Досліджується завдання обґрунтування кількісного складу вантажних партій при формуванні збірних відправок в контейнерах. В результаті дослідження сформульована загальна постановка завдання обґрунтування кількісного складу вантажних партій при організації LCL перевезень, визначені окремі варіанти її інтерпретації. Для вирішення локальних виробничих завдань розроблені певні технології, які враховують особливості ситуації та вихідної інформації про планову відправку. Застосування цих технологій забезпечує максимальне використання техніко-експлуатаційних можливостей контейнера при формуванні збірних відправок вантажів. Для перших двох варіантів завдання технологія передбачає реалізацію певних систем рівнянь і перевірку отриманих результатів на предмет якості використання вантажопідйомності і вантажомісткості контейнера. Для вирішення завдання по третьому і четвертому варіантах розроблені математичні моделі. Реалізація моделей забезпечує максимальне використання технічних параметрів контейнера за рахунок критеріїв оптимальності, відображених у відповідних цільових функціях. Тому перевірка отриманих результатів на предмет якості використання вантажопідйомності і вантажомісткості контейнера не потрібно.

На підставі запропонованих методичних положень проведені експериментальні дослідження, які показали універсальність для вирішення завдань оптимізації завантаження консолідованих контейнерів.

Розроблені положення мають наукове значення, сприяють розвитку теорії транспортних процесів і систем, становлять практичний інтерес для комерційних відділів транспортних компаній, що надають експедиторські послуги. Впровадження цих положень забезпечить підвищення ефективності виробничої діяльності представників транспортного бізнесу, а також дозволить формувати раціональні системи транспортно-експедиторського обслуговування вантажів в регіональному, міжрегіональному та міжнародному сполученнях

Ключові слова: контейнер, LCL (less than container cargo) перевезення, транспортно-експедиторська діяльність, завантаження контейнера

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SUBSTANTIATION OF QUANTITATIVE COMPOSITION OF CONSIGNMENTS IN ORGANIZING AGGREGATED SHIPMENTS IN CONTAINERS

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1. Introduction

Economic growth of any country cannot be imagined today without international trade. Containerized shipment plays an important role in transport provision of this trade. Organization of such shipments is practically impossible without participation of companies engaged in transportation and forwarding activities (TFA). One of the widespread services provided by such companies is organizing less than container load (LCL) deliveries. In the process of LCL transportation, delivery of a package cargo as a part of a consolidated container in which a small consignment of one customer is delivered together with small consignments from other senders is realized. In this case, payment is made not for a whole container but only for the space occupied by the corresponding consignment. LCL transportation is a good solution for small companies that do not need to rent a whole container as well as a profitable line of business activity for companies engaged in TFA.

One of the main and highly relevant tasks of the cargo forwarder in organizing LCL deliveries consists in substantiation of quantitative composition of consignments in container shipment with consolidated cargoes belonging to different customers of the cargo forwarding company (TFC).

2. Literature review and problem statement

The problems associated with technical and technological aspects of operation of container terminals are investigated in [1]. A system for improving operation of container terminals which enables more accurate and fast work of a gantry crane has been developed. The described procedure simplifies work for technical staff of the terminal, shortens container processing time and time of its staying at the terminal, speeds up handling operations and the process of rebilling. However, the analyzed study does not cover the issues of packaged shipment of containerized cargoes and does not consider loading of individual containers.

Processes of organizing and managing operation of vessels in container and ferry transport and technological systems were investigated in [2–4]. Implementation of a linear integer programming model developed in [2] enables substantiation of solutions for optimal distribution of container traffic between trunk and feeder lines. The model minimizes ship owner's expenses and restrictions take into consideration specifics of the regular form of shipping, structure of the shipping line, technical and operating features of container ships and transport characteristics of cargoes. Provisions were formulated in [3] to substantiate such loading of a ferry which ensures its commercially expedient operation and takes into consideration the possibility of a simultaneous placing aboard a ship the cargoes of various nomenclature and passengers. A mathematical model proposed in [4] optimizes composite ferry loading, takes into account its technical and operational characteristics, integrity of consignment of one sender, possibility of simultaneous transportation of cargoes and accompanying passengers. However, versions for using transport equipment (full container load (FCL) or less than container load (LCL)) and issues of loading are not clarified, hence are not taken into consideration in [2–4].

General theoretical and practical issues of transportation and forwarding service provision to enterprises and organizations regardless of specifics of the cargoes being shipped are described in [5–7].

A system for determining an optimal version of TFA was developed in [5] and a multi-purpose model of this system was proposed in [6]. However, sea transportation of cargoes is not considered and specifics of feasibility of cargoes transportation in containers are not studied in [5, 6].

A new TARRQUAL tool for estimating quality of transport and forwarding activity and customer's choice of a deliverer of forwarding services is presented in [7]. This approach complements the Delphi method and allows one to assess quality of cargo forwarding services based on factors established by customers. It takes into consideration specifics of the forwarding service of container traffic but does not consider the LCL shipment. Study [7] is geographically oriented towards the Czech Republic and is limited to this country interaction with domestic European markets.

Features of LCL shipments are considered and their problematic aspects are discussed in [8]. To solve them, the authors propose to build the LCL export platform (LEP) using the block chain information concept. As a result, it is proposed to optimize LCL operations by integrating and exchanging information between forwarding companies and their clients. At the same time, technical and technological aspects of LCL transportation as well as the design solutions in this area are not given attention in [8].

Study [9] addresses the problem of transshipment efficiency of port railway container intermodal terminal of LCL cargoes. The study is conducted on an example of a specific railway terminal. Based on the spatial-temporal and transport characteristics of LCL cargoes, a system of estimation indices was established. To this end, the DEA-AHP model and the method of analyzing main components using SPSS are used. The study results show that efficiency of LCL transshipment at the port railway container terminal is controlled by such key factors as arrival time, loading speed and cargo volume. The study is useful in development of LCL schemes for railway enterprises and contributes to development of intermodal cargo traffic. However, this study focuses on LCL cargo handling at the port railway terminals. At the same time, it does not address the issues related to substantiation of decisions on loading of consolidated containers at the stage of concluding contracts between cargo forwarders and customers.

Provisions on the use of a genetic algorithm with respect to container loading are set forth in [10]. An order of solving this problem based on successive procedures of the heuristic method was proposed. It allows one to efficiently place a certain size of cargoes in a minimum number of containers while maximizing cargo volume in one container. The proposed algorithm is focused on accurate data about the size of cargoes planned for transportation and does not imply coordination of this information with the client.

The overview of information sources necessitates addressing the issue of substantiation of quantitative composition of cargo batches in formation of container loading with consolidated cargoes when organizing the LCL deliveries.

3. The aim and objectives of the study

The study objective was to develop technologies of substantiating quantitative composition of consignments in loading a consolidated container when organizing less than container cargo (LCL) traffic.

To achieve the objective, the following tasks were solved:

– formulate a general statement of the problem of substantiating quantitative composition of consignments in loading a consolidated container;

– formulate particular versions of interpretation of this task reflecting the production situations that most often arise in practice between a cargo forwarder and a cargo owner;

– for each of the local production tasks, develop a solution technology that takes into account peculiarities of the situation and initial information about the planned shipment.

4. The materials of study on substantiation of quantitative composition of consignments in loading of a consolidated container

The quantity of homogeneous cargo in formation of the container cargo is advisable to carry out according to the procedure traditionally used in fleet and port operating practice [11]. Essence of the procedure in relation to formation of a mono container cargo is as follows:

– determination of the specific freightage of a container of dimension-type i (w^i):

$$w^i = \frac{W^i}{D^i} = \frac{W^i}{D^i_{\text{gross}} - D_0}, \ \text{m}^3/\text{t}, \qquad (1)$$

where W^i is the freightage of the container of dimension-type i, m^3, for example $W^{20'DC}$; $W^{20'HC}$; $W^{20'HQ}$; $W^{20'PW}$; $W^{20'HCPW}$, where DC (Dry Cube) is a dry universal container with standard dimensions of 8 feet, 6 inches in height, 8 feet in width; HC or HQ (High Cube) is a high container, i.e., enlarged in height by one foot; PW (Pallet Wide) is a container enlarged in width; $HCPW$ (Pallet Wide High) is a container enlarged in width and height; D^i is carrying capacity of a container of dimension-type i, t, for example, $D^{20'DC}$; $D^{20'HC}$; $D^{20'HQ}$; $D^{20'PW}$; $D^{20'HCPW}$; D^i_{gross} is the maximum permissible (gross) carrying capacity container of a dimension-type i, t; D^i_0 is weight of an empty container of dimension-type i, t;

– determination of the specific package volume:

$$u_r = (\text{l}_r \cdot \text{b}_r \cdot \text{h}_r) : \text{m}_r, \ \text{m}^3/\text{t},$$

where l_r, b_r, h_r, m_r are linear dimensions (length, width, height) of the cargo to be consolidated and its weight;

– determination of the specific loading volume of the package: $\overline{u_r} = u \cdot k^p$, m^3/t where k^p is the coefficient of placement taking into account peculiarities of placement of packages in the container, resulting technological voids between them, separation, etc.;

– determination of the category of cargo based on comparison of its specific loading volume and specific freightage of the container:

a) for any cargo r, if its specific loading volume ($\overline{u_r}$) is less than or equal to the specific freightage of the container (w^i), i. e., $\overline{u_r} \le w^i$, the cargo is "heavy" ($r \in R^h$) for the given transportation means. Under this condition ($\overline{u_r} \le w^i$), loading of the container is limited by its carrying capacity (D^i). Thus, during formation of full container load (FCL) of the shipment, quantity of "heavy" cargo (Q_r^h) in the container (taking into account weight of the cargo itself (Q_r), tare weight (Q_r^{tare}) and separation materials (Q^{sep})) corresponds to its freightage (D^i):

$$\forall r \in R(\overline{u_r} \le w^i \to r \in R^h) \Rightarrow Q_r^h = Q_r + Q_r^{tare} + Q^{sep} = D^i, \qquad (2)$$

where R is the set of cargoes which includes the subsets of "heavy" (R^h) and "light" (R^l) cargoes, respectively:

b) for any cargo r, if its specific loading volume ($\overline{u_r}$) is greater than the specific freightage of the container (w^i), i. e. $\overline{u_r} > w^i$, then the cargo belongs to the set of "light" cargoes ($r \in R^l$). In this case, only the container freightage (W^i) can be fully used. Thus, during formation of the shipment FCL, the quantity of "light" cargo (Q_r^l) in the container loading is determined by the formula:

$$\forall r \in R(\overline{u_r} > w^i \to r \in R^l) \Rightarrow Q_r^l = \frac{W^i}{\overline{u_r}} \le D^i. \qquad (3)$$

In the case of LCL delivery organization, the consolidated container houses small consignments belonging to various cargo owners who are the TFC clients. At the same time, the process of making decisions on loading of a consolidated container is much more complicated. This actualizes development of a technology for substantiation of such quantitative composition of consignments in loading of a consolidated container at which its technical and operational capabilities are used to the maximum degree. Moreover, this is relevant not only for the TEC but also for its customers because expenditures of each client (R_r^K), "participating" with his cargo r in this LCL shipment depends on quality of utilization of technical and operational characteristics of the container.

The following formulation of this problem is proposed in a general form.

A TFC has received a preliminary request $k = \overline{1,K}$ from a cargo owner for provision of appropriate forwarding services to a cargo with specific loading volume $\overline{u_r}$, m^3/t.

As is known, preliminary request of a cargo owner is a source of initial information about the cargo and its transport characteristics, points of departure and destination.

Upon receipt of a preliminary request, the cargo forwarder first analyzes it for compliance the transport characteristics of the cargo with the technical parameters of the container. In addition, the cargo forwarder considers the issue of compatibility of various cargoes and checks the possibility of their consolidation in one container.

The preliminary request $k = \overline{1,K}$ of the cargo owner contains either non-fixed (free) or fixed (solid) information on Q_r quantity of the cargo planned for transportation. Therefore, at the stage of processing offers coming from different cargo owners, before entering into an agreement with them, the cargo forwarder:

– may discuss with the cargo owner the possible quantity Q_r of the consignment planned for shipment for a subsequent introduction of this information in the main request and the contract for transport forwarding;

– may not discuss with the cargo owner the size of the consignment Q_r planned for shipment.

When considering the received requests, the cargo forwarder plans a aggregated shipment of consignments in a container of dimension-type i with the following main characteristics:

D^i: carrying capacity of the container of dimension-type i, t;

W^i: freightage of the container of dimension-type i, m^3.

The cargo forwarder needs to substantiate quantitative composition of the consignments of various customers in loading of the consolidated container at which its carrying capacity ($D^i \to$max) and/or freightage ($W^i \to$max) will be utilized to the maximum degree.

In production activities of the companies providing cargo forwarding services of organizing LCL shipments, the following typical practical situations reflecting specific conditions regarding the planned shipment are the most common:

Version 1 is characterized by the fact that the set of preliminary requests ($k = \overline{1,K} = \overline{1,2}$) received by the cargo forwarder from various cargo owners contains information on two consignments ($r = \overline{1,R} = \overline{1,2}$). Moreover, the size of the consignments is not fixed, and, therefore, subject to discussion.

Version 2 is characterized by the fact that the set of preliminary requests ($k = \overline{1,K} = \overline{1,2}$) received by the cargo forwarder from various cargo owners also contains information on two consignments ($r = \overline{1,R} = \overline{1,2}$). However, size of one consignment is strictly fixed, and that of the second consignment is subject to discussion.

Version 3 is characterized by the fact that the set of preliminary requests ($k = \overline{1,K}$; $K>2$) received from different cargo owners contains information on more than two consignments ($r = \overline{1,R}$; $R>2$). Moreover, sizes of all consignments ($r = \overline{1,R}$; $R>2$) in the considered set of requests ($k = \overline{1,K}$; $K>2$) are not fixed and can be coordinated with cargo owners.

Version 4 is also characterized by the fact that the set of preliminary requests ($K>2$) contains information on more than two consignments ($k = \overline{1,K}$; $R>2$). At the same time, sizes of some consignments in the considered set of requests are strictly fixed and are not negotiable and some have to be coordinated with the owners of the cargoes.

It is proposed to concretize general formulation of the problem for each of the above local production situations and propose a specific solution technology for each of them.

For *version 1*, formulation of the problem stated above is as follows. The TFC received two preliminary requests ($k = \overline{1,K} = \overline{1,2}$) from different cargo owners for provision of cargo forwarding services r ($r = \overline{1,R} = \overline{1,2}$; $R = R^h \cup R^l$):

– cargo 1 (r=1) is "heavy" ($r \in R^h$), its specific loading volume ($\overline{u_r}$) is

$$\overline{u_r} = \overline{u_1^h}, \text{ m}^3/\text{t};$$

– cargo 2 (r=2) is "light" ($r \in R^l$), its specific loading volume ($\overline{u_r}$) is

$$\overline{u_r} = \overline{u_2^l}, \text{ m}^3/\text{t}.$$

According to the preliminary information of the cargo owners, both requests contain non-fixed information about the quantity Q_r of the cargo planned for transportation, $k = \overline{1,K} = \overline{1,2}$, i. e., the batch size Q_r can be coordinated and defined more precisely in the course of negotiations.

The cargo forwarder must determine quantitative composition of the consolidated consignment shipment for the requests in question. The results of solving the problem are a guideline for further negotiations with cargo owners on the size of consignments.

In the case considered, it is advisable to use the approach that is used in the practice of fleet operation when forming a composite cargo of the vessel [11] to maximize utilization of the carrying capacity and freightage of the consolidated container. Based on this approach, it is proposed to solve the following system of equations:

$$\begin{cases} Q_r^h + Q_r^l = D^i; \\ Q_r^h \cdot \overline{u_r^h} + Q_r^l \cdot \overline{u_r^l} = W^i. \end{cases} \quad (4)$$

This system of equations (4) is based on the following conditions:

– the total weight of all cargoes $\sum_{r=1}^{R=R^h \cup R^l} Q_r$, submitted for transportation by customers to the TFC should be equal to the carrying capacity of the container of dimension-type i (D^i):

$$\sum_{r=1}^{R=R^h \cup R^l} Q_r = Q_1 + Q_2 = D^i; \quad (5)$$

– the total volume of all cargoes must be equal to the freightage of the container of dimension-type i (W^i):

$$\sum_{r=1}^{R=R^h \cup R^l} (Q_r \cdot \overline{u_r}) = Q_1 \cdot \overline{u_1} + Q_2 \cdot \overline{u_2} = W^i. \quad (6)$$

Thus, in the considered version 1, it is expedient to determine size of cargoes ($Q_r^h = X_1^h -?$; $Q_r^l = X_2^l -?$) as a result of solving the system of equations (4) which contains two unknown variables and takes the following form:

$$\begin{cases} X_1^h + X_2^l = D^i; \\ X_1^h \cdot \overline{u_1^h} + X_2^l \cdot \overline{u_2^l} = W^i; \end{cases} \quad (7)$$

$$X_2^l = D^i - X_1^h; \quad (8)$$

$$X_1^h \cdot \overline{u_1^h} + (D^i - X_1^h) \cdot \overline{u_2^l} = W^i;$$

$$X_1^h \cdot (\overline{u_1^h} - \overline{u_2^l}) + D^i \cdot \overline{u_2^l} = W^i;$$

$$X_1^h = \frac{W^i - D^i \cdot \overline{u_2^l}}{(\overline{u_1^h} - \overline{u_2^l})}. \quad (9)$$

Solution of the system of equations (7) results in a sought size of the cargo batch of "heavy" cargoes $X_1^h = Q_1^h$ (9). Substitute its value in (8) and determine the size of the cargo batch of "light" cargoes $X_2^l = Q_2^l$.

The problem formulated above for *version 2* is concretized as follows. Similar to *version* 1 discussed above, the TFC has received two preliminary requests ($k = \overline{1, K} = \overline{1,2}$) from different cargo owners for provision of cargo forwarding services, r ($r = \overline{1, R} = \overline{1,2}$; $R = R^h \cup R^l$). One of the cargoes is "heavy" ($r = 1$; $r \in R^h$; $u_r = u_1^h$), the other is "light" (r=2; $r \in R^l$; $u_r = u_2^l$). At the same time, one of the requests contains fixed information regarding the size of the consignment (Q_r) to be shipped and the other contains guide information ($\approx Q_r = X_r -?$) and is subject to agreement.

The cargo forwarder needs to determine the size of cargo ($\approx Q_r = X_r -?$) not indicated in the request at which carrying capacity ($D^i \rightarrow$max) and/or freightage ($W^i \rightarrow$max) of the container will be used to the maximum degree.

Thus, the size of only one of the consignments can be agreed in the course of subsequent negotiations. Its value is proposed to establish based on the above-mentioned approach [11]. At the same time, if the size of "heavy" cargo ($Q_r^h = Q_1^h$) is fixed in the request of the cargo owner and the size of "light" cargo ($Q_r^l = X_2^l -?$) is to be determined, then the considered system of equations (4) takes the following form for this production situation:

$$\begin{cases} Q_1^h + X_2^l = D^i; \\ Q_1^h \cdot \overline{u_1^h} + X_2^l \cdot \overline{u_2^l} = W^i. \end{cases} \quad (10)$$

The size of "light" cargo ($Q_r^l = X_2^l -?$) should be determined on the basis of the second equation of the presented system (10):

$$X_2^l = \frac{W^i - Q_1^h \cdot \overline{u_1^h}}{\overline{u_2^l}}. \quad (11)$$

In turn, the first equation of the system (10) should be used to check quality of utilization of the container carrying capacity:

$$\alpha^i = \frac{Q_1^h + X_2^l}{D^i}, \quad (12)$$

where α^i is the coefficient of the container carrying capacity utilization.

Along with this, quality of utilization of the container freightage should be checked. In this case, the container should be fully used, and the value of the corresponding indicator (k_W^i) should be equal to 1, i. e. be 100 %:

$$k_W^i = \frac{Q_1^h \cdot \overline{u_1^h} + X_2^l \cdot \overline{u_2^l}}{W^i} = 1 \ \ (100\,\%), \quad (13)$$

where k_W^i is the coefficient of utilization of the container freightage.

In turn, if the request of the cargo owner contains size of "light" cargo ($Q_r^l = Q_2^l$) which is fixed and size of "heavy" cargo ($Q_r^h = X_1^h -?$) is to be determined, then the considered system of equations (4) takes the following form for this production situation:

$$\begin{cases} X_1^h + Q_2^l = D^i; \\ X_1^h \cdot \overline{u_1^h} + Q_2^l \cdot \overline{u_2^l} = W^i. \end{cases} \quad (14)$$

The size of "heavy" cargo ($Q_r^h = X_1^h -?$), in turn, should be determined proceeding from the first equation in the represented system (14):

$$X_1^h = D^i - Q_2^l. \quad (15)$$

In this case, the second equation of the system (14) should be used to check quality of utilization of the container freightage as follows:

$$k_W^i = \frac{X_1^h \cdot \overline{u_1^h} + Q_2^l \cdot \overline{u_2^l}}{W^i} = 1 \ \ (100\,\%). \quad (16)$$

It is also recommended to check quality of utilization of the container carrying capacity which in this case should be fully used and the value of the corresponding indicator (α^i) should be equal to 1, i. e. be 100 %:

$$\alpha^i = \frac{X_1^h + Q_2^l}{D^i} = 1\,(100\,\%). \quad (17)$$

However, it should be noted that when a sufficiently large size of "light" cargo ($Q_r^l = Q_2^l$) is indicated in the cargo owner's request, the size of "heavy" cargo ($Q_r^h = X_1^h - ?$) should also be determined on the basis of the second equation from the represented system (14). Otherwise, as a result of calculation when checking the obtained results, it may turn out that the container carrying capacity is fully utilized during formation of the aggregated shipment and the freightage used exceeds its allowable value (W^i). This is unacceptable.

The problem formulation given above for *version 3* is concretized as follows. The TFC has received more than two requests (K>2) from different cargo owners for the provision of cargo forwarding services r ($r = \overline{1,R};\ R = R^h \cup R^l;\ R$>2):

– some cargoes are "heavy" ($r = \overline{1,(r-1)};\ r \in R^h$), specific freightage of these cargoes is $\overline{u_1^h}, \overline{u_2^h}, ..., \overline{u_{r-1}^h}$, m^3/t;

– some cargoes are "light" ($r = \overline{r,R};\ r \in R^l$), specific loading volumes of these cargoes are $\overline{u_1^l}, \overline{u_2^l}, ..., \overline{u_{R^l}^l}$, m^3/t.

All requests contain unrecorded information on the size of the consignments planned for transportation, i.e., sizes of all consignments can be coordinated and and made more precise in the negotiation process.

The cargo forwarder needs to determine quantitative composition of the consolidated consignment shipment according to the preliminary requests received.

To implement the formulated problem, the following mathematical model of linear programming is proposed with successively formalized objective function and constraints.

The objective function (18) maximizes the size of all cargoes by weight in the loaded consolidated container:

$$Z = \sum_{r=1}^{R=R^h \cup R^l} X_r = \sum_{r=1}^{R=R^h} X_r^h + \sum_{r=1}^{R=R^l} X_r^l \to \max$$

$$(r = \overline{1,R}; R = R^h \cup R^l). \quad (18)$$

At the discretion of decision maker, quality of solving the task of planning the aggregated shipment can be characterized by the objective function that finds the extremum of the total cargo size in terms of volume:

$$Z = \sum_{r=1}^{R=R^h \cup R^l} (X_r \cdot \overline{u_r}) = \sum_{r=1}^{R=R^h} (X_r^h \cdot \overline{u_r^h}) + \sum_{r=1}^{R=R^l} (X_r^l \cdot \overline{u_r^l}) \to \max$$

$$(r = \overline{1,R}; R = R^h \cup R^l). \quad (19)$$

The system of constraints of the problem is represented by the following equations and inequalities:

– the restriction (20) ensures full utilization of the container carrying capacity when forming a aggregated shipment. Writing of this restriction in a form of an equation makes sense only under the condition that the sizes of all consignments are not strictly fixed in the preliminary requests of the cargo owners and, therefore, can be coordinated with them. This is generally specified in the problem statement for *version 3*:

$$\sum_{r=1}^{R=R^h} X_r^h + \sum_{r=1}^{R=R^l} X_r^l = D^i \quad (i = \overline{1,I}); \quad (20)$$

– the restriction (21) ensures full utilization of the container freightage when planning a aggregated shipment. Writing of this constraint in the form of an equation also makes sense only under the condition specified in the problem statement for *version 3*:

$$\sum_{r=1}^{R=R^h} (X_r^h \cdot \overline{u_r^h}) + \sum_{r=1}^{R=R^l} (X_r^l \cdot \overline{u_r^l}) = W^i \quad (i = \overline{1,I}); \quad (21)$$

– the restrictions (22) reflect the fact that the task variables cannot take negative values due to their physical nature:

$$X_r^h \geq 0; \ \ X_r^l \geq 0 \ \ (r = \overline{1,R}; R = R^h \cup R^l), \quad (22)$$

where X_r is the control parameter to be optimized. It reflects the size of cargo in consignments recommended for cargo owners divided into "heavy" (X_r^h) and, accordingly, "light" (X_r^l) cargoes, t.

The task in above general formulation for *version 4* is concretized as follows. Similar to the previous *version 3*, the TFC has received more than two preliminary requests ($k = \overline{1,K};\ K$>2) from different cargo owners for a provision of cargo forwarding services r ($r = \overline{1,R};\ R = R^h \cup R^l;\ R$>2):

Some batches are characterized by "heavy" cargoes ($r = \overline{1,(r-1)};\ r \in R^h;\ \overline{u_r} = \overline{u_1^h}$), some by "light" ($r = \overline{1,R};\ r \in R^l;\ \overline{u_r} = \overline{u_2^l}$). Moreover, a number of requests contain fixed information regarding size of the consignment Q_r planned for shipment. The other part of requests includes approximate data on the cargo size ($\approx Q_r$).

The cargo forwarder needs to determine size of the cargo consignments not indicated in requests (($\approx Q_r = X_r - ?$) at maximum utilization of carrying capacity ($D^i \to$max) and/ or freightage ($W^i \to$max) of the container dimension-type *i*.

Thus, sizes of consignments that can be agreed upon in the course of subsequent negotiations with the cargo owners are determined as a result of implementation of the mathematical linear programming model proposed below (23)–(27). The model is represented by the following set of mathematical relationships describing essence of the problem being solved.

The objective function (23) maximizes loading of the container according to its carrying capacity taking into account those cargoes the size of which is indicated in the preliminary requests of the customers. At the same time, the control parameters reflect the size of "heavy" (X_r^h) and, accordingly, "light" (X_r^l) cargoes which must be agreed with the cargo owners depending on the results of the model implementation.

$$Z = \sum_{r=1}^{R=R^h \cup R^l} Q_r + \sum_{r=1}^{R=R^h \cup R^l} X_r =$$

$$= \left[\sum_{r=1}^{R=R^h} Q_r^h + \sum_{r=1}^{R=R^l} Q_r^l \right] + \left[\sum_{r=1}^{R=R^h} X_r^h + \sum_{r=1}^{R=R^l} X_r^l \right] \to \max$$

$$(r = \overline{1,R}; R = R^h \cup R^l). \quad (23)$$

At the discretion of the decision maker, the container loading according to its freightage (which must be maximized) can also be taken as the optimality criterion. It is also necessary to take into consideration cargoes the size of which is recorded in preliminary requests of the cargo owners (the first term in (24)).

$$Z = \sum_{r=1}^{R=R^h \cup R^l} Q_r \cdot \overline{u_r} + \sum_{r=1}^{R=R^h \cup R^l} X_r \cdot \overline{u_r} =$$

$$= \left[\sum_{r=1}^{R=R^h} Q_r^h \cdot \overline{u_r^h} + \sum_{r=1}^{R=R^l} Q_r^l \cdot \overline{u_r^l} \right] + \left[\sum_{r=1}^{R=R^h} X_r^h \cdot \overline{u_r^h} + \sum_{r=1}^{R=R^l} X_r^l \cdot \overline{u_r^l} \right] \to \max$$

$$(r = \overline{1,R}; R = R^h \cup R^l). \qquad (24)$$

The system of constraints is represented by the following inequalities describing limited resources in the considered version of the problem and the possible values of its control parameters:

– the restriction on the carrying capacity of the container (25) provides such sizes of non-fixed consignments that do not exceed carrying capacity of the container including cargoes the size of which is strictly stipulated in the requests:

$$\sum_{r=1}^{R=R^h} X_r^h + \sum_{r=1}^{R=R^l} X_r^l \le D^i - \left[\sum_{r=1}^{R=R^h} Q_r^h + \sum_{r=1}^{R=R^l} Q_r^l \right]$$

$$(r = \overline{1,R}; R = R^h \cup R^l); \qquad (25)$$

– the restriction on the freightage of the container (26) ensures formation of a aggregated shipment in which sizes of the consignments not given in the requests do not exceed the container capacity minus the size of cargoes that is not subject to coordination:

$$\sum_{r=1}^{R=R^h} (X_r^h \cdot \overline{u_r^h}) + \sum_{r=1}^{R=R^l} (X_r^l \cdot \overline{u_r^l}) \le$$

$$\le W^i - \left[\sum_{r=1}^{R=R^h} (Q_r^h \cdot \overline{u_r^h}) + \sum_{r=1}^{R=R^l} (Q_r^l \cdot \overline{u_r^l}) \right]$$

$$(r = \overline{1,R}; R = R^h \cup R^l); \qquad (26)$$

– constraints (27): conditions of nonnegativity of variables:

$$X_r^h \ge 0; \quad X_r^l \ge 0$$

$$(r = \overline{1,R}; R = R^h \cup R^l). \qquad (27)$$

The developed and presented mathematical models (18)–(22) and (23)–(27) belong to the class of linear programming problems. In them, the following are established as the objective functions at the discretion of the decision maker:

– either maximum utilization of the container carrying capacity (18), (23);

– or maximum utilization of its freightage (19), (24).

Moreover, it does not matter which of the above optimal criteria will be adopted by the decision maker in the proposed models (18)–(22) and (23)(27), since:

– if the corresponding objective functions are formalized as in (18) and (23), then the full utilization of the container freightage is provided by introducing conditions into models (21) and (26), respectively;

– if the corresponding objective functions are formalized as in (19) and (24), then the full utilization of the container carrying capacity is provided by introducing conditions (20) and (25), respectively, into the models.

5. Discussion of results obtained in studying the substantiation of the quantitative composition of consignments in loading of a consolidated container

As a result of the study, theoretical and methodological guidelines have been developed to substantiate quantitative composition of consignments during formation of container load with consolidated cargoes. Implementation of these provisions allows the cargo forwarder when organizing the LCL shipments to make decisions on optimizing the loading of the consolidated container in a real time mode. The developed provisions contain a methodological tool. Its use allows one to close the problem area identified above.

A general formulation of the problem of substantiating quantitative composition of consignments in loading the consolidated container was obtained in the course of the study. Based on possible typical practical situations occurring in present-day TFCs, this task was concretized for four versions. Each of them reflects a specific production situation most often taking place in practice between the cargo forwarder and the cargo owner. A corresponding solution technology has been developed for each version of the problem statement taking into consideration peculiarities of the initial information on the planned shipment.

For the first two versions, the solution technology includes a sequence of steps involving implementation of certain systems of equations (7), (10), (14) and testing the obtained results for quality of utilization of carrying capacity (12), (17) and freightage (13), (16) of the container.

For the third and fourth versions, the solution technology provides for implementation of linear programming mathematical models (18)–(22) and (23)–(27) developed in the study. Control parameters and restrictions on the effective values of the control parameters were set in the presented models as well as conditions and restrictions inherent in this study as to the input parameters and resources used were formalized. The maximum utilization of technical parameters of the container was ensured by optimality criteria reflected in the corresponding objective functions (18), (19), (23), (24).

Models (18)–(22) and (23)–(27) are adequately applicable to any number of consignments submitted for transportation. Model (18)–(22) can also be used to solve version 1 discussed above (instead of the system of equations (7)). In turn, models (23)–(27) can be used to solve version 2 discussed above (instead of the systems of equations (10) and (14)). The only condition for adequate use of models (18)–(22) and (23)–(27) is the ability to coordinate with cargo owners the dimensions of all (18)–(22) or part (23)–(27) of consignments as a part of the aggregated shipment.

The theoretical and methodological provisions developed and presented for discussion contribute to development of the theory of transportation processes and systems that are of practical interest to the commercial departments of transport companies providing cargo forwarding services. Introduction of these provisions will ensure an increase in efficiency of production activities of representatives of the transport business and will also allow them to form rational systems of cargo forwarding services for cargoes in regional, interregional and international shipments.

The proposed provisions can be applied in organization of systems for consolidated deliveries by wans (cars with cargo semi-trailers). In international practice, such deliveries are called less than truck load (LTL) deliveries and provide for an aggregated delivery of cargoes in one vehicle.

The use of the proposed theoretical and methodological provisions in the production activities of the companies providing cargo forwarding services allows one to:

– take into consideration peculiarities of specific production situations and initial information on the planned shipments;

– form a composite loading of a container or truck with maximum possible utilization of technical and operation parameters.

The provisions proposed in the study should be further developed in the following lines:

– substantiation of the tariff unit (weight or volume of the batch) for calculating the rate for organizing delivery of cargoes in a consolidated container or a truck;

– substantiation of expediency of the less than container load (LCL) delivery of cargoes compared with the full container load (FCL) delivery, as well as the feasibility of the less than truck load (LTL) delivery of cargoes compared to the full truck load (FTL) delivery.

7. Conclusions

1. A general formulation of the problem of substantiating quantitative composition of consignments in loading a consolidated container when organizing LCL shipments was obtained. It takes into consideration the fact that in the case of LCL delivery organization, the consolidated container houses small consignments belonging to different cargo owners. Customer requests for transportation may contain information on the planned shipment. At the same time, it is necessary to ensure maximum use of technical and operational characteristics of the container which complicates the decision-making process of its loading.

2. Particular versions of the problem of substantiating quantitative composition of consignments in the loading of a consolidated container reflecting specific production situations that most often arise in practice between the cargo forwarder and the cargo owner were formulated:

– versions 1 and 2 are characterized by the fact that the set of preliminary requests received by the cargo forwarder from different cargo owners contains information on two cargo shipments. At the same time, sizes of batches are not fixed in version 1, and, therefore, are subject to discussion. In version 2, the size of one batch is strictly fixed, and that of the other must be discussed;

– versions 3 and 4 are characterized by the fact that the set of preliminary requests received from different cargo owners contains information on more than two consignments. In this case, sizes of all batches are not fixed in version 3 and can be agreed with the cargo owners. In version 4, quantitative characteristics of all batches are strictly fixed and are not subject to discussion.

3. For each of the local production tasks, a solution technology has been developed that takes into consideration characteristics of the situation and the initial information about the planned shipment:

– for versions 1 and 2, the solution technology provides for implementation of certain systems of equations and verification of the results obtained for quality of utilization of the carrying capacity and freightage of the container;

– to solve the problem in versions 3 and 4, mathematical models have been developed that belong to the class of linear programming problems. Implementation of the models ensures maximum use of technical parameters of the container due to the optimality criteria reflected in the corresponding objective functions. The peculiarity of these models is that it does not matter which of the optimality criteria is taken as a basis by the cargo forwarder: either the maximum use of the container carrying capacity or the maximum use of its freightage.

References

1. Lavrukhin O. V., Nemyrovskyi B. M. Improvement of container terminals operation on the basis of introduction of intelligent advanced technologies // Transport systems and transportation technologies. 2017. Issue 13. P. 46–51. doi: https://doi.org/10.15802/tstt2017/110768
2. Kirillova O. V. Question for optimal distribution of container traffic between vessels serving transocean-feeder lines // Naukovyi visnyk Khersonskoi derzhavnoi morskoi akademiyi. 2014. Issue 2 (11). P. 55–68.
3. Justification of Financial Safety Analysis Approach in Cargo-and-Passenger Ferry Operations Management // Transport and Telecommunication Journal. 2014. Vol. 15, Issue 2. P. 111–119. doi: https://doi.org/10.2478/ttj-2014-0010
4. Kirillova Ye., Meleshenko Ye. Development of an ecomomic and mathematical model of loading a freight and passenger ferry // Eastern-European Journal of Enterprise Technologies. 2016. Vol. 3, Issue 4 (81). P. 28–37. doi: https://doi.org/10.15587/1729-4061.2016.71215
5. Pavlenko O. V. Rozrobka systemy dlia vyznachennia optymalnoho variantu transportno-ekspedytsiynoho obsluhovuvannia // Eastern-European Journal of Enterprise Technologies. 2007. Issue 6 (30). P. 25–28.
6. Pavlenko O. V. Analiz efektyvnosti bahatotsilovoi modeli systemy transportno-ekspedytsiynoho obsluhovuvannia // Eastern-European Journal of Enterprise Technologies. 2008. Issue 5 (35). P. 30–32.
7. Sramkova, Kolar, Hunak Container Shipping: The Evaluation of Quality Factors in Freight Forwarding Services // Transportation Journal. 2018. Vol. 57, Issue 3. P. 258. doi: https://doi.org/10.5325/transportationj.57.3.0258
8. Tan A. W. K., Zhao Y., Halliday T. A Blockchain Model for Less Container Load Operations in China // International Journal of Information Systems and Supply Chain Management. 2018. Vol. 11, Issue 2. P. 39–53. doi: https://doi.org/10.4018/ijisscm.2018040103
9. Efficiency Evaluation of LCL Transshipment at Port Railway Container Intermodal Terminal / Wei Q., Xu Y., Li C., Zhang Y. // Journal of Coastal Research. 2018. Vol. 83. P. 456–464. doi: https://doi.org/10.2112/si83-076.1
10. Application of Genetic Algorithms to Container Loading Optimization / Pino R., Gómez A., Parreño J., Fuente D. D. L., Priore P. // International Journal of Trade, Economics and Finance. 2013. P. 304–309. doi: https://doi.org/10.7763/ijtef.2013.v4.306
11. Bakaev V. G. Ekspluataciya morskogo flota. Moscow: Transport, 1965. 560 p.