Simulation Model of the Process of Delivering Small Consignments in International Traffic Through the Terminal System

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Abstract. The study examines alternative delivery technologies for small shipments (of cargo transportation by small batches) in international traffic based on the terminal system. The Terminal Cargo Delivery System is a complex system that requires continuous improvement of existing approaches and models to take into account the influence of more factors and features of modern conditions. The use of information technology and automated systems will reduce delivery times and improve the quality of cargo processing. In optimizing the operation of complex transport and warehousing systems, it is advisable to use modern information and communication technology and simulations to make a correct decision on the choice of a rational cargo delivery option to minimize the costs of logistics companies. Mathematical formalization of the process of cargoes delivery between terminals in intermodal transport under conditions of use of different transport and technological systems is proposed. For the delivery of small consignments in international traffic was developed a simulation model, which identifies priority parameters for alternative transport technology-based delivery systems, taking into account the random timing of certain process operations. The regression analysis determined that the most influential indicator for the total delivery time of the cargoes is the time of customs clearance, which is a random value and depends on external factors. To determine the delivery time of cargoes in international traffic is used the statistical modeling method, taking into account the random component (in particular the time of customs procedures) and the specified restrictions. The simulation and regression analysis results in the dependence of the total cost of small consignments in international traffic on the volume of consignments for the alternative transport and technology systems considered. These dependencies make it possible to define a rational transport and technological system for the given conditions.

Keywords: Small-Batch Cargoes, Process Parameters, Costs, Delivery time, Transportation system, Cargo terminal.

1 Introduction

The role of international terminal systems has increased significantly in recent years. The erroneous choice of terminal development strategy can lead to large economic losses, through the creation of large queues for servicing [1] and the redistribution of lucrative cargo flows to other terminals, including ports in other countries.

The efficiency of the operation of logistics transport distribution systems [2, 3] is achieved by optimizing the management [4] and planning of commodity and related information and financial flows [5-7] through a systematic approach [8] and harmonizing the economic interests of all participants in the logistics system [9, 10].

Multifunctional activities are not possible without the use of modern information technology [11-13] and automated systems [14-16]. The use of such systems reduces delivery times and improves the quality of cargo handling.

2 Literature Review

In the modern transport market, specialists and scientists considerably pay attention to the development of approaches to the development of regional transport systems [17, 18]. In addition, the introduction of resource-efficient technologies [19] in the transport field as a whole [20, 21] and its subdivisions [22, 23]. Researchers are considering the improvement of the efficiency of road freight transport through the synchronization of different types of flows in the international transport of cargoes [24, 25]. The study [24] shows that the duration of information and financial flows is approaching the duration of the flow of cargoes and vehicles, therefore, should be equal efforts should be to reduce the duration of all flows and to organize their harmonious movement [26].

Analysis of literary sources showed that the terminal delivery system was a rather complex system [27, 28], which requires continuous improvement of existing approaches and models to take into account the influence of more factors [29, 30] and features of contemporary conditions [31].

Demand forecasting during the operational period is important for improving the quality of transport services and the use of resources. For forecasting demand, the most promising is the application of artificial neural networks [32-35]. Moreover, the apparatus of neural network modeling can be effectively used in combination with other methods of simulation modeling [36-38].

The studies carried out to prove the usefulness of using modern information and communication technologies [39, 40] and simulation modeling [41] to make a correct decision on the choice of a rational cargo delivery option to minimize the costs of logistics companies [42].

To optimize the operation of complex transport and storage systems, it is advisable to apply simulation modeling [43, 44], which allow for taking into account temporarily, probabilistic, weight and other characteristics of the technological parameters and to investigate the functionality and continuity of the system as a whole.

To synchronize the handling of cargo at the terminal and inter-terminal transport, it is necessary to choose a rational transport and technological system for the delivery of cargoes, taking into account the time of transport, regularity, and availability of carriers. That is why this problem needs to be comprehensively researched and further developed

3 Research Methodology

3.1 Purpose and Task Setting

The main reasons for the lack of efficiency in the application of economic and mathematical models in the management of technological, organizational, technical, and other systems are:

- Lack of an integrated approach to identifying a management challenge framework;
- Lack of adequacy of the economic and mathematical model to the actual process that gave rise to the optimization task;
- Lack of universality of the model in the sense of its adaptability to changing the parameters and structure of real processes.

It is not possible to quantify the task in the proposed variant of formalization and, if possible, a considerable amount of time.

Therefore, to optimize the performance of complex transport and warehousing systems used simulation simulations, which are simpler and more flexible than most other optimization tools. The publication aims to develop a simulation model of the intermodal delivery process between terminals to improve the efficiency of terminal systems.

The objectives of the study are:

- formalization of the intermodal delivery of cargoes between terminals under different transport and technology systems;
- development of a simulation model for the delivery of small consignments between terminals in intermodal traffic under the conditions of the random timing of individual technological operations;
- identification of the area of efficiency of alternative transport and technology systems for the delivery of small consignments between terminals in intermodal traffic.

3.2 Methodology

Intermodal freight delivery technology was formalized, based on the analytical research method. The aid of mathematical simulations evaluates the effectiveness of the use of alternative transport and technological system for delivering cargo between terminals. To improve the efficiency of the intermodal terminal system (in the event of an occasional timing of individual technological operations). The technological system for delivering cargo between terminals is made based on simulation, correlation, and regression analysis.

4 Results

Because of the analysis of the technology for the delivery of small consignments between terminals in intermodal transport, alternative transport technology systems (TTS) have been selected (table. 1). The technological situation for each of the systems is presented as a set of technological operations ($u_{g_m g_{m+1}}, u_{s_m s_{m+1}}, u_{a_m a_{m+1}}, u_{g_n n}, u_{s_n n}, u_{a_n n}$), necessary for the delivery from point 1, item n. The total time for delivery of the cargo, express as:

$$t(\Theta_i) = \sum_{i=1,n} t_i(u_{m,m+1}), \quad (1)$$

$$u \in \Theta .$$

where $t_i(u_{m,m+1})$ - the time taken for technological operations to change from m to m + 1 when delivered via the i-system;

Θ - numbers of delivery systems using alternative systems.

Table 1. - Alternative systems interterminal delivery

Paradigm of the system	Technology
Piggyback delivery	$\Theta_{con} = \{u_{1g_1}; u_{g_1 g_2}; ...; u_{g_m g_{m+1}}; ...; u_{g_n n}\}$
Cargo delivery by rail	$\Theta_{zal} = \{u_{1s_1}; u_{s_1 s_2}; ...; u_{s_m s_{m+1}}; ...; u_{s_n n}\}$
Cargo delivery by road transport	$\Theta_{avt} = \{u_{1a_1}; u_{a_1 a_2}; ...; u_{a_m a_{m+1}}; ...; u_{a_n n}\}$

Then, as a criterion of optimality, it is possible to establish the delivery of:

$$D_t = \min t[\Theta_i]. \quad (2)$$

However, as a rule, the least time-consuming delivery option is not cost-effective. Therefore, unit costs should be taken into account:

$$C[\Theta_i] = \sum_{i=1}^{n} C_i(u_{m,m+1}), \quad (3)$$

$$u \in \Theta$$

where $C[\Theta_i]$ - unit costs for the delivery of cargoes under the i-system;

$C_i(u_{m,m+1})$ - unit costs associated with the execution of process operations from m to m + 1 during delivery on the i-system.

The target function will take the form of:

$$D_c = \min C[\Theta_i] \tag{4}$$

Change TTS from *r* to *j* changes the unit cost and time of delivery, i.e.

$$\begin{cases} t_r(\Theta_i) = t_j(\Theta_i) \pm \Delta t(\Theta_i) \\ C_r(\Theta_i) = C_j(\Theta_i) \pm \Delta C(\Theta_i) \end{cases}, \tag{5}$$

where $\Delta t(\Theta_i)$, $\Delta C(\Theta_i)$ - absolute changes in the time and unit costs of the cargo delivery between terminals when replacing the TTS delivery from r to j.

In summary, the optimal criterion is:

$$D_{tc} = t[\Theta_i]C[\Theta_i]. \tag{6}$$

With comparable delivery systems (other things being equal), the one that gives the minimum value of the criterion considered advantageous D_{tc} :

$$G_{opt} = \min D_{tc} = \min(t[\Theta_i]C[\Theta_i]) . \tag{7}$$

The random value when choosing a rational interterminal delivery system is the delivery time of the cargo. Based on standard time indicators simulations between terminal traffic, which are the mathematical expectation of the time of certain process operations and the generation of their random values.

$$T_h = T_{\text{norm}h} + x_{ih} \cdot \sigma_{i_h} , \tag{8}$$

where $T_{\text{norm}h}$ - the regulatory time of the *h*-th technological operation, h.;

x_i - the probability of a random value exceeding a certain value $T_{\text{norm}h}$ and there will be no more than the given value;

σ_i - Average deviation of the random time of the *h*-th process.

The total delivery time of:

- in piggyback transport:

$$T_{zag}=T_{pidv} + T_{viv} + T_{n\text{-}r}+ T_{navnazal} +T_{trzal}+ T_{mk}+ T_{ofdok}+T_{oc}; \quad (9)$$

where T_{pidv}, T_{vsv} – The time required to bring the goods to the dispatching station and to remove them from the arrival station, h.;

$T_{n\text{-}r}$ – loading and unloading times, h.;

$T_{navnazal}$ – time to load the car on train, h.;

T_{trzal} – time for carriage of goods by rail, h.;

T_{mk} – time of customs control across the state border, h.;

T_{ofdok} – paperwork time, h.;

T_{oc} - process waiting time technical operations, h.;

− Delivery by railway:

$$T_{zag} = T_{pidv} + T_{viv} + T_{trzal} + T_{mk} + T_{n\text{-}r} + T_{ofdok} + T_{perev}, \quad (10)$$

where T_{perev} – time to transfer cargo from vehicle to wagon, h.;

- in the case of delivery by a road vehicle, the calculation of the delivery time according to [45] reflects the continuous-time the vehicle is on the line during the performance of the journey. However, this approach does not fully take into account the specificity of international transport due to the limitations of the driver's work and rest according to the existing standards. Because of the specificity of international road transport, it is proposed to adjust the total voyage time as follows:

$$T_d = \sum_{i=1}^{A} t_{i,i+1} + \sum_{j=1}^{B} T_j + \sum_{k=1}^{C} \tau_k + \sum_{m=1}^{E} \Psi_m , \quad (11)$$

where $t_{i,i+1}$ – time of movement between *i* and (*i*+1) destinations, h.; T_j –time for processing customs documents *j*-s destination, h.; τ_k – loading and unloading times *in k* destination, h.; A, B, C, – Number of traffic sections, customs clearance points and loading and unloading points respectively; Ψ_m – a random component reflecting the limitations of ECTW, h.; *E* – The number of times a car stops while the driver is resting. For each driving day there are two limitations:

$$t_{i,i+1} < T_y; \qquad t_{i,i+1} + \tau_j + \Psi_m < T_d^n , \quad (12)$$

where T_y – continuous driving time;

T_d^n – standard delivery time, h.;

$$T_d^n = 24 - T_r\,, \tag{13}$$

where T_r – driver's rest time, h.

The statistical modelling method is used to determine the delivery time in international traffic under formula (11) taking into account the random component (in particular the time of customs procedures) and the constraints (12). Proposed principle structure of the simulation model of the estimation of parameters of interterminal delivery systems (fig. 1).

Block 2. Input arrays of input parameters: characteristics of the c vehicle and j the type of delivery system TZ_{ic}, the tariffs for the execution of the j-transport operation Tar_{ij}, the normative technical-operational parameters TER_{ij}, the volume of the traffic Q_1 and Q_y, the modeling step z, the distance of the transport L_i.

Block 3. Generation of random time values of certain process operations during delivery of $T_{d\,ij}$, probability of safety risks of cargoes $P(Q)_i$.

Blocks 4-7. Modeling for Q_y load range.

Block 5. Calculation of the performance criterion when meeting the delivery time requirement.

Block 6. Formation of an array of efficiency criteria values at defined load flows.

Block 7. The sub-program for finding the optimum value of the efficiency criterion under given constraint conditions.

Block 8. The sub-program for constructing regression models of the influence of the time of execution of individual technological operations interterminal delivery and the total time of delivery of cargo by the i-delivery system.

Block 9. Decision-making sub-program for choosing the optimal interterminal delivery system.

Block 10. Output the selected characteristics interterminal delivery system.

Software has been developed for the simulation model interterminal delivery of small-party cargoes in international traffic, oriented to the choice of rational TTS under certain conditions, taking into account the random nature of the time of execution of technological operations.Correlation and regression analysis are used to determine the impact of time indicators on the total delivery time.

The experiment was conducted in several phases:

- The total delivery time of small consignments in international traffic has been modeled on a random basis;
- The most significant indicator identified is the time taken for customs control;
- The influence of the random value on the time parameters is highlighted;
- The experiment was carried out at random.

The simulation and regression analysis results in the dependence of the total cost of small consignments in international traffic on the volume of consignments for the alternative transport and technology systems considered. These dependencies make it possible to define a rational transport and technological system for the given conditions.

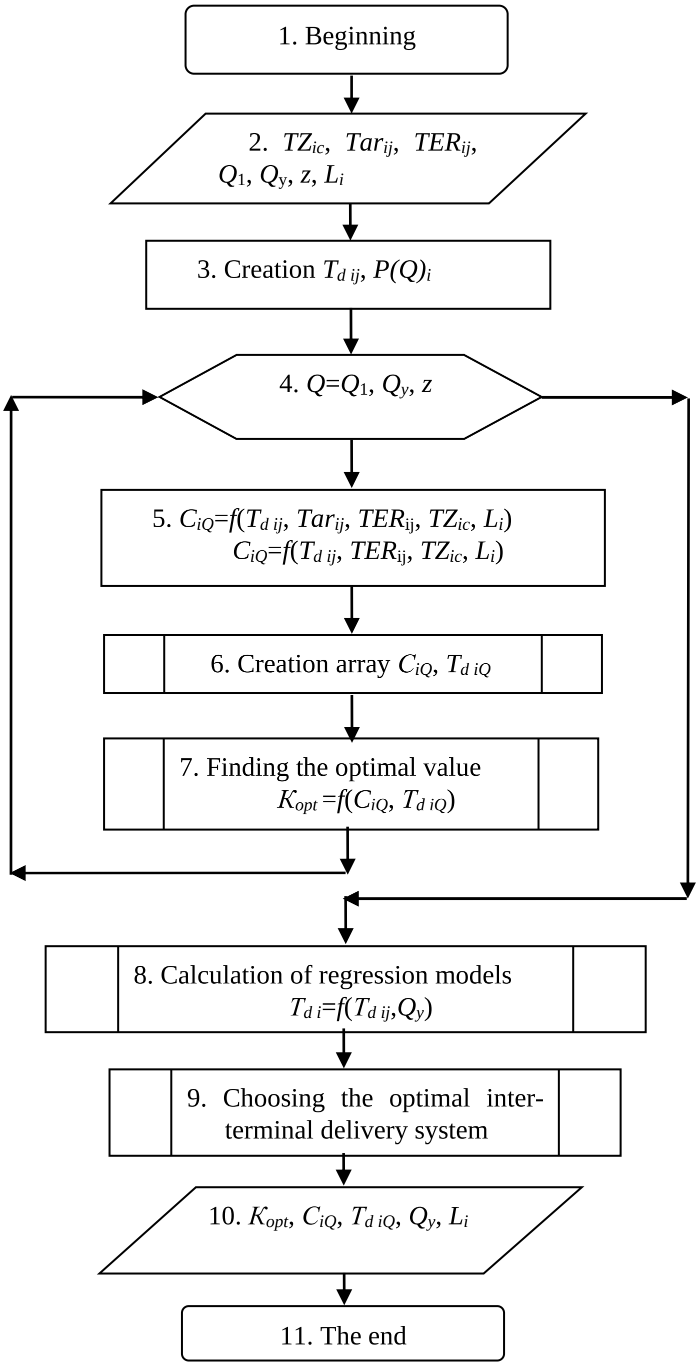

Fig. 1. Principal structure of the simulation model of the estimation of parameters of interterminal delivery systems

5 Conclusions

Mathematical formalization of the process of cargoes delivery between terminals in intermodal transport under conditions of use of different transport and technological systems is proposed.

To select a rational transport and technological system for the delivery of cargoes (taking into account the random nature of the time of certain technological operations), a simulation model has been developed for the delivery of small consignments in international traffic, which allows the prioritization of alternative delivery systems based on risk theory.

The simulation and regression analysis results in the dependence of the total cost of small consignments in international traffic on the volume of consignments for the alternative transport and technology systems considered. These dependencies make it possible to define a rational transport and technological system for the given conditions.

In the future, it is necessary to synchronize the technological processes of the terminal complex and the process of delivery of small consignments between the terminals, which will increase the efficiency of the terminal system as a whole.

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