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A METHOD TO FORM CONTROL OVER QUEUING SYSTEMS TAKING INTO CONSIDERATION THE PROBABILISTIC CHARACTER OF DEMAND

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Системи масового обслуговування (СМО) відносяться до класу систем, якість управління яких не можна оцінювати в режимі реального часу. Тобто, на етапі формування управління неможливо використовувати методи класичної пошукової оптимізації.

Сформована практика формування управління передбачає збір ретроспективних даних, необхідних для моделювання операційного процесу з метою вибору оптимального значення управління шляхом визначення необхідних параметрів. До таких параметрів належать: вид моделі прогнозування, розмір горизонту планування, інтервалу прогнозування. Всі ці параметри є ступенями свободи пошукової оптимізації. Після визначення цих параметрів процес моделювання повторюється для різних значень зміщення прогнозного значення попиту в область більш великих позитивних значень. Таке зміщення призводить до підвищення рівня запасів СМО і зниження ймовірності виникнення дефіциту продукції.

Ефективність процесу знижують як страхові запаси, так і дефіцит продукції. Однак практика показала, що деякий зсув управління в сторону підвищення рівня запасів підвищує ефективність управління.

Завдання управління запасами СМО полягає в тому, щоб обґрунтувати вибір параметрів управління в процесі циклічного моделювання операційного процесу на безлічі ретроспективних даних.

Незважаючи на тривалу історію питання, на сьогодні не існує методу, використання якого дозволяє отримати управління, параметри якого можна вважати обґрунтованими. Це пов'язано з тим, що на початковому етапі оптимізації параметри управління визначаються не шляхом дослідження якості економічних моделей операційного процесу, а дослідженням якості кількісних моделей з використанням статистичних критеріїв.

З метою розвитку теорії і методів управління розроблена економічна модель неузгодженою операції. Запропонована модель враховує результат взаємодії процесів каналу буферизації з процесами клієнтського каналу задоволення споживчого попиту, фактора інформаційного впливу маркетингових технологій на внутрішнього і зовнішнього споживача.

Структура моделі операції пройшла процедуру валідації на предмет несуперечності в процесі порівняння надлишкових та дефіцитних операцій.

Процедура оціночної оптимізації процесу, що моделюється, показала можливість визначення оптимальних параметрів управління за критерієм максимуму показника ефективності операційного процесу

Ключові слова: оптимальне керування, прогнозування попиту, прогнозування, страховий запас, формула ефективності

1. Introduction

In order to achieve a competitive advantage in future, an organized structure must operate efficiently now [1]. This task is achieved by the introduction of new technological solutions, increased levels of automation [2], by addressing the challenges of structural optimization, reliability of equipment operation, and by changing a technology of control [3].

Solving this problem is most difficult in queueing systems (QS), whose basic function is the process of buffering. That relates to that the patterns in the functioning of a basic technological part are overlapped with the peculiarities in the functioning of client part of the system, represented in the form of a probabilistic nature of demand for the primary output product of the system.

The probabilistic nature of demand for a system's product is a common attribute of QS [4]. Therefore, queueing systems with a basic mechanism of buffering include most finite systems at industrial enterprises, which sell their products not on a contractual basis, as well as trade structures.

It is well known that under conditions of the probabilistic demand the stabilizing function belongs to stocks. However, the need for optimal inventory management is characteristic only of those types of QS where it is economically justified [5]. For instance, at transportation QS, issues of fuel stock or spare parts are typically handled by external QS, whose operations are based on the use of buffering mechanisms.

This paper considers this particular class of QS, within the framework of which processes related to consumer service are integrated to patterns in the buffering process of demanded products.

The process of stock formation is accompanied by tying up considerable resources of an enterprise. Surpluses and shortages of raw materials or finished products lead at best to a decrease in their effectiveness, and, in severe cases, to the enterprise bankruptcy [1].

In QS, inventory management becomes more complex due to the probabilistic character of demand for its products. Therefore, the process of control design includes a demand forecasting stage. However, existing demand-forecasting technologies do not satisfy experts. Specialists point out that "...at the stage of verification, a forecasting method, which produced the result, is estimated rather than the quality of the actual result. That relates to the fact that there is still no any effective approach to estimating quality of a forecast prior to its implementation" [6].

Paper [7] notes that professionals responsible for ultimate management results correct predictions because they do not trust them.

At the final stage of control design, a forecasted value for demand is shifted toward an increase in its value in order to reduce the negative impact of deficit and improve the efficiency of QS operational process. However, no solution that would satisfy professionals in addressing this challenge has been found so far.

Study [8] considers a practical experience in determining the level of an insurance stock. The results from studying the two popular procedures revealed a difference of 20 %. Consequently, the "economical" method was accepted, since the use of the "generous" procedure implied the construction of additional storage facilities.

Since it is obvious that those products that sell at a greater economic effect must have a higher coefficient of insurance stock, paper [9] recommended establishing, for less important products, a 50 % stock level relative to the projected level, and 100 % for significant ones.

The above examples show that certain issues in the theory of inventory management in queueing systems require further development, hence the improvement of control quality is an important scientific task.

2. Literature review and problem statement

The distinctive feature of optimization of queueing systems management is the need for a proactive response to a task function, which is probabilistic in character. Since the tasks on inventory management within QS were tackled long before the construction of a general control theory, this field has formed its own conceptual framework that operates many established concepts. These include "order" [9], "demand" [10], "inventory management" [11], "forecasting", "insurance stock", "planning horizon" [12].

Because the pipeline of orders or requirements within QS exhibits a probabilistic character [13], the optimization criterion used is the statistical indicators [14]. Paper [11] notes that the class of these indicators does not necessarily yield an adequate assessment of both the quality of forecasting [15] and the magnitude of an insurance stock [16].

It has been conventionally believed [17] that the smaller the deviation of the forecasted value for restocking from the actual level of demand, the better. Accordingly, to determine the optimal control, a quantitative model of operation is applied. Thus, if the volume of a batch of products for restocking is numerically equal to a value RQ, and the volume of the actually sold products is numerically equal to PQ, then the smaller the squared difference between RQ and PQ, the better the result from forecasting. In this case, the value for PQ is determined from expression

$$PQ = \int_{t_S}^{t_F} pq(t)\,\mathrm{d}t,$$

where t_S is the time an operation starts; t_F is the moment the operation finishes; $rq(t)$ is the signal that registers the input flow of products; $pq(t)$ is the signal that registers the output flow of products (Fig. 1).

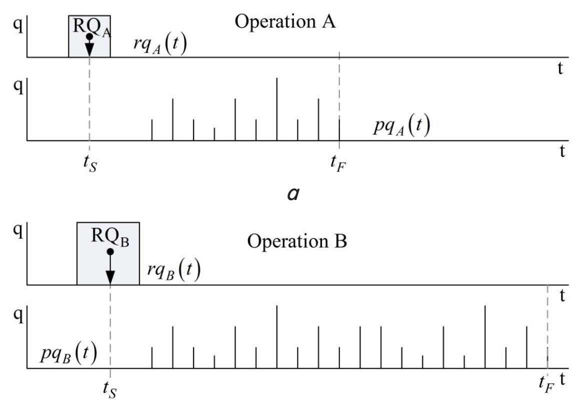

Fig. 1. Models of operations with different size of the input batches of products: model of operation with a smaller volume of input products (*a*); model of operation with a larger volume of input products (*b*)

Here, $pq_A(t)$, $pq_B(t)$ are the output functions of operations A and B in the form of volumes of sold products in the operation. The amplitude values for functions $rq_A(t)$ and $rq_B(t)$ are represented in the form of their integral assessments RQ_A and RQ_B.

Suppose that a study has shown that the choice of a smaller planning horizon leads to the greater magnitude of standard deviation. This means that rather than purchasing a batch the size of RQ_1, it is more profitable to purchase a larger batch of input products the size of RQ_2.

Suppose, however, that the accuracy of forecasting will increase by 2 %, and the size of the input batch should be increased by 2 times. This means that, most likely, the first option is more economically profitable, because at a slight increase in the amount of an insurance stock one would be able to significantly reduce the amount of finance and channel them to forming a parallel operation.

On the other hand, suppose that the statistical criterion has indicated the advantage of operation A. However, if the increased volume of the purchased batch could substantially reduce the unit cost of the input product, one may find that the second operation would be more efficient.

The above examples show that the criterion of optimization that should be used requires those indicators that are based on the economic components of the operation. However, the use of one or another economic indicator must also be justified by its verification.

This is exactly what typically occurs in practice when the results from control design that employ statistical criteria are adjusted using economic criteria. However, at the stage of statistical treatment, better options may have already been disregarded. In addition, the use of economic criteria does not warrant the best choice either.

To make a substantiated decision, one needs an adequate mathematical model of the examined object and the existence of a verified optimization criterion.

For example, a series of studies apply profit as an optimization criterion for inventory management systems [18, 19]. In this case, control at which a 5 % increase in profit is accompanied by a 20 % increase in costs will be considered to be the best control.

Similar problems will arise if the optimization criterion used is, for example, such a criterion as performance [20] or speed of service [21]. In technical systems, an increase in productivity leads to a disproportionate increase in the wear of equipment, and within QS it could lead to disproportionate growth of overall costs.

On the other hand, applying costs as the optimization criterion [22] may lead to a significant increase in the duration of an operation and/or reduce profits in the process when control seeks the point of minimum cost.

Paper [23] noted that any system or technological operation can be represented in the form of a quartet (RE, TO, PE, FE), where RE is the cost value of an operation's input products; TO is the operation duration; PE is the cost value of an operation's output products, FE is the cost value of damage due to a deficit of products.

Any change in the internal structure of the system, changing the parameters of stabilization or control, will be reflected by the change in the parameters of these three parameters upon completion of the operation.

Study [24] defined an estimate whose structure corresponds to the formal features of a single estimate, which passed verification [25–29] for its use as an optimization criterion.

However, the evaluation of effectiveness of the operational process, taking into consideration the peculiarities of the probabilistic character of demand, implies a possibility to assess uncoordinated operations. That is, such operations whose model assumes a deficit or surplus of the finished product at the output from the system.

Thus, as regards QS with a basic function of buffering, the task on control design, which could lead to a result with the highest expected performance, has not been accomplished.

3. The aim and objectives of the study

The aim of this study is to improve control over queueing systems, with the inherent basic buffering function, by advancing a method for constructing a model of the uncoordinated operation.

To accomplish the aim, the following tasks have been set:

– to build a formal method for determining the parameters of an economic-mathematical model of the uncoordinated operation;

– to validate the model of the operation for adequacy in assessing the redundant and deficient operations;

– to validate the operational process model in terms of defining a possibility to determine the substantiated level of insurance stocks.

4. 1. Development of a model of QS structure with a basic buffering process

Implementation of the inventory management process requires the existence of technological buffering mechanism (Fig. 2).

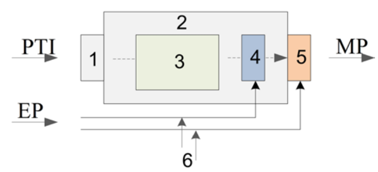

Fig. 2. Model of a technological mechanism of the buffering system: PTI – product of targeted influence; EP – energy product; MP – output main product; 1 – input to supply PTI; 2 – storage mechanism; 3 – buffered product; 4 – dosing mechanism; 5 – release mechanism; 6 – channels to feed energy products

The cost value for a buffering product is typically much higher than the valuation of energy products involved in dosing and release. Therefore, the overall consumption of energy products is, one way or another, accounted for in the input value of PTI, while channels that feed energy products are not represented in the model (Fig. 3).

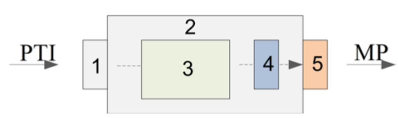

Fig. 3. Simplified model of the technological buffering mechanism: PTI – product of targeted influence; EP – energy product; MP – output main product; 1 – input to supply PTI; 2 – storage mechanism; 3 – buffered product; 4 – dosing mechanism; 5 – release mechanism

In queueing systems, a technological buffering mechanism integrates with a client part that represents a channel to displace and service customers (Fig. 4).

This class of systems can be attributed to the multiphase QS with refusals, a limited queue, a limited waiting time, which have identical channels to service a customer.

In the process of displacement, a customer is exposed to the means of internal advertising and order service. In addition, there is an external channel to displace potential customers, which is exposed to external advertising and mass media.

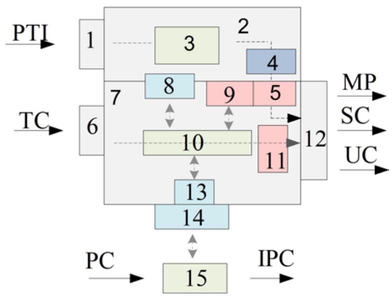

Fig. 4. Model of QS technological part: PTI — product of targeted influence; TC — target consumer; PC — potential customer; MP — main product (sold products); SC — satisfied customer; UC — unsatisfied customer; IPC — informed potential customer; 1 — input to supply PTI; 2 — storage mechanism; 3 — buffered product; 4 — dosing mechanism; 5 — mechanism to release a product of buffering; 6 — input to target customers; 7 — channel to displace target customers; 8, 11 — sources of informational influence on a target customer; 9 — functional systems of the target customer; 10 — release of main product, satisfied and dissatisfied customers; 12 — objects of functional service to target customer; 13 — sources of external informational influence on a potential customer; 14 — functional systems of potential customer

Upon passing the client side of the system, a customer status changes; it can be defined as a "satisfied customer" and "dissatisfied customer". One indication of the status of a "satisfied customer" is that he is satisfied with the subject of customer demand, in the form of the amount of the main product of the system required by him.

In a simulation process, solving this task is simplified because we determine not the status of the customer, but the amount of unmet demand. Its magnitude is determined from the difference between the amount of the input batch of stocks and the total volume of demand.

Unmet demand directly affects the enterprise in the form of lost profit, as well as the indirect damage, which must be considered because the enterprise heavily invests in advertising and mass media. The magnitude of the collateral damage from the lack of customer product is typically several times higher than the magnitude of direct damage.

4. 2. Essence of the method and its conceptual apparatus

In QS that are based on the buffering of a customer product, defining the optimal control parameters employs the integrated time series. Such series include, as a minimum, information regarding the volumes of sales.

The most common is the situation when current volumes of sold products are integrated within the daily sampling intervals (SI). Thus, an indexed discrete time series forms in the form of a source dataset (SDS) (Fig. 5).

If the SDS section did not experience any shortage of products, the time series of sales would be a demand time series (Fig. 6).

To the right, relative to SDS, one can determined a time section (Fig. 7), which is defined by the concept of a "planning horizon".

The purpose of control is to determine over a past time section [*a*, *b*] the expected better economic parameters for an operation that will be implemented over a future time section [*e*, *f*], taking into consideration SI of the uncertain present, specified by symbol *d*. In this case, a *g* parameter is also an optimization parameter.

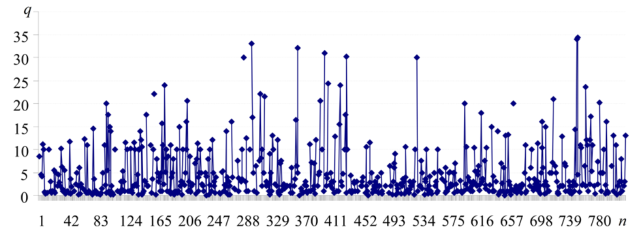

Fig. 5. Example of a source dataset in the form of product volumes integrated over a daily interval, to solve a task on control

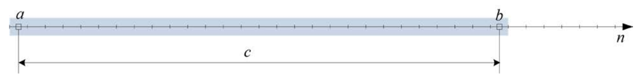

Fig. 6. Symbolic designation of boundaries and size of the source dataset

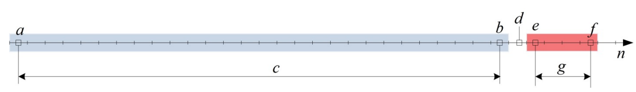

Fig. 7. Determining a planning horizon relative to the source dataset

A sampling interval within which any event is determined, shall be defined using the concept of "point in time". For example, the event that is defined by a symbol "d" over one SI, shall be determined by the term a "time of control design".

To solve a problem on control, it is necessary, based on data from section [*a*, *b*], to determine the hidden parameters in the model of predicting a customer demand. These are the kind of a demand forecasting model, the magnitude of prediction interval (segment [*h*, *b*]) (Fig. 8), and the magnitude of shifting a forecasted value for demand.

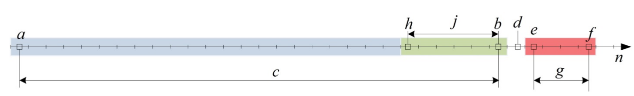

Fig. 8. Determining an interval of prediction relative to the time of control design

For the sake of certainty, we assume that the best forecasting model is the average volume of the past sales of products in the interval *j* for a planning horizon at intervals *g*.

The forecasted value for a future demand can then be determined from expression

$$P_d = \frac{(g+1)\sum_{x=h}^{b} pq_x}{j},$$

where P_d is the forecasted value for a future demand determined at moment *d*; pq_x is the sales volume within a current SI.

To determine the optimal control parameters, we model the process of control design over that part of the SDS range where it is possible to check the management model.

For example, by shifting the conditional moment of control design as far as possible to the left (Fig. 9), it will be possible to determine a response to control in the form of a model of the operation whose construction is possible based on the actual data (Fig. 9).

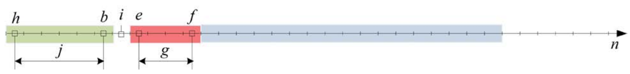

Fig. 9. Setting the moment of the conditional control design to the initial part of the source dataset

In this case, time point "a" of SDS will coincide with time point "h" in the forecasting interval.

In order to simplify comprehension of the method, we assume that the response to control is achieved within the framework of SI in a conditional control design.

Then the input of the conditional operation will receive the volume of products in accordance with control $RQ_i = U_i$, where i is the time moment of conditional control design.

Using the data on product sales in the interval g makes it possible to determine the actual volume of consumption from expression

$$PQ_i^{'} = \sum_{x=(e-1)}^{f} pq_x,$$

where $PQ_i^{'}$ is the actual volume of sales during operation over a planning horizon g.

Since the magnitude of RQ_i may coincide with $PQ_i^{'}$ only accidentally, there are three possible outcomes to finalize the simulated operation:

1. $RQ_i > PQ_i^{'}$ – redundant operation;
2. $RQ_i = PQ_i^{'}$ – coordinated operation;
3. $RQ_i < PQ_i^{'}$ – deficient operation.

The process of constructing an economic-mathematical model of the operation comes down to determining the parameters for the input and output products of the operation.

Such a model can be represented by a quartet (RE, TO, PE, FE), where RE is the valuation of the operation's input products, TO is the operation duration (a planning horizon), PE is the valuation of the product's output products; FE is the valuation of direct damage from a deficit during operation and negative consequences of the unmet demand by a potential customer.

For the case of forming a model of a redundant operation, three objects are generated at its output: a satisfied customer, a sales volume ($PQ_i^{'}$), and the rest of the operation's unsold products ($PQ_i^{''}$).

This in turn means that in a general case three types of objects arrive at the input to the operation that follows the redundant operation: a potential customer, an input batch from an external source ($RQ_i^{'}$), and the input batch of the remaining unsold products from the previous operation ($RQ_i^{''}$) (Fig. 10).

In a general case, the volume of replenishment of the current simulated operation (RQ_i) can be determined by a size of the rolling batch of stock or can be composed of a batch from external restocking ($RQ_i^{'}$) and a rolling stock batch ($RQ_i^{''}$)

$$RQ_i = \begin{cases} RQ_i^{''}, & \text{if } RQ_i^{''} > U_i, \\ RQ_i^{'} + RQ_i^{''}, & \text{if } RQ_i^{''} < U_i, \end{cases}$$

in this case, $RQ_i^{'} = U_i - RQ_i^{''}$.

Since redundant operations have no any unmet demand, we obtain

$$RE_i = \left(RQ_i^{'} + RQ_i^{''}\right) RS;$$

$$PE_i = PQ_i^{'} \cdot PS + PQ_i^{''} \cdot RS;$$

$$TO = t_f - t_e,$$

where RS is the valuation of the unit of the operation's input product; PS is the valuation of the unit of the operation's output product.

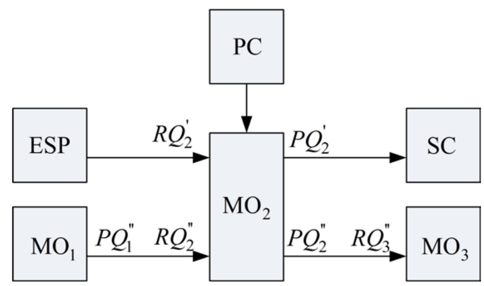

Fig. 10. Model of redundant operation: ESP – external source of the input product; MO_1 – model of the previous operation; MO_2 – model of the current operation; MO_3 – model of the following operation; PC – potential customer; SC – satisfied customer

The amount of transferred stocks is multiplied by the valuation of the unit of the input product, because it is not involved in forming the profit of an operation.

The output of the coordinated operation has neither any rolling stocks no product deficit. Therefore,

$$RE_i = \left(RQ_i^{'} + RQ_i^{''}\right) RS;$$

$$PE_i = PQ_i^{'} \cdot PS;$$

$$TO = t_f - t_e.$$

For a deficient operation, a planning horizon product volume reflects the volume of demand for the system's products

$$DQ_i = \sum_{x=(e-1)}^{f} pq_x,$$

where DQ_i is the demand for the system's products within the planning horizon.

For the case when $DQ_i > U_i$, a volume of the products sold is determined from expression $PQ_i^{'} = DQ_i - U_i$ (Fig. 11).

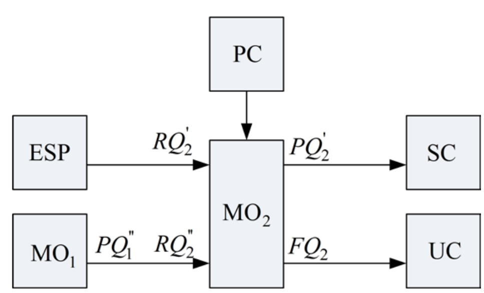

Fig. 11. Model of deficient operation: ESP – external source of the input product; MO_1 – model of the previous operation; MO_2 – model of the current operation; PC – potential customer; UC – unsatisfied customer; SC – satisfied customer

A possibility to determine the level of demand over a planning horizon makes it possible to determine the volume of unmet demand (FQ_i)

$$FQ_i = DQ_i - RQ_i^{'}.$$

Accepting that a direct damage from the unmet demand operation is determined by the magnitude of lost profit, we obtain for a model of the deficient operation

$$RE_i = \left(RQ_i^{'} + RQ_i^{''}\right)RS;$$

$$PE_i = PS\left(DQ_i - U_i\right);$$

$$FE_i = k\left(PS - RS\right)\left(DQ_i - RQ_i^{'}\right);$$

$$TO = t_f - t_e,$$

where k is an increase in the deficit penalty coefficient.

The introduction of a deficit penalty coefficient is predetermined by that the processes related to QS inventory management invest a great deal of money in the internal and external advertising, advertising in mass media. Because marketing costs are unique to a specific QS, the magnitude of k is determined in a separate study.

Using the developed models of operations, it is possible to build at SDS a model of the operational process and to assess its effectiveness using the estimate [30].

$$E = A/R,$$

where A is the potential effect of an operation; R is the resource intensity of an operation;

$$A = \left(PE - RE - FE\right)/2;$$

$$R = \frac{PE \cdot RE \cdot TO^2}{2 \cdot \left(PE - RE\right)}.$$

In turn, the effectiveness of an operational process can be determined from expression

$$E^* = \frac{\sum_{i=1}^{I} A_i}{\sum_{i=1}^{I} R_i},$$

where I is the number of operations within the analyzed process.

Thus, construction of the method for building an economic-mathematical model of the uncoordinated operation makes it possible to assess changes in the operational effectiveness of the process at a change in any variable parameter of control.

4. 3. Procedure for the validation of an economic-mathematical model of the operation and the operational process

The process of constructing a mathematical model must be finalized by testing its adequacy via a procedure of its verification or validation.

Given the fact that the value for coefficient k is individual for each system, we shall confine ourselves to the procedure of model validation.

Table 1 gives data on operations whose demand (CQ) varies from 5 to 10 units with a step of 1. In this case, revenues (RQ) are not changed, coefficient k=3.

Table 1

Change in the parameters and results of the operation at an increase in demand level

N	RQ	CQ	PQ	FQ	PQ*	RS	PS	E	б
1	10	5	5	0	5	1	1.5	0.15	5
2	10	6	6	0	4	1	1.5	0.185	4
3	10	7	7	0	3	1	1.5	0.22	3
4	10	8	8	0	2	1	1.5	0.257	2
5	10	9	9	0	1	1	1.5	0.295	1
6	10	10	10	0	0	1	1.5	0.333	0
7	10	11	10	1	0	1	1.5	0.233	1
8	10	12	10	2	0	1	1.5	0.13	2
9	10	13	10	3	0	1	1.5	0.033	3
10	10	14	10	4	0	1	1.5	0	4
11	10	15	10	5	0	1	1.5	0	5

Operations from 1 to 5 are redundant, and from 7 to 11 – deficient. The level of demand for the sixth operation coincides with the volume of sales. Therefore, this operation is coordinated.

Each operation was assessed using both the indicator of efficiency and the module of sales volume deviation magnitude from the level of demand (б).

Fig. 12 shows that the efficiency of operations grows in proportion to a decrease in the size of redundancy and reaches a maximum for the coordinated operation. It then again declines in proportion to the growth of the deficit volume.

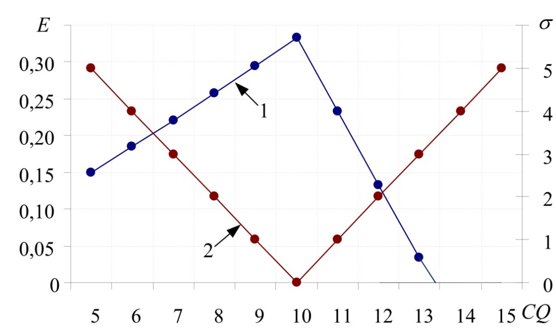

Fig. 12. Change in the operation efficiency and standard deviation at an increase in the level of demand: 1 — change in efficiency; 2 — change in the standard deviation

The research results demonstrate that the maximum efficiency in the utilization of resources corresponds to a minimum in the standard deviation. In this case, the slope of branches for the redundant and deficient operations naturally depends on cost estimates of the operation's input and output products, as well as on the factor that determines losses associated with a deficit of products.

At the next stage of verification, we estimated a possibility of using an operational process efficiency assessment to determine the substantiated magnitude of insurance stock.

Fig. 13 shows models of the three operational processes out of twelve, whose stocks vary from zero to 12 units.

For each operation, and for the operational process in general, we determined the efficiency of resource utilization (RS=1, PS=2, k=3).

Operational processes 0						
n	rq	rq*	cq	pq	fq	rest
1	10	0	3	3		7
2			3	3		4
3			3	3		1
4			3	1	2	0
5			3	0	3	0
6			3	0	3	0
7			3	0	3	0
8	10	0	1	1		9
9			1	1		8
10			1	1		7
11			1	1		6
12			1	1		5
13			1	1		4
14			1	1		3
15	7	0	3	3		7
16			3	3		4
17			4	4		0
18			4	0	4	0
19			3	0	3	0
20			3	0	3	0
21			3	0	3	0
22	10	0	2	2		8
23			2	2		6
24			2	2		4
25			1	1		3
26			1	1		2
27			1	1		1
28			1	1		0

a

Operational processes 6						
n	rq	rq*	cq	pq	fq	rest
1	10	6	3	3		13
2			3	3		10
3			3	3		7
4			3	3		4
5			3	3		1
6			3	1	2	0
7			3	0	3	0
8	10	6	1	1		15
9			1	1		14
10			1	1		13
11			1	1		12
12			1	1		11
13			1	1		10
14			1	1		9
15	7	0	3	3		13
16			3	3		10
17			4	4		6
18			4	4		2
19			3	2	1	0
20			3	0	3	0
21			3	0	3	0
22	10	6	2	2		14
23			2	2		12
24			2	2		10
25			1	1		9
26			1	1		8
27			1	1		7
28			1	1		6

b

Operational processes 12						
n	rq	rq*	cq	pq	fq	rest
1	10	12	3	3		19
2			3	3		16
3			3	3		13
4			3	3		10
5			3	3		7
6			3	3		4
7			3	3		1
8	10	11	1	1		21
9			1	1		20
10			1	1		19
11			1	1		18
12			1	1		17
13			1	1		16
14			1	1		15
15	7	0	3	3		19
16			3	3		16
17			4	4		12
18			4	4		8
19			3	3		5
20			3	3		2
21			3	2	1	0
22	10	12	2	2		20
23			2	2		18
24			2	2		16
25			1	1		15
26			1	1		14
27			1	1		13
28			1	1		12

c

Fig. 13. Operational processes with a varying insurance stock: *a* – operational process with a zero level of insurance stocks; *b* – operational process with a level of insurance stocks equal to 6; *c* – operational process with a level of insurance stocks equal to 12

Fig. 14 shows that the overall increase in the operational efficiency of the process at a decrease in the stock level is achieved by that the effectiveness of deficient operations grows faster than the effectiveness of redundant operations decreases.

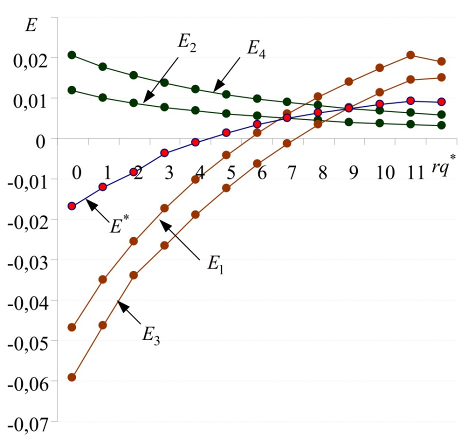

Fig. 14. Change in the effectiveness of operations and the operational process in general

A change in the stock level when changing a level of the insurance stock at a step of 6 units is shown in Fig. 15.

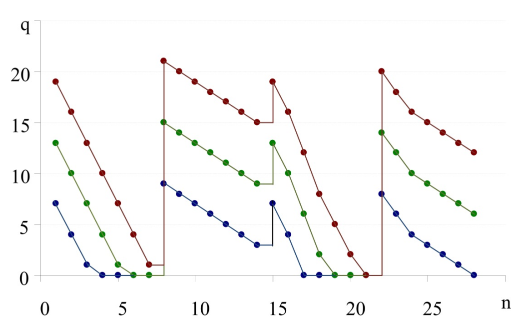

Fig. 15. Changing inventory levels while increasing the magnitude of an insurance stock

Fig. 16 shows that at the level of stocks equal to 11 units, the effectiveness of the operational process is extreme.

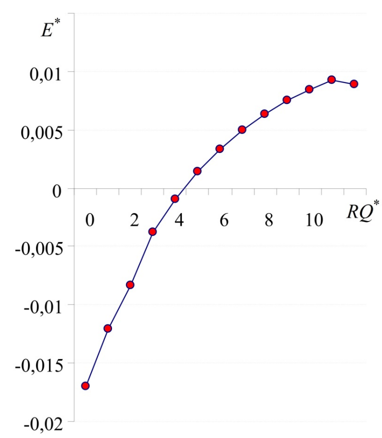

Fig. 16. Change in the effectiveness of the operational process at an increase in the level of an insurance stock

Consequently, this level of the insurance stock is adopted as a systematically substantiated one. In this case, the third operation remains deficient.

5. Discussion of research results related to the evaluation of the expected effectiveness of parameters

Similarly to classic control systems, the choice of optimal control over systems associated with the processes of buffering comes down to changing control parameters that have degrees of freedom. In this case, the main reason for a decline in the effectiveness of planned operations is the effectiveness of a demand forecasting operation.

A demand function that is commonly used is the time series of past volumes of product sales. However, the sales forecast based on the series of sales is not a very good idea. The time series of the volumes of goods sold does not contain information that could be used as a basis to really predict the future. Therefore, reserves to improve the efficiency of control over QS of this class should be searched for in building the fundamentally new methods to forecast demand, taking into consideration information from other time series.

The second issue on improving control efficiency could be a task on the justification of the amount of damage associated with a shortage of customer products. Thus, it is obvious that the size of lost profit is not the only factor that should be objectively considered. Thus, the deficit of the two products that yield the same profit causes a different damage to an enterprise if a first product draws 10 times more customers than a second one in the same time interval.

Thus, the method for improving the efficiency of inventory management within QS requires further development.

It may also be noted that the term "inventory management" is not quite correct. Control over processes in buffering systems can lead to changes in many parameters. For example, a decrease in the value of the output product could lead to a significant increase in demand and to a change in the cost and time of the operation.

Therefore, another promising area of research relates to the elucidation of terminology.

6. Conclusions

1. We have devised a method to construct an economic-mathematical model of uncoordinated operations in tasks related to the buffering processes within QS. The following concepts have been suggested: a redundant operation, a coordinated operation, and a redundant operation. The operation model makes it possible to take into consideration the effect of moving stocks and the damage due to a lack of products.

2. We have performed a validation procedure of the constructed mathematical model of the operation in terms of adequacy of evaluating the level of surplus and considering the damage due to a deficit of customer products. It was established that the squared deviation in the integrated assessment of demand from the volume of products sold for the redundant and deficient operations is symmetric. These results are not consistent with the established practice of control over QS with a basic buffering function, since the forecasted demand value is always shifted in the direction of increasing the level of an insurance stock. At the same time, the evaluation of effectiveness of the deficient and redundant operations yields a non-symmetric estimate, which leads to the preferred choice of redundant operations relative to deficient operations given the equality of module of their deviations.

3. A validation procedure for the model of an operational process was performed using an example of determining the substantiated magnitude of an insurance stock. It is shown that the determination of the level of an insurance stock is based on an unequal change in the effectiveness of the operation at an increase in inventory levels while reducing the deficit of customer products.

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