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Methodological Approaches to Accounting Uncertainty When Planning Lgistic Business Processes

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***Abstract*— The practice of managing logistic business processes in companies has many examples when negative scenarios are realized in the course of events that are unforeseen at the planning stage, and ultimately lead to significant damage. These circumstances define the necessity to develop methods to reduce the risks of the negative impact of uncertainty or inadequate information, which is typical for the planning stage, on the final results. The paper describes methodological approaches to accounting uncertainty in models and methods which are used to plan logistics business processes in a company in order to reduce these risks. At the same time, in order to ensure that the plans are sound, it is proposed to form arbitrary reserves of allocated resources that compensate for uncertainty. Taking into account various types of the information situation at the planning stage, methods are proposed for determining appropriate levels of such reserves of allocated resources. The suggested methodological approaches to accounting uncertainty form a basis for building specific models and methodologies to be used for planning logistics business processes of various companies, given their features. These models and techniques are an important element in the digital transformation of logistics business processes. Their use leads to lower costs in the implementation of these processes.**

Keywords — digital logistics, logistics business processes, planning, uncertainty, risks, soundness and feasibility of plans

I. INTRODUCTION

Today logistics is one of the most important components of business models, not only for a logistic, trading or distribution company, but also for virtually any manufacturing enterprise. The quality of logistics processes management is a key condition for ensuring the efficiency and competitiveness of the company. Failures in the implementation of plans concerning logistics business processes cause significant material and reputational damage. [1-3] As an example, we can cite the suspension of automobile production by AvtoVAZ from July 3, 2019 at factories in Tolyatti and Izhevsk. The reason for the downtime was a breach of obligations under a supply agreement and a failure in the supply of necessary components by the Plant Autocomponent in Nizhny Novgorod.

An analysis of the causes of such failures indicates that consistent execution of relevant plans for logistic business processes can only be achieved if necessary resources are actually available [4 - 8]. The availability of these resources at each stage of business processes is determined by many factors that cannot be accurately defined during planning. Therefore, the actual and planned amount of resources may differ significantly. Thus, with a realistic approach to the planning of logistic business processes, it is not advisable to focus on full availability of all allocated resources. This is due to a significant risk of nonrealizability of respective planned decisions.

To minimize such risks, logistics business processes should be planned on the basis of reduced levels of available resources. For example, when optimization models of mathematical programming are used as a tool to generate planned solutions, this is formally expressed in a decrease in the upper limits of the amount of allocated resources in the respective balance constraints [9 - 13]. In fact, this reduction is equivalent to the creation of arbitrary reserves of corresponding resources to compensate for uncertainty. At the same time, both insufficient and excessive reservation ultimately leads to reduced quality of planning [14–16]. In this regard, the task of determining the appropriate levels of reservation to ensure the required reliability of realizable plans for logistic business processes in conditions of uncertainty seems to be highly relevant.

The development of approaches to solving this problem in the context of digitalization of logistics processes is the goal of this article.

II. Description of approaches

When solving the problem of determining appropriate reserve levels, the criterion for achieving the required reliability of compliance with each *n*-th balance condition in optimization models used in the practice of planning logistic business processes can be represented as a certain relation:

$$K_\nu = \theta(\alpha_\nu \le x_\nu), \quad \nu \in G, \tag{1}$$

where G is the set of balance restrictions on used resources;

ν is a resource type identifier;

α_ν is the upper limit of the quantity of the resource of the ν-th type used when solving the optimization problem;

x_ν is the actual amount of the resource of the ν-th type.

Value α_ν is related to the maximum amount B_ν of the corresponding resource by the following equation:

$$\alpha_\nu = B_\nu - C_\nu, \quad \nu \in G, \tag{2}$$

where C_ν is the arbitrary reserve of the resource, taken into account by the ν-th limit, allocated when solving a problem to compensate for uncertainty.

Let us denote:

$\Delta B_\nu = [B_\nu - x_\nu]$ is the largest absolute deviation of the actual quantity of a resource of the ν-th type from the maximum (absolute interval of uncertainty);

$\varphi_\nu = \Delta B_\nu / B_\nu$ is the greatest possible relative deviation of the actual quantity of a resource of the ν-th type from the maximum (relative interval of uncertainty);

J_ν is the actual deviation of the resource quantity from the center of the uncertainty interval during implementation of the plan.

With the agreed notation, the actual availability of the resource can be represented by one of the following dependences:

$$x_\nu = B_\nu\left(1 - \frac{\Delta B_\nu}{B_\nu}\right) + \frac{\Delta B_\nu}{2} + J_\nu; \quad -\frac{\Delta B_\nu}{2} \le J_\nu \le \frac{\Delta B_\nu}{2}, \nu \in G, \tag{3}$$

$$x_\nu = B_\nu(1 - \varphi_\nu) + \frac{B_\nu \varphi_\nu}{2} + J_\nu; \quad -\frac{B_\nu \varphi_\nu}{2} \le J_\nu \le \frac{B_\nu \varphi_\nu}{2}, \nu \in G. \tag{4}$$

These dependences express the actual availability of the resource through the known deviation J_ν of its value from the center of the uncertainty interval. They are linear transformations that transfer the coordinate origin, in which the value of the resource is measured, to the center of the uncertainty interval.

Let us denote $\Delta B_\nu / 2 = B_\nu \varphi_\nu / 2 = \varepsilon_\nu, \quad \nu \in G$.

Then from (2) - (4) we have

$$x_\nu = B_\nu - \varepsilon_\nu + J_\nu, \quad -\varepsilon_\nu \le J_\nu \le \varepsilon_\nu, \quad \nu \in G. \tag{5}$$

Here, the criterion (1) can be represented as follows

$$K = \theta(C_\nu \ge \varepsilon_\nu - J_\nu), \quad \nu \in G. \tag{6}$$

Taking into account the specific type of criterion dependence (1), the following three basic approaches can be distinguished for solving the problem of ensuring the realizability of the elements of a logistic business process plan under conditions of uncertainty:

1. Provision of an absolute guarantee of realizability.

2. Provision of probabilistic guarantee of realizability.

3. Provision of minimal efficiency losses associated with reserving resources to compensate for uncertainty.

In the first case, uncertainty is modeled by fixing the boundaries of a possible region of variation of the parameter value. Here, the task of ensuring the realizability of the elements of the plan for the innovative development of the defense industrial complex is formulated as follows.

Identify the vector $C = \|c_\nu\|$ of the smallest values of parameters c_ν, for which $c_\nu \ge \varepsilon_\nu - J_\nu$, for all possible values J_ν from the uncertainty interval $-\varepsilon_\nu < J_\nu < \varepsilon_\nu \quad \nu \in G$.

At the same time, the diversity of possible combinations of uncertain factors is ignored and only their worst combination is taken into account, leading to the actual deviation $J_\nu = -\varepsilon_\nu$. The components of vector C in this case are taken equal to

$$\mu\iota\nu\ X\} = 2\sum\} \quad \nu \in G. \tag{7}$$

Such a straightforward approach to ensuring the realizability of the elements of the plan cannot be considered appropriate, since the probability of the realization of an unfavorable combination of parameters may be very small [17,18]. In this case, the determination of parameters C_ν from formula (7) leads to an unreasonable narrowing of the search for optimal solutions and, in general, to a reduced quality of planning.

The second approach is based on introduction of a probabilistic measure of the uncertainty of the values of the parameters J_ν $\nu \in G$ and setting a guarantee of realizability through a certain value of this probabilistic measure [19]. Here, the task of ensuring the realizability of elements of the plan for innovative development formally consists in determining the vector

$$C = \|c_\nu\|, \quad \nu \in G, \tag{8}$$

such that

$$K = P(C_\nu \ge \varepsilon_\nu - J_\nu) \ge \gamma_\nu, \nu \in G, \tag{9}$$

where γ_ν is the required guaranteed probability of fulfillment of the ν-th balance limit;

$P(.)$ is the probability of the fulfilment of condition $c_\nu \geq \varepsilon_\nu - J_\nu \quad \nu \in G$.

In solving problem (8) - (9), the hypothesis that each random variable $J_\nu, \quad \nu \in G$ is distributed according to the corresponding normal law can be used. Then the components of vector C for given values of γ can be determined by the formula

$$\min C_\nu = \varepsilon_\nu - \Phi^{-1}(1-\gamma_\nu)\sigma(J), \nu \in G, \quad (10)$$

where

$$\Phi = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{t} exp\left(Z^2/2\right)dz.$$

In the calculations, instead of the standard deviation $\sigma_\nu(J)$, its estimate $\sigma_\nu^0(J) = \frac{1}{3}\varepsilon_\nu \quad \nu \in G$ can be used.

Then

$$C_\nu = \varepsilon_\nu\left(1 - \frac{1}{3}\Phi^{-1}(1-\gamma_\nu)\right) \quad \nu \in G \quad . \quad (11)$$

Comparing the minimum values of C_ν obtained by formulas (7) and (11) shows that even when choosing γ_ν close to one, taking into account the probability of occurrence of different values of the parameters J_ν reduces the need for reserves. For example, for γ_ν = 0.98, this gain is 16%. To determine the appropriate values of the required probabilities γ_ν we can use the condition

$$\gamma_\nu = \varepsilon\xi\pi(\lambda\nu(\gamma)/\nu), \ \nu \in G, \quad (12)$$

where γ is the required guaranteed probability of the implementation of the entire set of limits included in subset G;

n is the number of limits included in subset G.

In the calculations it is advisable to use the values γ = 0.8 ... 0.95.

The *third approach* providing the necessary guarantees of the realizability of plans for logistic business processes is based on estimating losses associated with overestimating or underestimating the values of the components of vector C relative to some optimal levels [17, 18].

Let us denote:

λ_ν is the specific loss caused by overestimation of the value of parameter C_ν;

μ_ν is the specific loss caused by underestimation of the value of parameter C_ν.

Then the loss function can be represented as follows

$$P_\nu = \begin{cases} (j_\nu - C_\nu)\mu_\nu, & npu \ \ C_\nu^* < J_\nu, \\ 0, & npu \ \ C_\nu^* = J_\nu, \\ (C_\nu - J_\nu)\lambda_\nu, & npu \ \ C_\nu^* > J_\nu, \end{cases} \quad (13)$$

where $C_\nu^* = \varepsilon_\nu - C_\nu, \quad \nu \in G$.

The mathematical expectation of losses in this case is equal to

$$\overline{P}_\nu = \int_{-\infty}^{C_\nu^*}(C_\nu - J_\nu)\lambda_\nu f(J_\nu)dJ_\nu + \int_{C_\nu^*}^{\infty}(J_\nu - C_\nu)\mu_\nu f(J_\nu)dJ_\nu \quad , \quad (14)$$

where $f(J_\nu)$ is the distribution density of the random variable J_ν.

In accordance with (14), the mathematical expectation of losses depends on parameter C_ν^*.

To minimize losses, the condition must be met

$$\frac{d\overline{P}_\nu}{dC_\nu^*} = 0, \quad \nu \in G \quad . \quad (15)$$

Using the rule of differentiation by parameter, we obtain

$$\frac{d\overline{P}_\nu}{dC_\nu^*} = \int_{-\infty}^{C_\nu^*} f(J_\nu)dJ_\nu + \mu_\nu \int_{C_\nu^*}^{\infty} f(J_\nu)dJ_\nu = 0, \quad \nu \in G \quad (16)$$

Taking into account that

$$\int_{-\infty}^{C_\nu^*} f(J_\nu)dJ_\nu + \int_{C_\nu^*}^{\infty} f(J_\nu)dJ\nu = 1, \quad \nu \in G \ ,$$

from (16) we obtain that the optimal value C_ν^* must satisfy the condition

$$\int_{-\infty}^{C_\nu^*} f(J_\nu)dJ_\nu = \frac{\lambda_\nu}{\lambda_\nu + \mu_\nu}, \quad \nu \in G \quad . \quad (17)$$

It can be shown that for those C_ν^* which satisfy the necessary conditions (17), sufficient minimum conditions are also satisfied. Thus, knowing the density function of the distribution of the random variable J_ν and the specific losses λ_ν and μ_ν we can obtain the optimal values $C_\nu = C_\nu^*$. In particular, with the normal distribution law

$$C_\nu^* = \varepsilon_\nu - \Phi^{-1}\left(\frac{\lambda_\nu}{\lambda_\nu + \mu_\nu}\right)\sigma(J_\nu), \nu \in G, \quad (18)$$

or taking into account the estimation $\sigma_\nu^0(J) = \frac{1}{3}\varepsilon_\nu$,

$$C_\nu^* = \varepsilon_\nu\left[1 - \frac{1}{3}\Phi^{-1}\left(\frac{\lambda_\nu}{\lambda_\nu + \mu_\nu}\right)\right], \nu \in G, \quad (19)$$

where Φ-1 is the inverse Laplace function.

III. Conclusions

In general, the considered approaches to modeling uncertainty in the conditions of digital logistics make it possible to obtain sustainable versions of plans for logistic business processes.

The second approach can significantly reduce the level of resource reservation and at the same time provides a high probability of realizability of the elements of the plans under consideration.

The third approach minimizes the loss of resource efficiency associated with the reservation required for the implementation of logistic business processes plans.

The proposed methodological approaches to accounting for uncertainty form the basis for constructing specific mathematical models and techniques for digitalizing logistics business processes and applying modern information technologies when planning them, taking into account the characteristics of various companies.

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