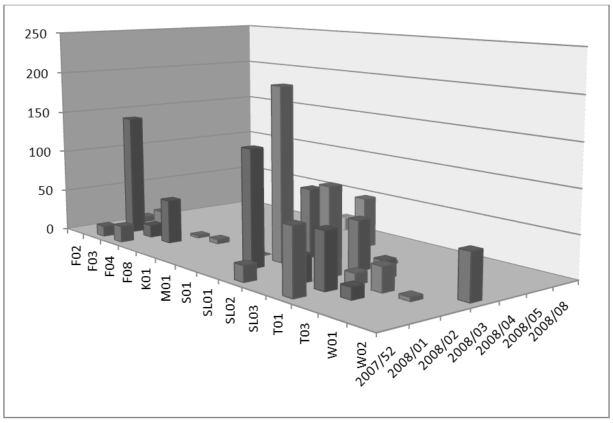

Fig.3. Graph of tasks' overloading in the week's period.

5.2. Searching for tasks from time ranges in the bottlenecks - DP_APS_2 procedure

The operation of the procedure for tasks searching in bottlenecks – DP_APS_2 consists in defining the area of possible exchanges of alternatives of production process. In order to do it, it is necessary to find all tasks {J_1, J_2, ..., J_n} for which operations {w_{ac}, w_{ik}, ..., w_{az}} in a weekly time range show overload $pc_{kt} > 0$. In order to speed up the calculations the outcomes are written down in the supporting table D_APS_3. Additionally, apart from the tasks list also the element code and number of units produced are searched for. The above information will be the input data to the procedure of searching for alternatives of a production process for the elements.

5.3. The analysis of possible production variants for tasks in the bottleneck - DP_APS_3 procedure.

BOTTLENECK	ELEMENTS	ALTERNATIVE	Tui	$\mathcal{J}_i$	ξ_i	QUANTITY
F02	2837-12120-4	1	32,995	1,750	18,854	5,000
F02	2837-12120-4	2	32,995	1,750	18,854	5,000
F03	0160 1063 00	1	600,717	58,000	10,357	24,000
F03	0160 1063 00	2	600,717	44,400	13,530	24,000
F03	0160 1063 00	3	600,717	44,400	13,530	24,000
F03	0322 2053 00	1	256,849	29,500	8,707	16,000
F03	0322 2053 00	2	256,849	17,200	14,933	16,000
F03	0863 1213 00	1	464,101	3,600	128,917	2,000
F03	0863 1213 00	2	464,101	3,600	128,917	2,000
F03	0863 1213 00	3	464,101	3,200	145,032	2,000
F03	0863 1213 00	4	464,101	2,800	165,751	2,000

Fig. 4. The rate of throughput per time of capacity constraint resources.

The operation of the procedure for tasks searching in bottlenecks – DP_APS_3 consists in the analysis of possibilities connected with the change of process variant into less overloading for the bottleneck. In order to do that it is necessary to build the matrix of possible solutions for elements from D_APS_3 matrix and for every a_i variant to calculate job intensity of a variant in the bottleneck and the rate of value stream flow through the bottleneck. The essence of the procedure is connected with the evaluation of value stream flow through the bottleneck. What was used in this case was the assumptions of Theory of Constraints connected with cost evaluation of the variant used to solving the traditional problem PQ [1]. We calculate the rate of throughput per time of capacity constraint resources (CCR)

$$\xi_k = \frac{Tu_i}{\mathcal{J}_i}, \quad \mathrm{Tu_i = P\text{-}TVC_i}, \tag{5.1}$$

where

P – price of product,
$\mathrm{TVC_i}$ – total variable cost in i variant. Total variable cost is calculating according to Throughput Accounting (TA) [1]. In this case, equals material purchase costs), J_i denotes job intensity of the bottleneck (CCR) in the i variant.

The higher this rate, the better is $\xi_{opt} = \max_{1 \le i \le n} \xi_i$. In analyzed cases there appeared in some variants the cases of lack of work of the bottleneck.

Then $\xi_k = \infty$, which means optimal variant from the point of view of capacity constraint resources (CCR) in the given time range (Fig. 4).

5.4. The analysis of limitations to exchange of alternatives for tasks matrix – DP_APS_4 procedure.

The operation of the procedure for searching of limitations to exchange of variant DP_APS_4 consists in the analysis of limitations connected with:

- limitation of availability of alternatives number,
- limitation of material charging,
- limitation of advancement elements performance for tasks.

In case of appearing limitations for task J_i the limitation status is calculated and written down in the alternatives exchange table D_APS_5.

5.5. Optimization of choice of alternatives exchange – DP_APS_5 procedure

The operation of the procedure of searching for optimization of choice of alternative exchange DP_APS_5 generally consists in searching through the set of possible solutions of D_APS_5 taking into account the limitations analyzed in procedure DP_APS_4 in connection with the demand for decreasing overloads of the bottleneck from the set D_APS_2. Optimization consists in arranging exchange variants according to the cost criterion of the rate of ξ_k values stream flow to the moment when demand for job intensity after exchange of variants > 0. Additionally, there follows the checking of next limitation relating to conformity of material demand in optimal variant with a variant so far appearing in task $\mathcal{J}_k$.

5.6. Exchange of tasks for optimal variants - DP_APS_6 procedure

schedule of tasks performance and exchange in the ERP system database of the tasks list into an optimal list according to the DP_APS_5 procedure and of outcomes saved in matrix D_APS_5 and D_APS_2. After conducting DP_APS_6 procedure we perform another iteration starting from scheduling with backwards method. In practical conditions, after undergoing three iterations there was neither improvement nor further decrease of overloads noticed.

6. Experimental research

The research was done on 6 enterprises marked A-G, of different production characteristics. Appropriate samples concerning production system were taken from the companies (Fig. 5.). Input data come from accumulated databases of the REKORD.ERP system.

6.1. Exemplary analysis of research outcomes – Sample B2.

The objective of examination of the second sample was to define both the degree of method's usefulness and

FIRMS		AMOUNT OF ORDERS	AMOUNT OF JOBS	AMOUNT OF TASKS	AMOUNT OF MACHINES	SUM OF THE TASKS' WORKING TIME (IN HOURS)	SUM OF THE CYCLES' LENGTH (IN DAYS)	SUM OF THE OVERLOADING (IN HUORS)	AMOUNT OF ELEMENTS
A	1	803	26729	116652	178	222174,24	62726,25	33062,42	10576
	2	821	27973	123003	179	231508,96	65697,86	33429,60	10828
	3	827	28017	121482	177	223398,92	66117,97	32335,44	11115
B	1	364	2195	19182	29	88361,93	11621,05	2490,52	1617
	2	356	2576	25616	30	115101,59	17210,21	4495,61	1717
C	1	466	5099	16318	38	29275,61	4505,45	1838,00	4101
	2	365	3976	14079	40	23747,51	6313,22	729,32	3140
D	1	1081	3008	18865	127	51296,30	62120,92	14044,83	1588
	2	834	2303	12820	125	32363,26	55673,33	7702,45	1445
E	1	1937	3468	11480	153	16967,56	1952,12	4879,67	2250
F	1	131	50102	59789	33	5870,15	764,67	417,00	2579
G	1	60	60	500	22	8891,48	940,35	0,00	59

Fig. 5. Input data for researches algorithm's usefulness.

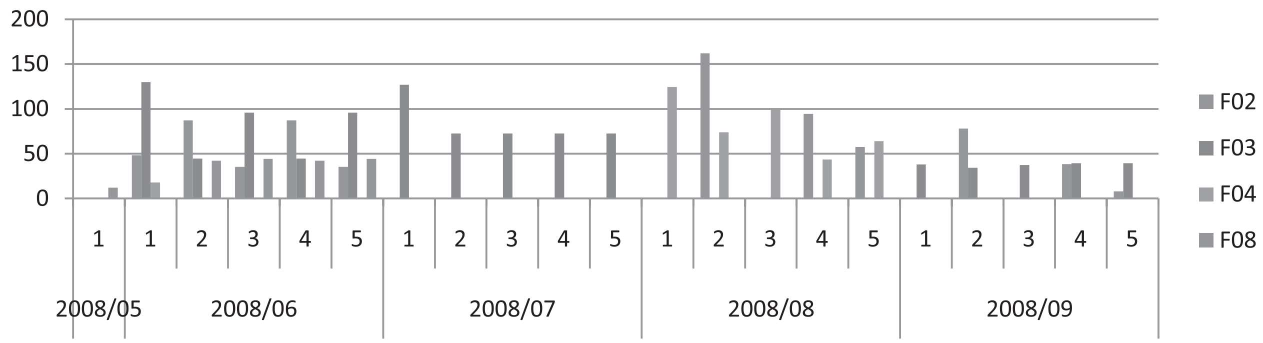

Fig. 6. Layout's graph of overloading after individual itera-tions in the period – in the B2 sample (F02,F04, F08 groups).

NUMBER OF THE ITERATION	AMOUNT OF ORDERS	AMOUNT OF JOBS	AMOUNT OF TASKS	AMOUNT OF MACHINES	SUM OF THE TASKS' WORKING TIME (IN HOURS)	SUM OF THE CYCLES' LENGTH (IN DAYS)	SUM OF THE OVERLOADING (IN HUORS)	AMOUNT OF ELEMENTS	AMOUNT OF ELEMENTS (I GROUP)	AMOUNT OF ELEMENTS (II GROUP)	AMOUNT OF ELEMENTS FOR EXCHANGE
1	356	2576	25616	30	115101,59	17210,21	4495,61	1717	5	1420	2755
2	352	2536	24527	30	107586,76	16280,19	3129,82	1695	12	383	2306
3	352	2526	24409	30	106729,51	16181,50	2683,65	1691	5	400	2395
4	352	2523	24385	30	106722,55	16193,80	2684,03	1688	11	232	2194
5	352	2523	24397	30	106735,14	16192,41	2648,64	1688	11	249	2315
6	352	2523	24384	30	106702,89	16190,84	2657,67	1688	9	248	2185
7	352	2523	24389	30	106608,51	16179,76	2582,47	1688	5	241	2301
8	352	2523	24392	30	106841,64	16203,76	2787,31	1688	11	293	2187
9	352	2523	24389	30	106594,04	16177,04	2580,07	1688	5	281	2308
10	352	2523	24383	30	106722,86	16193,81	2683,97	1688	12	251	2193

Fig. 7. Results of the optimization procedure operating in the B2 sample.

necessary number of iterations and to confirm the outcomes of sample 1 examination. In order to do that, 10 iterations in each sample were conducted. The phenomenon of bottlenecks moving was confirmed also in sample 2. In individual iterations, while exchanging variants, to unload the overloads in one place, in one group of machines, the system can move them to the other machines. Let us check the conduct of a group of millers. Presented below is the configuration of overloads on the weekly axis with details of overloads after each of key iterations (Fig. 6). Sample 2 was taken in the time of intensive growth of the order portfolio. It has a greater normative summary length of cycles, the number of tasks and job intensity in comparison with B1. The above relationship is a result of a production workshop assuming a bigger number of tasks in relation to its realizations in the preceding period. The number of orders has also increased together with the sum of overloads reaching the value of 4495,61 h. The number of groups of machines taking part in the operation plan has slightly increased (from 29 to 30). In the research 10 iterations were inducted.

As a result of procedures operation the number of orders changed (falling by 4). It is connected with choosing the variants of full cooperation.

The relations of the number of jobs change similarly to sample B1, deceasing by 50 items. The characteristic of tasks number in individual iterations also tends to decrease, while it also stabilizes at a certain level. The numbers of tasks after a rapid jump in the first iteration (sending tasks to cooperation) are gradually decreasing and stabilizing in subsequent routes. The characteristic of a rate, which is most interesting for us, has been shown above (Fig. 7). It behaves quite predictably and similarly to sample B1. After initial considerable decrease of the rate in the first three iterations the further decrease was observed not until iteration 6. The number of available variants does not allow for further decreasing of the rate, what is more, even in iterations from 4 to 10, the rate oscillates around a certain value (2700 h). In the later phase, while exchanging some variants into others the system only causes transfer of the overload form one bottleneck to the other, not contributing anything new.

As can be seen in this case using subsequent iterations (after 5) will not bring much profit but will only lengthen the time of calculations. The system starts „to vibrate" and the amplitude of "vibrations" of the system is running at around 100 h. In absolute numbers, the decrease of sum of overloads amounted to 1811,64 h, and in percentages it reached over 40% - while the maximum value was observed in iteration 9. The above result was reached using to the full the production process alternatives.

As a result of algorithm operation the summary job intensity also decreased together with summary length of cycles, while there can be observed oscillation around certain value.

Similarly to A1, A2, A3 the graphs have similar characteristics. Also the rate of company's preparation to working in alternative production processes looks similar to a B1. The above rate of relatively high values in absolute system, from around 1400 in the first route to 250 in routes 6-10 allows for a considerable reduction of overloads. It happens so thanks to great saturation with alternative variants the overload has improved by nearly 40%. It is worth noticing the fact of growth in the number of group 1 elements.

6.2. Repeating of the experimental research

After the period of 3 quarters of the year in selected enterprises experiment was repeated. DP_APS_1 procedure was used to three databases downloaded from the system ERP. A period of fifteen weeks was taken into consideration from 01.12.2008 to 16.03.2009.

After applying the procedure to all three bases (called F1, F2, F3), resources being bottlenecks were identified. Received results were presented on the graphs (Fig. 8, Fig. 9, Fig 10).

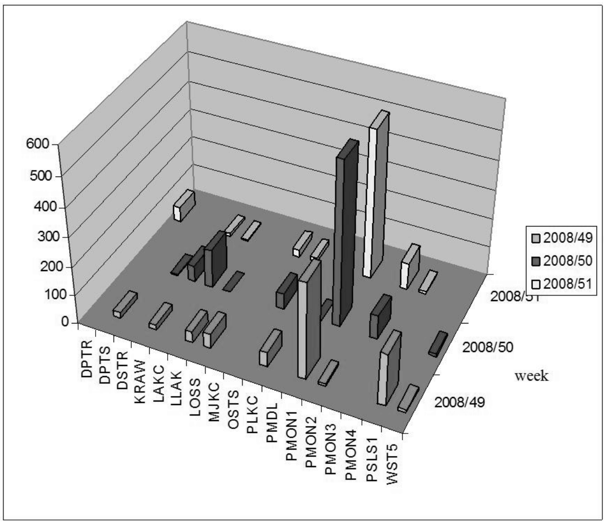

Fig. 8. Moving bottlenecks in F1 sample.

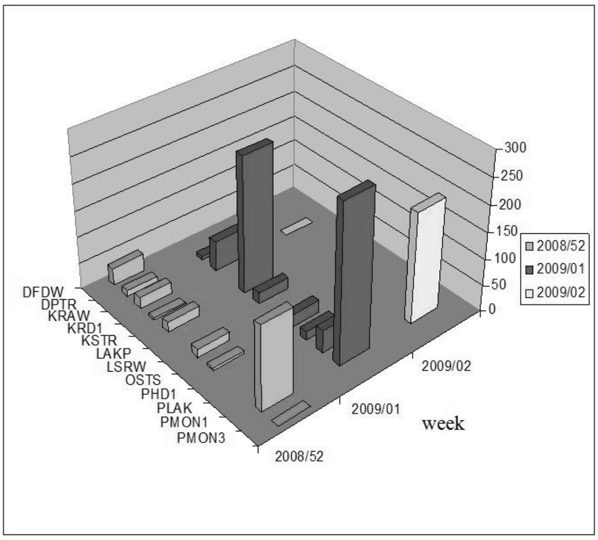

Fig. 9. Moving bottlenecks in F2 sample.

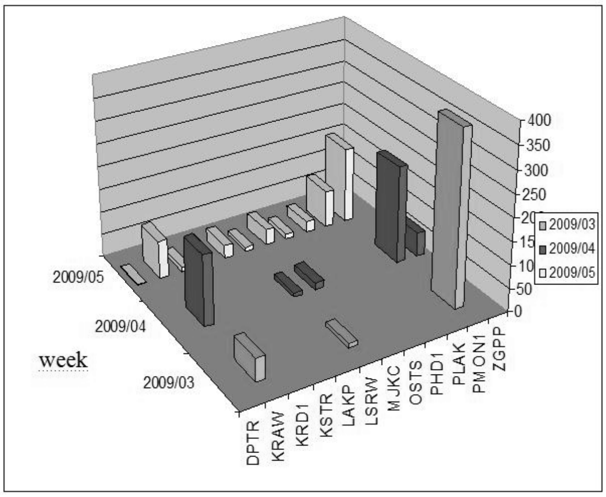

Fig. 10. Moving bottlenecks in F3 sample.

Next results from all three bases were compared between themselves. It turned out that bottlenecks were appearing in all bases, and their disintegration developed similarly. In every of bases it was possible to observe how critical resources are changing in time periods. In all three cases chronic bottlenecks, i.e. being stores overloaded by the entire analyzed period appeared. Also swimming bottlenecks were observed. It was easier for graphs made out to observe the thanks, as „are moving" critical stores. They are turning up at one week in order to disappear in consecutive and then again are returning in the next week. In every base there were resources, which turned out to be limitations only in one or in two weeks. Only difference, which is appearing between, bases F1, F2 and F3 it is a size of overloading on some positions. Stated the structure of all bases were similar.

6.3. Summary of the experimental research results

Summary of the experimental research was shown below (Fig. 11).

While examining the above enterprises it has been found that:

- Among examined companies the usefulness of the above method is visible in companies, which have, for a long time been using alternative processes in which the attained decrease of overloads reaches 60%.
- Efficiency of the above method does not cause problems in practical implementation.
- In case of companies with elaborate products structures usefulness is particularly visible.
- In companies which lack overloads (G1) using of the method is groundless.
- Repeating experiment confirmed previous examinations.

There exists the whole range of companies not prepared for using this method (e.g. sample F).

7. Conclusion

In research papers there can be found descriptions of many test problems of tasks ordering. It is difficult to find an example of a problem solved in real conditions of such a number of tasks and job resources. Therefore, the author has presented the analysis of the problem of tasks ordering on real data in a broad spectrum of many production companies. The author's aim is not to prove superiority of this method over others.

The task was to state usefulness of the method of process alternatives exchange in real conditions. The results below refer to states before optimization and after its application. Providing the above results helped to define the rim conditions of companies in which usefulness of this method is sufficient. Heuristic algorithms cannot be proven using mathematical methods. A number of tests on real data have been carried out to prove this method. What is new in that approach? Considerable an advantage of the method is automated data collection for simulation in conditions of unit and small batch production. In conditions of unit and small batch production collection is an extremely time consuming process predominantly because the task is manually orientated. Hence, automating process of data collection would be extremely advantageous. This paper presents one of examples how simulation could utilize the ERP system as the simulation data source. It may be one of steps for Digital Factory creating [9].

FIRMS AND SAMPLES		SUMMARY OF THE OVERLOADING (START OF OPTIMIZATION)	SUMMARY OF THE OVERLOADING (FINISH OF OPTIMIZATION)	SIZE OF REDUCED OVERLOADING (IN HOURS)	SIZE OF REDUCED OVERLOADING (IN PERCENT)	AMOUNT OF ELEMENTS FOR EXCHANGE	SUMMARY OF REDUCED THE CYCLES' LENGTH (IN DAYS)	SUMMARY OF THE REDUCED WORKING TIME (IN HOURS)	TOTAL OPERATING TIME
A	1	33062,42	30095,82	2966,60	8,97	10634	809,31	4469,70	2:17:26
	2	33429,60	31334,17	2095,43	6,27	10185	610,16	3222,19	2:15:44
	3	32335,44	30405,81	1929,63	5,97	9136	593,41	3017,13	2:14:11
B	1	2490,52	1885,23	605,29	24,3	870	797,64	5287,23	0:27:52
	2	4495,61	2580,07	1915,54	42,6	1425	1033,17	8507,55	0:33:46
C	1	1838,00	732,27	1105,73	60,1	4	12,12	62,95	0:26:16
	2	729,32	721,36	7,96	1,09	6	10,62	1,13	0:28:39
D	1	14044,83	13449,53	595,30	4,24	3933	203,74	1175,34	0:38:59
	2	7702,45	7477,96	224,49	2,91	699	146,06	745,54	0:19:23
E	1	4879,67	4423,40	456,27	9,35	385	46,47	490,44	34:03,6
F	1	417,00	417,00	0,00	0,00	0,00	0,00	0,00	00:01,1
G	1	0,00	0,00	0,00	0,00	0,00	0,00	0,00	00:00,0

Fig. 11. Overall comparison of findings.

The concept of automatic data collection through an interface between the simulation model and ERP class system could not be a distant future. The above method can be called the simulation "on line". This method found application to the industrial scale, as extension of the ERP class system. It is a problem demanding separate consideration and further research.

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