Stock Management Algorithms in a Passenger Wagon Depot

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Abstract: The process of delivering spare parts and components of different moving unit elements to the passenger wagon depot warehouse under the supervision of railway transport "Uztemiryolyolovchi" Joint Stock Company (JSC, also known as the Joint Stock Company) was examined in the article, along with the challenges of efficient stock management. The automated warehouse management system for railroad transportation is explained, along with its components, stages of development, concepts, and implementation. The efficient automation of warehouse accounting for prompt rolling stock (wagon) maintenance and repair is a special concern in the administration of passenger transportation, and simulation modeling is employed in this research. A multi-level research methodology is suggested in order to increase resource management efficiency: a) Conduct preliminary analysis of stock management systems; b) select the indicators required for the object's efficient operation and identify the factors influencing them; c) develop a simulation model of reserve management's block diagram and program, conduct an experiment based on it, and create a mathematical regression model with a set of equations; d) optimize the stock management system using the mathematical model that has been developed. The interconnectedness of the indices characterizing the reserves was examined using correlation-regression analysis. The correlation analysis's findings allowed for the determination of the regression equations, which in turn allowed for the evaluation of the elements' degree of influence on the final indicator of the stock management system's efficiency.

1 INTRODUCTION

Optimizing inventory management reduces costs and boosts business productivity, making it a crucial component of manufacturing company management. The improvement of inventory control models and algorithms has been the subject of numerous studies in recent years. Some of the most significant works in this field are listed below.

The study "Inventory Optimization Based on Simulation" by A. Bikov [2] concentrated on production planning techniques, inventory management strategies, mathematical models, and optimization techniques. The writers addressed a number of stock management-related topics, such as order quantity and manufacturing time optimization.

The unpredictability of the delivery procedures for spare parts and components of different moving unit elements (henceforth referred to as goods in the text) is a defining feature of the stock management systems of JSC "Uztemiryolyolovchi" passenger wagon depot warehouse. Both the delivery delay and the demand for the commodities during the completion of equipment and repair work (referred to as REW) are examples of supply uncertainty. Because demand varies over time and its average value (demand) varies throughout the year, it is vital to assess how items are used. As a result, activities involving the uncertainty of the order's delivery time and the variation of the demand value over time are extremely complicated, and using deterministic mathematical models in these circumstances is nearly impossible. It is suggested that in these situations, simulation techniques be used to ascertain the required stock of items.

2 MATERIALS AND METHODS

Improving the efficiency of the stock management system for carrying out REW in the passenger wagon depot is accomplished by lowering the costs of their (stock) storage, material transportation, and downtime due to a shortage of essential items in the warehouse. It is required to identify the research objectives, which contain the primary eight stages of work accomplished to reach the research objective. The 8-step process outlined below is recommended to improve the effectiveness of passenger wagon depot warehouse stock management [6].

1) An first assessment of inventory management systems. Choosing the sort of system, establishing indicators for its effective functioning, and determining the elements that influence them.
2) The simulation model is used to create a stock management challenge.
3) Create the simulation model's block diagram and program.
4) Create a strategic plan for executing a simulation experiment.
5) Follow the strategic plan's simulation modeling (SM) guidelines.
6) Developing a mathematical regression model using a set of equations to determine the relationship between performance indicators and the factors that influence them.
7) Using the generated mathematical model, optimize the stock management system.
8) Calculating elasticity coefficients and factor specific weights.

Order size is an important element in an inventory management system with a set order size. This system is distinguished by the fact that it operates when the order level approaches the warehouse's existing stock limit. Note that this method is effective for the passenger wagon depot's manufacturing processes, and serial production is distinguished by the use of REW with, in most cases, the same operations, moving units.

The analysis of passenger wagon depot stocks and their management system was conducted using four effective indicators, two optimal factors impacting them, and five objective (fixed) elements. Table 1 outlines the variables used in the mathematical model.

Currently, there are two traditional approaches for evaluating and selecting suppliers: the point method and hierarchical analysis. Each approach has its own set of drawbacks, such as the level of subjectivity in the assessment, the availability of a sufficient number of criteria for assessing huge, uncertain data, and so on. The suggested simulation-optimization approach allows for the simulation of the passenger wagon depot's operation under various initial conditions, obtaining results for each scenario, and selecting the optimal supplier.

Table 1: Variables employed in the mathematical model for the investigation.

No	Code	The name of the variable
Performance indicators of the system of efficient management of reserves		
1	y_1	Total manufacturing expenses, soums.
2	y_2	average product storage, pcs
3	y_3	quantity of supplied items
4	y_4	number of days of REW suspension due to lack of goods
Factors to be optimized		
5	x_1	order delivery volume in product units
6	x_2	threshold level of stock in stock ordered in commodity units
Objective factors		
7	x_3	The average amount of goods required by the enterprise in a month
8	x_4	transportation costs of one batch of material, soums
9	x_5	cost of keeping a unit of product in one day, m
10	x_6	Losses incurred by REW during one-day interruptions of goods, sum
11	x_7	The average number of days it takes to deliver a product
12	x_8	product balance in the warehouse in commodity units

x_8 - taken modeling time is the same in all variants.

3 RESULTS

Taking into account the management system of reserves without deficit, it can be noted that it is characterized by constant demand, the uniformity of spending reserves and the absence of shortages. At the same time, the calculation of the optimal volume of delivered products can be done using the classic (1). Wilson formula [4, 5]:

$$Q = \sqrt{\frac{2\mu g}{S}} \quad (1)$$

where Q is the optimal volume of product delivery; μ - product consumption intensity; s-product unit storage fee; g-payment for delivery of one batch.

The dependence of the studied parameter on the influencing indicators is carried out by correlational analysis methods.

Using correlation-regression analysis, we study the interrelationship of indicators describing reserves, if the relationship between them is not strictly functional or is broken by the influence of extraneous, random factors. After searching and assessing the narrowness of the relationship between two random features or factors based on correlation analysis, we establish a specific type of relationship between the studied parameters by applying regression analysis.

The automated "Backup" system based on the object-oriented approach is described in [3; 6; 15]. The "Reserve" program provides modeling of each block (object) using selected methods (Fig. 1).

By combining these models, it is possible to simulate different inventory management systems. We will build the models that make up the program.

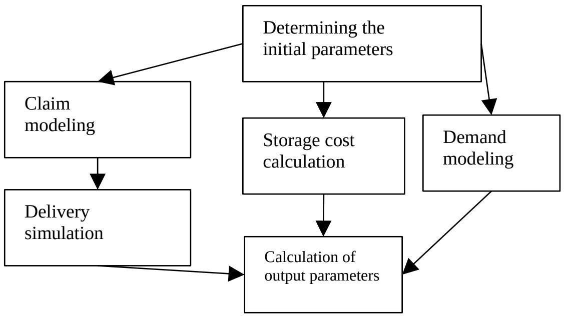

Figure 1: Reserve management system blocks.

The theory of resource management takes into account a vast variety of mathematical models. Two models are shared by them: EOQ (Q-model) (Economic Order Quantity) and periodic (P-model) [18, 19]. Many adjustments have been made to these models to cater for certain extra situations.

The generated models can be solved utilizing techniques such as linear programming, stochastic optimization, interval analysis apparatus, dynamic programming, queuing theory, and adaption theory. Because of the a priori uncertainty (demand, supply, delay time, etc.) of inventory jobs in passenger wagon depot warehouses, an effective solution (belonging to the given set of unknown demand) is conceivable utilizing concepts such as set theory and the concept of "unknown but bounded".

Imitation methods have grown popular as a result of advancements in computer technology, programming languages, and the use of object-oriented programming languages to solve resource management challenges.

Due to the development of computer technologies, programming languages, and the support of object-oriented programming languages in finding solutions to resource management problems, imitation methods have become widespread.

Below are some modeling algorithms of stock management systems developed on the basis of a modification of the classical algorithm.

The main tasks of the correlation-regression analysis in the logistics of supplying the warehouse with goods can be:

- to search and evaluate the correlation of the volume of consumption of goods with one or more of the above factors in order to formulate the right plans for ensuring the need for goods and materials;
- to determine the compatibility of inventory and the level of utilization of inventory by comparing the dynamics of receiving and spending warehouse resources;
- forecasting and budgeting of indirect costs related to stocks in the planning of goods purchases, etc.

Among the parametric criteria, the most common is the linear coefficient of Pearson's pairwise correlation:

$$r = \frac{\sum_{t=1}^{n}(x_t - \bar{x})*(y_t - \bar{y})}{n*\sigma_x*\sigma_y}, \quad (2)$$

the strength of the relationship between the selected variables can be determined by the formula that calculates the values of the linear correlation coefficients:

$$r_{xy} = \frac{m_{1xy}^* - m_{1x}^* * m_{1y}^*}{\sigma_x^* * \sigma_y^*}. \quad (3)$$

Using statistical tables, we determine the critical value of Student's criterion, and also calculate the critical value of the linear correlation coefficient according to the following (4):

$$r_{crit} = \pm\sqrt{\frac{t_{crit}^2}{t_{crit}^2 + n - 2}}. \quad (4)$$

In the next step, regression equations are determined based on the results of correlation analysis. Linear correlation coefficients make it possible to assess the degree of influence of factors on the resulting indicator of the efficiency of the stock management system.

Mathematical model of the system A set of controls that relate the resulting indicators of stock performance to the factors that influence them through regression equations.

Mathematical model presents simple regression equation, the relationship between the results of the effectiveness of the system management and the influencing factors.

$$y_j = f_j(x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8); j = \overline{1,4} \quad (5)$$

According to dependencies (5) the degree of influence of factors on the resulting indicators of the stock management system according to elasticity coefficients is evaluated and optimized.

Optimization is carried out separately for each variant of the strategic plan with specific values of the objective factors in these variants. The objective function is determined by the amount of total costs arising from the waiting, storage, transportation and downtime of the goods used in the execution of the REW to the mobile units in the workshop sections:

$$y_i = f_i(x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8); \rightarrow \min \quad (6)$$

Restrictions are placed on the effectiveness of the resulting indicators:

$$a_j \leq y_j \leq b_j ; j = \overline{2,4}. \quad (7)$$

Constraints are placed on the factors to be optimized:

$$c_i \leq x_i \leq d_i ; i = \overline{1,2}. \quad (8)$$

a j , b j ;j=(2,4)‾, c i , d i ; i=(1,2)‾the minimum and maximum values obtained during the simulation are taken as constraints.

Objective factors do not change during optimization.

$$x_3 - x_9 = \text{const.} \quad (9)$$

The values of the factors to be optimized are determined by the values of the objective factors according to the formulas obtained from the results of the regression analysis.

$$x_{iopt} = f_i(x_3, ..., x_8); i = \overline{1,2}. \quad (10)$$

4 DISCUSSION

It is necessary to highlight that research contains an interpretation and comparative analysis of the other researchers as Mitsel A.A., Gribanova YE.B. “Simulation modeling of economic objects”, Rijikov Y.I. “Queue Theory and Inventory Management” [11] and paper results obtained with link of these authors research respectively.

The simulation modeling method can be successfully used for human-machine evaluation of structural construction options of complex warehouse systems in order to achieve their optimal parameters and functional value characteristics within the existing constraints [1], [13]. This method takes into account the possible changes in the system caused by the influence of various factors, i.e. "what if...".

As mentioned above, the automated system of accounting for goods (ASAG) was implemented based on an object-oriented approach. ASAG includes simulation modeling of each computational process block (object) shown in Figure 1 based on a combination of models. Using selected methods, it allows to simulate different stock management systems by combining models. Note that among the classic simulation models there is the Q-model, whose algorithm has been discussed in detail in various works [7, 14]. According to the rules of this model, the next order for the delivery of goods is executed when the value (order point) falls to the level of Smin.

In addition, there is a P-model, according to which the order is made after a predetermined time. The algorithm of this model is built on the basis of making the following changes to the standard model (Figure 2).

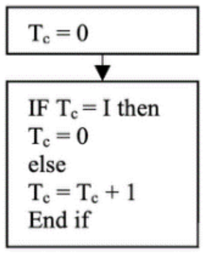

Figure 2: Algorithm for modeling systems with a periodic strategy.

Where T_c is a counter; i- order interval.

In this algorithm, the order placement symbol is no longer used, and there may be a situation where the order is placed before the next batch is delivered. Therefore, an array rather than a variable is used to store the value of the batch size.

In inventory management systems, product demand can be:

- deterministic or stochastic;
- continuously distributed or discrete.

Delivery time can also be random or deterministic (including zero). Modeling of random variables in the program is carried out according to the algorithms presented in. Input (demand, delivery time) they can have a normal.

Figure 3 presents a modification of the standard algorithm for modeling delayed demand. Based on the EBQ (Economic Batch Quantity) and EPQ (Economic Production Quantity) mathematical models presented in [9], [12], [16], [20], simulation models and algorithms were created.

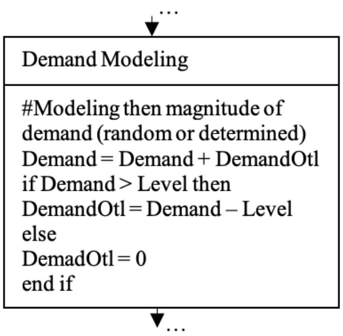

Figure 3: Delayed demand modeling algorithm.

Where demand - demand quantity; DemandOtl-deferred demand; Level - the current reserve level.
A distinctive feature of these models is that the delivery of batches is not carried out immediately, but over a period of time. The difference between the EBQ model and the EPQ model is that only material stocks are accumulated during the delivery period of goods without consuming them. Standard modeling to the algorithm we present the changes made (Fig. 4) [10], [17].

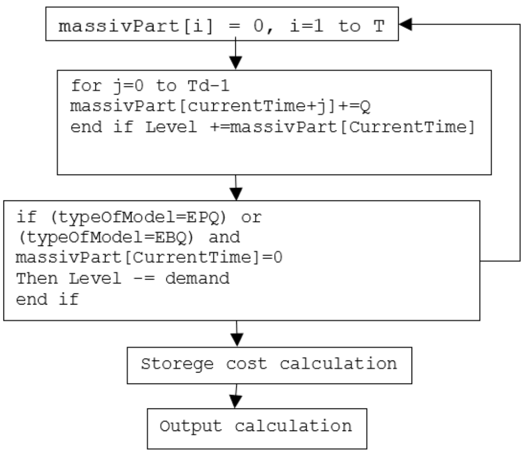

Figure 4: Algorithm for simulation of supply and demand.

In systems operating according to the EBQ and EPQ schemes: where CurrentTime is the time of the current model; T - modeling period; Td - goods delivery time to the warehouse; Q is a commodity of the party size; massivPart –one time for delivery to be given goods of the party value own_into received massive .

The manual mode of the ASUT program allows modeling of dynamic systems [8]. In this case, the input parameters of the model change over time. For example, demand may vary depending on the day of the week.

Let's look at the methods of calculating costs in inventory management systems. A model's cost function typically includes three types of costs: storage, order placement, and shortage penalties, and these may be volume-dependent and/or constant, and may not be considered in the modeling. In addition, when modeling systems in the ASUT program, discounts can be taken into account if the ordered product is ordered in a larger volume than specified [19].

We can conclude that since each enterprise has its own characteristics in defining the problem of cash flow management, production organization, and modeling, the cost function changes. For example, costs include the corresponding capital costs for holding stocks, which are calculated as the product of the cost of goods by the discount rate.

In the simulation model presented in primary financial statements are taken as input, and annual total costs include costs resulting from the loss of marginal profit and capital freeze. In addition, the following indicators can be used: the level of customer service, the implementation of the plan for the sale of goods, the evaluation of the work of suppliers (delivery on time), the reduction of excess stocks, the profitability of assets, etc.

5 CONCLUSIONS

Algorithms for determining and managing warehouse reserves at the "Uztemiryolyolovchi" JSC's passenger wagon depot have been developed by changing the classical algorithm. This method aims to optimize the order on the Reserve while also simulating the demand for reserves. The proposed algorithm allows you to replenish reserves and maximize their volume while taking into consideration the stochastic nature of demand and delivery time.

Key results demonstrate that the use of simulation-based optimization significantly reduces total inventory costs, minimizes REW (repair and equipment work) delays, and enhances resource allocation efficiency. The study also proved the effectiveness of a hybrid modeling strategy that includes deterministic formulas (e.g., Wilson's formula) and stochastic simulation algorithms, thus addressing the limitations of using purely analytical or static methods in dynamic environments. The integration of the ASAG system and object-oriented simulation blocks has shown promising outcomes in real-world application scenarios. The simulation-optimization framework developed can be adapted to other industrial depots facing similar logistical uncertainties.

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