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Developing an efficient road-based batch freight delivery technology for intercity connections with a focus on resource conservation

In this paper, we propose the solution of the scientific and applied problem of batch freight delivery in the intercity by road in terms of system's limited resource of the system due to the development of long-distance freight delivery technology in terms of resource savings and the observation of the established level of reliability of the freight delivery functioning of the logistics system (FDLS). For certain parameters of cargo flow with limited resources of the transport market entities involved in the delivery process, the formation of a resource-saving delivery technology allows maximising the effect of the functioning of the system of delivery of consignment cargo by road in intercity traffic.

To solve the problem, we used methods of mathematical modelling, a systematic approach, optimization methods (functions of many variables), the provisions of probability theory and mathematical statistics, methods of regression analysis.

For the given operating conditions of the developed logistics system, the rational technology of long-distance batch freight delivery has been determined in terms of resource savings. It will reduce overall costs by 13.9% for the given level of the readiness of FDLS.

Keyword: *road transport, resource savings, delivery, batch freight, readiness factor*

Introduction. The events of the armed conflict on the territory of Ukraine led to massive disruptions in the movement of road and rail transport. Extraordinary disruptions were observed both on the roads of the country's eastern border, most of which were destroyed or occupied, and on the roads of the western border, which were used by refugees to travel to neighbouring EU countries [1]. The trucking industry has taken on a huge burden due to the blockade of the sea ports and the closure of airspace. The recovery of logistics supply chains for goods under the influence of various risks is slow. According to the developed national program "Expansion and Integration of Logistics with the EU" within the framework of the Recovery Plan of Ukraine, one of the priority areas is the development of road transport, which, in our opinion, can be achieved using a balanced approach that responds to the future projected growth and changes in demand for transportation services, promoting economic development, improving the quality of life of the population and efficient use of resources. Therefore, the task of developing transport and technological delivery schemes in which delivery resources will be minimal is of particular relevance to achieve a balance between marketing requirements and logistics capabilities. It will allow FDLS to make extra profit and distribute it between participants in the delivery process according to their contribution.

It is known that the bulk of the demand for long-distance transportation in Ukraine is occupied by batch freight transportation [2]. Modern road transport conditions dictate the need to find efficient resource- and energy-saving freight delivery technologies that provide high quality customer service and cost-effective road transport.

Currently, the issue of resource savings has not been fully explored in Ukraine. There is no forecast of further development of resource savings in the context of the world economy. This makes it impossible to formulate a state resource savings policy, to develop appropriate regional and state strategic plans for development, and to promote resource savings in Ukraine. Additionally, the issue of resource-saving technologies and the development of computerization will remain a question without improving information technology in road transport, which contributes to reducing of problematic indicators of the transport market.

Today's realities require freight owners to look constantly for new, progressive ways to improve their performance. The extensive experience of developed foreign countries testifies to the necessity of introduction of scientifically grounded approaches to planning and organization of freight delivery in the intercity connection with the use of logistics delivery systems. Within these systems for logistics services and freight owners there is a possibility of operative planning of freight delivery with the maximization of resource efficiency of the delivery process participants.

Therefore, the question of the formation of technology of long-distance batch freight delivery by road in terms of resource savings is relevant and needs further research.

Analysis of recent research and problem statement. The research of the theoretical and practical aspects of increasing the efficiency of long-distance freight delivery was carried out by many scientists, such as B. Anikin, S. Artemyev, D. Bauersoks, V. Belyaev, O. Velmozhin, A. Vorkut, A. Gorev, M. Goryaev, O. Goryainov, V. Gudkov, O. Kalinichenko, I. Levitsky, L. Mirotin, Ye. Nagorny, V. Naumov, V. Nefedov, N. Potaman, M. Pravdin, A. Smekhov, A. Chebotaev, N. Shramenko, O. Shulika, and other scientists.

The task of increasing the efficiency of FDLS in intercity connection can be solved both by updating the technical base and by increasing the efficiency of technological solutions, taking into account resource savings. Insufficient working capital for the acquisition of new rolling stock and historically formed transport and technological delivery schemes do not provide optimal costs and time for long-distance freight transportation. In market conditions, when planning production capacities and implementing transport services, it is necessary to align the logistical goals of the production system with the marketing needs of consumers - freight owners.

The issues of the development of approaches and models aimed at the implementation of resource-saving technologies were addressed by both foreign scientists [2-14] and domestic scientists and scientists from the near-outlands, among whom Ye. Aloshinsky, V. Bobrovsky, V. Gubenko, M. Danko, D. Lomotko, V. Mironenko, Ye. Nagorny, V. Naumov, V. Negri, R. Khabutdinov, N. Shramenko etc.

In [2-4], it is observed that traditional competitive barriers between participants in the logistics supply chain are mitigated to create mutually beneficial relationships. It leads to an increase of information flows, reduction of uncertainty, and a more profitable supply chain. An important aspect in the development of technologies for the implementation of logistics chains is to take into account the principles of "green" logistics [11, 12]. That means reducing the environmental impact of logistical operations. Scientists have stated that the main direction of increasing the efficiency of transport system operation in conditions of fuel and energy deficit [6-10] is the development of resource-saving technologies [9, 13, 14].

Today, scientists are deeply analysing the problem of the so-called "last mile" [15]. Last Mile Logistics is the least efficient step in the supply chain, accounting for up to 28% of total shipping costs. New innovative Industry 4.0 technologies and organizational strategies make it possible to create a real-time planning optimization model focusing on energy efficiency of operations, development of management systems for information and advertising activities of cargo owners, etc. [2]. In the traditional supply chain, increasing energy efficiency is focused on the level of individual parts of the value chain. Industry 4.0 technologies allow you to create hyper communication logistics solutions that aim to reduce energy consumption and reach economically globally.

Regarding the practical aspect of the issue, it can be noted that at present most manufacturers are actively involved in developing variants of their products delivery to final consumers or coordinating them with freight forwarding companies, since the competitiveness of manufacturers depends on the efficiency of delivery. Today, companies that compete solely on the basis of product specifications, sooner or later, find themselves in a disadvantageous situation compared to firms that strengthen their market position, improving the quality of service for freight owners and carriers. In this process, an important role belongs to an effectively organized integrated logistics service, which should be implemented not only at the level of the individual enterprise, but also be a process that unites all participants of the delivery process. Therefore, at the current stage of the long-distance transportation market development, it is advisable to develop new innovative resource-saving technologies to improve and optimize the co-operation and interaction of the long-distance transportation market actors.

In the study [16] four sets of measures have been proposed to introduce a system of long-distance shipping system, taking into account the resource savings. These four types of measures are developed to support economic, social and environmental goals to achieve sustainability. The first set of measures is related to material infrastructure: linear (refers to interconnections) or nodal (refers to areas that may be reserved for freight operations, such as terminals). The second set of measures is related to the intangible infrastructure, which includes road information systems, freight exchange systems, route optimization services, other information services via the Internet and centralized traffic planning (intelligent transport systems). The third set of measures concerns equipment including rules relating to the loading, traction and transportation of new low emission vehicles. The last set of measures is related to traffic management, namely the definition of regulatory rules (such as access time, heavy-duty vehicle network, maximum stopping time, etc.). In long-distance freight transportation by road, the most common are two transport and technological schemes: direct delivery scheme (first scheme) and terminal delivery scheme (second scheme).

The main advantage of the first scheme is direct door-to-door freight delivery. The disadvantage of this is that the collection and transportation of freights inefficiently used the mileage and load of the car, and the load of goods and paperwork in each enterprise associated with considerable time. Often, such an organization requires additional loadings. These further increases downtime and impedes freight delivery. This scheme is used mainly for intra-regional freight transportation.

The second scheme (terminal delivery scheme) consists in the delivery of freights with their transhipment at the terminal only at the point of departure or destination. In the latter case, the freight from the consignor is loaded directly into the vehicle intended for intercity transportation.

The main purpose of the terminal system in the service of freight owners is to take into account their interests in ensuring a full and high quality processing of freights with the rational use of transport and warehouse resources. Thus, in this research, the terminal system was adopted as a modern resource-saving technology for the batch freight delivery. When choosing the best variant of resource-efficient freight delivery technology, the most important parameters are time and cost [17], their correlation in different terms forms the sum of logistics costs associated with the organization of such technologies.

Having analysed the scientific research in the direction of development of resource-saving technologies of cargo delivery, we can note the following. Among the priority areas for improving batch freight delivery, most researchers point to the formation of rational freight delivery technologies, taking into account resource saving and determining the rational amount of resources in the operation of systems of different levels based on the use of logistics principles. Thus, for certain parameters of freight traffic with limited resources of transport market entities involved in the delivery process, the formation of resource-saving delivery technology will maximize the effect of the functioning of the batch freight delivery system by road in the intercity direction.

Purpose and objectives of the study. The aim of the work is to increase the efficiency of cargo delivery on the basis of resource saving and compliance with the established level of reliability of the logistics system of cargo delivery (FDLS) by road transport.

To achieve this purpose, the following tasks need to be solved:

to carry out theoretical studies of the issue of increasing the efficiency of organization of the technological process of delivery of consignment cargo in intercity connections, taking into account the condition of resource conservation

to develop a mathematical model of the process of delivery of consignment cargoes by alternative technologies in intercity connections, taking into account the condition of resource saving

to carry out experimental studies on the selection of a rational technology for the delivery of consignments in intercity connections, taking into account the condition of resource conservation

to determine the optimal areas for the effective use of certain technologies for the delivery of consignment cargo in intercity connections

Materials and methods of the study. The object of research is the technological process of batch freight delivery in the intercity road connection. Direct delivery and terminal delivery systems are considered as alternative delivery schemes (Fig. 1).

The subject of research includes four main participants: consignor (CR), consignee (CE), carrier and terminal. Each participant has an internal structure. The nature and properties of the object of study were revealed between participants and internal communication structures.

The managed object of this system is the market of freight forwarding services (FFM), and terminal services. It consists of the totality of transport and forwarding companies (FFC), terminals (T) that form the offer for long distance batch freight delivery and exist on FFM, and the totality of freight owners (FO) that make up the demand for delivery. FFM is influenced by many external factors, including the economic performance of FFM participants, the road network, etc. (external factors).

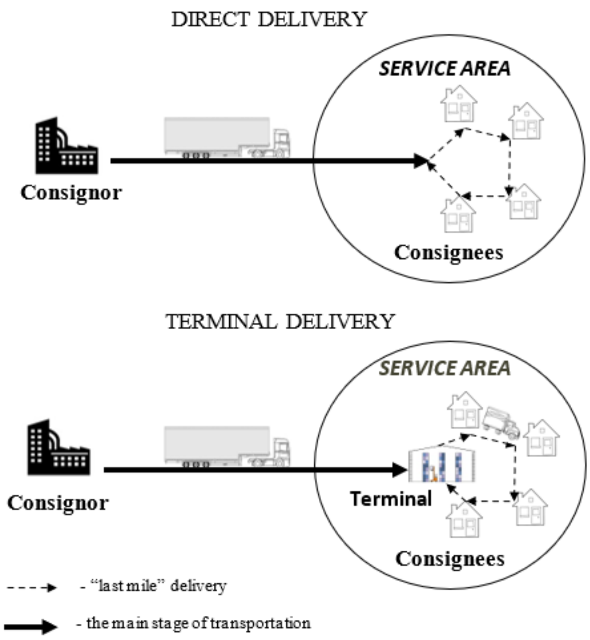

Fig. 1. **Direct and terminal delivery systems for batch freight in the intercity connection**

The process of rendering freight forwarding services in FDLS can be represented in the form of a contour of the functional connections of the formation of technology of batch freight delivery in the intercity connection by road in terms of resource savings (Fig. 2).

The consumer subsystem is formed by freight owners according to the characteristics determined by the complex of necessary feasibility services. Demand for delivery is formed by the flows of FO' requests. The operating parameter of a CR is the manufacturer's processing capacity (*PC*, t/h). The parameters of the FO request flow are: the volume for the request (*Q*, t), the distance of delivery (*l*, km) and the delivery density of the points of delivery in the territory of the service area (λ, km^{-2}).

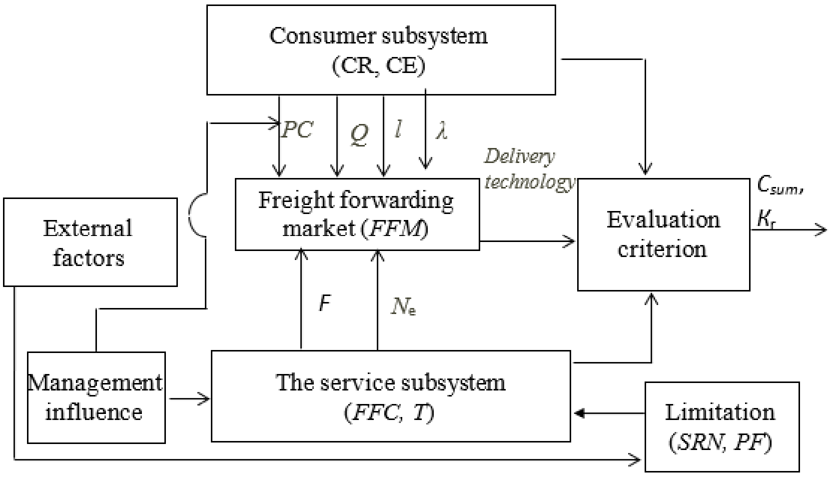

Fig. 2. **Functional link contours for the formation of batch freight delivery in intercity connection by road in terms of resource savings**

Freight forwarding enterprises and terminals form a service subsystem with controlled parameters, which is the amount of labor resources, dispatchers at a freight forwarding enterprise (N_d, person) and the service area (*F*, km^2).

The limitation system takes into account the production facilities (PF) of the service system and the limitations caused by the parameters of the street-road network (SRN).

In this research, to select a rational transport and technological scheme for the batch freight delivery in long distance, the overall cost of freight delivery (C_{sum}) and the readiness factor (K_r) were taken as the criterion of efficiency.

Cost reduction is achieved through the formation of resource-saving technology for the batch freight delivery in long distance. Reducing the overall cost of delivery is an important means of reducing tariffs and thus attracting additional customers. In this case, the use of resource-saving technologies involves ensuring the reliability of freight delivery. Thus, the target function is as follows

$$\begin{cases} C_{sum} = f(Q, l, F, \lambda, PC, N_d) \rightarrow min; \\ K_r = f(Q, l, F, \lambda, PC, N_d) \rightarrow 1. \end{cases} \tag{1}$$

The total cost of long-distance freight delivery is calculated by the formula

$$C_{sun} = C_{FO} + C_C + C_{FF} + C_T + C_{fc}, \tag{2}$$

where C_{FO} – costs of FO operations, UAH;

C_C – carrier transportation costs, UAH;

C_{FF} – forwarding operations costs, UAH;

C_T – costs for processing and storage of freight at the terminal, UAH;

C_{fc} – capital freezing, UAH.

The article suggested that the service area has the shape of a circle (Fig. 1), where one terminal operates, located in the conditional centre of the service area. The system of restrictions and assumptions is as follows

$$\begin{cases} 0{,}4 \le \gamma_s \le 1; \\ Q \le q; \\ 1 \le Q \le 5; \\ 50 \le l \le 1800; \\ 0{,}5 \le \beta \le 1; \\ 13{,}5 \le F \le 350; \\ 1 \le N_d \le 5; \\ 5 \le PC \le 100; \\ 0{,}1 \le \lambda \le 2, \end{cases} , \tag{3}$$

where γ_s – an automobile load factor;

q - automobile carrying capacity rated, t;

β – the mileage utilisation factor;

The costs of FO operations are calculated according to the formula.

$$C_{FO} = Q \cdot \left(\frac{C_L^{CR}}{PC} + \tau_{UL}^{CE} \cdot C_{UL}^{CE} \right), \tag{4}$$

where C_L^{CR} – unit costs of loading 1 ton at the CR, UAH/h;

τ_{UL}^{CE} – time for unloading of 1 t of cargo at the CE, h/t;

C_{UL}^{CE} – unit costs of unloading 1 ton at the CE, UAH/(t·h).

For direct delivery, carrier's costs are defined as follows

$$C_C^D = Q \cdot \left[\frac{l}{q^D \cdot \gamma^D \cdot \beta^D} \cdot \left(C_{zm}^D + \frac{C_{post}^D}{V_t} \right) + C_{post}^D \cdot \left(\frac{1}{PC} + \tau_{UL}^{CE} \right) \right], \tag{5}$$

where C_{zm}^D, C_{post}^D – the variable and constant component of transportation cost, UAH/km and UAH/h;

V_t – the average technical vehicle speed, km/h.

For the terminal delivery system, transportation costs consist of the costs of the main stage of transportation and transportation costs to the customers in the service area [17]. They are defined as follows

$$C_C^T = Q \cdot \left[\frac{l - \sqrt{\frac{F}{\pi}}}{q^D \cdot \gamma^D \cdot \beta^D} \cdot \left(C_{zm}^D + \frac{C_{post}^D}{V_t} \right) + C_{post}^D \cdot \left(\frac{1}{PC} + \tau_{UL}^{CE} \right) \right] +$$

$$+Q \cdot \left[\begin{array}{l} \left(\frac{4}{3} \cdot \sqrt{\frac{F}{\pi}} + \frac{4}{5} \cdot \left(\frac{q^{lm} \cdot \gamma^{lm}}{Q} - 1 \right) \cdot \frac{1}{\sqrt{\lambda}} \right) \cdot \frac{Q \cdot F \cdot \lambda}{q^{lm} \cdot \gamma^{lm}} \cdot \left(a_{zm} + в_{zm} \cdot q^{lm} \right) + \\ \left(\left(\frac{4}{3} \cdot \sqrt{\frac{F}{\pi}} + \frac{4}{5} \cdot \left(\frac{q^{lm} \cdot \gamma^{lm}}{Q} - 1 \right) \cdot \frac{1}{\sqrt{\lambda}} \right) \cdot \frac{Q \cdot F \cdot \lambda}{q^{lm} \cdot \gamma^{lm} \cdot V_t^{lm}} + 2 \cdot \tau_{L(UL)} \cdot q^{lm} \cdot \gamma^{lm} \cdot \right) \times \\ \times \left(a_{post} + в_{post} \cdot q^{lm} \right) \cdot \frac{1}{Q \cdot F \cdot \lambda} \end{array} \right], \quad (6)$$

where q^{lm} – rated carrying capacity of “last mile” automobile, *t*;
γ^{lm} – a load factor of “last mile” automobile;
$a_{zm}, в_{zm}$ – coefficients of the regression model of the dependence of the variable component of transportation cost on the automobile’s carrying capacity [17];
V_t^{lm} – medium technical vehicle speed during “last mile” transportation, *km/h*;
$\tau_{L(UL)}$ – time to load (unload) 1 ton of freight at the terminal, *h/t*;
$a_{post}, в_{post}$ - coefficients of the regression model of the dependence of the constant component of the cost of transportation on the automobile’s carrying capacity [17].

Forwarding operations costs are determined by the formula

$$C_{FF} = D \cdot \delta + \frac{C_{kom} \cdot t^{obs}}{T} + \frac{C_{or} \cdot q}{Q} + \frac{C_{zv}}{N_r} + q \cdot C_{1h}^d \cdot \left(t_{supr}^{1t} \cdot N_d \right), \quad (7)$$

where D – the income of FFC from servicing of freight owner’s request, UAH;
δ – the share of the costs of the dispatcher’s salary (depends on the specific FFC, on average $\delta = 0.1$);
C_{kom}, C_{or}, C_{zv} – costs for utility bills, rent of FFC’s premises, payment of communication services, UAH/time period;
t^{obs} – service time of the freight owner’s request, *h*;
T – the total operating time of the dispatcher for a month, h/time period;
C_{1h}^d – unit costs for 1 hour work of dispatchers, UAH/hour;
t_{supr}^{1t} – specific time to accompany the cargo owner's request, *h/t*.

Costs for processing and storage of freight at the terminal

$$\begin{array}{c} C_E = Q \cdot (t_1 \cdot C_1 + N_t \cdot (C_2^{1t} + C_3^{1t} + C_4^{1t} + C_5^{1t}) + \\ +(2 \cdot \tau_{L(UL)} + \tau_{per}) \cdot C_{LUM}^{1t \cdot h} \cdot N_{LUM} + t_{st} \cdot C_{st}^{1t \cdot h}) + Q \cdot t_s \cdot C_s^{1t \cdot h}, \end{array} \quad (8)$$

where t_1 – reception time of 1 ton of freight, *h*;
C_1 – reception costs of 1 ton of freight, UAH/(t·h);

C_2, C_3, C_4, C_5 - unit costs of the terminal's employee's work to check the integrity of the freight packaging in the automobile; receiving and stacking freight in the reception area at the terminal; moving the freight unit to the departure area; check of cargo and documents before departure, UAH/*t*;

N_t – the number of terminal workers involved in the handling of freight at the terminal, person;

τ_{per} – specific time to move a freight unit to the departure zone, *h/T*;

$C_{LUM}^{1t\cdot h}$ $C_{LUM}^{1t\cdot h}$ – unit costs of 1 hour of loading and unloading mechanism (LUM), UAH/(*t·h*);

N_{LUM} – the number of LUM involved in the handling of freight at the terminal, units;

t_{st} – storage time of the freight at the terminal, *h;*

$C_{st}^{1t\cdot h}$ – the cost of storing 1 ton of freight at the terminal for 1 hour, UAH/(*t·h*).

Costs of freezing capital is calculated by the formula

$$C_{fc} = Q \cdot \frac{C_t \cdot H_p}{36500} \cdot t_p \cdot \left(\frac{1}{2} + \frac{R_s}{Q} \right), \tag{9}$$

where C_t – the cost of 1 ton of freight, UAH/*t*;

H_p – internal rate of return,%

t_p – time between two consecutive deliveries, days;

R_s – insurance stock, *t*.

Thus, optimisation of total costs will allow us to choose rational resource-saving technology of batch freight delivery in long distance while ensuring the established level of reliability of freight delivery system, which requires the use of resource-saving technologies.

The main task of ensuring the reliability of freight delivery is the complete exclusion or minimisation of losses of the participants of the transport process in the freight delivery from the freight forming to the freight absorbing points. For customers of transport services, high reliability of freight delivery means coordination of working parameters in all participants of transport process and absence of delays, as well as losses or damage of cargo. Considering that the logistics system of the transport service consists of logistical links – participants of the process, it is necessary to ensure that the above requirements are met for all participants of the transport process.

State Union standard 51006-96 "Transport services. Terms and definitions" gives the following definition: 'the reliability of transport services is the totality of the characteristics of the transport services that determines their provision of them to consumers in specified volumes and quality for a specified time'. In this research, reliability is proposed to be determined by the method using the readiness factor.

The readiness factor is the probability that the logistics system of the transport service with the logistics chains of all components of the process included in it will be working condition at any time. Namely, this coefficient assesses the potential of the logistics links or the logistics system of batch freight delivery in long distance

$$K_r = (1 - p_f), \tag{10}$$

where p_f – the probability that the logistic link of the system (logistic system) will find itself in a state of failure at any point in time.

In this work, the forwarder is a key link in the logistics system, organizes and coordinates the entire delivery process. Therefore, as part of the task, it is necessary to determine the readiness factor of FFC as a key link in the logistics system of the batch freight delivery.

In queuing systems (the specificity of FFC operation allows them to be considered from the point of view of queuing systems), in which requests for elementary operations arrive at random times or are serviced at random intervals, the appearance of queues is a failure of the production process. For a large number of service channels (operators), the system suffers losses due to possible long downtime. With a small number of service channels, system losses cause accumulated queues.

By a flow of events is understood a sequence of homogeneous events that occur one after the other at some random time (for example, the flow of calls received by dispatchers, the flow of failures, etc.). The flow is characterised by intensity (λ) – the frequency of occurrence of the event or the average number of events entering the queueing system (QS) per unit of time.

The effectiveness of QS with failures is determined as follows.

Absolute bandwidth is an indicator that shows the average number of requests served per unit of time. It is calculated by the formula

$$A = \frac{\lambda \cdot \mu}{\lambda + \mu}, \tag{11}$$

where λ – the intensity of the request flow, units/h;
μ - the intensity of the service flow, units / h.

The intensity of the service flow is the inverse of the average service time

$$\mu = \frac{1}{t^{obs}}. \tag{12}$$

Relative bandwidth is an indicator that characterises the average proportion of requests received and served by the system

$$B = \frac{\mu}{\lambda + \mu}. \tag{13}$$

Failure probability - a value that characterises the probability that a request will leave the queuing system unsupported. It indicates the proportion of request s that will be denied a service

$$p_f = \frac{\lambda}{\lambda + \mu}. \tag{14}$$

Average number of channels used (for multichannel system). This parameter is calculated as follows

$$\bar{k} = \frac{A}{\mu}. \tag{15}$$

Channel load intensity (or reduced flow rate) is also an indicator that expresses the average number of requests that exceeds the average service time of a single request. It is calculated by the formula

$$P = \frac{\lambda}{\mu}. \tag{16}$$

In multichannel QS with limit probabilities, formulas are used for the limit probabilities of a state. The probability of a QS failure is the marginal probability that all n channels of the system will be occupied

$$P_f = \frac{P^n}{n!}\cdot, \tag{17}$$

$$P_0 = (1 + p + \frac{p^2}{2!} + ... + \frac{p^n}{n!}). \tag{18}$$

$$\begin{cases} P_1 = p \cdot p_0; \\ P_2 = \frac{p^2}{2!} \cdot p_0; \\ .... \\ P_n = \frac{p^n}{n!} \cdot p_0. \end{cases} . \tag{19}$$

The relative throughput (the probability that the request will be served) is determined

$$Q = 1 - P_{\text{від}} = 1 - \frac{p^n}{n!} \cdot p_0. \tag{20}$$

The absolute throughput is calculated

$$A = \lambda \cdot Q. \tag{21}$$

For the QMS, the discipline of service is important. It determines the order of selection of requests from among the received and the order of their distribution among the free channels. On this basis, the request servicing can be organised according to the principles of the order of receipt: in the order of receipt (from the beginning) or vice versa, those who received at the end (from the end) are serviced with priority of service (first, the most important requests are served).

The concept of organising the technological process of batch freight delivery in the intercity connection by road in terms of resource savings can be represented in the form of a diagram (Fig. 3).

Thus, the developed theoretical studies will allow the organization of the technological process of batch freight delivery in the intercity connection.

Pilot studies are planned in three stages.

At the first stage of the experiment information is collected on the parameters that affect the batch freight delivery in the intercity connection. On the basis of them, the values of the model parameters that are random in nature are determined.

At the second stage of the experiment, by conducting a full-factor experiment taking into account the modelling of request flow parameters and the limited resources of the transport market entities, rational resource-saving technologies of batch freight delivery in the intercity connection (according to the chosen efficiency criterion) under various operating conditions are determined and their reliability is evaluated.

At the third stage, a regression analysis is performed to determine regression models of the dependence of total costs on the parameters of request flow of transport services and the amount of resources of transport market entities. In the next step, the optimal areas for the use of certain technologies of batch freight delivery technologies are determined in the inter-city connection. That is, the intervals of the input parameters of the model are determined at which the value of the efficiency criterion is optimal.

Thus, a mathematical model has been developed for alternative technologies of batch freight delivery. It is possible to conduct experimental studies to determine resource-saving delivery technology under specified operating conditions.

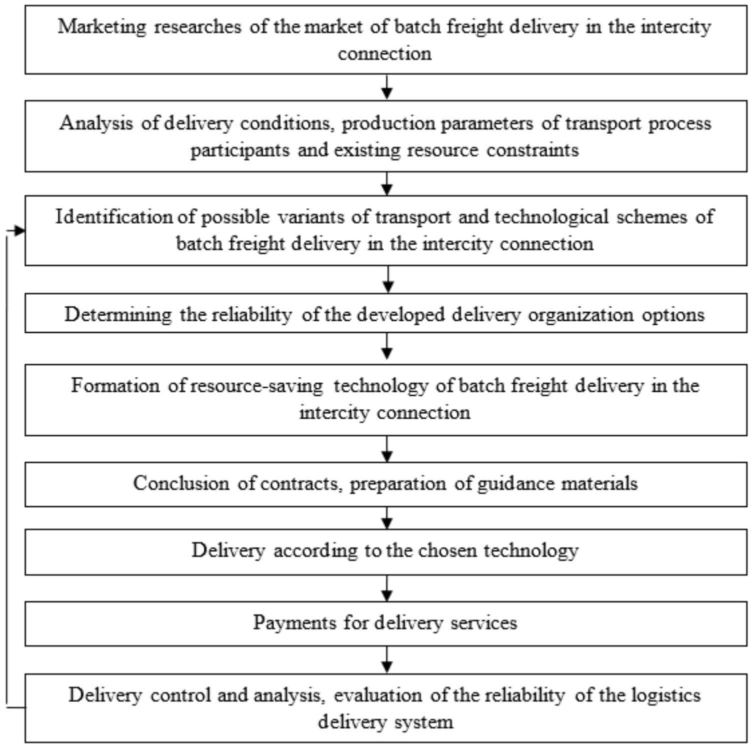

Fig. 3. **Organisation of the technological process of batch freight delivery in the intercity connection by road in terms of resource savings**

Given the number of parameters that affect the end result and recommendations for the requirements for the plans, the study used the plan of a full-factorial experiment, which as a result of which determines the value of the parameters of the state of the object with all possible combinations of levels of variation of parameters.

The ranges of variation of each parameter involved in the experiment are given in Table. 1.

Based on the developed of the full-scale experiment, taking into account the variation of factors in the experimental calculations, indicating the maximum and minimum values of the arguments, the values of the total cost of delivery for two delivery schemes (direct and terminal) for 64 series of experiments were obtained. The obtained data are the basis for applying the regression analysis toolkit.

Table 1. **Levels of variation of input factors**

The value of the input factors	The level of variation of the factor	
	The minimum value	The maximum value
X_1 – F, km^2	13,5	350
X_2 – Q, t	1	5
X_3 – l, km	50	1800

$X_4 - \lambda$, km^{-2}	0,1	2
$X_5 - PC$, t/h	5	100
$X_6 - N_d$, person.	1	5

The functional dependence of the total costs of batch freight delivery on the parameters of the request flow and technological parameters of the participants of the delivery process is carried out in the following sequence: formation of alternative hypotheses about the type of regression model; determination of coefficients of regression models according to the proposed alternative hypotheses; estimation of adequacy of the obtained regression models and selection of the most adequate one.

The functions of the MS Excel analysis package (Data Analysis - Regression) were used as the main tool for determining the coefficients of regression models when processing the results of experimental studies.

Testing the hypotheses about the form of regression models showed that the highest values of the coefficient of determination are characterized by a linear model for direct delivery (C^1_{sum}) and exponential for terminal delivery (C^2_{sum}):

$$C^1_{sum} = 22{,}58227 + 18{,}86497 \cdot Q + 9{,}03902 \cdot l - 0.37956 \cdot PC, \quad (22)$$

$$C^2_{sum} = 95{,}51644 \cdot 1{,}008185^{F} \cdot 1{,}770343^{Q} \cdot 1{,}000503^{l} \cdot 2{,}304923^{\lambda} \cdot 1{,}01766^{Nd}. \quad (23)$$

Testing the model for the possibility of its practical application is carried out according to the criteria of accuracy, reliability and adequacy. All parameters must be performed simultaneously. Inconsistency with one of the criteria means the absence of a model at all.

The accuracy is estimated by the value of the correlation coefficient r, the determination coefficient r^2, the calculations of which are given in Table 2.

Table 2. **Model accuracy check**

Criterion	Critical value	Estimated value	
		For the direct delivery	For the terminal delivery
Correlation coefficient	> 0,7	0,87	0,97
Determination factor	> 0,5	0,99994	0,901646

The reliability and adequacy of the model is estimated by the value of the Fisher F test, the calculated values are shown in Table 3.

Table 3 **Checking the reliability and adequacy of the model**

Critical value		Estimated value	
		For the direct delivery	For the terminal delivery
Fisher's test, F	$F > F_t$	1661340	87,1
The significance of the criterion F	< 0,05	$1{,}7 \cdot 10^{-147}$	$7{,}26 \cdot 10^{-27}$

The results show that the models can be used to choose a rational delivery system. Thus, the results obtained are the basis for performing the analysis of the influence of factors on the efficiency of consignment delivery in long distance, taking into account the reliability of the freight forwarding enterprise. The degree of influence on the total cost of consignment delivery by a certain delivery technology of such factors as the consignment volume for the request, the service area, delivery distance, the density of the points of delivery in the territory of the service area and the number of dispatchers (at a fixed position at the average level of other factors) is graphically shown in Fig. 4–8.

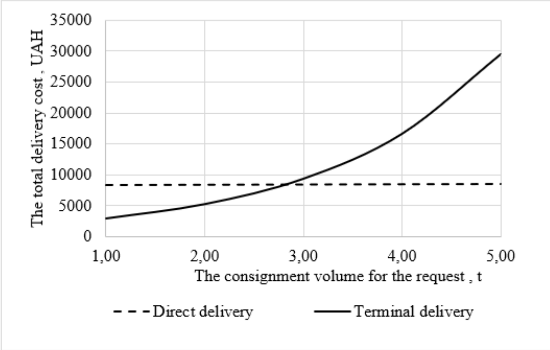

Fig. 4. **Graph of the total cost dependence on the volume for the request**

Fig. 5. **Graph of the total cost dependence on service area**

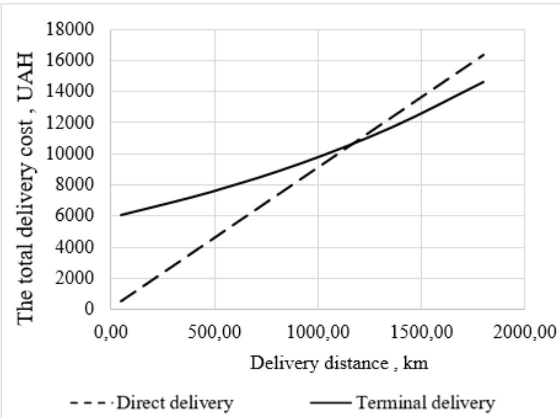

Fig. 6. **Graph of the total cost dependence on delivery distance**

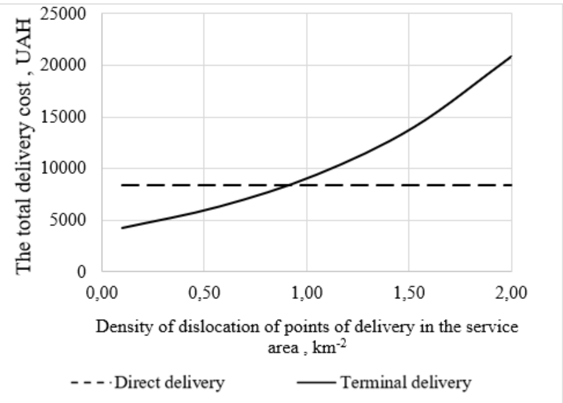

Fig. 7. **Graph of the total cost dependence on the density of delivery dislocation of points in the service area at a fixed position at the average level of other factors**

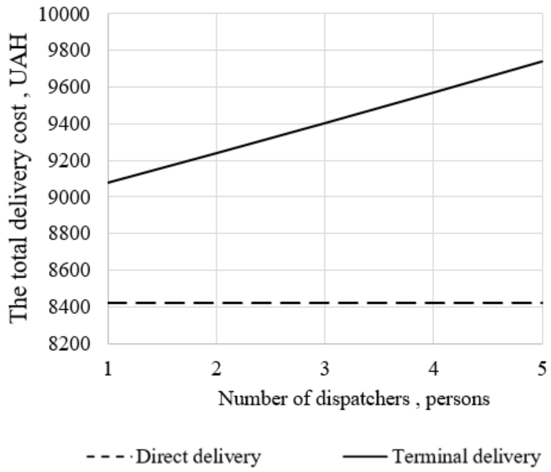

Fig. 8. **Graph of the total cost dependence on the number of dispatchers at fixed position on average of other factors**

Determine the effectiveness of QS with refusals by formulas (11) – (21) for the following conditions of work of dispatchers LLC “Deliveri”": duration of processing – 15 minutes, the intensity of request receipt – 8 units/h for one dispatcher.

Intensity of service flow

$$\mu = \frac{60}{15} = 4 \text{ units/h.}$$

Relative bandwidth (the average proportion of requests received and served by the system)

$$B = \frac{4}{4+8} = 0{,}33,$$

$$p_f = \frac{8}{8+4} = 0{,}67..$$

Absolute bandwidth

$$A = \frac{8 \cdot 4}{8+4} = 2,67.$$

Thus, on average, the dispatcher will process almost 3 requests per hour.

Similarly, we calculate the main characteristics of queuing systems for 2, 3, 4 dispatchers and summarize them in Table 4.

Table 4. **Main characteristics of service requests in the warehouse depending on the number of posts**

Indicator	Number of dispatchers, persons		
	1	2	3
Relative bandwidth (B)	0,33	0,8	1,31
Absolute throughput (A)	2,67	6,4	10,48

The schedule of dependence of readiness factor on the number of dispatchers is shown in fig. 9.

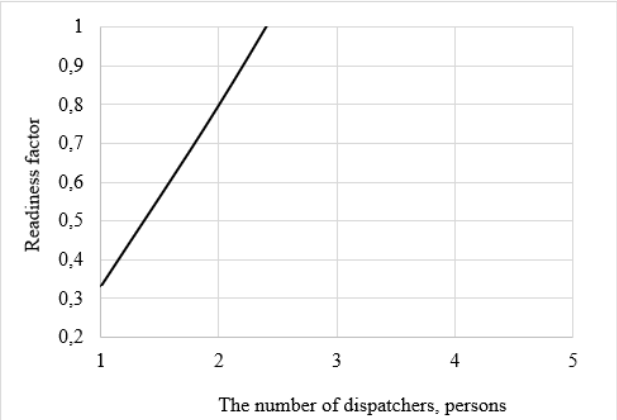

Fig. 9. **Schedule of readiness factor on the number of dispatchers**

This means that, if optimality is met (satisfaction with an average of 10 requests at least 8 requests for cargo delivery (K_f = 0,8), an average of two dispatchers is optimal.

For the considered ranges of the values of the transport request parameters:

– at the consignment volume for the request up to 2.81 t (Fig. 4), terminal delivery is more resource-saving and direct delivery is more than 2.81 t;

– at service area up to 169 km^2 (Fig. 5), resource delivery is terminal delivery, and over 169 km^2 – direct delivery;

– at delivery distance up to 1172 km (Fig. 6), resource delivery is direct delivery, and over 1172 km – terminal delivery;

– at the density of the deployment of points of delivery in the territory of service up to 0.95 km^{-2} (Fig. 7), resource delivery is terminal delivery, and more than 0.95 km^{-2} – direct delivery;

– the number of dispatchers (Fig. 8) affects the total costs only at the terminal system in this formulation of the problem, so the optimal number of dispatchers at the normative value of the coefficient of readiness for the terminal delivery system was 2 persons.

Introduction to the production of innovations allows to obtain effect and increase efficiency.

The effect associated with the total cost of delivery, is determined by the following formula

$$E = C_{sum}^{rs} - C_{sum}^{b}. \quad (24)$$

where C_{sum}^{rs} – the total cost of freight delivery using resource-saving delivery technology, UAH/request; C_{sum}^{b} – the total cost of basic freight delivery technology, UAH/request.

Efficiency (E_f) when implementing resource-saving delivery technology is calculated

$$E_f = \frac{E}{C_{sum}^{rs}} \cdot 100\%. \quad (25)$$

There are three dispatchers at the Delivery LLC in the Kharkiv branch. The transit terminal is one in the city. Other offices for collecting and transporting requests around the city. The Kharkov area is 350 km^2. For the consignment volume 3.0 tons delivery distance is 675 km. LLC Delivery uses a terminal system for batch freight delivery. The total costs of the company in this case (C_{sum}^{b}) are 7040 UAH. Total costs proposed in the work (including the optimal number of dispatchers – two)

$$C_{sum}^{rs} = 22,58227 + 18,86497 \cdot 3 + 9.03902 \cdot 657 - 0.37956 \cdot 52,5 = 6179 \text{ UAH.},$$

$$E = 7040 - 6179 = 861 \text{ UAH},$$

$$E_f = \frac{861}{6179} \cdot 100\% = 13,9\%.$$

The economic effect of the implemented measures is E = 861 UAH.

When using direct batch freight delivery in intercity connection, total costs can be reduced by 13.9 %.

Conclusions. In this paper, we propose the solution to the scientific and applied problem of batch freight delivery in the intercity road connection in terms of system's limited resource due to the formation of technology of long-distance freight delivery in terms of resource savings and observing the established level of reliability of the functioning of the logistics system of freight delivery.

After analysing scientific research in the direction of developing resource-saving technologies of freight delivery, it can be noted the next. Among the priority areas for improving the process of batch freight delivery, most researchers highlight the formation of rational technologies of freight delivery in terms of resource savings and determining a rational amount of resources when functioning systems of various levels based on the use of logistics principles.

In the research of freight delivery in long distance, two transport and technological scheme were considered as alternatives. The first technology involves direct freight delivery from consignor to consignee, and the second - a terminal delivery system.

Considering that the criterion of effectiveness in the study is justified the use of the total cost of delivery and readiness factor, for the considered ranges of the values of the transport request parameters: at the consignment volume for the request up to 2.81 t (Fig. 4), terminal delivery is more resource-saving and direct delivery is more than 2.81 t; at service area up to 169 km^2 (Fig. 5), resource delivery is terminal delivery, and over 169 km^2 – direct delivery; at delivery distance up to 1172 km (Fig. 6), resource delivery is direct delivery, and over 1172 km – terminal delivery; at the density of the deployment of points of delivery in the territory of service up to 0.95 km^{-2} (Fig. 7), resource delivery is terminal delivery, and more than 0.95 km^{-2} – direct delivery; the number of dispatchers (Fig. 8) affects the total costs only at the terminal system in this formulation of the problem, so the optimal number of dispatchers at the normative value of the coefficient of readiness for the terminal delivery system was 2 persons.

The economic effect of the implemented measures may be 861 UAH. When using direct delivery in the intercity connection for a request with specified parameters, it is possible to reduce total costs by 13.9%. Reducing the total cost of batch freight delivery due to the choice of resource saving technology will allow FDLS to receive additional income and distribute it among the participants in the delivery process according to their contribution.

REFERENCES

1.Butko, T.V., Horsin, Th., &Yashchuk, Yu.I. (2022) Orhanizatsiia podorozhei pasazhyriv na osnovi tekhnolohii ryzyk-menedzhmentu z vykorystanniam kraudsorsynhovykh danykh pro trafik. *Collection of abstracts of the III International Scientific and Technical Conference Intelligent Transport Technologies*, 14-16. [in Ukrainian].

2.Naumov, V., Shulika, O., Orda, O., Vasiutina, H., Bauer, M., & Oliskevych, M. (2022) Shaping the Optimal Technology for Servicing the Long-Distance Deliveries of Packaged Cargo by Road Transport. *Sustainability*, 14 (12), 7283 https://doi.org/10.3390/su14127283.

3. Marchi, B., Zanoni, S., Ferretti, I., & Zavanella, L.E. (2018) Stimulating investments in energy efficiency through supply chain integration. *Energies*. 11, 4, 858.

4. Marchi, B., & Zanoni, S. (2017) Supply chain management for improved energy efficiency: Review and opportunities. *Energies*, 10 (10), 1618.

5. Maloni, M.J., & Benton, W.C. (1997) Supply chain partnerships: Opportunities for operations research. *European Journal of Operational Research*, 101, 3, 419-429.

6. Wang, Y. (2004) Low-Carbon Logistics and Sustained Economic Cycle for Manufacturing Engineering. *Applied Mechanics and Materials*, 264 – 267.

7. Zhang, D.P., & Hua, X. Y. (2003) International Experience and Enlightenment of Energy Saving and Emission Reduction in Logistics Industry. *Advanced Materials Research*, 734 – 737.

8. Zhang, D.P., & Hua, X.Y. (2014) Research on Energy Saving and Emission Reduction Countermeasures for China's Logistics Industry. *Advanced Materials Research*, 1925-1928, 734-737.

9. Malak, R.C., Adam, M., Waltemode, S., & Aurich, J.C. (2014) Lifecycle Oriented Assessment of Resource Efficiency in the Commercial Vehicle Industry. *Advanced Materials Research*. 907, 475 – 487.

10. Zhang, L., Zhang, Y., He, Y.H., & You, X.R. (2013) The Behavior Strategy in Energy Saving and Emission Reduction of Transportation. *Advanced Materials Research*. 718 – 720.

11. Zou, X., Zhao, W., Zhang, & T.T. (2015) Study of Green Logistics Technology to Manufacturing Based on Green Supply Chain Theory. *Advanced Materials Research*, 2438-2442, 1073 – 1076.

12. Nowak, S., & Grabara, J. (2015) Green Logistics and its Solutions in Polish Companies. *Applied Mechanics and Materials*, 708, 65-69.

13. Lomotko, D. V., & Mkrtychian, D. I. (2006) Optymizatsiia systemy dostavky vantazhiv na osnovi mnozhyny kryteriiv resursozberihaiuchykh pidkhodiv. *Eastern-European Journal of Enterprise Technologies*, 3(2), 6 – 9. [in Ukrainian]

14. Potaman, N.V., Shulika, O.O., & Orda, O.O. (2021) Modeliuvannia marshrutnoi merezhi dostavky shvydkopsuvnykh vantazhiv u rehionalnomu spoluchenni za dopomohoiu merezh Petri. *Municipal economy of cities. Series: Engineering science and architecture*, 4, (164), 240-245. [in Ukrainian] https://doi.org/10.33042/2522-1809-2021-4-164-240-245.

15. Bányai, T. (2018) Real-time decision making in first mile and last mile logistics: How smart scheduling affects energy efficiency of hyperconnected supply chain solutions. *Energies*, 11 (7), 1833.

16. Russo, F. A. (2010) Classification of city logistics measures and connected impacts. *Procedia-Social and Behavioral Sciences*, 2, 6355 – 6365.

17. Pavlenko, O. V., Kalinichenko, O. P., & Nefodov, V. M. (2018) Metodyka formuvannia resursozberihaiuchoi tekhnolohii dostavky vantazhiv transportno-lohistychnym tsentrom. Municipal economy of cities. Series: Engineering science and architecture, 142, 96 – 102. [in Ukrainian]

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Розробка ефективної технології доставки партіонних вантажів автомобільним транспортом у міжміському сполученні з урахуванням умови ресурсозбереження

Логістичні рішення з відновлення та розвитку галузі автомобільних перевезень вантажів потребують застосування ефективних інструментів, що дозволять забезпечити гнучкість логістичним ланцюгам постачань, в умовах змінного попиту на транспортні послуги, сприяючи економічному відновленню та розвитку, підвищенню якості життя населення, ефективному використанню ресурсів. В роботі вирішена науково-прикладна задача підвищення ефективності функціонування логістичної системи доставки партіонних вантажів автомобільним транспортом у міжміському сполученні в умовах розподілу обмеженого ресурсу системи за рахунок формування технології доставки вантажів на умовах ресурсозбереження та дотримання встановленого рівня надійності функціонування логістичної системи доставки вантажів автомобільним транспортом. В досліджені для вирішення поставленої задачі використані методи математичного моделювання, системний підхід, методи оптимізації (функції багатьох змінних), положення теорії ймовірності та математичної статистики, методи регресійного аналізу. Для заданих умов функціонування розробленої логістичної системи визначено раціональну технологію доставки партіонних вантажів у міжміському сполученні з урахуванням умови ресурсозбереження, що дозволить на 13,9 % зменшити загальні витрати при заданому рівні готовності логістичної системи доставки вантажів.

Ключові слова: *автомобільний транспорт, ресурсозбереження, доставка, партіонні вантажі, коефіцієнт готовності*