

# Algorithms of digital transport corridors of 3PL logistics

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**Abstract**— Cooperating between countries in the field of digital economy on labeling and traceability of goods, and creating digital transport corridors were the issues addressed at the meeting of the Supreme Eurasian Council held in 2019. This requires conducting research in the cyberspace development on machine-to-machine information exchange in real time. Organizing cost-effective work of all parties in such business calls for developing automated intelligent systems for making the best management decisions. They should be based on expert algorithms that process information in real time and produce results by the criterion of maximum economic effectiveness. The difficulty consists in the fact that the work of a third party logistics operator usually requires a multimodal regime involving a distribution center technology in a pick-by-line or cross-docking mode, and total costs have to be optimized, since the owners of the transport infrastructure are also interested in maximizing profits. To build the algorithm, we used the connection of these tasks through capacity and tariff regulation data. As a result, a mathematical model of multimodal transportation has been developed and a method has been proposed for optimizing the 3PL operator's strategy by the criterion of the balance of economic effectiveness of a participant in logistics activities. This objective is important because advancement of digital technologies plays a decisive role both in the competitiveness of the EAEU, countries and economic unions in the whole world.

**Keywords**— *logistics, transport, digital, algorithm*

## I. INTRODUCTION

Today the market of transport and logistics services is developing due to the achievements of information technology. Its specific nature lies in a wide, geographically extended field of activity, including cross-border interaction. There is also a significant variety of both loading and unloading points and the choice of options for cargo movement. The constant movement of vehicles and participants is also its specificity. The effective interaction of all participants involved in such business requires mobile management systems [1] based on cloud solutions, and creating automated intelligent systems for making optimal management decisions. They should be based on expert

algorithms that process information in real time and produce results by the criterion of maximum cost effectiveness. In such a case two interrelated tasks must be approached. Since the contractual work of a 3PL (Third party logistics) operator in a vast majority of real cases takes place in a multimodal mode, where, according to the concept of the external logistics side, there is a DC (distribution center) in either a pick-by-line or a cross-docking mode, total costs have to be optimized. On the other hand, the owners of the transport infrastructure, such as toll roads, railways, DC, etc., are interested in maximizing profits. The connection between these two tasks is that the infrastructure has a limited capacity resource [2], so tariff regulation should be based on minimizing time loss and wear, and, on the other hand, on maximizing traffic.

While the first problem is solved by stochastic programming, the second one is tackled by methods of mathematical game theory. This allows us to take into account the risks of long-term planning concerning the costs of transportation and income from the provision of transport infrastructure. Today, a 3PL operator and transport infrastructure owners on the outer contour of their business are fully connected not only with economic and information [3] relations. In this field of commercial activity, they are also united by material, physical interaction, and a coordinated solution will allow doing business with a maximum benefit for both participants. The obtained methods can serve as a basis for the formation of digital transport corridors and will facilitate the execution of smart contracts as much as possible. In addition, 3PL operators rely on the digital environment, machine-to-machine interaction, machine-readable codes, and the formalization of supply chain management, and it is necessary to bring it to the level of algorithms. Optimization with the use of computer methods will minimize physical contact with the cargo, and will ensure online control of forwarding regardless of its location.

Globalization, as a dominant factor of development, was reflected in the concentration of retailers' business. Stable

network trading structures were formed, and the strive for specialization resulted in logistics becoming an individual segment of the economy. However, the success of information technology [4], standardization of encodings provided a high level of M2M (Machine-to-Machine) interaction and the growth of the online trading segment. Within this paradigm, there is a need to effectively manage the movement of goods from manufacturers to network distribution centers, as well as to optimize supply within the nodes of the distribution network. Solutions in this sphere belong to the SCM (Supply Chain Management) class, which considers the movement of goods and the optimal management of such processes. SCM algorithms have only just begun to develop. The analysis of advanced methods for solving problems shows that today the 3PL concept has no alternatives. According to the reports of the CSCMP (The Council of Supply Chain Management Professionals), a recognized expert in the field of logistics and the activities of distribution centers, the developers' efforts are concentrated on improving the algorithms [5] of multimodal logistics, and methods used on contact surfaces. This is not only cross-docking or pick-by-line, but also coordinating the use of such a common resource provided to all logistics operators, as transport infrastructure.

## II. STATEMENT OF THE PROBLEM

The interaction of the 3PL operator with the transport infrastructure is considered. The logistics company works in a multimodal mode involving an intermediate DC (distribution center). In turn, the owners of transport routes act in the conditions of limited resources such as the carrying capacity of a highway or railway, and the distribution centers, as finishing points of transport routes, have a limited capacity of the loading and unloading terminals. A mathematical model of the functioning of such a system has to be created. Since the business participants have opposite goals, it is necessary to find the optimal stable solution, from which no participant finds it beneficial to deviate.

## III. MATHEMATICAL MODELING

To search for optimal management decisions and develop a mathematical model [6] let us formulate the conditions and limitations, and also denote the corresponding formalisms. Since the current commercial activity takes place in the market environment of stochastic demand [7], the solution methods must take into account the fact that the model parameters are described by probability distribution functions. The corresponding mathematical methods, computer modeling, optimization principles are used to solve the problem. Also, when describing the activities of the distribution center, CSCMP standards are needed as a reference for unifying the practical results of calculations.

### 1) Interaction task

Comprehensive business planning of the 3PL operator is carried out taking into account the limited resources on the

outer contour. This is primarily the carrying capacity of the transport routes of both highways and railways. In addition, the concept of multimodal transportation in its essence includes the limited resources of the distribution center. Since all the abovementioned objects are necessary for the business participants [8] competing for the use of these services, with an increase in the intensity of their usage a number of negative factors are bound to emerge. It is not only delays in cargo transits, queues, traffic jams which directly cause financial losses for logistics operators. The owners of the infrastructure bear the cost of expanding the routes, building interchanges. Moreover, today they are held responsible for environmental damage and taking measures to reduce the adverse impact on the environment. The result is the need for tariff restriction of traffic. Thus, in the system "3PL operator-transport infrastructure" the feedback [9] path closes through financial regulation.

Based on the above, we can formulate one of the aspects of the problem discussed in the paper. We have to present a mathematical model of the interaction of the transport infrastructure load and the traffic costs of a logistics company, taking into account the balance of profits of both parties involved in this commercial activity. As a result of the calculation, it is necessary to obtain forecast data on the traffic cost and the maximum intensity of transport usage in logistics business.

To formalize the problem and to generate dynamic equations, we introduce the following definitions. The transport infrastructure has  $n$  users, including logistics companies. The load on the resources of each of them is equal to  $L_i$  where  $i=1..n$ . The general transport situation is described by a vector  $\bar{L} = (L_1, L_2, ..., L_n)$ . Then the total load is  $\check{Y} = \sum_{i=1}^n L_i$ . Its values are used to describe the density of traffic flow  $\lambda_T$  by introducing a coefficient of proportionality  $\check{Y} \xrightarrow{\kappa_T} \lambda_T$  and to calculate the load  $\lambda_D$  of the distribution center  $\check{Y} \xrightarrow{\kappa_D} \lambda_D$ . Then, using the Erlang formulas obtained in the queuing theory, we write the expressions for calculating the queues  $Q^*$  and the average time  $\bar{t}_T, \bar{t}_D$  spent on the tracks and on the service in the distribution center.

$$\bar{t}_D = \frac{Q^*}{\lambda}; \quad Q^* = \frac{\alpha^{n+1} p_0}{n \cdot n! \left(1 - \frac{\alpha}{n}\right)^2},$$

$$\text{where } p_0 = \frac{1}{\sum_{k=0}^n \frac{\alpha^k}{k!} + \frac{\alpha^{n+1}}{n! (n - \alpha)}}; \quad \bar{t}_T = \frac{N}{\lambda}; \quad N = Q^* + \alpha.$$

Now, as we know the mathematical expectation of the value of variable costs  $U$ , we can determine for calculations a set of functions  $g(L_i)$  that show the amount of revenue from the activities of each of the logistics operators. On the assumption of the limited resources [10] of the transport infrastructure, with a total load  $\check{Y}$  starting

from the value  $\check{Y} > \check{Y}^*$ , the profitability of business decreases. Formally, we write it in a form of negativity of the first derivative  $g'(L_i) < 0$ . In addition, the statement of the problem indicates the limitation of transport infrastructure, which contributes to the negative impact on the profits of each of  $n$  users, including logistics operators. Then we can formulate an additional condition on the second derivative:  $g''(L_i) \leq 0$ .

In this form, the formula for  $R_i$  - income of  $i$ -th user, where  $i = 1...n$ , is as follows:

$$R_i = L_i g_i(L_1 + L_2 + \dots + L_n) - U L_i = L_i g_i(\check{Y}) - U L_i \quad (1)$$

In this case, according to the Nash theorem, there is always a level of load on the resource by the  $i$ -th enterprise  $L_i^*$ , at which the value of expression (1) reaches a maximum with the remaining components of vector  $\bar{L} : \bar{L}_i(L_1^*, L_2^*, \dots, L_{i-1}^*, L_{i+1}^*, \dots, L_n^*)$ . To search for an extremum, taking a set of partial derivatives of the form  $\frac{\partial R_i}{\partial L_i}$  for all

$i = 1...n$  and equating them to zero  $\frac{\partial R_i}{\partial L_i} = 0$ , we introduce

sums  $L_{-i} = \sum_{k \neq i} L_k^*$ , which allow us to write the following

equation:  $g_i(L_i + L_{-i}) + L_i g'_i(L_i + L_{-i}) - U = 0$  for each  $i = 1...n$ . If we then calculate the sum at the equilibrium

point  $\check{Y}^*$ , we get the following result:  $\check{Y}^* = \sum_i \frac{U - g_i(L_i^*)}{g'_i(L_i^*)}$ .

Since we are interested in finding the maximum from the point of view of the owner of the transport infrastructure, then the level  $\check{Y}^*$  is the optimal load of the resource, its

value is determined from:  $\check{Y}^* = \sum_i \frac{U - g_i(L_i^*)}{g'_i(L_i^*)}$ .

Thus, a part of the mathematical model was formed [11], which derivation shows the interrelation of the activities of logistics operators and transport infrastructure enterprises.

## 2) The task of organizing multimodal logistics

The practical implementation of digital transport corridors is based [12] on expanding the concept of Machine-to-Machine interaction. Today, the problems of cargo identification in any container have already been solved. Within a number of countries and economic unions, standards have been adopted that allow the formation of a unified cyberspace. For example, the European Train Control System (ETCS), a set of common railway traffic standards developed in the framework of international cooperation, has been operating for more than 15 years. Note that the concept of a digital economy is adopted by the Eurasian Economic Union (EAEU) as the basis for ensuring sustainable economic growth. Within this paradigm, machine-readable addressing codes are standardized throughout their movement process. Intelligent automation tools have been implemented at all stages of the supply chain. Notably, data from laser and radio frequency scanners, GPS/GLONASS navigation are processed in a

single cloud server, and information about the operation of robotic distribution centers and warehouse complexes is received in real time. In general, the work of interoperable autonomous transport [13] is based on the use of machine-readable codes. The entire toolset is used for identification, from linear barcode and two-dimensional QR (Quick Response Code) to recognition tools based on RFID (Radio Frequency Identification) tags. Alternative mobile Internet channels are used for all nodes to interact.

The concept of digital transport corridors includes the use of ITF and EAN/UCC standards, which allows the M2M interaction [14] of equipment and cargo on the entire route. Additionally, the rules regulate the use of error correction levels above M, Q to H, due to the need to preserve and restore information. On long logistical routes, part of the digital information may be lost and high levels of encoding restore up to 30% of the information lost due to the influence of the external environment [15] and other adverse factors.

The current machine-to-machine interaction passes through cloud storage gateways [16], and therefore, in algorithms [17], the control object can include not only individual cargoes, but packets. For this purpose, combined RFID schemes are used with access to the freight forwarding server. This is crucial for M2M algorithms of cross-docking procedures and pick-by-line selection, implemented 3PL logistic schemes. In addition, each of the product items must be provided with machine-readable label. Such pass-through digital corridor operates in commercial networks based on SCM (supply chain management) technologies in DC [18] (distribution centers).

On the basis of the afore-mentioned factors, let us develop a mathematical model to optimize management decisions. At first, define the necessary formalisms. We define that the planning of a multimodal transport operator activities takes place in the conditions of market uncertainty. It is reflected in a set of random variables  $c_j$ , where

$j = 1, 2, \dots, m$ , such as requests for delivery, the volume of goods, raw materials, components, traffic. The data of such a consolidated set are determined from statistical analysis. They are the parameters of the distribution function. The values of the mathematical expectation  $m_j = E(c_j)$  and dispersion  $D_j$  are influenced by such factors of market environment as demand, prices, personnel costs, and risks. The only limitation is the Lindeberg condition: for any  $\tau > 0$ , the following must be true:

$$\lim_{n \rightarrow \infty} \frac{1}{B_n^2} \sum_{k=1}^n \int_{|x-m_k| > \tau B_n} (x-m_k)^2 c_k(t) dt = 0,$$

where  $B_n = \sqrt{\sum_{k=1}^n D_k}$ ,  $c_k(t)$  - is distribution density.

Moreover, the dependences of values  $c_j$ , as a rule, are seasonal. For the analytical representation of  $m_j$  we use the

Fourier expansion:  $m_j = A_{0j} + \sum_k A_{kj} \cos(2\pi \frac{1}{12}(k + \theta_j))$ ,

where  $k$  is the number of the planning period,  $A_{0j}, A_{kj}, \theta_j$  are the corresponding coefficients. Let us introduce

controlled variables  $x_j : x_j \geq 0 ; j = 1, 2, \dots, n$ . These are the volumes of transportation [19] by certain types of transport, choice of routes, and capacity. The performance indicators of the distribution centers used in the nodes of the route are also controlled variables.

It is necessary to determine variables  $x_j, j = 1, 2, \dots, n$  under the conditions of the stochastic nature of the information on the actual values taken  $c_j, j = 1, 2, \dots, n$ . The deterministic parameters, such as the carrying capacity of transport units, timetables, volumes of the distribution centers, fixed costs are also used in calculations. We represent them in a parameter set  $a_{ij} ; i = 1, 2, \dots, m, j = 1, 2, \dots, n$ . In addition, we introduce restrictions on them as  $b_i$  set. The deadweight of transport pool is an example of such restrictions.

#### IV. DETERMINING THE CRITERION FOR SOLVING THE PROBLEM

Finally, we formulate the problem as follows: it is necessary to optimize [20] the functional  $\sum_{j=1}^n c_j x_j$  with constraints  $\sum_{j=1}^n a_{ij} x_j = b_i, i = 1, 2, \dots, m$ .

For a multidimensional model, it is necessary to take into account many factors. First of all, a long-term planning is considered, and the solution will be multi-step. With a large dimension of the optimization vector, it is necessary to develop iterative procedures that are convenient for programming. Under these conditions, we propose the following method for obtaining the desired result.

#### V. DECISION ALGORITHM

In this section, we show the development of an optimal solution for a distribution and commercial network when generating a plan for multimodal transportation and workload of distribution centers for a known extended time period. For this, the total quantity of cargo required for business activity during the planning period is assumed to be equal to  $T$  (dimension is arbitrary, for example, in tons or packages).

At the beginning of each of the planning periods, a computer must calculate the following controlled variables:  $x_1$  - is the quantity of goods and cargo transported by one type of transport;  $x_2$  - is the number of goods and cargo transported by the second type of transport;  $x_3$  - is goods and cargo that are processed at distribution centers.

Then, in order to fulfill the delivery program  $x_1$  units of the first type  $a_1 x_1$  of transport will be required for the planned period, and  $a_2 x_2$  units of the second type of transport are required for delivery  $x_2$ . We also denote  $D_1$  and  $D_2$  as the restrictions on the number of each type of transport available for multimodal transportation.

The cost of transporting a cargo unit by the first type of transport is equal to  $r_1$ , and for the second one  $r_2$ . The costs for each shipment are equal to  $r_j(a_j x_j)$  for each  $j$  ( $j = 1, 2$ ). Further, we should take into account the associated costs of servicing a unit of transport, i.e. stevedoring, insurance, etc. Let us denote their size per unit of each type of transport  $j$  ( $j = 1, 2$ ) equal to  $e_j$ . Consequently,  $e_j x_j$  is equal to the total associated costs for the type  $j$ . The optimization criterion will be the amount of expenses  $Q$ :

$$Q = (a_1 x_1 r_1 + e_1) x_1 + (a_2 x_2 r_2 + e_2) x_2 + c_3 x_3 \quad (2)$$

where  $c_3$  is the DC cost per unit of cargo  $x_3$ . By denoting  $c_j = r_j a_j + e_j, (j = 1, 2)$  we rewrite the criterion as

$Q = \sum_{j=1}^3 c_j x_j$ . With determined  $a_j$  ( $j = 1, 2$ ),  $c_j$  ( $j = 1, 2, 3$ ) and  $D_j$ , the problem can become trivial and be reduced to a solution using the linear programming method. In commercial applications, it is necessary to minimize  $Q$ , considering restrictions:

$$\sum_{j=1}^3 x_j = T, a_1 x_1 + s_1 = D_1, a_2 x_2 + s_2 = D_2, x_j \geq 0, s_i \geq 0 \quad (3)$$

where  $s_i$  is a shortage of the relevant units of transport.

Due to market uncertainty, after making a decision on values managers may have real data on costs  $r_1, r_2$  (and, accordingly, values  $c_1, c_2$ ), with a time delay after decision about  $x_1, x_2, x_3$ . Also, values  $a_1, a_2$ , as well as potential levels of  $D_1, D_2$ , are known only in a certain range of random variables. Therefore, in practice, indicators  $s_1, s_2$  will be known only after obtaining accurate data on the values of  $a_j$  and  $D_j$ . It follows that in conditions of market uncertainty, coefficients  $a_j$  and  $D_j$  are random. In order to fully define the optimization task, it is necessary to take into account that the multimodal transport operator delivers an additional amount of cargo which is not specified in the contract at a higher price. This formally corresponds to the excess of  $a_j x_j$  over  $D_j$ . To take this factor into account,  $(t_1, t_2)$  is added to the left side of the balance relations (3), and  $(f_1 t_1 + f_2 t_2)$  is added to formula (2) of the objective function. Values  $t_i \geq 0$  simulate the excess of volumes over the contractual ones for transport  $j$ , and  $(f_i t_i)$ , introduces appreciation factor  $f_j$  for the mode of delivery of  $t_i$  units of cargo.

Finally, we formulate the optimization problem as the search for the minimum cost of extended criterion  $Q^*$  of the following form:  $Q^* = \sum_{j=1}^3 c_j x_j + f_1 t_1 + f_2 t_2$ , under condition

$$a_1 x_1 + s_1 - t_1 = D_1; a_2 x_2 + s_2 - t_2 = D_2; \sum_{j=1}^3 x_j = T.$$



The direction-specific appreciation factors  $f_i$  are also of a random nature, their values at the beginning of the planning period and at the time of determining indicators for  $x_j$  are known only at the level of the probability distribution function. In addition, real data  $t_i$ , and, accordingly  $s_i$ , are calculated after the values of random variables that define this mathematical model are determined.

The solution to the problem is reduced to an iterative algorithm of machine-to-machine interaction. At the same time, the data on cargo parameters, such as dimensions, weight, destination, deadlines for storage and restrictions on the type of transport are written in QR encoding and read by computer automatically. This serves as the initial data for the calculation. Let us present the main steps of the solution algorithm on a computer:

- On the basis of values  $e_1, e_2$  and  $c_3$ , values  $x_1, x_2, x_3$  are calculated using a simplex-method
- From analytics, we obtain values  $c_1, c_2$ ,  $f_1, f_2$ ,  $a_1, a_2$ ,  $D_1, D_2$  and the degree of their correlation with values  $x_1, x_2, x_3$ .
- Carry out the calculation of  $c_1, c_2$ ,  $t_1, t_2$ .
- In conclusion, the required values  $x_1, x_2, x_3$  are calculated. from the condition of minimizing the functional  $Q^*$ .

## VI. THE CALCULATION PROCEDURE

Since risk management is carried out when conducting a real commercial activity, it becomes possible to determine a finite number of states  $W$  as a set of indicators ( $f_1, f_2$ ,  $a_1, a_2, D_1, D_2$ ) and a vector of their probabilities  $\bar{P}$  of the same dimension. To program the algorithm, we reduce these states into matrix  $\Omega$  of size  $W \times 6$ . If  $W = 3$ , then the matrix and vector have the form:

$$\Omega = \begin{bmatrix} f_{11}, f_{12} & a_{11}, a_{12} & D_{11}, D_{12} \\ f_{21}, f_{22} & a_{21}, a_{22} & D_{21}, D_{22} \\ f_{31}, f_{32} & a_{31}, a_{32} & D_{31}, D_{32} \end{bmatrix}, \bar{P} = (p_1, p_2, p_3), \sum_i p_i = 1.$$

In this case, the calculation is carried out using mathematical expectations. We obtain:  $E[a_j] = \sum_{q=1}^3 p_q a_{qj}$ ,

and knowing  $E[r_j]$  and  $e_j$ , we define  $E[c_j] = E[r_j] \cdot E[a_j] + e_j$ ,  $j = 1, 2$ .

The final formulation of the model is as follows:  
Minimize expression

$$E[c_1]x_1 + E[c_2]x_2 + c_3x_3 + p_1[f_{11}t_{11} + f_{12}t_{12}] + p_2[f_{21}t_{21} + f_{22}t_{22}] + p_3[f_{31}t_{31} + f_{32}t_{32}]$$

with the following limitations:  $\sum_{j=1}^3 x_j = T$ ;

$$\begin{aligned} a_{11}x_1 + s_{11} - t_{11} &= D_{11}; a_{12}x_2 + s_{12} - t_{12} = D_{12}; \\ a_{21}x_1 + s_{21} - t_{21} &= D_{21}; a_{22}x_2 + s_{22} - t_{22} = D_{22}; \\ a_{31}x_1 + s_{31} - t_{31} &= D_{31}; a_{32}x_2 + s_{32} - t_{32} = D_{32}. \end{aligned}$$

The resulting set of formulas is a mathematical model developed to solve the problem of optimizing multimodal transportation. The resulting model is presented for a dimension of three. However, expressions allow us to calculate a real set of indicators of a larger size, since the presented formulas are scalable and the algorithm can be written in a matrix form. The dimension of the model is not limited, not only parameters related to multimodal transportation, but also related processes, such as cross-docking, pick-by-line, included in a common machine-to-machine interaction chain, can be used as control variables.

Also, such important indicators for cross-border digital corridors as customs clearance, passing of the border control, including delays in transportation when crossing state borders and changing of carriers, can be included in the parameters. At the same time, it is necessary to control the dimension of machine readable codes on transported cargo so that it contains the necessary information for the algorithm.

## VII. CONCLUSION

The algorithms presented in the paper are aimed at implementing the concept of a digital transport corridor. Such methods can be used primarily by companies associated with complex logistics solutions. This will contribute to further convergence of economies of different countries. Efficient functioning and optimization of digital transport corridors in the context of active globalization of all branches of the economy provide a wide field for the implementation of innovative methods for managing the movement of goods in cross-border supply chains. The success of the first organizational measures in that process in the framework of the Eurasian Economic Commission was noted in May 2019 at a meeting of the Supreme Eurasian Council. The importance of cooperation between countries in the field of digital economy in labeling and traceability of goods was noted at the state level. This provided incentives for the research towards forming cyberspace on machine-to-machine information exchange in real time. Reducing the share of physical contact with goods, permanent control over their movement, allows for a deeper assessment and minimization of risks. Another crucial implication of these studies will be the growth and automation of the smart contract segment. Since they are based on a computer algorithm, their use is logically justified in digital transport corridors, and the presented results are specifically aimed at machine-to-machine interaction at all stages of multimodal logistics. At the same time, the main role is assigned to deep scientific optimization methods. Systems engineering of 3PL business also takes into account RM (The Risk Management Process), through choosing optimal business strategy options. In turn, in this task the quality of managerial decisions criterion is balanced by maximum profit, which

will make it possible to realize a serious competitive advantage using innovative methods.

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