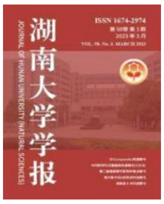

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INVENTORY MANAGEMENT OF PRODUCTS WITH A LIMITED SHELF LIFE IN CONDITIONS OF DEMAND UNCERTAINTY

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Abstract: The article discusses the process of replenishing stocks of a single product by a trading organization. It is assumed that the product has a limited shelf life, after which it is removed from circulation (disposed of without additional costs, disposed of at additional costs, sold at a reduced price). The question is raised about finding an economically feasible volume and time for replenishing stocks. The uncertainty factor of the model is demand, which is described by a random variable with a known distribution. The distribution of a random demand variable can be either static or have a dynamic dependence on time. A criterion for the economic efficiency of a new supply of goods has been introduced, namely, the mathematical expectation of the density of the profit flow from the sale of a new batch is maximized. A simulation model has been built that allows optimization according to this criterion based on the variable's delivery volume and delivery time. Numerical examples of calculations are given based on the software implementation of the proposed optimization model.

Keywords: inventory management, shelf life, uncertain demand, order volume, delivery time, profit flow density.

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Introduction

Inventory management in retail plays a key role in ensuring the success of stores and chains. In a highly competitive environment with rapidly changing consumer preferences, effective inventory management becomes an essential tool for achieving sustainable growth and profitability. The key issues in the perishable goods management process are determining the optimal order quantity and maintaining optimal inventory levels. On November 28, 2018, the President of Russia signed a law banning the return of unsold products to the manufacturer. The law prohibits reimbursement of costs associated with the disposal or destruction of unsold food products for retailers and suppliers of relevant types of products. With the adoption of the law, the need for competent inventory management increases, in particular, the most correct determination of the order size of perishable goods. If you purchase too much product, the risk of write-off due to expiration increases. If you purchase a small amount of goods, this can lead to situations with the lack of goods on the shelf and, as a result, to lost profits.

Thanks to the development of computer technology, the simulation method has become widely used to solve problems of optimizing inventory management. Publications have appeared using this method to study and optimize inventory management [1, 2]. The influence of inventory management strategies on the economic performance of an enterprise is widely presented in the scientific literature [3-5]. The greatest difficulty for analysis are processes containing random or uncertain parameters [6-8]. Taking into account uncertainties is a complex task that requires the efforts of highly qualified specialists, which may be the reason that only a part of large companies in the Russian Federation use mathematical modeling and, in particular, stochastic modeling to optimize decisions related to inventory management. In the works of G.L. Brodetskiy considered a wide range of models for optimizing the size of product lots, taking into account the uncertainty of demand, the cost of goods and the selling price. He, in contrast to the formulations considered in this work, considered a scenario approach to taking into account uncertainty [8].

The study [9] proposes approach which is based on the use of direct methods of multicriteria optimization and methods for selecting solutions under conditions of uncertainty

For certain types of random demand distributions, analytical models of inventory management have been developed, for example, for normal distribution [10] or triangular distribution [11, 12].

Article [13] formalizes the problem of finding the optimal supply volume under conditions of uncertainty for two types of goods: with a long shelf life and with a limited shelf life.

Modification of the EOQ model allowing the formation of an optimal inventory management strategy, taking into account the possibility of deferred payments, delays in receipt of revenue and limitations on the capacity of vehicles presented in the study [14].

Another modification of the EOQ model is presented in study [15], which considers the inventory management system for deteriorating items with inventory-dependent demand at two levels of trade credit.

1. Formulation of the problem

The process of trading operations for a certain product with a fixed shelf life (use) is considered. An example of this type of product is food. The product is delivered to the retail chain in certain batches, each of which has a fixed use-by date. It is assumed that upon reaching this period, the unsold part of the batch is withdrawn from trade. For certain types of products, a recycling process may follow, requiring additional financial costs that must be taken into account when quantitatively analyzing the trade turnover process. It is also possible to consider the case when the overdue balance of the batch can be sold at a dumping price, for example, at a time on a contract basis. In both cases, we will assume both the value of disposal costs and the amount of revenue from the sale of an overdue batch to be linear depending on the remainder of the batch. As for the cost of delivery, it is possible to consider at least two options, namely, that the cost of delivery of products is included in the purchase price of the goods or the cost of each delivery is fixed and does not depend on the volume of delivery. We also assume that delivery is carried out exactly on time set by the retail outlet. The uncertainty in the situation under consideration is demand. To be specific, we will consider daily demand. We assume that this uncertainty is formalized in the form of a known random variable. Two cases are possible, namely, when the random variable the volume of daily demand does not depend on time and when such a dependence occurs. The main question is determining the date for ordering a batch with a known expiration date and the volume of the batch. We will denote such a solution by (Q, T). A significant difficulty in finding an optimal solution to this problem is created by the continuity of the process. Because of this, the choice of optimization criterion for making regular decisions becomes not obvious. Next, we will build a mathematical model of the trading process under consideration.

2. Mathematical model

To find the optimal delivery volume and optimal delivery time, it is proposed to build a simulation model. The general structure of the simulation model for assessing a specific solution Q – delivery volume and T – delivery time is shown in Fig. 1.

Below we give a description of the notation used in the model.

S(*t*, *x*) is the distribution density of the random variable of daily demand at time t, the value of t will be calculated in days for definiteness;

T_0 – current moment of time;

Q_0 - unsold volume of the current batch at time T_0;

t_0 – random variable, the duration of the sale of the current batch.

A – random variable, end time of sales of the current batch;

B – random variable, the start time of the sale of a new batch;

C is a random variable, the end time of sales of a new batch;

d_0 – time interval from the current moment T_0 until the expiration date of the current batch, i.e. the maximum possible duration of sales of the current batch;

d_1 - time interval from the moment T of delivery of a new batch until the expiration date of the new batch, i.e. the maximum possible duration of sales of a new batch;

t_1 – random variable, the duration of the sale of a new batch;

V_1 – random variable, the volume of sales of a new batch through the retail network;

q – selling price per unit of production;

r – purchase price per unit of production;

P – fixed delivery cost, *P*=0, if the delivery cost is included in the purchase price;

k - the coefficient of expired products, if *k*>0, then this is the selling price of expired products at a reduced price, if *k*<0, then this is the specific cost of disposal of expired products;

N – number of iterations in the simulation model;

L(*Q*, *d*, *S*(*t*, *x*), *T*) – built-in simulation model for determining the implementation period and sales volume;

W(*Q*, *T*) – averaged evaluation criterion for solution (*Q*, *T*).The mathematical meaning of the obtained result is an estimate of the mathematical expectation of the random variable *W*. The economic meaning of the *W* criterion is to correlate the profit from the sale of a new batch with the value of the time interval between the end of the sale of the current batch and the end of the sale of the new batch. Apparently, it would be appropriate to call this criterion "profit flow density." The logic of using this criterion is to make decisions regarding the timing and volume of new supplies in such a way that the "profit flow density" would be maintained at the highest possible level. Obviously, the ideal result of inventory management would be to organize a process in which demand would be fully realized every day and there would be no expired products.

Let's consider the procedure (1):

$$L(Q, d, S(t, x), T) \rightarrow t_1, \quad (1)$$

V_1 built into the simulation model algorithm. This procedure is also implemented using the simulation method. At moment *T*, the sale of volume of goods *Q* with expiration date *d* begins, based on random demand *S*(*t*, *x*). The procedure determines two parameters, namely, the duration of the sale of the consignment and the volume sold in the distribution network, which are derived random variables from the original data. A general view of the simulation model for this procedure is shown in Fig. 2.

Search for optimal parameters. Below we present a general scheme for searching for an optimal solution to the problem. We will consider the required parameters Q and T as belonging to some segments $[Q_1, Q_2]$ and $[T_1, T_2]$, respectively. For example, it is reasonable to define Q_1, no less than the amount of daily demand, and Q_2 no more than the volume consumed during the shelf life of the product, increased by the safety stock. Parameter T_2 is obviously less than the sum of the remaining shelf life of the current batch and the shelf life of the imported batch. Next, you need to decide on the steps to view both the *HQ* and *HT* bands. The choice of the *HQ* parameter may, for example, be determined by the size of the minimum packaging (box, pallet, etc.), and the *HT* parameter may be determined, for example, by the shelf life unit (hour, day, week, etc.).

Let

$$Q_2 = NQ \cdot HQ \quad (2)$$

And

$$T_2 = NT \cdot HT. \quad (3)$$

Next, we consider the following pairs of values (Q_i, T_j), where

$$Q_i = i \cdot HQ, i = \overline{0,\ NQ}, \quad (4)$$

And

$$T_j = j \cdot HT, j = \overline{0,\ NT}. \quad (5)$$

The pairs under consideration form a rectangular grid with dimensions $(NQ + 1) \cdot (NT + 1)$. For each node of the constructed grid, we calculate the assessment of economic feasibility according to the above algorithm, and select the node (Q^*,T^*) that has the maximum assessment value. The resulting pair of values determines the required optimal delivery parameters.

3. Numerical examples

3.1. Example 1.

Let daily demand be a normally distributed static random variable $N(\mu,\sigma)$. Let's consider an example with the following numerical initial parameters: Q_0=2000, q=50, r=30, P=5000, k=10, μ=100, σ=20, d_0=10, d_1=20, N=1000, Q_1= 500, Q_2=2500, HQ=100, T_1=5, T_2=20, HT=1. As is easy to see, in this case the likelihood that the current balance of the product will be sold out before its expiration date is extremely low. In this choice of initial parameters, the simulation model proposed above evaluates 26*16=416 variants of parameters (Q, T), playing 1000 evaluation cycles for each of them according to the algorithm (Fig. 1). Each such cycle contains two built-in simulation procedures with an indefinite number of simulations, described by the algorithm (Fig. 2). The optimal calculated parameters are the values Q*=2000, T*=11. With an estimated result of W*=1799. The upper estimate for the mathematical expectation of the profit flow density is obviously the value (50-30)*100=2000, but it is unattainable due to the presence of transportation costs and uncertainty of demand. A graphical representation of estimates of the parameter W for various combinations (Q, T) is presented in Fig. 3.

3.2. Example 2.

Example 2. In example 2, all the parameters of example 1 are saved, except for Q_0, which in this example is equal to 500. As you can easily see, in this case, the probability that the current balance of the product will be sold out before its expiration date is extremely high. The optimal calculated parameters are the values Q*=2000, T*=5. With an estimated result of W*=1752. A graphical representation of estimates of the parameter W for various combinations (Q, T) is presented in Fig. 4.

3.3. Figures.

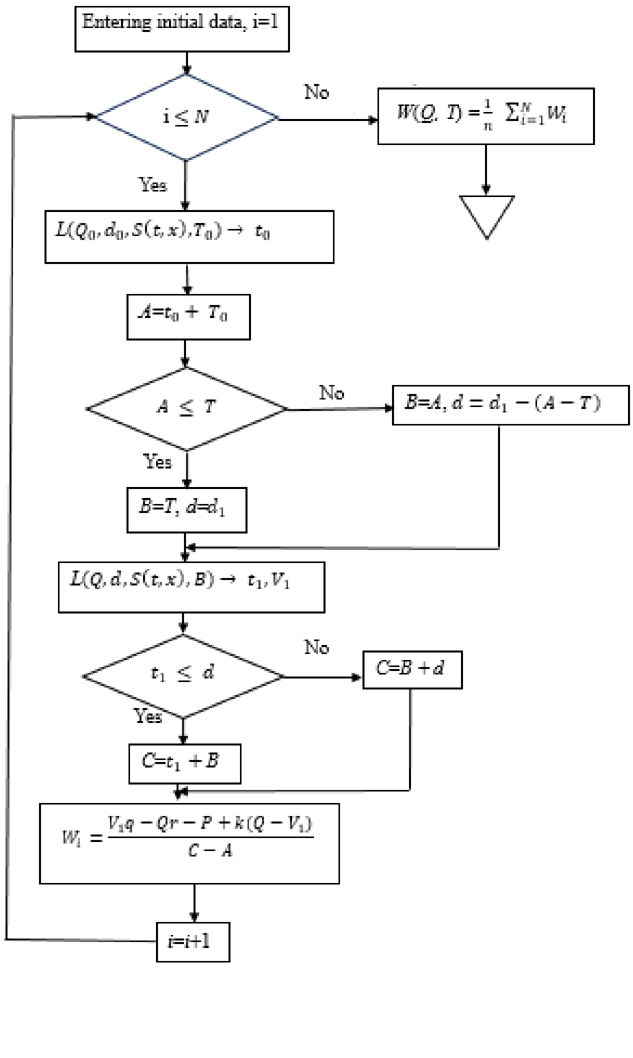

Fig.1 Simulation model for evaluating the solution (Q, T)

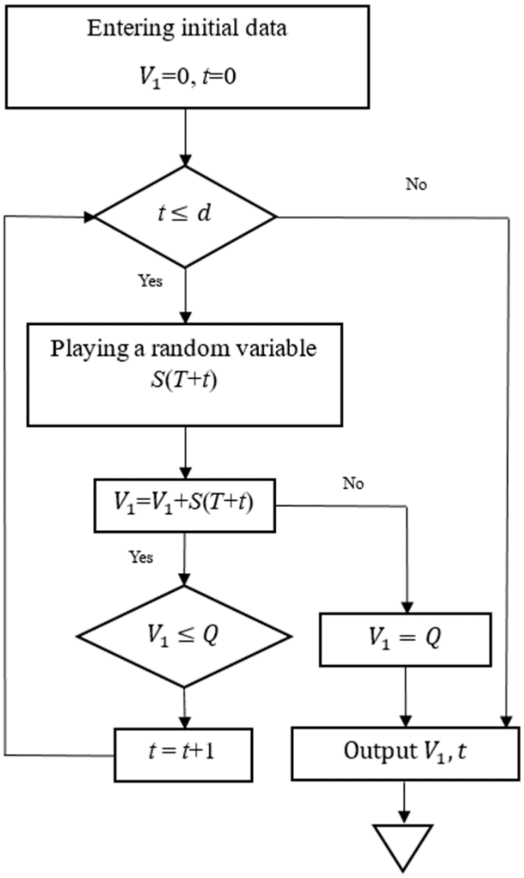

Fig.2 Simulation model for calculating the timing and volume of sales

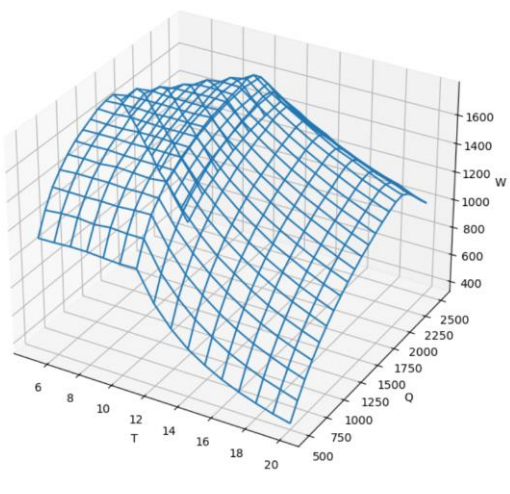

Fig. 3. Graphical representation of the results of example 1.

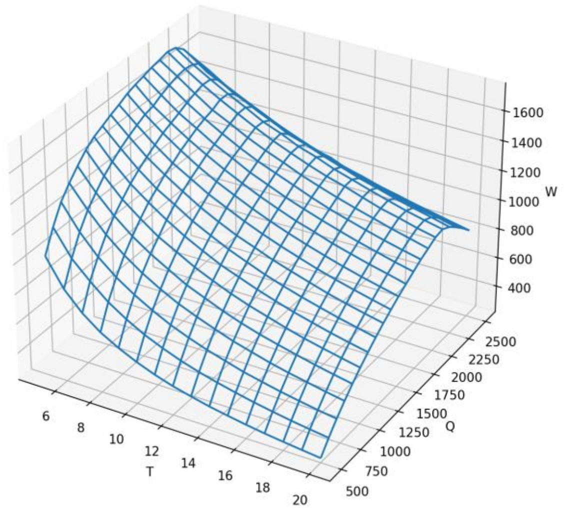

Fig. 4. Graphical representation of the results of example 2.

4. Conclusion

The article discusses the process of replenishing stocks of a single product by a trading organization. It is assumed that the product has a limited shelf life, after which it is removed from circulation (disposed of without additional costs, disposed of at additional costs, sold at a reduced price). The question is raised about finding an economically feasible volume and time for replenishing stocks. The uncertainty factor of the model is demand, which is described by a random variable with a known distribution. The distribution of a random demand variable can be either static or have a dynamic dependence on time. A criterion for the economic efficiency of a new supply of goods has been introduced, namely, the mathematical expectation of the density of the profit flow from the sale of a new batch is maximized. A simulation model has been built that allows optimization according to this criterion based on the variables delivery volume and delivery time. Numerical examples of calculations are given based on the software implementation of the proposed optimization model.

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