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Approach to the Forming of Rational Technology for the Export Cargoes Delivery in Supply Chain on the Principles of Co-Modality

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***Abstract*. In this article, we propose an approach to the forming of rational technology for the export cargoes delivery in the supply chain on the principles of co-modality in the context of effective interaction of delivery participants, which allows reducing the costs of all them through the optimal use of resources related to delivery and increasing the competitive advantages of products. Taking into account the strengthening of cooperation between road and rail transport, under modern conditions, combined transport within the international transport corridor is proposed as an alternative option to promote cargo flow in the supply chain. As a result of experimental studies carried out on the basis of the simulation model of the delivery process in the Petri Nets, the time characteristics of technological processes under alternative schemes depending on the input parameters of the model have been determined. A comparative assessment of alternative delivery schemes based on mathematical models has made it possible to establish that the rational scheme for the delivery of export cargo from Ukraine to Germany via the Pan-European Corridor III is the Rolling Highway technology, which ensures compliance with the cargo owner's requirements for delivery time and cost established by the contract. The proposed approach is recommended as a tool for making managerial decisions when planning and organising the delivery of export cargoes from Ukraine to the EU countries in order to effectively manage supply chains by minimising the cost of delivery and environmental damage.**

Keywords: Co-modality, export cargoes, supply chain, sustainability of transportation.

I. Introduction

The reorientation of the lion's share of cargo flows of export products of Ukrainian producers from sea to other modes of transport under martial law has revealed acute problems in existing supply chains related to technological limitations, destruction of transport infrastructure and low level of development of transport and logistics technologies, intermodal and multimodal transport in Ukraine compared to global trends. All this leads to high cost of services, restructuring of logistics supply chains, and as a result, low delivery speeds within the timeframe set by customers. At the moment, the government in Ukraine is emphasising the need to create a flexible logistics system that can respond to external threats as quickly and effectively as possible. Furthermore, the ongoing process of integrating the Ukrainian transport system into the European one requires the development and implementation of advanced logistics solutions based on sustainability principles [1]. Therefore, in the current environment and with the further recovery of the transport industry, new approaches to the development of rational technology for the delivery of export goods in the supply chain are needed, which would minimise the use of resources related to the delivery, reduce the costs of all participants in their interaction, and increase the attractiveness of products for customers [2].

According to Informall BG, huge resources are currently being spent on organising complex intermodal logistics for the export of goods from Ukraine. The consequences of an increase in shipping costs by about 25-40% are the rise in global prices for Ukraine's leading export products and the increase in global prices for Ukraine's leading export products and the risks of a global food crisis [3]. The negative consequences of “Transport visa-free regime” for Ukrainian road carriers are felt both

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for the environment and for European carriers. And many more problems need to be resolved immediately.

Under conditions of increased risk, achieving optimal conditions in the supply chain with a certain level of efficiency is possible only with use of digital logistics technologies [4]. The development and implementation of intelligent transport systems with the introduction of integrated transport technologies based on the principles of co-modality are indicated as key areas for the transformation of the European transport system [5]. Co-modality requires increasing the efficiency, compatibility and interconnection of different modes of transport, as well as the stations and transport hubs connected between them. At the same time, all modes of transport are considered as complementary subsystems, the combination of which can provide users and society with maximum economic, environmental and social benefits [6]. The principle of co-modality is gaining relevance in the context of increased cooperation between different modes of transport, especially for Ukraine in the current environment, when the main freight flows of road and rail transport are directed to western international railway crossings to the EU. Sustainable development and optimal use of resources can only be ensured through the coordinated interaction of all modes of transport in the formation of logistics chains at the macro level [1], which can be achieved by developing delivery technologies within the framework of the ITC. Ukraine is part of several international transport corridors and Ukrainian transport networks are included in the TEN-T indicative maps. The modality of European policy is to ensure the efficiency of cargo delivery through seamless transport corridors with door-to-door service [6]. Ukrainian railways already have experience in organising container trains, the “Viking” transit train between Lithuania and Azerbaijan, and the “Yaroslav” transit train between Ukraine and Poland. Under the current conditions, it is necessary to organise new routes between Ukraine and the EU countries for running of container or contrail trains as part of combined trains. Therefore, we believe that one of the perspective areas of research is the formation of a technology for the export cargo delivery (TDC) in supply chains based on the principles of co-modality by building rational routes through International Transport Corridors (ITC).

Decision-making on the choice of delivery technology is complicated by existing problems of interaction between the players of the transport market due to constant changes in the market itself and the presence of a large number of interconnections between participants in the cargo delivery process [2]. Therefore, we are developing new approaches to the formation of TDC. Most of the approaches are based on the principles of integrated logistics [1], [2], [4], [6] – [14] and aim to solve problems of improving the efficiency of the delivery process in individual logistics chains as subsystems of the logistics system [9]. The analytical models proposed by the authors of [7], [9], [10], [15] to improve the efficiency of the delivery process by forming a rational technology and structure of the supply chain do not take into account the complex impact of random factors of the process.

The author [11] proposes a two-stage stochastic model of a sustainable multimodal system that allows taking into account the uncertainties of the delivery of the shippers and the uncertainties in the performance of the intermodal terminals, without taking into account the risks during the transportation of goods. The approach based on genetic algorithms developed in [14] to optimize a sustainable multimodal freight and logistics system in terms of time, distance, and CO_2 emissions allows the development of strategies to organise the transportation of containerized cargo by rail and river transport to reduce the road transport domination.

The models developed on the basis of Petri Nets in [2], [4], [13] have advantages related to ease of use and visibility compared to the approaches described above. In addition, these models allow one to take into account the probability factors, to study the behaviour of the system and its individual elements, and to obtain their characteristics. However, as a criterion for the efficiency of cargo delivery, the authors of [4], [13] propose to consider only the time parameters of the technological process without a cost estimate that affects the final consumer value of export products in the market.

The purpose of the study is to develop an approach to the forming of a rational technology for the export cargo delivery under modern conditions by choosing an effective option to move cargo flow in the supply chain in a mixed scheme within the framework of the ITC on the principles of co-modality to ensure a high level of quality of service to cargo owners by meeting the established delivery time and ensuring environmental friendliness of transportation.

II. MATERIALS AND METHODS

We believe that the cargoes delivery within the ITC in the direction of Ukraine - EU countries can be classified as combined transport, since the transportation of cargoes along the routes can be carried out according to three alternative schemes considered in the study: by road, by rail and by contrail transit system (Rolling Highway) using road and rail.

The integrated process of combined transportation of goods from the consignor to the consignee involves the performance of certain groups of operations in each module of the system to select modes of transport, connections and transport and technological delivery schemes, prepare the cargo for transportation, load the mainline transport, load and unload and warehouse operations, transport by mainline transport, transport a consignment from the mainline transport terminal to the consignee's warehouse, unload at the warehouse [2], [15]. The set of operations in the modules of the delivery system can vary as well as the characteristics of production resources (types and number of mechanisms, number of workers), ways and methods of organising work. The determination of the rational TDC from a set of alternative ones on the basis of co-modality is determined by the technical and economic characteristics of transport modes, the availability and location of transport and logistics infrastructure of mainline carriers, as well as an indicator that determines the level of service quality in accordance with customer requirements.

The object of research is presented in the form of a structural outline of functional links of the cargo delivery system on the route according to alternative schemes, consisting of modules and related subprocesses performed in the modules (Fig.1).

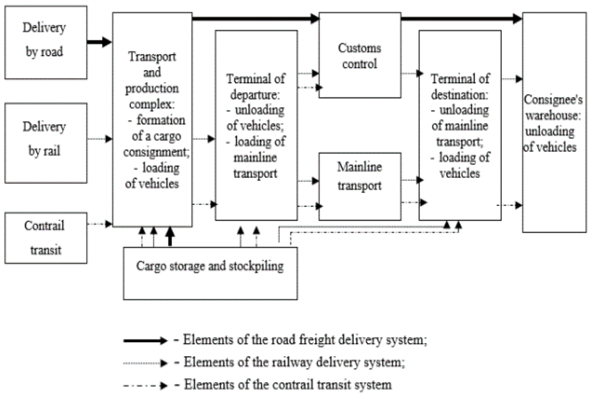

Fig. 1. Structural outline of the functional links of the export cargo delivery system through alternative schemes.

Reliability of the delivery system under certain conditions of the system's operation should be ensured by moving the cargo flow through the system modules with a minimum delay time in each module and the time of the cargo consignment in the system, in accordance with the customer's delivery time and costs.

The level of specific costs for the delivery of cargoes significantly affects the final cost of the cargo, therefore, it is proposed to consider the minimum total specific costs for the transportation of cargoes during the delivery period as an efficiency criterion, as in (1).

$$B_z(t) = f(Q, I, N_{LUi}, K_w, T_d) \rightarrow min, \qquad (1)$$

where B_z are total specific costs, [c.u./t]; Q is the consignment weight, [tons]; I is the time interval between the moments of current request reception and the reception of the next request in a flow, [hours]; N_{LUi} is the number of mechanisms involved in servicing the material flow in the system modules, [units]; K_w is the number of employees involved in the maintenance of material flow in the system modules, [people]; T_d is the time of delivery of a consignment, [hours].

Delivery of cargoes is carried out on a "just-in-time" basis

$$T_d = \sum_{j=1}^{n} t_{ij} \leq T_{agr}, \qquad (2)$$

where t_{ij} is the time for performing consecutive *i-th* technological operations in the *j-th* module of the system, [hours]; T_{agr} is the delivery time according to the agreement with the cargo owner, [hours].

The chosen efficiency criterion allows for a comprehensive consideration of the interests of all delivery participants when choosing a rational cargo delivery scheme. Of the alternative delivery schemes compared, the one with the lowest total specific costs for the delivery period under the "Just-in-time" condition is considered to be the most efficient.

We use mathematical modelling methods to establish the mathematical dependence between the parameters of the research object, to study in detail the processes of the cargo delivery system on the route, to establish accurate quantitative relationships between the input parameters of the model and the output function.

The functioning of individual elements of the cargo delivery system on the route within the ITC is considered as a set of consistently interconnected incoming flows of service requirements (vehicles, cargo delivery orders, cargo flow), service channels (checkpoints, warehouses, terminals, etc.) and outgoing flows of requirements after service. When determining the efficiency of each module and the system as a whole, it is necessary to take into account the unevenness of work that occurs at their "docking points", the occurrence of queues and delays due to downtime of rolling stock and reloading facilities.

We determine the efficiency criterion for each alternative delivery scheme.

The total specific costs of cargo delivery are determined for the delivery period [2], as in (3),

$$B_z = \frac{(B_{TPC} + \sum_1^S B_{Ts} + B_{OC} + B_{MT} + B_{Wcown})}{Q}, \qquad (3)$$

where B_{TPC} is the cost of technological operations in the module TPC, [c.u.]; B_{Ts} is the amount of payment for using the services of the *s-th* terminal, [c.u.]; B_{OC} is the amount of payment to the delivery system operator determined by the cost of organising the delivery of a consignment via the ITC route, [c.u.]; B_{MT} is the cost of delivery of a consignment by mainline transport, [c.u.]; B_{Wcown} is the costs of performing technological operations at the warehouse of freight owners, [c.u.].

The alternative nature of the existing schemes for the delivery of export cargo within the ITC determines the search for a rational TDC of the appropriate level of service, taking into account the resource capabilities of the system elements on the principles of co-modality. The simulations based on the proposed models are carried out taking into account the average time characteristics of the cargo flow through the system, which are obtained as a result of simulation modelling. The simulation model is formalised on the basis of the developed mathematical model (3) using the mathematical apparatus of the Petri Nets (Fig.2). The properties of Petri Nets allow to study the behaviour of the system being modelled and obtain information about its most important characteristics using formal methods.

As a result of the experiment, we determine the characteristics of changes in the time parameters of the cargo delivery system depending on the input parameters. On the basis of the results obtained, we perform mathematical modelling. To determine the dependence of the efficiency criterion on the parameters of the order flow and the numerical parameters of the production resources, we apply regression analysis methods.

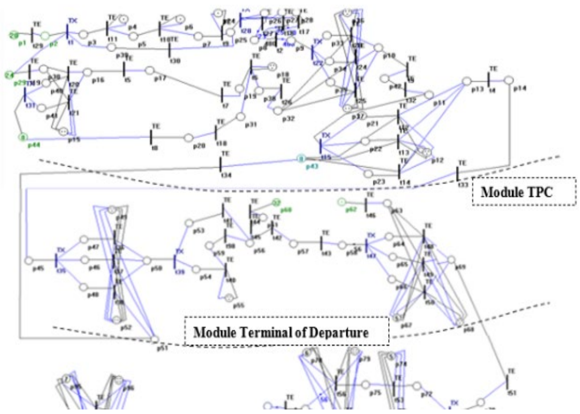

Fig. 2. Fragment of the simulation model of the cargo delivery process by routes within ITC.

To evaluate and select a rational TDC, we determine the economic efficiency of the scheme by the value of the integrated total effect (E_{INT}): the sum of cost estimates of reducing delivery costs (E_1), early release of money due to reduced delivery times (E_2) and reduction of environmental damage (E_3)

$$E_{INT} = E_1 + E_2 + E_3 \rightarrow max \qquad (4)$$

The cost estimate of the reduction in delivery costs when applying the rational TDC, the early release of money due to reduced delivery times, and the reduction of environmental damage can be defined as the difference between the values of the indicators under the rational TDC and the existing option.

The value of environmental damage reduction, as a social effect, is determined by the difference in indicators that characterise changes in the environment as a result of the relevant measures. This measure is the reduction of the vehicle on the route during delivery.

The basis of calculations for determining the social effect of reducing the negative impact on the environment is the determination of fuel consumption and harmful compound emissions during delivery under the existing option (road transport) and under the rational TDC.

III. Results and discussion

The implementation of the proposed approach is presented as an example of the case of transport processes for the Transport Company "Neolith Logistic" (Ukraine), which organises international freight transport, especially between Ukraine and the EU countries. According to the company, one of the most demanded services is cargoes delivery in the direction of Ukraine - Germany. The presented approach was used to develop the rational technology for the delivery of electrical equipment on the route "Kyiv-Berlin" by ITC № 3.

Cargoes are transported by road with a capacity of 22 tonnes using DAF FT 85.340+Schmitz SPR 24/L trucks. The company's data report indicates that there are problems with excessive downtime while waiting for technological operations to be performed during delivery. ITC № 3 passes through the territories of Germany, Poland and Ukraine on the route Berlin (Dresden) - Wroclaw - Lviv - Kyiv. The length of public roads on the Krakowiec - Lviv - Rivne - Zhytomyr - Kyiv section is 617 km. The railway route by ITC № 3 (Mostyska - Lviv - Krasne - Ternopil - Khmelnytsky - Zhmerynka - Kozyatyn - Kyiv) is 648 km long and is fully electrified, double-tracked and equipped with auto-locking devices.

The process of cargo delivery on the Kyiv-Berlin route can be considered under three alternative schemes: TDC.1 - by road through Kyiv - Lviv – Krakow - Katowice - Wroclaw - Berlin; the total length of the route is 1640 km; TDC.2 - by rail on the Kyiv - Zhmerynka - Lviv - Mostyska - Wroclaw – Berlin route; the total length is 1046 km; TDC.3 - by contrail transit system using road and rail transport on the route Kyiv - Lviv - Mostiska - Wroclaw - Berlin as part of a combined train.

To conduct an experiment on three alternative schemes, taking into account the impact of all possible combinations of input parameters within the range of variation on the efficiency criterion, we developed a full factorial experiment plan, consisting of 64 series of experiments.

When varying the input parameters of the model, we monitor the dynamics of the system's functioning in order to solve the problem of coordinating the parameters of technological processes and obtaining optimal values of the efficiency criterion, provided that the delivery time set by the customer is met.

Based on the results of simulation modelling the dynamics of cargo flow in the system for a request with specified characteristics, we determine the time indicators that are the input data for modelling the total specific costs for each of the alternative TDCs.

These are indicators of the time a consignment is located in each module and the total time of cargo delivery, which value, according to the reporting and statistical data, differs from the result of the modelling using the Petri Nets by no more than 10%, which indicates the adequacy of the results obtained (Table 1).

TABLE I. TOTAL TIME OF CARGOES DELIVERY ON THE KYIV - BERLIN ROUTE BY ROAD

Value of incoming flow of cargoes, tonnes	Value of total cargo delivery time, hours			
	Reporting and statistical data		Modelling results	
	Minimum number of resources	Maximum number of resources	Minimum number of resources	Maximum number of resources
15	105	98	120	105
22	120	100	140	128
45	154	120	180	155

At the next stage, we perform a modelling of the total specific costs of cargo delivery based on the time characteristics of the process in the MS EXCEL environment according to the mathematical models using alternative schemes.

The results of the regression analysis showed that among the hypotheses tested, the hypothesis of a step dependence is characterised by the smallest deviation of the variance of experimental values from the variance of the values obtained by the model. The value of the coefficient of determination, close to 1, indicates that the obtained dependence is practically functional. The obtained regression dependencies are proposed to be used to substantiate managerial decisions on the organisation of cargo delivery by routes within ITC.

On the basis of the results of the calculations, the values of the criterion for choosing the rational TDC were as follows: the rational scheme is contrail transit, which ensures compliance with the cargo owner's requirements for delivery time and delivery costs established by the agreement. Compared to the existing scheme, the reduction in specific delivery costs under the rational scheme is 9,80 c.u./t.

The determination of the rational TDC involves the optimisation of the independent variables of the model, numerical parameters of the production resources, based on the simulated time characteristics of the cargo delivery process.

The results of calculations of the components of the integrated total effect for the delivery of a cargo consignment of 22 tonnes on the Kyiv-Berlin route using the rational TDC are presented in Table 2.

TABLE II. THE VALUE OF THE CRITERION FOR THE EFFICIENCY OF CARGO DELIVERY ON THE KYIV - BERLIN ROUTE BY THE RATIONAL TDC

Cargo consignment volume, tons	Components of the total integrated effect			Value of the total integrated effect, E_{int} c.u.
	Value of E_1, c.u.	Value of E_2, c.u.	Value of E_3, c.u.	
22	90,8	15,6	22,0	128,4

When increasing the volume of a consignment or reducing the delivery time of a consignment by increasing the number of production resources at the points of "docking" of the participants' activities, it should be taken into account that delivery costs increased moderately, since the involvement of additional production resources leads to an increase in the cost of technological operations in the system module.

IV. CONCLUSIONS

This paper proposes an approach to the formation of the rational technology for the delivery of export cargo under modern conditions from the standpoint of sustainable logistics. The results of the analysis of the current state of export cargo delivery from Ukraine show that there are problems, in particular, non-compliance with conditional deadlines due to exceeding the normative indicators of cargo delivery time by road. As alternative delivery schemes, the authors consider delivery by road, rail and the technology of combined transport within the framework of the ITC (Rolling Highway).

The mathematical models proposed in this paper allow us to evaluate alternative delivery schemes taking into account demand parameters resource constraints and average time characteristics of cargo flow through the system.

The developed simulation model based on the Petri Nets allows tracking the dynamics of system behaviour, modelling the time characteristics of the process for each TDC depending on the numerical parameters of demand and production resources, making timely management decisions to eliminate commercial risks associated, in particular, with failure to meet the established delivery time.

As a result of the experiment, the total unit costs of cargo delivery under alternative TDC were modelled. The regression models obtained as a result of the experiment allow us to formalise the dependence of the efficiency criterion on the numerical parameters of demand and production resources for alternative schemes. The practical significance of the obtained dependencies is to choose a rational technology under the "just-in-time" condition. It is determined that the rational technology for the TDC of export cargo on the Kyiv - Berlin route is contrail transit as part of a combined train according to the criterion of minimum specific delivery costs. Compared to the existing technology by road, the reduction in specific delivery costs is 9,80 c.u./t.

The performance indicator is integrated and takes into account the main aspects of the transport service, including economic, social and environmental components, in a comprehensive way. The use of the proposed approach ensures the selection of rational technology based on the principles of co-modality and allows taking into account the interests of all delivery participants in the conditions of uncertainty. The integral effect of the forming of a rational technology in the amount of 128.4 c.u. for the delivery of 22 tonnes of cargo is obtained.

The practical application of the proposed approach is to use it in the work of transport companies in planning and organising the delivery of export cargo within the framework of the ITC from Ukraine to the EU countries.

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