METHODOLOGY FOR THE DEVELOPMENT OF MULTIMODAL TRANSPORT SYSTEMS IN THE INTERACTION OF RAILWAY AND SEA TRANSPORT

In modern conditions of development of production processes in Ukraine and the world, a special place is the functioning of multimodal transport systems. The effectiveness of multimodal transportation is due to the presence of methods for organizing the processes of delivery of goods on the basis of modern logistics principles with the involvement of various types of transport. Available levels of efficiency, assortment and quality of transport services for users of a multimodal transport system in Ukraine does not meet modern world requirements. Missing methods for developing multimodal projects for infrastructure development and rolling stock, determining the size of investment resources for the development of competitive infrastructure, methods of interaction between public and private sectors. To develop and implement these projects in multimodal transport systems there is the accumulation and analysis of practical experience in implementing such logistics schemes.

Each of the participants of multimodal transportation – rail transport, sea transport, port – play an important role in the movement of cargo. And crashes in the work of any transport circuit center leads to losses for all participants in the transport process.

In the scientific literature, a lot of attention is paid to mixed cargo transportation, but very little information on multimodal logistics schemes of transportation. Scantily works are devoted to the creation of scientific and substantiated methods for developing multimodal transport systems development projects.

In the 1930-s, Academician I. G. Alexandrov gave the definition of a united transport network and described the role of each type of transport during interaction with each other in mass transportation of cargoes. Academician V. N. Obraztsov first substantiated the need for various types of transport within the framework of the complex transport theory *(Образцов, 1945)*. V. V. Zvonkov proposed a classification of combined combinations according to schemes: consistent (one mode of transport replaces another on the route), parallel (from the point of departure and to the destination at the same time can be reached by various types of transport), the parallel-sequential (circle between departure and destinations can be realized the first two schemes) *(Звонков, 1953)*. In *(Комаров, 1957)* the problem of integrated use of modes of transport is considered as a national network covering the entire movement path from the sender to the recipient.

In the 1970-s, it became comprehensibly that the technological work of railway stations and seaports in the points of transshipment of cargo, although it is an important element of the transport process, but can not lead to the improvement of the transport management system. The point of cargo transshipment is an important separate element of the transportation process of mixed transportation, at the work of which reflects the inconsistency of the interaction of other elements: the point of departure, transportation by rail transport, transportation by water transport.

The next step was the link of railway and sea types of transport in large transport nodes based on the creation of unified technological processes of work of railway and water transports and of railway and of automotive transports in points of processing of cargoes *(Golinska and Hajdul, 2012)*.

Structure of a mathematical model of interaction of various types of transport. The effectiveness of multimodal cargo transportation is determined by the coherence of cargo owners, railway and sea transport and ports *(Fechner and Szyszka, 2012)*. Compliance with the bandwidth of transshipment complexes in ports and terminals of cargo owners, carrying capacity of railway and sea modes – the main condition for ensuring effective multimodal transportation. For a certain volume of transport work and the structure of the cargo turnover, the task can be solved by choosing a variant of the ratio of the production capacity of the multimodal transport system elements, in which minimum total cash expenses have been obtained during a certain period of time. The task can be solved and reversed when the capacities of cargo terminals of cargo owners, rail and sea transport, stevedoring companies is determined optimal cargo turnover. In addition to these two basic tasks, additional tasks are defined, such as the justification of specialized reloading devices, the norms of simultaneous treatment of rail and sea transport, the number and production capacity of the cargo mechanisms and others that can be solved as cases of solving the main task.

When transporting export cargoes on delivery terms CIF («Cost, Insurance and Freight» – the trade term of international rules Incoterms 2021) (fig. 2.9.1) there are the following main activities:

1 – accumulation of cargoes in the warehouses of cargo owners: supply of products to the rear front of the warehouse; Interaction of the rear front of the warehouse with a cargo that supplied; storage of products in stock; work of the shipment of the warehouse for transportation of products to rail transport;

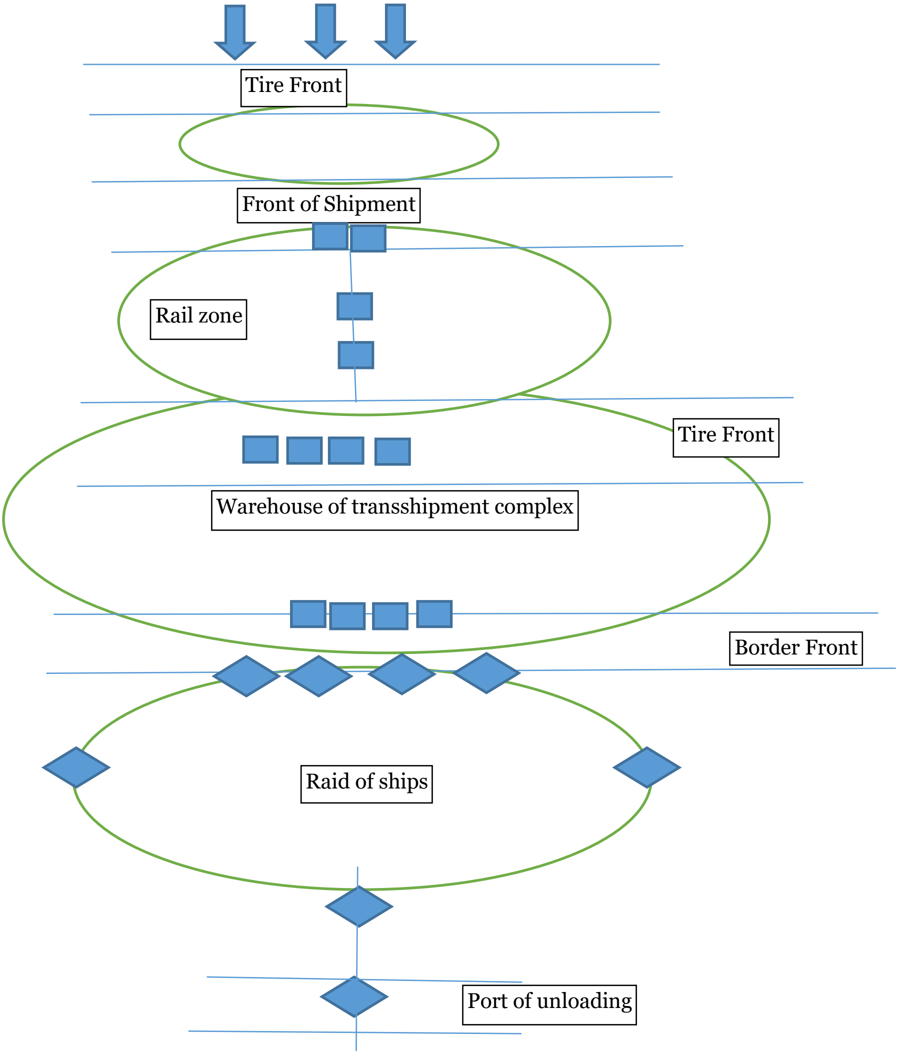

Fig. 2.9.1. Multimodal cargo transportation on delivery terms CIF

2 – moving the goods by rail from the place of production to port transshipment complexes (the formation of court parties of cargo, for overloading in a direct variant, with shipments to the warehouse, storage and loading on board of ship, or a combined overload option);

3 – interaction of the railway rolling stock with the rear front of the transshipment complex, which includes: the accumulation of railroad cars on port stations, the supply of railroad cars to the rear fronts of transshipment complexes, the activity of the rear front of the processing of railroad cars;

4 – storage of cargo, arriving in railway cars can be carried out on a warehouse territory of a transshipment complex, in railway cars, part of the judicial party in the warehouses of a stevedore company, and the other part in railway cars;

5 – the transshipment of cargo for sea transport has the following peculiarities: the interaction of flow of ships with a border front of the transshipment complex, the operation of the border front in a warehouse, direct and combined load option, the possibility of a freight front for the recycling of a cargo flow, which follows the complex;

6 – delivery of goods by sea to the port of the recipient with linear ships, if in this direction there are linear companies, a tramp marine that fragrant under the terms of charter contracts;

7 – interaction of the marine that arriving, with elements of a transshipment complex of a cargo exhauster in accordance with the requirements of the transport component of the contract and the terms of the carriage agreement.

Modeling of the process of determining the optimal number of railway cars in the supply to the cargo owner. In the warehouses of the consignor, cargo is accumulated in the process of production or delivery for shipment to consignees by rail. In most cases, such warehouses are not specialized sites for cargo handling and preparation for departure at the port *(Andrzejewski et al., 2012)*, so the main task in such a warehouse is to load cargo into wagons as soon as possible and send by rail to the port of departure *(Porter, 1998)*. As the finished product is delivered to such a warehouse, the responsible service of the shipper's company makes an order for the supply of a certain number of wagons. The value of such an order is determined by the classical model of inventory management *(Pedersen et al, 2010)*, which is based on the replenishment of stocks in accordance with the production capacity of goods to the warehouse for the period under study P.

Let c_x – the cost of storage of goods, and c_0 – the cost of work in the warehouse, including the processing of the shipment of goods shipped ρ.

The optimal value ρ for the composition of the enterprise is determined by determining the extremum of the function of total costs per unit time, which is determined by the ratio:

$$R(\rho) = \rho \cdot c_x (1 - \frac{V_s}{V_p}) / 2 + c_o \cdot P / \rho,$$

$$\frac{dR(\rho)}{d\rho} = c_x (1 - \frac{V_s}{V_p}) / 2 + c_o \cdot P / \rho^2 = 0, \quad (2.9.1)$$

$$\rho = \left\{ 2c_0 P / \left[c_x (1 - \frac{V_s}{V_p}) \right] \right\}^{1/2},$$

where V_s – the average intensity of production or supply of products; V_p – the average intensity of sales of products from the warehouse; $(V_p - V_s)$ – average intensity of increase in inventories, $(V_p - V_s) \geq 0$.

A similar approach allows to determine the optimal average number of railway cars in the supply to the front of the shipment of the shipper. Warehouse costs for storage of a batch of wagons w, when they are loaded on the tracks of the freight front are $c_{sg} w$, where c_{sg} – the cost of storage of one wagon on the warehouse tracks per unit time. The costs associated with loading a batch of wagons per unit time are $c_0 s / w$, where s is the production capacity of the shipment front.

Then the total warehouse costs for loading cars will be:

$$R(w) = c_{sg} w + c_0 s / w. \quad (2.9.2)$$

The value of the optimal for the composition of the number of wagons in the supply is defined as:

$$\frac{dR(w)}{dw} = 0, w = \sqrt{\frac{c_0 s}{c_{sg}}}. \quad (2.9.3)$$

Thus, the optimal for the composition of the enterprise the number of wagons in the supply under load is greater, the greater the production capacity of the shipment front and the greater the ratio of load costs to the cost of storage of railway wagons on the tracks of the loading front *(Congli and Yixiang, 2016).*

If from the railway station fig. 1 from the front of the shipment daily arrives on average W wagons, the daily cost of wagon-hours of waiting for the accumulation of wagons for supply to the warehouse of the transshipment complex will be:

$$C_w = \frac{24Wk_n}{N} = 24wk_n, \tag{2.9.4}$$

where N – number of feedings of wagons $N = \frac{W}{w}$,

k_n – coefficient that takes into account the intensity of replenishment of wagons on the accumulation tracks of the port station.

The cost of wagon-hours of waiting for shifting wagons from the load tracks will be:

$$C_{sh} = (\frac{24}{N} - t)W = 24w - tW, \tag{2.9.5}$$

where t – duration of cargo operations in the warehouse of the shipment front.

The number of locomotive hours per day to move the feed of wagons from the station to the warehouse of the shipment front is equal to (fig. 2.9.2–2.9.3):

$$C_l = \frac{W}{N}(t_{tech} + 2t_w), \tag{2.9.6}$$

where t_{mex} – time for technical operations,

$t_{xo\partial}$ – time of movement of the locomotive at delivery of one giving.

Then the total costs are determined by the ratio:

$$R(N) = (C_w + C_{sh}) \cdot c_{w-h} + C_l \cdot c_{l-h} = \\ = (\frac{24 \cdot k_n}{N} + \frac{24}{N} - t) \cdot M \cdot c_{w-h} + (t_{tech} + 2 \cdot t_w) \cdot N \cdot c_{l-h}, \tag{2.9.7}$$

where c_{w-h}, c_{l-h} – respectively the cost of a wagon-hour and a locomotive-hour.

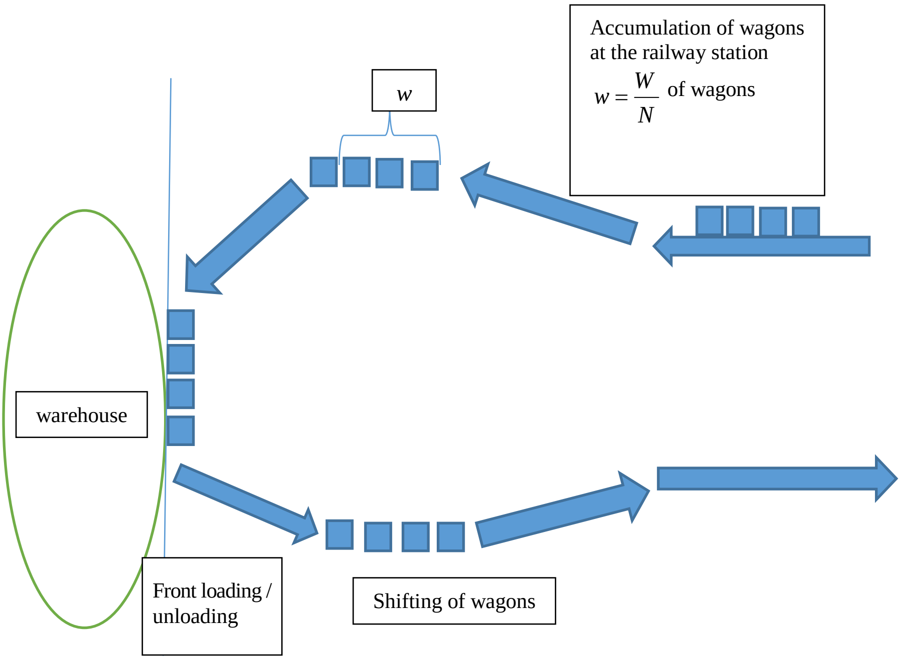

Fig. 2.9.2. Scheme of accumulation of wagons at the railway station and supply / shift to / from the warehouse of the enterprise

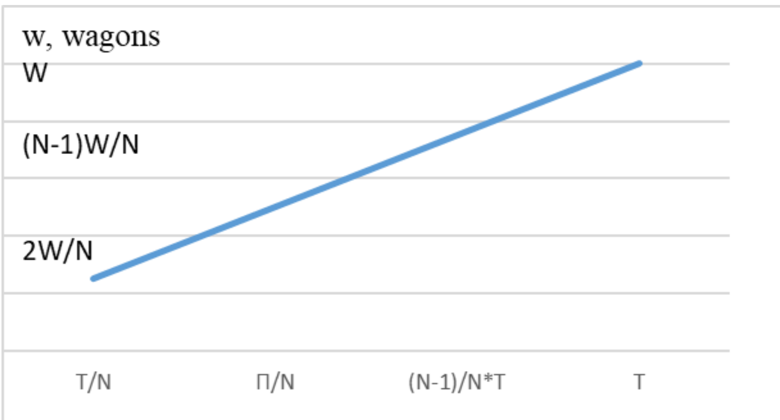

Fig. 2.9.3. Scheme of accumulation of wagons for a time interval T (T = 24 hours)

The optimal number of shiftings of cars is obtained $R(N)=0,$ that is

$$\frac{24(k_n+1)}{N^2}\cdot M\cdot c_{w-h}=(t_{tech}+2\cdot t_w)\cdot c_{l-h}, N=$$
$$=\sqrt{\frac{24(k_n+1)\cdot M\cdot c_{w-h}}{(t_{tech}+2\cdot t_w)\cdot c_{l-h}}}, w=\sqrt{\frac{(t_{tech}+2\cdot t_w)\cdot c_{l-h}\cdot M}{24(k_n+1)\cdot c_{w-h}}}. \quad (2.9.8)$$

With such a rank, the optimal number of wagons for feeding is more, more than an hour, and the part of the locomotive's work, as well as the size of the additional number of wagons, which is fed to the warehouse of the re-entangling complex *(Вернигора и др., 2017)*. Optimal is the number of wagons for deliveries that are smaller than those with higher coefficient k_n and parity for the number of wagons.

It is also possible to obtain the optimal number of feeds and the number of wagons in the supply to the warehouse, when the supply / shifting of wagons are carried out on the readiness of the next batch:

$$N=\sqrt{\frac{24(k_n+\frac{M}{q_0})\cdot M\cdot c_{w-h}}{(t_{tech}+2\cdot t_w)\cdot c_{l-h}}}, w=\sqrt{\frac{(t_{tech}+2\cdot t_w)\cdot c_{l-h}\cdot M}{24(k_n+\frac{M}{q_0})\cdot c_{w-h}}}, \quad (2.9.9)$$

where q_0 – intensity of loading / unloading of wagons in a warehouse.

Thus, while reducing the capacity of the warehouse to perform loading / unloading operations, it is necessary to increase the number of feeds and reduce the number of wagons in the feed.

Failure to coordinate the organization of this process leads to irrational filling of warehouses with railway tracks, and to the excessive accumulation of wagons on the access tracks.

Deterministic model of rolling stock processing on the rear front of the port.

Queues of wagons while waiting for unloading at the rear of the port occur when the rhythm of the transshipment complex is broken, so this process is probabilistically *(Marinov, 2009)*. In probable processes, regular relationships arise between averaged characteristics. Therefore, the task of deterministic models is to determine such relationships.

For example, there is a rear section of processing of railway wagons with cargo with technological lines of unloading. During the operating period T of the day in this section it is possible to unload on average N feeds from the w wagons, which corresponds to the S ton of cargo. The total number of working days for overloading of all feeds of railway wagons is T_u, and the total number of days of waiting for unloading is T_0.

The operating time of one freight line per day is t_d. It is necessary to determine the relationship between the initial parameters of the cargo front and the average performance:

– average weight of goods in one supply of wagons, ton:

$$g_m = \frac{S}{N} \cdot n, \tag{2.9.10}$$

– average intensity of cargo supplies to the rear front, ton / day:

$$q = \frac{S}{T}, \tag{2.9.11}$$

– average daily intensity of unloading of wagons, ton / day:

$$I = \frac{S}{T_u} \cdot \frac{t_\partial}{24}, \tag{2.9.12}$$

– capacity of the cargo front, ton / day:

$$P_m = n \cdot I, \tag{2.9.13}$$

– average time of unloading of one supply of cars, hours:

$$T_g = \frac{24 \cdot T_u}{N}, \tag{2.9.14}$$

– average waiting time for unloading of one batch of wagons, hours:

$$T_c = \frac{24 \cdot T_0}{N}, \tag{2.9.15}$$

– coefficient for determining the operating time of the freight line per day:

$$k_d = \frac{t_d}{24}, \tag{2.9.16}$$

– average number of feedings of wagons unloaded daily (average number of operating freight lines):

$$a = \frac{N}{T} \cdot \frac{T_g}{t_d} = \frac{T_u}{T} \cdot \frac{24}{t_d}, \tag{2.9.17}$$

– the average number of feeds of wagons waiting to be unloaded daily:

$$m_s = \frac{N}{T} \cdot \frac{T_s}{t_d} = \frac{T_0}{T} \cdot \frac{24}{t_d}, \tag{2.9.18}$$

– average number of feedings of wagons unloaded daily (average number of operating freight lines):

$$M_s = m_s \cdot w, \tag{2.9.19}$$

– load factor of work of cargo lines:

$$k_u^m = \frac{q}{w} = \frac{T_g}{T_i}, \tag{2.9.20}$$

where $T_i = \frac{n \cdot T \cdot t_d}{N}$ – the average unloading period of one feed (operational period), which corresponds to the average time between the supply of railway cars to the unloading front, reflects the occupancy of the rear line.

Since the cargo line can be busy or can be free, then k_u^m < 1.

Thus, we obtain the condition of stability of the cargo front:

$$k_u^m < 1,\ a = k_u^m \cdot n < n,\ T_g < T_i,\ q < P_m. \tag{2.9.21}$$

And the degree of stability of the cargo front is determined by the level of relevant reserves:

– loading of the cargo line:

$$1-k_u^m > 0, \tag{2.9.22}$$

– by number of freight lines:

$$n-a > 0, \tag{2.9.23}$$

– by processing time of wagons:

$$T_i - T_g > 0, \tag{2.9.24}$$

– on the capacity of the rear front:

$$P_m - q > 0. \tag{2.9.25}$$

The rhythm of work of the cargo front is characterized by the ratio of time periods. So, if the freight front works in the mode of an optimum rhythm, the quantity of giving of the wagons waiting for unloading is equal to zero, then $T_g = T_i$. When the rhythm is disturbed, there is a queue of railway wagons and the accumulation period increases:

$$T_g = T_i + \Delta T \geq T_i, \tag{2.9.26}$$

where ΔT – queue accumulation period.

The turnover of the accumulation period S_z is equal to the sum of the turnover of the operational S_i and additional S_Δ periods:

$$S_z = S_i + S_\Delta = \frac{S \cdot T_i}{T \cdot t_d} + \frac{S \cdot \Delta T}{T \cdot t_d} = g_m \cdot n + \frac{S \cdot \Delta T}{T \cdot t_d} = V_n + S_\Delta, \tag{2.9.27}$$

where V_n – average unloading of wagons on the freight front.

Then the turnover of carriages of the accumulation period $z = N_z$, the operational period $n = N_i$, and the additional period $\Delta = N_x$:

$$z = n + \Delta = \frac{N \cdot T_i}{T \cdot t_d} + \frac{N \cdot \Delta T}{T \cdot t_d}. \qquad (2.9.28)$$

If the feed rhythm is disturbed, there is a queue of cars on the access tracks.

Graphic interpretation of this model of the cargo rear of the seaport is shown in fig. 2.9.4. Coordinate origin point is moved to the origin of the queue on the approach to the port.

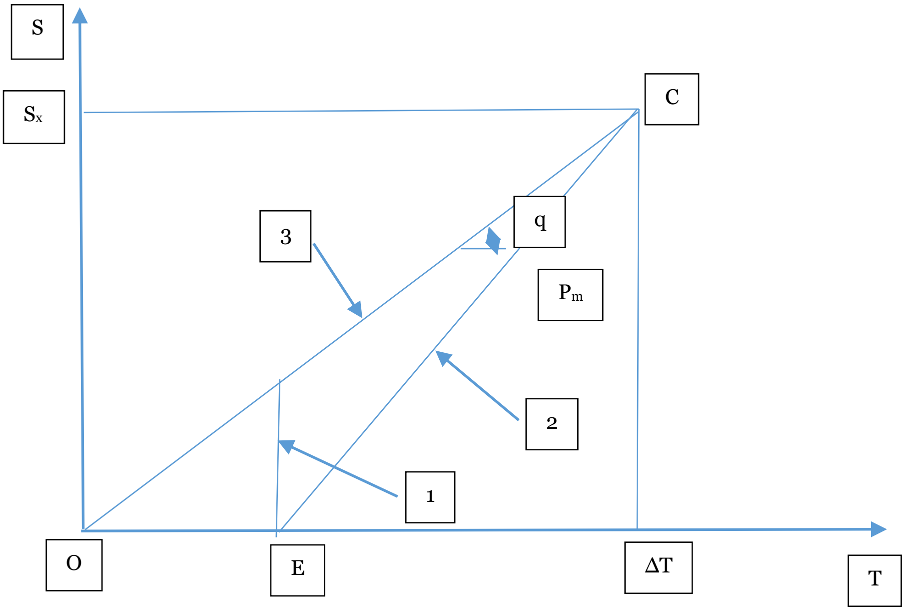

Fig. 2.9.4. Model of the rear cargo front of the seaport

Line 1 shows the process of increasing the arrival of goods in railway wagons at the port station q, t / day. And line 2 shows the operation of cargo lines of the rear front with the capacity P_m, t / day. At point C, the queue of wagons to the port is completely eliminated due to the operation of cargo lines of the rear. The area of the triangle OCE corresponds to the waiting time of wagons for the period of their accumulation. Segment 3 corresponds to the maximum feed queue of wagons with a total weight $V_n = s \cdot g_m$.

Organizational and technological structure of multimodal transportation projects with the participation of railway transport.

On the basis of the given data the organizational mechanism of functioning of multimodal transport systems can be constructed. In this case the main important processes are political and economic aspects. However, the tool by which the system of multimodal transport is launched and operates is a system of contracts for the transport of certain goods. Based on the analysis of the structure of international contracts for the supply of products, it can be argued that the dominant role is played by the transport conditions of the main positions of multimodal freight. This analysis allows us to present the mechanism of functioning of multimodal transportation in the form of a diagram illustrating the interaction of participants in logistics projects of multimodal transportation (fig. 2.9.5). This scheme allows us to consider multimodal transportation projects not as a set of independent elements of individual modes of transport, but as a system of interconnected processes of rail, sea transport and industrial enterprises. Thus activity of the main participants of multimodal transportation is regulated by the contract between the consigner and the consignee. The transport conditions of these agreements determine the main characteristics of the transportation process and the requirements for the transport infrastructure and facilities involved in the implementation of multimodal transportation *(Lavrukhin et al., 2017)*.

Within the framework of this model of delivery of cargoes from the cargo owner (producer of production) to ports of unloading of the consignee of cargoes consists of four basic technological stages of multimodal transportation:

– accumulation of goods and shipment of products from the shipper's warehouses to railway wagons;

– delivery of cargo by rail from the place of production to the warehouse of the port transshipment complex;

– accumulation of cargo in the port to the size of the shipping party and shipment of cargo from the port to sea transport;

– delivery of cargo from the port of transshipment to the port of destination.

Each stage of the multimodal transportation model characterizes a certain phase of the technological process of delivery. In addition, a system of restrictions is set that apply at a certain stage and for the model as a whole. Foreign experience of using such a model in the practice of organizing the operation of multimodal transport systems allows us to consider the technological process of multimodal transportation as a superposition of processes occurring in successive stages of delivery *(Panchenko et al., 2017)*.

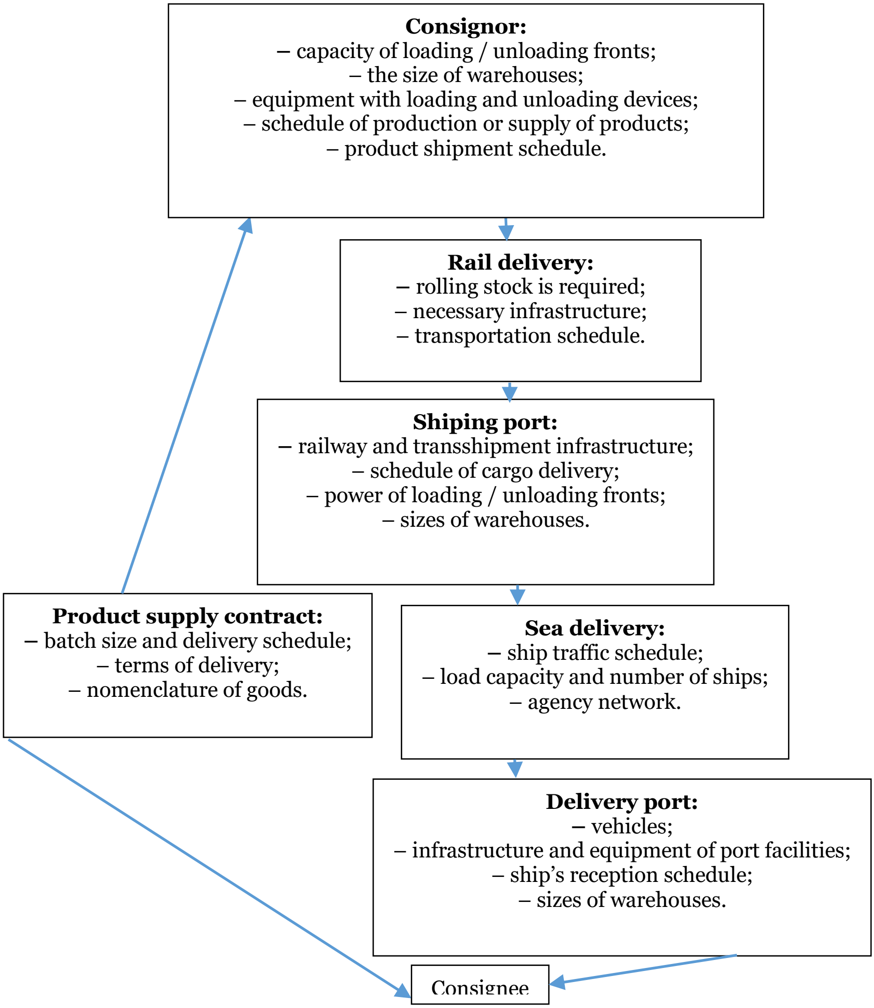

Fig. 2.9.5. Structural block diagram of multimodal transportation by rail and sea

The model of transport process in multimodal communication with participation of two types of transport by rail and sea with transshipment in ports is considered.

In accordance with paragraph 3.1 of the rules of Incoterms-2020, there are four groups of international delivery: E, F, C, D. The most complete are the conditions of DDU and DDP, in which the delivery of products from the place of production is carried out to the enterprise of the final consumer. Such conditions most fully reveal the efficiency of multimodal transportation.

However, when unloading goods at the port of destination (CIF delivery terms) to the final consumer's establishment (DDP delivery terms), the transport infrastructure and rolling stock in another country may be used *(Лосев и Руккас, 2006)*. Assume that the warehouse of the end user is located not far from the port of unloading, then you can consider this process under the terms of delivery CIF. The cargo is delivered to the port by rail. The port is accumulating cargo to the size of a shipping consignment. The cargo is loaded on the ship, and then transported by sea to the port of consignee. Transport works are organized by the operator of multimodal transportation. The main stages of the multimodal transportation operator are shown in fig. 2.9.6.

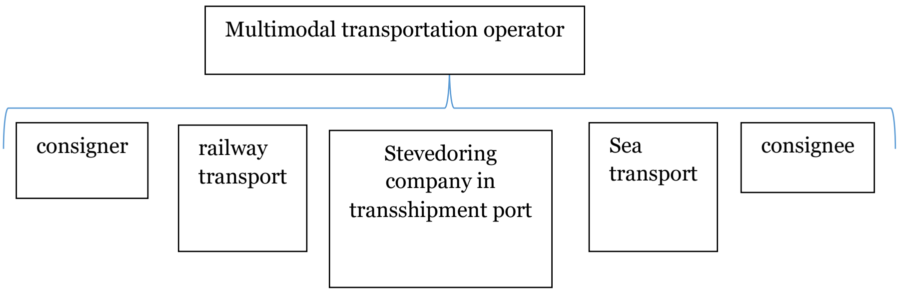

Fig. 2.9.6. Participants in multimodal freight transportation

To organize the delivery process, the multimodal transport operator interacts with the shipper, rail transport, transshipment complex in the port, sea freight carrier, consignee or its agent in the port of unloading. And the process of organizing multimodal transportation consists of two tasks *(Котенко и др., 2015)*:

– calculation of the parameters of the required infrastructure and the number of vehicles at all stages of delivery;

– determining the efficiency of delivery taking into account the costs at each stage of multimodal transportation.

Mathematical model of multimodal transportation process.

We will accept K shippers. Which in accordance with the contracts, in accordance with the production capacity, technological features, the availability of technological infrastructure at the industrial enterprise and in the port of transshipment supply products to consignees on CIF terms. To determine the required number of railway wagons and ships required to move a given amount of cargo V in the estimated period T of time from the warehouse of the shipper to the port of unloading of final consumers with minimal transport costs.

In this case, the capacity of the warehouse infrastructure in the ports should correspond to the capacities of loading and unloading devices of shippers, and each of them should ensure the processing of the respective cargo flows *(Prokhorchenko et al., 2019)*. As well as the capacity of the main railway and sea transport.

The objective function of this problem is as follows:

$$\sum_{k=1}^{K}\sum_{l=1}^{L}\sum_{i=1}^{P(l)} A_{kli}\cdot m_{kli}\cdot f_{kli} \to \min,\ A_{kli} = A^{0}{}_{kli} + \int_{0}^{t_{kli}} A_{kli}(t)dt, \quad (2.9.29)$$

where A_{kli} – total, and $A^{0}{}_{kli}, A_{kli}(t):(i \neq 2)$ – the amount of party costs for the ship, $(i = 2)$ for one car dependent and independent of time, respectively;

l – stage of transportation, consists of four stages $(L = 4)$: l_1 – processing of goods in the shipper's warehouse; l_2 – transportation by rail; l_3 – cargo handling at port transshipment complexes; l_4 – transportation by sea;

$P(l)$ – $(l \neq 2)$ number of parties for ships, $(l = 2)$ number of tariff groups of railway transportation;

m_{kli} – $(l \neq 2)$ the number of batches for ships of a given capacity, $(l = 2)$ the number of wagons of the specified tariff groups;

f_{kli} – $(l \neq 2)$ the number of dispatches of batches for ships of a given capacity, $(l = 2)$ the number of dispatches of wagons of the specified tariff groups.

The system of limitations of the task is as follows:

$$\begin{cases} 0 \le m_{kli} \le m^{*}_{kli} \\ 0 \le f_{kli} \le f^{*}_{kli} \\ \sum_{k=1}^{K} \sum_{i=1}^{P(l \ne 2)} V^{c}_{ki} \cdot m_{ki} \cdot f_{ki} = \sum_{k=1}^{K} \sum_{i=1}^{P(l=2)} q^{w}_{c} \cdot m_{ki} \cdot f_{ki} \ge V \end{cases} ; \quad (2.9.30)$$

where $m^{*}_{kli} = \frac{T}{t^{p}_{kli}}, t^{p}_{kli} = 2 \cdot t^{pyy}_{kli} + 2 \cdot t^{cm}_{kli}$,

$t^{p}_{kli}, t^{pyy}_{kli}, t^{cm}_{kli}$ – round trip time, traffic and parking for ships and wagons, respectively;

f^{*}_{kli} – restrictions on the number of ships (wagons) of the specified tonnage (tariff) groups;

V^{c}_{ki} – the amount of cargo in the batch for the ship;

q^{w}_{c} – the average amount of cargo in the railway wagon.

The solution of this problem is to determine the optimal number of railway wagons and ships for transportation of a given amount of cargo for the estimated period of time.

The practice of organizing multimodal transportation in the world shows that for operational purposes, we can consider the process of delivery of goods from each company as an independent multimodal process. As a result of solving a general nonlinear problem, the objective function breaks down into K independent nonlinear problems, the solution of which is possible by modern methods *(Śliwczynski et al., 2012)*.

Identification of material and technical resources and investments necessary for the effective organization of multimodal transportation in logistics projects.

Determining the parameters of the mathematical model of multimodal transportation $A^{0}{}_{kli}$, which means the stationary monetary costs per ton of cargo transported during multimodal transportation, is an important task of the methodology of multimodal delivery. Methods for determining these parameters can be used in the calculation of feasibility studies for investment projects of multimodal transportation with the participation of rail, sea transport and cargo handling in port transshipment complexes *(Golinska and Hajdul, 2011)*.

Junction points of different types of transport are intended for transportation and transshipment of different types of cargo of cargo owners. The points of contact include the points of interaction of industrial and main types of railway transport, including freight fronts, receiving and dispatching and sorting tracks, loading and unloading mechanisms and warehouses for temporary storage of goods *(Villa, 2002)*.

The main general requirement in determining the production capacity of the transport network is to ensure mutually agreed throughput and processing capacity of all devices, that is involved in the transport process *(Butko et al., 2020)*. All devices must ensure the continuity of the transport process. And their power should be such that the capacity of each subsequent element was equal to or greater than the previous one. In determining the technical and economic performance of cargo fronts are based on existing experience in the operation of existing similar facilities *(Jennings and Wooldridge, 1998)*. The length of the feed front is determined by the formula:

$$l_{feed} = n \cdot l_w + l_l + 10, \qquad (2.9.31)$$

where n – the number of wagons in the supply;

l_w, l_l – respectively the length of the wagon and the length of the locomotive;

10 – the number of meters of admission to the train stop.

The feed length usually coincides with the length of the cargo front *(Kawa et al., 2010)*. This allows optimal use of technological solutions for selected schemes of mechanization of loading and unloading operations. The stock of stored cargo is determined by the formula:

$$Q = \frac{P \cdot t}{365}, \qquad (2.9.32)$$

where P – annual freight turnover;

t – regulatory stock of days.

Then the required area of the shipping area of the warehouse is determined by the formula:

$$f_{sh} = \frac{Q_{sh}}{k_{us} \cdot q_n}, \qquad (2.9.33)$$

where Q_{sh} – stock of cargo placed on the shipping area;

k_{sh} – the utilization factor of the warehouse area;

q_n – technological load per 1 m² of warehouse area from the cargo stored there.

Knowing the length of the cargo front and the required area of warehouses, you can determine the width of the warehouse area:

$$W = \frac{f}{l}, \qquad (2.9.34)$$

where f – the required area of the relevant warehouse area;

l – the length of one of the cargo fronts.

Depending on the nature of the cargo, warehouses or open areas are designed. Depending on the operating conditions of the warehouse and the technological justification, the means of mechanization of loading and unloading operations are selected. Warehouse equipment and loading and unloading mechanisms are selected on the basis of technical and economic indicators.

Railway devices are one of the main elements of equipment of transshipment areas of the port. Port railway devices means the whole set of track development of railway transport, which is used for transshipment of cargo to ships and in the opposite direction *(Russo and Sansone, 2015)*. This set includes a pre-port station of the general railway network (or a station adjacent to the port branch), a port station (or freight fleet), connecting tracks between the station and transshipment fronts, loading and unloading tracks at berths and near warehouses. Logistic analysis of the components of multimodal transportation in the railway component consists of initial and final operations, transportation of cargo to the transshipment port, initial and final operations in the transshipment port.

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