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MODEL FOR TRANSPORT FLOW OPTIMISATION IN FLEXIBLE MANUFACTURING SYSTEM

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Summary. The articles describes a set of mathematical models to find the structure of transport flows in flexible manufacturing systems. It is shown that the suggested models can significantly increase performance of industrial systems. Fig. 3, Table. 4. sources 20.

Key words: flexible manufacturing system, transport flow, palettes, machine tools, assembly center, industrial robot, flexible assembly systems.

INTRODUCTION

The effectiveness of modern automated production systems (APS) is mostly determined by the efficiency of the transport system. The functioning process of APS is exposed to many influences that have a random nature. Furthermore, the degree of mutual influence of various subsystems APS is very high. These causes make little use to describe the functioning of the APS existing analytical methods [Krushevski, 1982,]. Unlike analytical models, simulation models allow to describe the work of APS more adequately. The use of simulation models allows the development of methods for assessing the impact assessment of the structure of transport flows on the effectiveness of APS work under the influence of numerous random factors that are random in nature. An increasing number of organizations are implementing Flexible Manufacturing Systems (FMS) to achieve competitive advantage [Talavage, 1999].

ANALYSIS OF PUBLICATIONS

Problems streamlining traffic flows were considered in many papers [Krushevski, 1982, Valkov, 1978]. There are many paper suggested different analytical method for defining optimal parameter of FMS. In [Solot, 2003] surveys the analytical methods that have been developed for optimizing the design of flexible manufacturing systems. A rough-cut analysis tool that quickly determines a few potential cost-effective designs at the initial design stage of FMS was presented in [Heungsoon, 2001]. The state-of-the-art research on flexible manufacturing systems (FMS) design and planning was described in [Kouvelis, 2001]. In [Vide, 1986] method for work flow optimization in an FMS to decrease requirements of secondary resources based on using a combination of static analysis and computer simulation, dynamic analysis have been developed. Set of mathematical models for solving vehicle routing problem was suggested in [Toth, 2002]. Different multi-criterion approaches to FMS scheduling problems have been described in [Gupta, 1991]. In [Pinot, 2007] was developed different solutions for jobs scheduling problem in flexible manufacturing systems. Set of problem concerning the operations aspect of FMS was reviwed in [Basneta, 1994]. In the process of operational management of APS is necessary to solve the problem, significantly different from the traditional, covered in papers [Lu, 2001, Qiao, 2002, Qiao, 2003]. The difference lies in the fact that APS is allowed simultaneous processing of products of various kinds. Problems for creating simulation models of FMS was discribed in [Felix, 2000, Ozdena, 1988, Park, 2005].

THE GOAL OF RESEACH

In here we propose the methods of searching a rational structure of transport flows APS.

In the basis of the developed method is a hybrid approach that combines simulation and analytical modeling. The effectiveness of the proposed approach is shown in the example of optimizing traffic flows in automated flexible assembly system. Proposed in this paper, the method allows to consider the influence of random factors on the functioning of the APS.

MAIN PART

Consider the functioning process of automated flexible assembly system (AFAS). Such systems are often used in the assembly of various instruments (pressure gauges, ammeters, etc.) [Heungsoon, 2001]. AFAS is a collection of units of main process device, combined into a single non-synchronous transporter system. As the main process device often use assembly centers (AC), built on the basis of industrial robots (IR), control-measuring machines. Non-synchronous transporter operates independently of the cycle of the major items of process device. Palettes (P), to which assembled appliances are being attached, are transported with the help of this transporter. Technological process of unit assembling starts with the installation of the unit case to the free P. Then in accordance with the established technological assembly routes the P is transported from one AC to another. Route of each P in the AFAS is defined by assembly process installed on the device. When choosing the route of a few ACs that can perform the requested operation, the AC which has the smallest load factor is selected. P is suited to the selected AC, and loaded on it with help of IR. If the AC is busy, the P stays on the transporter. In this case every next P stops when approaches the first, forming the line of P.

If the number of (P) caught in queue is more than the transporter can fit, then AC before which this queue was formed, will be blocked by this queue. It can not be loaded or unloaded until the clog is removed. As soon as the first P from a queue is loaded on the AC, the line disappears or moves up to the next P on the AC.

The functioning process of the AFAS is characterized by the following indicators: productivity, utilization level of basic technological equipment, loading diagram non-synchronous transporter, the average queue length of each AC, the average time P spends in each queue, the average time locked status of each AC, the matrix of the intensity of the traffic flows between different AC.

The formation of P queues reduces productivity of AFAS and utilization level of equipment. These numbers depend on many factors: the accidental loss of the equipment operability and its recovery; potential rerouting of P due to the changed situation in the operational process of the AFAS, the duration of technological operations.

A rational strategy for traffic flows management is to minimize losses from bursts of P's and AC's downtime. In order to search for a rational strategy of traffic flows management, AFAS are encouraged to use the method that combines advantages of analytical and simulation modeling. Analytical model of the functioning process of the AFAS is formulated in terms of integer linear programming problem [Kuznecov, 1980, Katta, 1983, Gartner, 2007]. At the present time, we have effective methods and standard software packages for computers developed for such tasks.

Simulation model of the AFAS (fig. 1) consists of software modules that simulate the interaction of real equipment. Initial data for the simulation is the number of AC (N), the nomenclature of K collected devices and technological processes of their assembly, the duration of technological operations and their distribution among the AC, the number of Ps, placement of the equipment along the non- synchronous transporter. The developed model allows the monitor to observe the process of functioning of the AFAS (P movement, the mechanism of P queues and blocking situations for each AC). At the request of the researcher information that characterizes the functioning of the AFAS in time is given in the form of tables, charts or diagrams.

One of the main indicators characterizing the operation of the AFAS, is a matrix of traffic between the AC:

$$\omega_{i,j}\ ,\ i,j=1,2\ldots N,\quad i\neq j,$$

where: N - the number of AC in the AFAS.

Under a stream of P is the average number of P sent from the i-th AC on the j-th unit time. Experiments with simulation model showed that at constant input data streams $\omega_{i,j}$ do not change. One of the main factors reducing productivity AFAS are the formation of P queues and blocking AC. On length of stay in P queues is significantly affected by the alignment along the AC non-synchronous transporter.

We introduce the variables $x_{i,j}$ $i,j=1,2..N$, $i\neq j$. $x_{i,j}$ is interpreted as the number of intermediate AC between the i-th and j-th AC in the direction of motion of non-synchronous transporter. These variables can take any integer values in the range from 0 to $N-2$.

The optimality criterion of traffic flows in the AFAS is proposed to use the losses associated with potential downtime P in the queues. In this case, the objective function can be written as follows:

$$\sum_{i=1}^{N}\sum_{j=1}^{N}\omega_{i,J}x_{i,j} \tag{1}$$

To ensure the effective functioning of the AFAS is required to find such $x_{i,j}$,for which the function (1) reaches a minimum . In this case, should be performed a number of limitations:

1. P with the i-th AC routed to any of the (*N-1*) AC;
2. The j-th AC P comes with any of *(N-1*) machines;
3. If the direction of movement of the conveyor between the i-th and j-th AC distribution relies *L* AC, then in the opposite direction (from the j-th AC to the i-th) should be placed (*N-L-2*) AC.

These restrictions can be written as follows:

$$\sum_{j=1}^{n}x_{i,j}=(N-1), \qquad i=1..N,\ i\neq j,$$

$$\sum_{i=1}^{N}x_{i,j}=(N-1), \qquad j=1..N,\ j\neq i.$$

$$x_{i,j}+x_{j,i}=(N-2), \qquad i=1..N,\ j=1..N,\ i\neq j.$$

To obtain the diagram we divide the last load transporter-making at a fixed number of M cells and for each cell we define the ratio of its use:

$$\eta_q=\frac{t_q}{T_{ц}}.100, \qquad q=1..M, \tag{2}$$

where: t_q - the total time during which the q-th cell transporter was P; T - time simulation of the AFAS.

The obtained values η_q, drawn on a graph is a diagram of the transporter loading (fig. 2). This diagram has a characteristic sawtooth shape. On the chart we can identify a number of specific fragments (fig. 2c), each of which η_q increases with the number cell *q*. The number of such fragments in the diagram load equal to the number of AC in the AFAS. H_i height of each peak is characterized by the total flow to the i-P to the AC, and the value of h_i - the average time of the blocked state of the *i*-th AC.

Experiments conducted with a simulation model of AC, showed that $h_1=h_2=\ldots=h_N=h$ increases overall system performance. Such equality is achieved by varying the distance between the loading positions of neighboring AC at constant values of H_i.

To achieve this equality, each fragment of the diagram is approximated by straight lines. Then, using the least squares method we obtain the equations of these lines. For a fixed length transporter obtain a system of *N +1* equations. Solving this system, we define a cell transporter, which should accommodate the loading position for each AC, the mean time, they blocked the state was roughly equal.

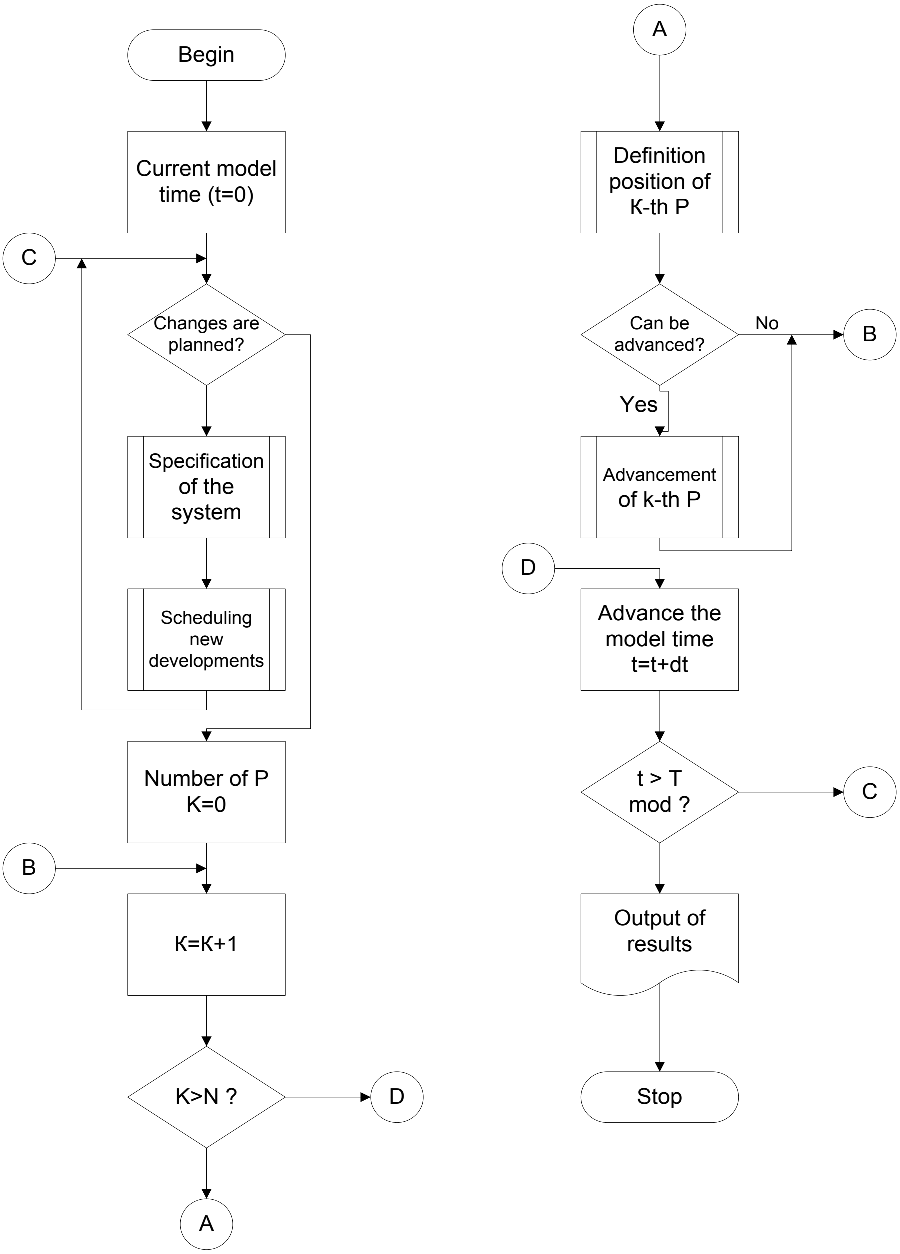
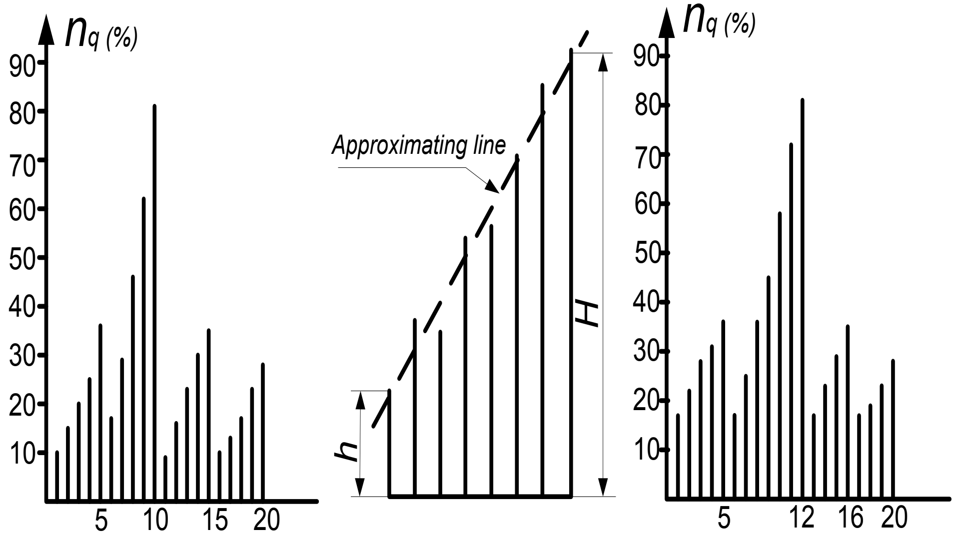


Fig.1. Block diagram of algorithm of simulation model AFAS

Example. In accordance with the following procedure is required to determine the placement of equipment in the AFAS assembly devices (fig. 3). In these production systems, the main technological equipment are AC that are based on highly functional industrial robots (IR). In consideration of the AFAS includes 4 AC, each of which carries four manufacturing operations. A total of AFAS runs 16 different manufacturing operations. In a production system produced 3 types of devices. Technological processes of assembly devices include 12 different types of manufacturing operations. From industrial experience it is known that the duration of each manufacturing operation can be regarded as a random variable distributed normally with mathematical forward 3 seconds and standard deviation - 1.5 sec. Table 1 shows the technological processes for assembly units.



a) according to equipment initial arrangement;

b) according to equipment final arrangement ;

c) loading diagram fragment.

Fig.2. Variants of transporter loading diagram

Table 1. **Technological processes of assembly device.**

Unit	**Technological operations**													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1	2	11	6	2	4	2	5	12	10	4	2	6	7
2	10	4	2	7	11	8	10	12	9	3	6	3	-	-
3	5	12	4	11	3	10	5	7	9	3	8	12	6	5

As for the assembly of devices of various types need 12 different types of transactions, all the AC in the AFAS can be configured to perform 16 types of manufacturing operations, the most common types of manufacturing operations are duplicated on multiple AC. Table 2 shows the distribution of manufacturing operations between the AC.

Table 2. **Distribution of manufacturing operations between the AC**

AC	**Technological operations**			
1	1	2	11	6
2	4	2	3	7
3	10	8	4	5
4	2	9	5	12

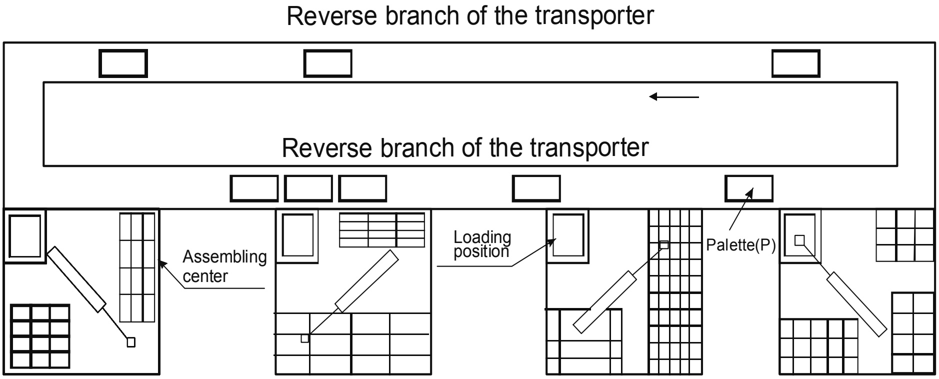


Fig. 3. Scheme of automated flexible assembly system (SSIA)

As a result of the experiments with simulation model AFAS we obtained matrix of flows Ps between the ACs (table 3).

Table 3. **Flows Ps between ACs in the AFAS**

		AC			
		1	2	3	4
AC	1	0	54	21	65
	2	78	0	66	174
	3	0	129	0	12
	4	54	139	54	0

From the analysis of the matrix flows implies that the initial placement of ACs along the transporter is not rational. The worst situation is dumping on a pair of ACs (i, j), which corresponds to the maximum term function (1). In this example, this applies to the AC № 3 and № 2, for which $\omega_{3,2}$= 129. When moving from AC № 3 to AC № 2, P can get into the two intermediate stages in AC № 4 and № 1.

We define rational arrangement of the equipment by minimizing adopted restrictions on expression:

$$54x_{1,2}+21x_{1,3}+65x_{1,4}+78x_{2,1}+66x_{2,3}+174x_{2,4}+$$

$$129x_{3,2}+12x_{3,4}+54x_{4,1}+139x_{4,2}+54x_{4,3}.$$

As a result of solving this problem by Gomory [Kuznecov, 1980], we obtain:

$$x_{1,2} = x_{2,4} = x_{3,1} = x_{4,3} = 0,$$

$$x_{1,4} = x_{2,3} = x_{3,2} = x_{4,1} = 1,$$

$$x_{1,3} = x_{2,1} = x_{3,4} = x_{4,2} = 2.$$

These variables correspond to the following arrangement AC 1-2-4-3. Retesting of simulation experiments yields the following matrix flows of the AC between P.

In our AFAS ACs are located only along the forward portion of the transporter (see fig. 3). To obtain the loading diagram this branch of the transporter is divided into 20 cells. Originally loading position AC were located in the cells 5, 10, 15 and 20. Under this option of AC arrangement the distance between the loading positions are the same and equal to 5 cells each. Since before the first AC there is the reverse branch of the transporter, then last, fourth AC can not be blocked by P queue. It is therefore necessary to determine the distance of the first and second, second and third, third and fourth AC. For this reason, counting should be carried out from the sixth cell ($M = 12$).

Table 4. **P flows between AC in the AFAS**

		AC			
		1	2	3	4
AC	1	0	119	72	48
	2	0	0	174	112
	3	143	69	0	54
	4	96	97	21	0

In our AFAS ACs are located only along the forward portion of the transporter (see fig. 3). To obtain the loading diagram this branch of the transporter is divided into 20 cells. Originally loading position AC were located in the cells 5, 10, 15 and 20. Under this option of AC arrangement the distance between the loading positions are the same and equal to 5 cells each. Since before the first AC there is the reverse branch of the transporter, then last, fourth AC can not be blocked by P queue. It is therefore necessary to determine the distance of the first and second, second and third, third and fourth AC. For this reason, counting should be carried out from the sixth cell ($M = 12$).

From the diagram loading transporter (fig. 2) follows that the AC № 1 was in a blocked state in average 2 times longer than the AC № 2 and № 3, because h_1 two times greater than h_2, and h_3 .. Using the method of least squares, we obtain the equations of the lines for the second, third and fourth fragments of diagram loading transporter, and then presented as in the above method of system of linear equations:

$$8.79y_1 + 65.1h = 0.3,$$

$$3.75(y_3 - y_2) + 23.5h = 0.4,$$

$$32(y_4 - y_3) + 26.3h = 0,$$

$$y_4 = 15$$

By solving this system of equations we received following results $y_2 = 7$, $y_3 = 11$, $y_4 = 15$ (relative to the first cell, $y_2 = 12$, $y_3 = 16$, $y_4 = 20$) $h = 12{,}2$.

To reduce the blocked state of AC loading position should be placed in a cell № 5, 12, 16, 20. Simulation experiments with the developed model show that the performance of the AFAS was increased by 12% under the new arrangement of the loading position. The loading diagram of the transporter for this equipment arrangement option is shown in fig. 2.b.

CONCLUSIONS

Problems of optimization transport flow in flexible manufacturing systems were described. Mathematical model for defining arrangement of assembly center along the transporter was developed. This model has effective solution method based on mathematical programming. Suggested algorithm can significantly improve performance of flexible assembly system. New kind of diagram for estimating of quality management transport system in FMS has been suggested. Such diagrams can be used for finding optimal strategy of transport system control. Numerical experiments were conducted on a real flexible assembly system to compare the performances of suggested models. The results show very good performance of developed models.

REFERENCES

1. Krushevski A.V., 1982.: Handbook on economic-mathematical model and methods(in Russian), Kiev: Technika, 1982.-207 p.
2. Valkov A.V., 1978.: Optimal machine-tools arrangement (in Russian).- Manufacturing Mechanisation and Automation , 1978, № 2, p.6-8.
3. Kuznecov J.N., Kuzubov V.I., Voloshenko A.B., 1980.: Mathematical Programming (in Russian).- M.: Vysshaja shkola, 1980. – 300 p.
4. Basneta C., Mizeb J. H. 1994.: Scheduling and control of flexible manufacturing systems: a critical review.- International Journal of Computer Integrated Manufacturing vol.7, pp 340 – 355.
5. Felix T. S., 2000.: The development of intelligent decision support tools to aid the design of flexible manufacturing systems.- International Journal of Production Economics.- vol. 65, num. 1, pp. 73-84.
6. Gartner B., 2007.: Understanding and Using Linear Programming.- Springer, 2007.- 226 p.
7. Gupta Y.P., Evans G. W., Gupta M. C., 1991.: A review of multi-criterion approaches to FMS scheduling problems.- International Journal of Production Economics vol. 22, pp. 13-31
8. Heungsoon F. L., Johnson R. V., 2001.: A line-balancing strategy for designing flexible assembly systems.- International Journal of Flexible Manufacturing Systems, 2001, vol. 2, num. 2, pp. 91-120.
9. Katta G. M., 1983.: Linear Programming.- N.Y., John Wiley & Sons, 1983.- 457 p.
10. Kouvelis P., 2001.: Design and planning problems in flexible manufacturing systems: a critical review.- International Journal of Flexible Manufacturing Systems, 2001, vol. 2, number 2, 75-90,
11. Lu R., Gross L., 2001.: Simulation Modeling of a Pull and Push Assemble-to-order System, The European Operational Research Conference, Rotterdam, The Netherlands

12. Ozdena M., 1988.: A simulation study of multiple-load-carrying automated guided vehicles in a flexible manufacturing system.- International Journal of Production Research, 1988, vol.26 , num. 8, 1988, pp. 1353 – 1366.
13. Park S.C., 2005.: A methodology for creating a virtual model for a flexible manufacturing system.- Computers in Industry, vol. 56, num 7, 2005, pp. 734-746.
14. Pinot G., Cardin, O., Mebarki, N., 2007.: Jobs scheduling problem in flexible manufacturing systems.- Man and Cybernetics. ISIC. IEEE International Conference: 7-10 Oct. 2007.- pp. 151 - 156
15. Qiao G., Lu R., Riddick F, 2003.: Flexible Modeling and Simulation for Mass Customization Manufacturing, Proceedings of the 2003 IIE Annual Conference, Portland, OR
16. Qiao G., McLean C., Riddick F., 2002.: Simulation System Modeling for Mass Customization Manufacturing, Proceedings of the 2002 Winter Simulation Conference, San Diego, California
17. Solot P., van Vliet M., 2003.:Analytical models for FMS design optimization: A survey.- International Journal of Flexible Manufacturing Systems, 2003, Volume 6, Number 3, pp.209-233,
18. Talavage J., Hannam R.G., 1999.: Flexible manufacturing systems in practice: application, design and simulation, Marcel Dekker Inc., New York, 358.
19. Toth P., Vigo D., 2002.: The vehicle routing problem, Society for industrial and applied mathematics. Philadelphia.
20. Vide J. J., Cyr T. P. 1986.: FMS work flow optimization.- Summer Computer Simulation Conference; Reno; NV (USA); 28-30 July 1986. pp. 705-710.

МОДЕЛЬ ДЛЯ ОПТИМИЗАЦИИ ТРАНСПОРТНЫХ ПОТОКОВ В ГИБКИХ ТРАНСПОРТНЫХ СИСТЕМАХ

Олег Малахов, Марина Матвеева, Сергей Стоянченко

Аннотация. В статье предлагается ряд математических моделей для определения оптимальной структуры транспортных потоков в гибких производственных системах. Показано, что использование разработанных моделей в реальных условиях может значительно увеличить показатели производственных систем. Фиг. 3, таблиц. 4. источников 20.

Ключевые слова: гибкие производственные системы, транспортные потоки, палетты, металлорежущие станки, сборочные центры, промышленные роботы, гибкие сборочные системы.