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integrated production and transportation system; logistic costs;
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DECISION MAKING ON CARGO-FLOWS MANAGEMENT IN INTEGRATED PRODUCTION AND TRANSPORTATION SYSTEM

Summary. The problem of real time cargo-flows management in the integrated production and transportation system on example of machine-building enterprise is viewed optimal number of order cards in production and transportation system, which provides reduction in logistic costs. The building approach of membership function of linguistic terms, which characterize work-in-process level and waiting time, based on deterministic stock management model and queuing system is proposed.

ПРИНЯТИЕ РЕШЕНИЙ ПО УПРАВЛЕНИЮ ГРУЗОПОТОКАМИ В ПРОИЗВОДСТВЕННО-ТРАНСПОРТНОЙ СИСТЕМЕ

Аннотация. Рассмотрена проблема управления грузопотоками в производственно-транспортной системе в режиме реального времени на примере предприятия машиностроения. Разработана математическая модель принятия решений по управления грузопотоками, основанная на совместном применении теории нечетких множеств и теории вероятностей, позволяющая определять оптимальное количество карт-заказов, при котором логистические издержки в системе будут минимальными. Предложен подход к построению функций принадлежностей терм-множеств лингвистических переменных, характеризующих уровень запаса и время ожидания в системе, основанный на вероятностной модели управления запасами и теории систем массового обслуживания.

1. INTRODUCTION

The efficiency of integrated production and transportation system (PTS) of machine-building enterprise consists in logistic methods of material- flow management at all stages, from ordering spare parts and materials from the supplier to delivering to the buyer.

The peculiarities of internal transport processes of production and transportation system are closely interrelated with technological process, great cargo range, size and weight, short transportation distance, possibility of distant workshops location.

PTS exists and functions in conditions of external variable factors such as: updating offers depending on market demand; changing production volume; maintenance dysfunction, including terms of work-in-process delivery; improving finished product modification, which leads to production reorganization and replenishment.

The internal variable factors, which cause production failure, are: failure and breakdown of the main equipment; peripherals breakage; finished products and work-in-process defects; staff failure.

In the condition of existing environment of PTS functioning the main features and shortcomings of PTS management are: lack of communication between workshops, transportation and final assembly line; lack of quick decision-making in response to changes in production conditions. As a result, logistic costs in PTS such as high stock level, waiting time for loading and uploading operations in workshops grow.

To increase interaction and improve joint management of production and transportation processes in PTS, the scheme of material flow movement, which is controlled and visualized by means of order cards, was proposed and described in [16]. The offered scheme functioning is based on pull-type logistic systems in which the material flow movement is initiated by the last production stage.

Cargo flow is moved in standard batches, size is specified for all cargo types and depends on production conditions. One order card initiates movement for one batch.

After production, batches are stored at the production stage buffer with fixed capacity. At the next stage, there is storage space for one batch (Kanban-container), because batches accumulate at production stage and move to the next stage as needed.

There are three tools of material flow movement control: (1) set of cards; (2) electronic cards in form of electronic messages; (3) controlling board.

In an emergency, the production and transport workshops can correct daily plans by changing the number of order cards. For the successful functioning of the offered material flow movement scheme, it is necessary to develop models and algorithms of decision- making on optimal order cards number, which provides minimal logistic costs.

The authors consider the following logistic costs parameters: work-in-process level, waiting time of replenishment, waiting time of unit loading, waiting time of transportation units, percentage of served demand (PSD), percentage of immediately served demand (PISD), financial index of logistic costs etc. [5 - 7].

The decision making process in cargo- flow management is physically uncertain, connected to probabilistic nature of appearance of events, linguistically uncertain, resulting from paucity of information and knowledge [11].

Thus, the models, which take physical uncertainty into account, are based on queuing theory methods, robust optimization methods, Pareto optimization [4, 5, 17]. The main weakness of such models, based on logistic costs, is in the limited number of criteria identifying these costs.

In [1, 4, 17], logistic costs are represented as cost minimization function. The shortcoming of this approach is the impossibility of including qualitative indexes such us percentage of served demand (PSD), percentage of immediately served demand (PISD) to the model. Besides , monetary value of quantitative indexes such as work-in-process level, and waiting time are dependent not only on value of these indexes, but also on resource unit market price, so, the cost minimization-based decisions can quickly lose relevance.

Multicriteria problem of decision making in PTS cargo flow management has been solved by joint application of queuing theory and multicriteria decision making methods (MCDMM). Queuing theory was applied for modeling values of logistic costs indexes dependent on cargo flow volume and parameters., MCDMM, such as Analytic Hierarchy Process (AHP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), allowed to evaluate and select the best PTS cargo flow parameters [1, 3]. However, such approaches do not fully display the linguistic uncertainty of decision-making process.

Grounded on research of PTS cargo flows pattern, the PTS model is based on Continuous Time Markov Chains for decision making, initial data simulation was developed and described in [5, 14].

The linguistic uncertainty of decision making process is fully described by fuzzy logic theory [11, 13].

Fuzzy logic-based models solved the next PTS cargo flows management problems separately: production scheduling and rescheduling [8], lot sizing, inventory management [8, 9], lead- time estimation [10]. The optimal solutions for these problems contain conflicting goals. For example, work-in-process minimization leads to stock holding costs reduction, and reduces PTS stability at the same time; lot size reduction leads to stock holding costs minimization, but increases transportation costs; to reduce lead time, it is necessary to provide PTS stability by all resources available and reduce waiting time, including setup time. It is necessary to take into account conflicting goals in developing PTS decision support model of cargo flow management.

The aim of the paper is to develop decision support model of cargo flow management in order cards controlled pull-type PTS, which is grounded on joint application of queuing theory and fuzzy logic theory. Such approach will allow to manage all types of decision making uncertainty, and provide a real time cargo-flow management for logistic costs reduction.

2. MATHEMATICAL DESCRIPTION OF CARGO-FLOW MANAGEMENT MODEL

2.1. Task statement

The task of cargo flow modeling in PTS managed by order cards is stated as follows: there are sets of alternatives of order cards number $A=\{a_1,a_2,...,a_m\}$ and set of criteria $C=\{c_1,c_2,...,c_n\}$ for alternatives evaluation. As a criteria the underlisted indexes of logistic costs were chosen:

1. Work-in-process - WIP (c_1) is limited by capacity of inventory storage buffer and safety stock. In the described card -controlled material flow movement scheme, work-in-process quantity equals to number of batches.
2. Waiting time - WT (c_2) before loading cargo batch on the vehicle in production stage m.
3. Percentage of served demand – PSD (c_3) and percentage of immediately served demand – PISD. (c_4). Cargo movement between workshops flows in conditions of uncertainty. Probability of positive event outcome (delivering cargo batch in case of index c_3 and delivering cargo batch without waiting in case of index c_4) depends on such factors as readiness of production and transportation vehicles and changing the production capacity, etc.

The decision making of optimal order cards in PTS flows in conditions of linguistic uncertainty. Since human judgments, including preference, are often vague and cannot be expressed by exact numerical value, the application of fuzzy concepts in decision making is deemed to be relevant.

Mamdany's fuzzy inference method was chosen for the task solution. Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The structure of Mamdany's fuzzy inference is presented in fig. 1.

The criteria of alternatives evaluation are represented with linguistic variables whose values are given in linguistic terms. Linguistic terms can be intuitively easy to use in expressing the subjectiveness and/or qualitative impressions of a decision maker's assessment.

The initial data for fuzzy inference implementation are:
(1) values of internal linguistic variables which are criteria of alternatives evaluation - y,t_w,P_{sd},P_{isd}; (2) membership functions of terms of internal linguistic variables - $\mu(y),\mu(t_w),\mu(P_{sd}),\mu(P_{isd})$; (3) membership functions of terms of external linguistic variables, which summarize evaluation criteria - $\mu(LC)$; (3) rules base of fuzzy inference.

Before fuzzy inference, running the fuzzification should be done to take the inputs and determine the degree to which they belong for each of the appropriate fuzzy sets via membership functions. Fuzzification is obtaining the values of membership functions for all terms, for all internal linguistic variables - $\tilde{y},\widetilde{t_w},\widetilde{P_{sd}},\widetilde{P_{isd}}$, which are used in preconditions of fuzzy inference rules base. General description of Mamdany's fuzzy inference is presented in 2.4.

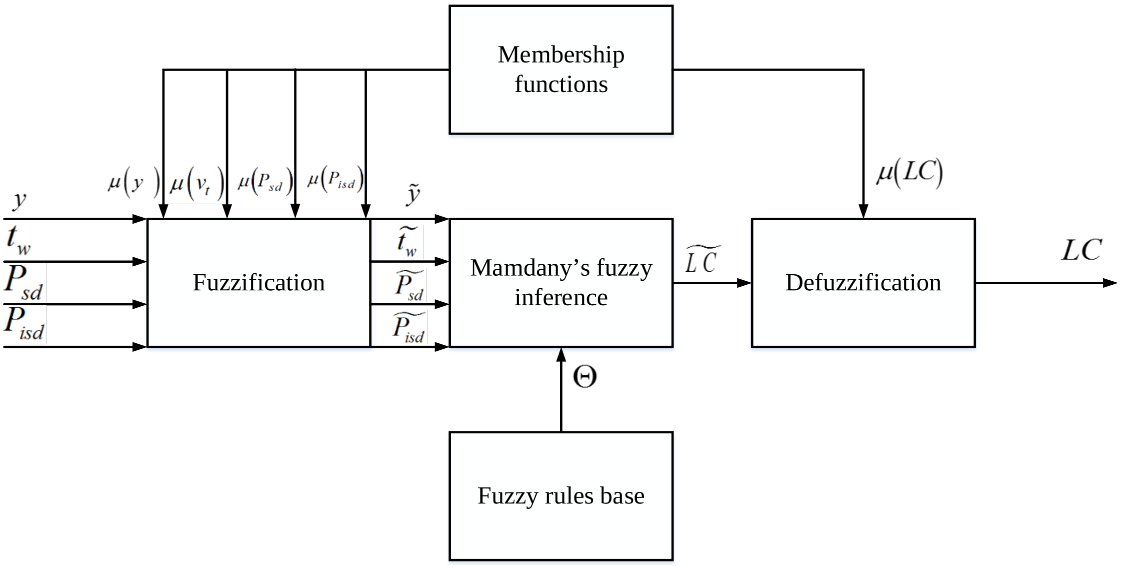

Fig. 1. The structure of Mamdany's fuzzy inference
Рис. 1. Структура нечеткого логического вывода Мамдани

2.2. Membership functions of terms of external and internal logistic variables setting

Membership functions of terms of internal and external linguistic variable are Gaussian [13]:

$$\mu(c) = \exp\left(-\frac{(u-b)^2}{2z^2}\right) \tag{1}$$

where: b - membership function center; z - membership function width; c - linguistic variable value;

Based on analysis of PTS functioning, an example of machine-building enterprise the approach to terms of linguistic variables membership functions setting was developed. These variables are:

- internal: "work-in-process" - c_1, "waiting time" - c_2, "percentage of served demand" - c_3, "percentage of immediately served demand" - c_4;
- external: "logistic costs" - v.

Membership functions of linguistic variables are based on five terms: very good (VG), good (G), satisfactory (S), bad (B), very bad (VB), and are set by two parameters: $\{b, z\}$. Membership functions of terms of linguistic variables are set based on analysis of machine- building enterprise functioning (Tab. 1).

Center of term function "very good" of linguistic variable "work-in-process" is fixed as safety stock level - $Q_{\min}$, which is necessary for continuous production process. Deterministic stock management model, which allows to define safety stock level, is described in [14]. Center of term function "satisfactory" of linguistic variable "work-in-process" is fixed at maximal allowed stock level, equal to inventory storage buffer capacity - $Q_{\max}$.

For terms membership functions of linguistic variable “waiting time,” the following explanations are necessary:

- the main condition is that demand flow intensity rate λ (a number of orders per time unit) should not exceed production rate μ (a number of products, produced per time unit). In case production will not satisfy demand; (1) $t_w \to 0$; (2)if $t_w \in \left[0\,;\frac{1}{\lambda}-\frac{1}{\mu}\right]$, waiting time will not be the result of a queue, even in safety stock absence;(3) if $t_w > \left(\frac{1}{\lambda}-\frac{1}{\mu}\right)$, in the event of safety stock absence, the queue will appear; (4) if $t_w \in \left(\frac{1}{\lambda}-\frac{1}{\mu};\left(\frac{1}{\lambda}-\frac{1}{\mu}\right)\cdot Q_{\min}\right)$, the queue will be eliminated at the expense of safety stock $Q_{\min}$ during time equals to $\left(\frac{1}{\lambda}-\frac{1}{\mu}\right)\cdot Q_{\min}$; (5) if $t_w \in \left(\frac{1}{\lambda}-\frac{1}{\mu};\left(\frac{1}{\lambda}-\frac{1}{\mu}\right)\cdot y\right)$, the queue will be eliminated only if work-in-process y will exceed safety stock $Q_{\min}$; (6) if $t_w > \left(\frac{1}{\lambda}-\frac{1}{\mu}\right)\cdot y$, then PTS will be in critical state because there will not be enough stock to eliminate the queue.

Based on terms described above, the terms of membership functions of the linguistic variable “waiting times” are set (Tab. 1).

Membership functions of terms of linguistic variables “percentage of served demand” and “percentage of immediately served demand” are set, based on experts’ evaluation. Parameters of membership function terms of external linguistic variable “logistic costs” are determined based on rating scale of qualitative indexes values (Tab. 2) [2].

Table 1

Parameters of terms of internal and external membership functions

Term	Membership function				
	$\mu(y)$	$\mu(v_t)$	$\mu(P_{sd})$	$\mu(P_{isd})$	$\mu(LC)$
VG	$\left\{Q_{\min};\ z_y\right\}$	$\left\{0;\ z_{v_t}\right\}$	$\left\{1;\ z_{P_{sd}}\right\}$	$\left\{1;\ z_{P_{isd}}\right\}$	$\left\{0;\ z_{LC}\right\}$
G	$\left\{\frac{Q_{\max}-Q_{\min}}{2};\ z_y\right\}$	$\left\{\frac{1}{\lambda}-\frac{1}{\mu};\ z_{v_t}\right\}$	$\left\{0,8;\ z_{P_{sd}}\right\}$	$\left\{0,8;\ z_{P_{isd}}\right\}$	$\left\{0,3;\ z_{LC}\right\}$
S	$\left\{Q_{\max};\ z_y\right\}$	$\left\{\left(\frac{1}{\lambda}-\frac{1}{\mu}\right)Q_{\min};\ z_{v_t}\right\}$	$\left\{0,6;\ z_{P_{sd}}\right\}$	$\left\{0,6;\ z_{P_{isd}}\right\}$	$\left\{0,5;\ z_{LC}\right\}$
B	$\left\{0;\ z_y\right\}$	$\left\{\left(\frac{1}{\lambda}-\frac{1}{\mu}\right)y;\ z_{v_t}\right\}$	$\left\{0,45;\ z_{P_{sd}}\right\}$	$\left\{0,4;\ z_{P_{isd}}\right\}$	$\left\{0,7;\ z_{LC}\right\}$
VB	$\left\{1;\ z_y\right\}$	$\left\{\left(\frac{1}{\lambda}-\frac{1}{\mu}\right)Q_{\max};\ z_{v_t}\right\}$	$\left\{0;\ z_{P_{sd}}\right\}$	$\left\{0;\ z_{P_{isd}}\right\}$	$\left\{1;\ z_{LC}\right\}$

Table 2

Rating scale of qualitative indexes values

Linguistic valuation	Linguistic variable value
Very good	1.00 - 0.80
Good	0.80 - 0.63
Satisfactory	0.63 - 0.37
Bad	0.37 - 0.20
Very bad	0.20 - 0.00

2.3. Rule base setting

Fuzzy inference rules base is based on fuzzy linguistic expression [13]:

$$\text{If } c_1 \text{ is } A_{c1} \text{ and } c_2 \text{ is } A_{c2} \text{ and } c_3 \text{ is } A_{c3} \text{ and } c_4 \text{ is } A_{c4},$$

$$\text{then } v \text{ is } B_v,$$

where: c_1, c_2, c_3, c_4, v - internal and external linguistic variables; $A_{c1}, A_{c2}, A_{c3}, A_{c4}, B_v$ - terms of linguistic variables;

A part of fuzzy rules base is in Tab. 3.

Table 3

Rules base of fuzzy inference

Rule number	c_1	c_2	c_3	c_4	v	Rule number	c_1	c_2	c_3	c_4	v
1	S	VB	VG	VB	B	21	G	VG	G	VG	G
2	S	B	VG	VB	B	22	G	G	G	VB	S
3	S	VB	G	VB	B	23	G	VG	S	VG	G
4	S	B	G	VB	B	24	G	G	S	VB	B
5	S	VB	S	VB	VB	25	VG	S	VG	VB	B
6	S	B	S	VB	VB	26	VG	G	VG	VB	S
7	G	VB	VG	VB	B	27	VG	S	G	VB	B
8	G	B	VG	VB	B	28	VG	G	G	VB	S
9	G	VB	G	VB	B	29	VG	S	S	VB	B
10	G	B	G	VB	B	30	VG	G	S	VB	B
11	G	VB	S	VB	S	31	VG	VG	G	VG	VG
12	G	B	S	VB	B	32	VG	VG	VG	VG	VG
13	G	S	VG	VB	S	33	VG	VG	S	VG	G
14	G	B	VG	VB	S	34	G	G	VG	G	G
15	G	S	G	VB	S	35	G	VG	VG	G	G
16	G	B	G	VB	S	36	G	G	G	G	G
17	G	S	S	VB	B	37	G	VG	G	G	G
18	G	B	S	VB	B	38	G	G	S	G	G
19	G	VG	VG	VG	VG	39	VG	G	VG	B	S
20	G	G	VG	VB	S	40	VG	VG	VG	B	G

2.4. Mamdany’s fuzzy inference

Mamdany’s fuzzy inference is carried out according to the knowledge base [13]:

$$(x_1 = \tilde{a}_{1j}\ \Theta_j\ x_2 = \tilde{a}_{2j}\ \Theta_j\ x_1 = \tilde{a}_{1j}\ \Theta_j ... \Theta_j\ x_n = \tilde{a}_{nj}) \Rightarrow q = \tilde{d}_j,\ j = \overline{1,m}, \tag{2}$$

Let us consider several definitions: $\mu_j(x_i)$ membership function of internal linguistic variables $x_i \in [\underline{x_i}, \overline{x_i}]$ to the fuzzy term $\tilde{a}_{ij}$ that is $\tilde{a}_{ij} = \int_{x\in[\underline{x_i},\, \overline{x_i}]} \mu_j(x_i)/x_i$.

where: $\mu_{d_j}(y)$ - membership function of external linguistic variables $d_i \in [\underline{d_i}, \overline{d_i}]$ to the fuzzy term $\tilde{d}_j$ than is $\tilde{d}_{ij} = \int_{y\in[\underline{y_i},\, \overline{y_i}]} \mu_j(y_i)/y_i$.

Θ_j - logical operator, $\Theta_j = AND$.

The degree to which the input vector $X^* = (x_1^*, x_2^*, ..., x_n^*)$ satisfy rule *j* is founded by equation:

$$\mu_j(X^*) = w_j(\mu_j\ (x_1^*) \wedge \mu_j\ (x_2^*) \wedge ... \wedge \mu_j(x_n^*)),\ j = \overline{1,m}, \tag{3}$$

where $\wedge$ means t-norm, because in rule j of rules base, the logical operator AND is applied ($\Theta_j = AND$).

The result of fuzzy inference is:

$$\tilde{q}^* = \left(\frac{\mu_1(X^*)}{\tilde{d}_1}, \frac{\mu_2(X^*)}{\tilde{d}_2}, ..., \frac{\mu_m(X^*)}{\tilde{d}_m} \right). \tag{4}$$

Fuzzy set carrier $\tilde{y}^*$ is the set of fuzzy terms $\{\tilde{d}_1, \tilde{d}_1, ..., \tilde{d}_m\}$. For conversion to the fuzzy set on the carrier $\left| \underline{q_i}, \overline{q_i} \right|$ aggregation and implication are applied.

The result of fuzzy inference for rule j is fuzzy value of external linguistic variable:

$$\tilde{d}_j^* = imp(\tilde{d}_j, \mu_j\ (X^*)),\ j = \overline{1,m}, \tag{5}$$

where imp – implication by minimum operator, or cutting membership function $\mu_j(X*)$:

$$\tilde{d}_j^* = \int_{q\in[\underline{q}, \overline{q}]} \min(\mu_j\ (X^*), \mu_{d_j}(q))/q\,. \tag{6}$$

The result of fuzzy inference is found by aggregation of fuzzy sets for all rules base:

$$\tilde{q}^* = agg\ (\tilde{d}_1^*, \tilde{d}_1^*, ..., \tilde{d}_m^*), \tag{7}$$

where agg – fuzzy sets aggregation by maximum operator.

Defuzzification is obtaining the crisp value of linguistic variable output, which corresponded to the input vector X^* by centroid method [13]:

$$q_d = \frac{\int_{\min}^{\max} q \cdot \mu(q)\, dq}{\int_{\min}^{\max} \mu(q)\, dq}, \tag{8}$$

where: q_d - the result of defuzzification; $\mu(q)$ - membership function of fuzzy set, which corresponded to external linguistic variable after aggregation; *min, max* – the left and the right points of fuzzy set carrier of external linguistic variable.

As the result, we get crisp value of external linguistic variable.

3. THE MODEL APPLICATION RESULTS

A numerical experiment was executed on simulation data of logistic indexes value for all possible number of order cards in PTS. For simulation, the TPS model based on continuous time Markov chain was developed and described in [14].

Initial data for Markov chain simulation are presented in tab.4. Simulation results and diagram of logistic costs values dependence on number of order cards are in Tab. 5 and Fig. 2.

Simulation was also used to obtain safety stock value and it is equal to $Q_{\min} = 2,46$.

Table 4

Initial data for Markov chain simulation

Parameter	Reference	Value
Demand flow intensity	λ	9
Order delivery intensity	μ	10
Traffic intensity	ρ	0,9
Possible number of orders	A	1-10
Inventory storage buffer capacity	$Q_{\max}$	4

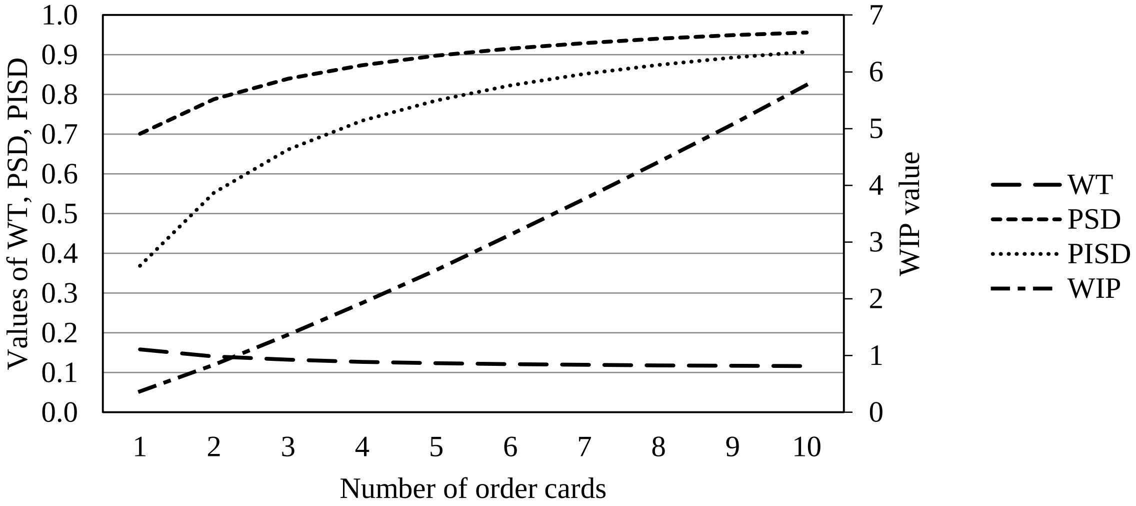

Fig. 2. Diagram of logistic costs values dependence on number of order cards

Рис. 2. График зависимости значений показателей, характеризующих логистические издержки от количества карт-заказов

Table 5

Values of logistic costs indexes

Index values	Orders number									
	1	2	3	4	5	6	7	8	9	10
y	0,37	0,84	1,37	1,93	2,51	3,13	3,76	4,41	5,08	5,77
t_w	0,016	0,014	0,013	0,013	0,012	0,012	0,012	0,0118	0,0117	0,0116
P_{sd}	0,701	0,788	0,840	0,874	0,898	0,916	0,930	0,941	0,949	0,956
P_{isd}	0,369	0,552	0,662	0,734	0,785	0,823	0,852	0,874	0,893	0,908

Cargo -flow management model was built and tested in Fuzzy Logic Toolbox (MATLAB).

Based on membership functions setting approach (Tab. 1), and simulation data of logistic costs indexes values, membership functions of internal and external linguistic variables were built. Parameters of membership functions terms are in Tab. 6 and diagrams at Fig. 3.

Fuzzy inference rule base is presented in Tab. 3.

Table 6

Membership functions parameters of linguistic variables

Membership function	Term				
	VG	G	S	B	VB
$\mu(y)$	(0,29; 2,46)	(0,25; 3,23)	(0,18; 4)	(0,31; 5)	(0,76; 0)
$\mu(t_w)$	(0,026; 0)	(0,026; 0,069)	(0,026; 0,077)	(0,056; 0,3)	(0,12; 0,69)
$\mu(P_{sd})$	(0,05; 1)	(0,05; 0,8)	(0,05; 0,6)	(0,05; 0,45)	(0,13; 0)
$\mu(P_{isd})$	(0,06; 1)	(0,06; 0,8)	(0,06; 0,6)	(0,06; 0,4)	(0,11; 0)
$\mu(LC)$	(0,08; 1)	(0,06; 0,7)	(0,06; 0,5)	(0,06; 0,3)	(0,07; 0)

The result of Mamdany’s fuzzy inference is values of external linguistic variables “logistic costs” for all alternatives of order cards number were obtained (Tab. 7, Fig. 4).

Table 7

Value of external variable “logistic costs”

Alternatives	1	2	3	4	5	6	7	8	9	10
LC	0,349	0,471	0,451	0,599	0,679	0,705	0,698	0,581	0,583	0,618

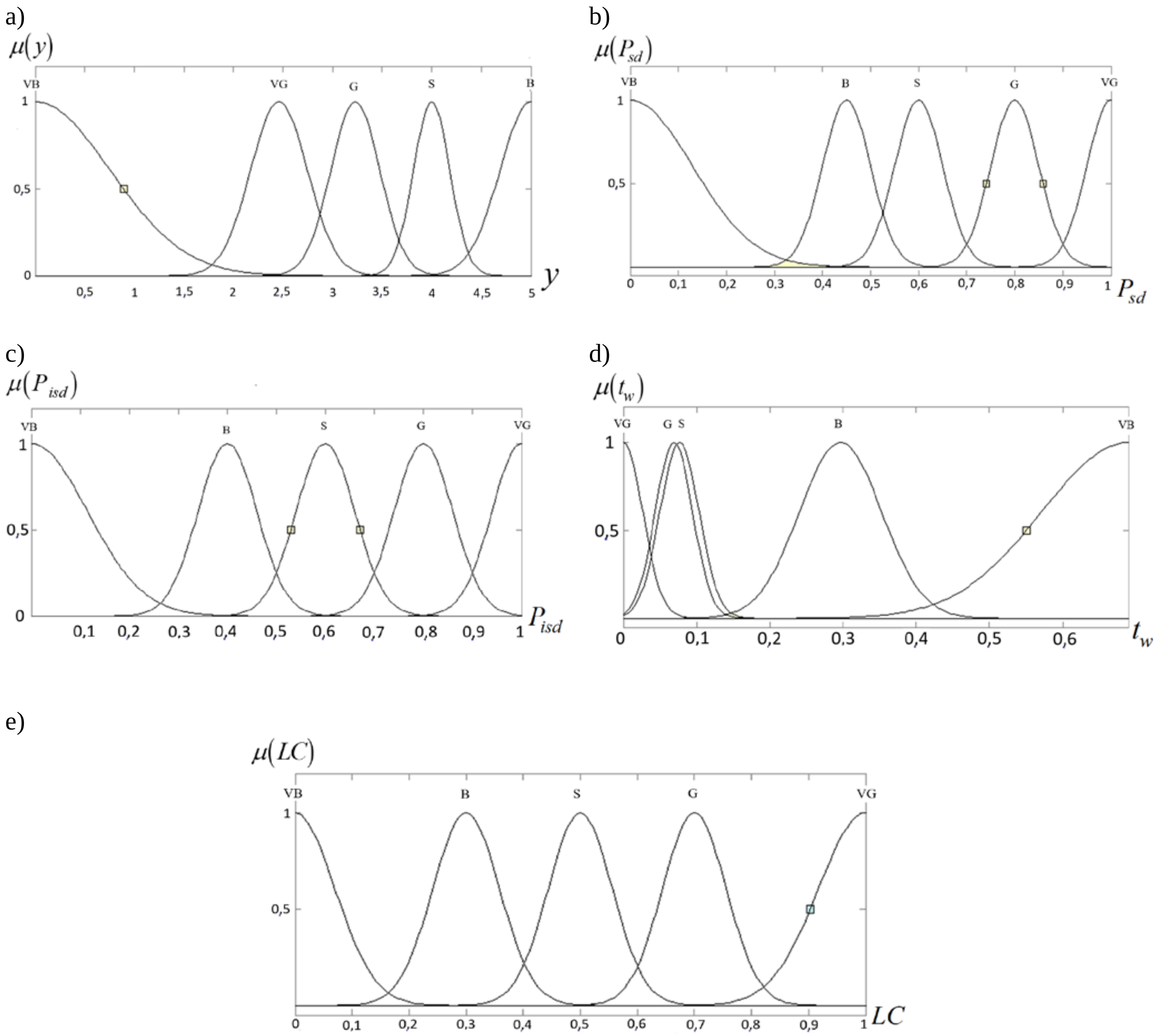

Fig. 3. Membership functions of linguistic variables terms: a) work-in-process; b) percentage of served demand; c) percentage of immediately served demand; d) waiting time; e) logistic costs

Рис. 3. Графики функции принадлежности термоввходных и выходной лингвистических переменных a) запас; b) вероятность обслуживания заявки; c) вероятность обслуживания заявки без ожидания; d) время ожидания; e) логистические затраты

As the criterion “Logistic costs” is negative, the best alternative is one with the maximum value of external linguistic variable “Logistic costs”. According to data obtained, the decision is that 6 order cards in PTS will provide minimal level of logistic costs.

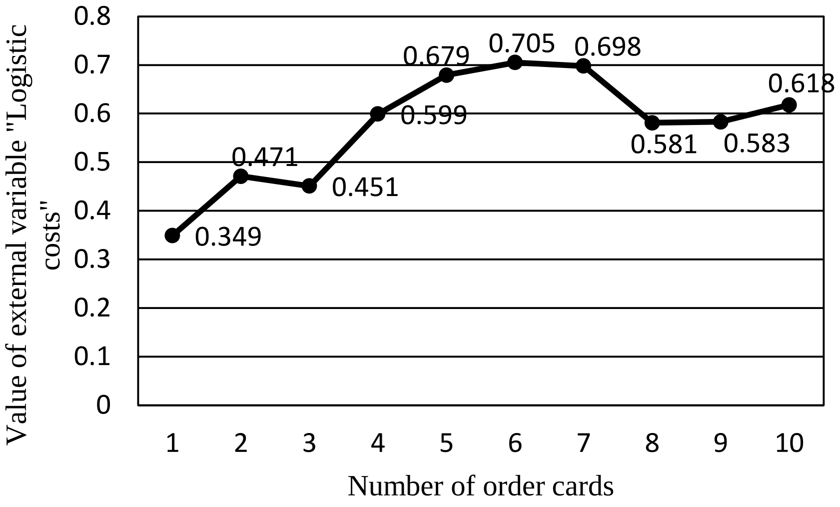

Fig. 4. Diagram of external variable value dependence on number of order cards
Рис. 4. График зависимости значений выходной лингвистической переменной от количества карт-заказов

4. CONCLUSIONS

The research has shown that the methods of efficient PTS management in the conditions of continuously changing internal and external environments are directed to increase the system adaptation to the dynamic condition for the production plans execution and minimization of logistic costs.

The decision making model of optimal order cards quantity has been developed, which will provide real time cargo -flow management and lead to minimization of the logistic costs in pull-type PTS. This model is based on joint application of probability theory and fuzzy logic theory, which takes into account physical and linguistic uncertainty of the decision making process. The intellectual decision support system, which is grounded on the developed decision making model, will increase promptness of pull-type PTS reaction on environment changes.

The proposed decision making model of PTS cargo flow-management differs from the existing approaches in the following ways: PTS logistic costs and stability criteria are included; the approach to membership function of linguistic terms “work-in-process” and “waiting time” building, based on deterministic stock management model and queuing system respectively.

Since the PTS functioning environment is dynamic for PTS cargo flow management decisions realization, the data on which the decisions were grounded, can change, so the decisions can become irrelevant. Further researches should aim to solve the problem of multicriteria decision making on cargo-flow management in PTS, applying robust optimization methods.

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