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Provision of the required performance of technological processes on the basis of iterative directed enumeration

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Abstract. This article considers the problem to optimize technological processes via optimization of the material flows distribution. It demonstrates the possibility to solve the problem of optimizing the spatial forms of the material flows movement while eliminating several mutually influencing bottlenecks. It is shown that the unloading of the bottlenecks should be performed proportionally to their workload. The work proposes the procedures of iterative directed enumeration, which allows to minimize the cost of changing the values of the route matrix while ensuring the required performance. The simulation results prove the possibility to use coefficients that take into account the proportion of the bottleneck workloads in the iterative method of directed enumeration to obtain a gain in performance cost. The efficiency and practical significance of the scientific and methodological apparatus proposed in the work is confirmed by a methodological example.

1 Introduction

Automation of technological processes (TP) involves the management of internal and external resources of the production system (PS), taking into account restrictions. The goal is to optimize the spatial forms of the movement of material flows [1-5] in time and space, and to achieve the required performance [6-9].

Ensuring the required performance of the PS only by redistributing spatial forms of material flows between copies of the same type of resources without additional introduction of copies of certain types of resources into the system is considered in [4]. This is achieved by eliminating bottlenecks (BN) using the procedures of the main and mirror changes in the route matrix in the model of an open queuing network.

In practice, as a rule, PSs have several mutually influencing BNs [10-15]. Therefore, for cases of simultaneous elimination of several BNs, it is necessary to clarify the features of solving the problem of redistributing flows between copies of the same type of resources [4, 7]. Therefore, taking into account the mutual influence of simultaneously eliminated several BNs should additionally provide a gain both in the production system performance and in the its reconfiguration costs, and, as a result, in the price of performance.

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Thus, the development of a scientific and methodological apparatus for optimizing the spatial forms of the movement of material flows in TP, in cases of simultaneous elimination of several mutually influencing BNs, is relevant scientific and technical task.

The purpose of the article is to develop a scientific and methodological apparatus to solve the problem of optimizing the spatial forms of the movement of material flows while simultaneously eliminating several mutually influencing BNs.

To achieve this goal, it is necessary to do the following [16-17].

1) To formalize of the optimization problem.
2) To justify the method for solving the optimization problem.
3) To perform the simulation.

2 Formulation of the problem

Formulation of the problem of optimization of TP in a meaningful form is presented in [4]. "Initial data. The initial state of the TP is characterized by a set of resource types with several copies in each type. External load is the input for the TP. The interaction of elements during the system operation is known. Each element of the system is characterized by parameters reflecting its performance.

The optimization criterion is the minimum cost of transferring the TP from the initial state to the optimal state. Variable parameters are the parameters characterizing the interaction of elements. It is the change of these parameters that demands the flows redistribution. Limitations: performance after optimization should be no worse than required; distribution of flows is carried out between copies of resources of the same type. In addition to these limitations, there may be others, depending on the specific model and problem."

Formulation of the problem of optimization of TP in a formalized form is presented in [4] (expressions (1)–(3)).

3 Theoretical part

Justification of the method for solving the optimization problem. In the problem under consideration, the variable parameters are the elements of the routing matrix $q(i, j)$; $i = \overline{0, L}$, $j = \overline{0, L}$, where L is the number of the TP elements. The common space of variable parameters has ($L \times L$) parameters in general form, and each parameter can vary in a range corresponding to the restriction on changes of the elements of the route matrix (for technical and other reasons). At the same time, the solution of the optimization problem is reasonable for complex systems with L>10, when the number of options considered will be large (at least (L+1)×(L+1)×L). Therefore, in this case the use of the complete enumeration method is inefficient. So, in order to reduce the number of variables under consideration, it is reasonable to use the directed enumeration method [15]. To determine the enumeration direction, we can use an essential feature of the variable parameters, namely that all variable parameters are elements of a two-dimensional set (route matrix).

This feature determines the following properties [9, 18-19].

1) Each element of the set is uniquely specified by the row number and column number of the matrix, which are the reason to include the element in the list of the problem solution.
2) All elements of this matrix are interconnected, i.e. changing some parameters implies changing other parameters.

The possibility of taking into account these properties is shown in work [4], which defines the system elements: $r(i)$; $rq(i)$; $rl(i)$; $rz(i)$. By the numbers of these parameters the variable parameters (numbers of rows and columns) of the routing matrix can be selected to include them in the list of effective coordinates for solving the problem. The effectiveness of the coordinates is justified by the possibility of eliminating a BN by the minimum total number of changes in the elements of the route matrix [20]. Let us denote the effective coordinates of the directed enumeration method as follows:

$$X(i) = \{x1(i);\ x2\ (i);\ x3\ (i);\ x4(i)\}. \tag{1}$$

The elements of the four-dimensional vector of effective coordinates take the following values:

$$x1(i) = r(i);\ x2(i) = rq(i);\ x3(i) = rl(i);\ x4(i) = rz(i). \tag{2}$$

In accordance with the indicated effective coordinates, the changes in the values of the elements of the route matrix are carried out in the same way, see article [9]:

$$\begin{cases} q(x3(i), x1(i)) = q^*(x3(i), x1(i)) - \Delta 1; \\ q(x3(i), x2(i)) = q^*(x3(i), x2(i)) + \Delta 1, \end{cases} \tag{3}$$

where * - is the membership sign of the parameter value before changing its value;
$\Delta 1$ - is the value of the main change in the elements of the route matrix.

$$\begin{cases} q(x2(i), x3(i)) = q^*(x2(i), x3(i)) + \Delta 2; \\ q(x2(i), x4(i)) = q^*(x2(i), x4(i)) - \Delta 2, \end{cases} \tag{4}$$

where $\Delta 2$ is the value of the mirror change in the elements of the route matrix.

If, for example, for the efficiency of the redistribution of information flows in the TP, one more BN, namely element $r(k)$, is simultaneously considered, and, accordingly, elements $rq(k)$, $rl(k)$, $rz(k)$. This means that the main and mirror changes of the route matrix is simultaneously performed to unload the two BN in the TP $\{r(i), r(k)\}$. Accordingly, one more vector of effective coordinates is considered

$$X(k) = \{x1(k);\ x2\ (k);\ x3\ (k);\ x4(k)\}. \tag{5}$$

For three BNs, we have $\{r(i), r(k), r(j)\}$ and the third vector of effective coordinates

$$X(j) = \{x1(j);\ x2\ (j);\ x3\ (j);\ x4(j)\}. \tag{6}$$

Depending on the specific problem of optimizing the TP, a larger number of BNs can be considered. Thus, the determination of effective coordinates allows to change from complete enumeration to directed enumeration and answer the question: "What should be changed and in what direction (increase or decrease)?" But the question: "How much to change?" remains open.

When unloading several interdependent BNs at the same time, it is necessary to justify the values of the main and mirror changes in the elements of the route matrix ($\Delta 1$, $\Delta 2$). In the work [4] it was assumed that these values should be of the same order as the values of the routing matrix elements. But in this case, the result of unloading the BN may not be as significant as it could be. Indeed, it is possible to simply slip past the optimal result, and by a significant value. To prevent this, we need to apply the iterative method of directed enumeration, and the iteration step should be taken an order of magnitude less than the order of the route matrix values. Let us denote them as $DP1$, $DP2$ for the main and mirror changes of the route matrix respectively.

If there are several BNs in the TP, then these BNs are loaded differently. Therefore, the unloading of the BNs should performed in proportion (in accordance) with their workload, that is, using the adaptation coefficient $K_a(i)$, calculated for each BN. Then the iteration steps can be defined as follows:

$$\Delta 1 = DP1 \cdot K_a(i) \cdot n; \tag{7}$$

$$\Delta 2 = DP2 \cdot K_a(i) \cdot n, \tag{8}$$

where n is the number of the iteration performed.

As the value of $K_a(i)$ we can take the ratio of the workload of the considered BN to the workload of the most loaded BN (i.e., to the value of the workload with the maximal value among the workloads of all elements)

$$K_a(i) = \frac{p(i)}{\max\limits_{j=\underline{1,L}} p(j)}. \tag{9}$$

Therefore, for the most loaded BN $K_a(i) = 1.0$, and for the rest BNs $K_a(i) < 1.0$. The positive effect of the use of the adaptive coefficient is due to that all BNs exhaust the possibilities of their unloading at the same time. Otherwise, BNs exhaust these possibilities earlier than the most loaded BN does that, and the solution of the problem during an iteration slips past the optimal result. In addition, there is a gain not only in efficiency, but also in costs.

Let's illustrate this with a simple example. Let us consider a system that has three bottlenecks, and for the first BN $K_a(i) = 1.0$, for the second BN $K_a(i) = 0.9$, for the third BN $K_a(i) = 0.8$. The costs to perform the unloading of the first BN are b in arbitrary units (a.u.). These costs are proportional to changes in the values of the route matrix. The unloading of the BN is performed in two ways, the first option: without taking into account the adaptation coefficients, the second option: taking into account the adaptation coefficients.

It is required to compare, with other factors, including the number of iterations, being equal the relative gain in costs to perform unloading of the considered BNs of the system.

Solution. Let C_{BN1}, C_{BN2}, and C_{BN3} be the costs to perform the unloading of the first BN, second BN, and third BN, respectively. Then the following two options are possible.

The first option (without taking into account the adaptation coefficients, when $C_{\text{BN1}} = C_{\text{BN2}} = C_{\text{BN3}}$). If unloading one BN requires b a.u., then the costs to unload all three BNs for this option are:

$$C_1 = C_{\text{BN1}}+C_{\text{BN2}}+C_{\text{BN3}} = 3\ C_{\text{BN1}} = 3b \text{ a.u.}$$

The second option (taking into account the adaptation coefficients, i.e. when $C_{\text{BN1}} = b$ a.u.; $C_{\text{BN2}} = 0.9b$ a.u.; $C_{\text{BN3}} = 0.8b$ a.u.)

The costs to unload all three PAs according to the second option are:

$$C_1 = C_{\text{BN1}}+C_{\text{BN2}}+C_{\text{BN3}} = b+0{,}9b+0{,}8b = 2{,}7b \text{ a.u.}$$

Comparative analysis. The absolute gain consists:

$$\Delta C = C_1 - C_2 = 3b\text{-}2.7b = 0.3b \text{ a.u.}$$

The relative gain consists:

$$\delta_C = \frac{\Delta C}{C_1} \cdot 100\% = \frac{0,3b}{3b} \cdot 100\% = 10\% \cdot$$

4 Suggestions and results of implementation

4.1 Simulation results

Let us consider an example illustrating the practical feasibility and significance of the proposed approach.

Example. Let us consider a TP consisting of 15 elements (L=15). Source intensity is H0= 2 flow units/h. The system has 5 types of resources, 3 copies in each type of resources. The rest of the initial data are given in Table 1. Table 1 also shows the correspondence of the element number to one of the 5 resource types. The first type of resource includes elements: 1; 2; 3. The second type of resource includes elements: 4; 5; 6. The third type of resource includes elements: 7; 8; 9. The fourth type of resource includes elements: 10; 11; 12. The fifth type of resource includes elements: 13; 14; 15.

Values of steps of iterations (changes) of the route matrix: main DP1= 0.02; mirror DP2= 0.01.

Table 1. The initial data of the example

Resource type															
No. / Elem.	**Elements of the 1st resource type**			**Elements of the 2nd resource type**			**Elements of the 3rd resource type**			**Elements of the 4th resource type**			**Elements of the 5th resource type**		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
M(i) [flow un./h]	3.0	3.0	3.0	3.0	3.0	3.0	4.5	4.5	4.5	4.0	4.0	4.0	2.0	2.0	2.0
CB(i)	0.3	0.3	0.3	0.7	0.7	0.7	1.2	1.2	1.2	1.5	1.5	1.5	0.8	0.8	0.8
COA(i)	0.7	0.8	0.9	–	–	–	–	–	–	–	–	–	–	–	–

The initial routing matrix Q0 is represented in Table 2.

Table 2. Initial routing matrix q0

Resource types																
		Elements of the 1st resource type			**Elements of the 2nd resource type**			**Elements of the 3rd resource type**			**Elements of the 4th resource type**			**Elements of the 5th resource type**		
j / i	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0		0.25	0.20	0.55												

1	0.40				0.4			0.20								
2	0.30					0.5			0.20							
3	0.40						0.3			0.30						
4		0.30									0.70					
5			0.40									0.60				
6				0.50									0.50			
7		0.15		0.05							0.30			0.50		
8			0.25									0.35			0.40	
9				0.20									0.40			0.40
10					0.6			0.40								
11						0.5			0.50							
12							0.4	0.10		0.50						
13								1.00								
14									1.00							
15										1.00						

The costs are determined by the total changes in the elements of the routing matrix $\sum_{i=0}^{L}\sum_{j=0}^{L}|\Delta q(i,j)|$, so the cost function can be conventionally expressed by this value.

It is required to perform a comparative analysis of the possibilities to unload the bottlenecks available in the TP.

Solution. We determine the performance of the system based on the mathematical model given in [4, 7] and using the MS Excel program. The simulation allows to obtain the initial performance of the system, corresponding to the initial data of the example, being t_0 = 9.1446 s.

In accordance with [4] and the above expressions (1), (2), (5), (6) we have three BN: $r(i)$=3 with workload $p(3)$=0.8617; $r(k)$=9 with workload $p(9)$=0.6463; $r(j)$=13 with workload $p(13)$=0.6398.

The effective coordinates are $X(i)$ = {3, 2, 6, 5}, $X(k)$ = {9, 8, 12, 11}, $X(j)$ = {13, 14, 7, 8}. Values of adaptation coefficients are: $K_a(i)$ = 1.0; $K_a(k)$ = 0.75; $K_a(j)$= 0.7425.

The procedures for unloading the BN without taking into account the adaptation coefficients are shown in Fig.1.

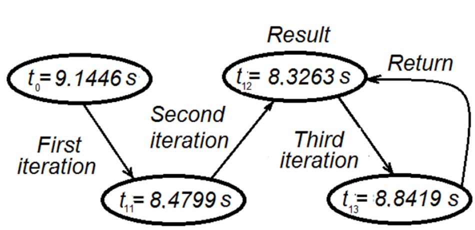

Fig. 1. Results of unloading bottlenecks without taking into account adaptation coefficients

The result is the value obtained in the second iteration t_{12} = 8.3263 s, while the third iteration does not provide a performance gain and is removed from consideration. Performance gain (latency decreasing) is:

$$\Delta t_1 = t_0 - t_{12} = 9.1446\text{ s} - 8.3263\text{ s} = 0.8183\text{ s}.$$

The cost of changing the values of the route matrix when unloading the three BNs is

$$C_1 = C_{BN1} + C_{BN2} + C_{BN3} = 3\, C_{BN1},$$

and for the case of unloading the BN without taking into account the adaptation coefficients $C_{BN1}=C_{BN2}=C_{BN3}$, so for a system in which m bottlenecks are considered, these costs in general form are as follows:

$$C_1 = (DP1\cdot 2 + \cdot DP2\cdot 2)\cdot n\cdot m,$$

where n is the number of iterations performed.

Multiplying $DP1$ and $DP2$ by "2" is due to the fact that direct and mirror changes in the route matrix change two probability values.

Therefore, for the given example

$$C_1 = (0.02\cdot 2 + \cdot 0.01\cdot 2)\cdot 2\cdot 3 = 0.36\text{a.u.}$$

The procedures for unloading the BN taking into account the adaptation coefficients are shown in Fig.2.

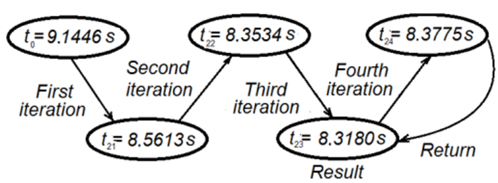

Fig.2. Results of unloading bottlenecks taking into account adaptation coefficients

The result is the value obtained in the third iteration t_{23} = 8.3263 s, while the fourth iteration does not provide a performance gain and is removed from consideration. Performance gain (latency decreasing) is:

$$\Delta t_1 = t_0 - t_{23} = 9.1446\text{ s} - 8.3180\text{ s} = 0.8266\text{ s}.$$

Taking into account the adaptation coefficients, the costs for the unloading of all three BNs take the form

$$\begin{aligned} C_2 &= C_{УМ1} + C_{УМ2} + C_{УМ3} = K_a(i)\cdot(DP1\cdot 2 + \cdot DP2\cdot 2)\cdot n + \\ &+ K_a(k)\cdot(DP1\cdot 2 + \cdot DP2\cdot 2)\cdot n + \\ &+ K_a(j)\cdot(DP1\cdot 2 + \cdot DP2\cdot 2)\cdot n = \\ &= 3\cdot(1.0 + 0.75 + 0.7425)\cdot(0.02\cdot 2 + 0.01\cdot 2) = 0.4787\text{a.u.} \end{aligned}$$

Let's perform a comparative analysis of the obtained results based on the indicator of the cost of changing a unit of performance

$$V_i = \frac{\Delta t_i}{C_i}, \qquad i\{1,2\}.$$

The cost of changing one unit of performance when unloading the BN without taking into account the coefficients of adaptation is

$$V_1 = \frac{\Delta t_1}{C_1} = \frac{0.8183}{0.36} = 2,2731\frac{\text{s}}{\text{a.u.}}.$$

The cost of changing one unit of performance when unloading the BN taking into account the coefficients of adaptation is

$$V_2 = \frac{\Delta t_2}{C_2} = \frac{0.8266}{0.4780} = 1.8422\frac{\text{s}}{\text{a.u.}}.$$

Let us estimate the gain of applying the proposed approach using the indicator of the relative change in the unit of performance when unloading the BN

$$\delta V = \frac{V_1 - V_2}{V_1}\cdot 100\% = \frac{2.2731 - 1.8422}{2.2731}\cdot 100\% = 18.96\%.$$

Thus, the use of coefficients that take into account the percentage of the bottleneck workloads for the iterative method of directed enumeration gives a performance gain of 18.96% with the initial data of the example.

5 Conclusions

1. It demonstrates the possibility to solve the problem of optimizing the spatial forms of the material flows movement while eliminating several mutually influencing bottlenecks.
2. The work proposes the procedures of iterative directed enumeration, which allows to minimize the cost of changing the values of the route matrix while ensuring the required performance.
3. The simulation results prove the possibility to use coefficients that take into account the proportion of the bottleneck workloads in the iterative method of directed enumeration to obtain a gain in performance cost.

References

1. N. V. Mokrova, *Methodology and results of mathematical modelling of complex technological processes*, IOP Conference Series: Materials Science and Engineering. Shanghai China 4th International Conference on Advanced Engineering and Technology (4th ICAET), **317**, 012038 (2017)
2. E. P. Kozlova, S. N. Kuznetsova, E. V. Romanovskaya, N. S. Andryashina, *Automation of technological processes in mechanical engineering*, IOP Conference Series: Materials Science and Engineering, **1111(1)**, 012030 (2021)

3. Y. Dong, Research on the application of computer technology in the design manufacture and automation of machinery, Journal of Physics: Conference Series. Dalian China First International Conference on Computer Applied Science and Information Technology (ICCASIT2020), **1574(1)**, 012070 (2020)
4. V. V. Evstafiev, N. V. Rudenko, *Provision of the Required Performance of Technological Processes on the Basis of Automation of Flows Redistribution*, Proceedings - International Ural Conference on Measurements, UralCon, 102–107 (2022)
5. W. Hong, L. Y. Ying, Application of intelligent control in industrial process control automation, Journal of Physics: Conference Series, **1617**, 012012 (2020)
6. K. Tokarev, *Mathematical modeling of technical and economic systems in agriculture*, IOP Conference Series: Earth and Environmental Science. Volgograd Russian Federationvol Mathematical modeling of technical and economic systems in agriculture III-2020, **786**, 011001 (2020)
7. V. V. Evstafiev, N. V. Rudenko, *Improving the dynamics of information flows for optimizing telecommunication systems*, IOP Conference Series: Materials Science and Engineering Rostov-on-Don Russia Dynamics of Technical Systems (DTS 2020), **1029**, 012131 (2020)
8. N. V. Vasilyeva, N. I. Koteleva, E. R. Fedorova, Real-time control data wrangling for development of mathematical control models of technological processe, Journal of Physics: Conference Series, **1015**, 032067 (2018)
9. C. Smansub, B. Purahong, P. Sithiyopasakul, C. Benjangkaprasert, A study of network bandwidth mana gement by using queue tree with per connection queue, Journal of Physics: Conference Series. Tokyo Japan 11th International Conference on Computer and Electrical Engineering, **1195**, 012019 (2018)
10. M. Siek, R. M. G. Mukti, *Business process mining from e-commerce event web logs: Conformance checking and bottleneck identification*, IOP Conference Series: Earth and Environmental Science Jakarta Indonesia International Conference on Biospheric Harmony Advanced Research (ICOBAR 2020), **729**, 012133 (2020)
11. X. Li, Application research of power system automation based on electrical automation technology, Journal of Physics: Conference Series. China The 2nd International Conference on Computing and Data Science, **1881**, 022045 (2021)
12. I. V. Plotnikova, L. A. Redko, N. V. Chicherina, O. N. Efremova, S. G. Serebryakov, *Study of the technological process parameters basis on a mathematical model*, IOP Conf. Series Materials Science and Engin., **457(1)**, 012021 (2018)
13. A. Obukhov, M. Krasnyanskiy, M. Nikolyukin, *Mathematical modeling and optimization of adaptive information system*, IOP Conference Series: Materials Science and Engineering, **971**, 032062 (2020)
14. I. Subiantoro, Lukmandono, P. I. Santoso, H. C. Suroso, *The improvement of sea highway route by using parallel insertion and exhaustive search*, IOP Conference Series: Materials Science and Engineering Surabaya Indonesia The 2nd International Conference on Advanced Engineering and Technology (ICATECH 2020), **1010**, 012025 (2020)
15. L. Alekseeva, *Choice of mathematical models for technological process of glass rod drawing*, IOP Conference Series Earth and Environmental Science, **87(8)**, 082001 (2017)
16. G. P. Basharin, P. P. Bocharov and Y. A. Kogan, Analysis of queues in computing networks. Theory and methods of calculation, Moscow: Nauka, 336 (1989)

17. P. Yin, Application of artificial intelligence technology in electrical automation control, Journal of Physics: Conference Serie, **1915**, 042031 (2021)
18. I. A. Hasugian, Fernando and Supriadi, *Simulation of queuing system for customer service improvement: a case study*, IOP Conference Series: Materials Science and Engineering Batam Indonesia The 2020 International Conference on Information Technology and Engineering Management (ITEM 2020), **851(1)**, 012030 (2020)
19. Y. Pu, H. Xu, X. Nie, *Study on the bottleneck of urban rail transit station based on the operation safe ty*, IOP Conference Series: Materials Science and Engineering, **392(6)**, 062140 (2018)
20. W. C. Yang, W. J. Jun, G. Z. You, Properties of bottleneck on complex networks, Communications in Theoretical Physics, **55(4)**, 725 (2011)