ISSN 1822-296 X (print)
ISSN 2351-7034 (on-line)

KAUNAS UNIVERSITY OF TECHNOLOGY
KLAIPĖDA UNIVERSITY
IFToMM NATIONAL COMMITTEE OF LITHUANIA
LITHUANIAN SOCIETY OF AUTOMOTIVE ENGINEERS
THE DIVISION OF TECHNICAL SCIENCES
OF LITHUANIAN ACADEMY OF SCIENCES
VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

TRANSPORT MEANS 2023

Sustainability: Research and Solutions

PROCEEDINGS OF THE 27th INTERNATIONAL SCIENTIFIC CONFERENCE

PART II

October 04-06 , 2023
Hybrid Conference - Palanga, Lithuania

CONFERENCE IS ORGANIZED BY
Kaunas University of Technology,
In cooperation with
Klaipeda University,
IFToMM National Committee of Lithuania,
Lithuanian Society of Automotive Engineers,
The Division of Technical Sciences of Lithuanian Academy of Sciences,
Vilnius Gediminas Technical University

The proceedings of the 27th International Scientific Conference Transport Means 2023 contain selected papers of 9 topics: Aviation, Automotive, Defence Technologies, Fuels and Combustion, Intelligent Transport Systems, Railway, Traffic, Transport Infrastructure and Logistics, Waterborne Transport.

All published papers are peer reviewed.

The style and language of authors were not corrected. Only minor editorial corrections may have been carried out by the publisher.

doi: 10.5755/e01.2351-7034.2023.P2

D. Lomotko, H. Prymachenko, O. Shkurenko, M. Perepichko. Research of the Main Criteria for Planning Multimodal Routes 651

V. Malashkin, M. Berezovyi, R. Korobiova. Introduction of Bimodal Technologies for Transportation of Grain Cargoes 657

L. Filina-Dawidowicz, W. Durczak. Factors Influencing Vessel Traffic Organization during the Dredging Works on Świnoujście-Szczecin Fairway 662

M. Kovtanets, V. Mogila, O. Serhiienko, V. Nozhenko, T. Kovtanets. Study of the Dynamic Capabilities of the Controlled Friction Damper 668

F. Škultéty, J. Čerňan, M. Janovec, K. Šajbanová. Towards a Unified Framework: Assessment of Licensing and Airworthiness Standards for European Ultralight Aviation 674

N. Konon, O. Pipchenko, Yu. Kazak. Virtual Reality Application and Usability in the Context of Maritime Education and Training: Assessment and Perspectives 680

S. Goolak. Methodological Guidelines for Choosing a Method of Compensation of Higher Harmonic Current Components in Traction Drive Systems of Electric Rolling Stock 685

Z. Rosnerova, E. Kicova, O. Ponisciakova. Public Mass Passenger Transport Versus Individual Transport from the Perspective of Customers and their Requirements During the COVID-19 Pandemic 691

D. Juodvalkis, R. Skvireckas. A Study of the Efficiency of a Plug-in Hybrid Car 696

P. Skolilova, E. Glaserova, P. Horazdovsky. Student Project – Analysis of Transport Opportunities 2050+ for the Regions in the Czech Republic 700

Y. Monastyrskyi, V. Sistuk, I. Maksymenko. Prospects for Using Truck Trolley-Assisted Haulage Systems in Deep Iron Ore Open Pit Mines 705

E. Valionienė, B. Plačienė. Improving the Technological Sustainability of Seaport Organizational Ecosystem Based on Flexible Leadership 710

M. Kovtanets, O. Serhiienko, S. Semenov, E. Mikhailov, T. Kovtanets. Computer Programming for Predicting the Traction and Braking Locomotive Performance 716

A. Ručinskis, V. Lukoševičius, A. Povilionis. Analysis of Lightweight Vehicle Suspension Using MSC.Adams/Car 722

A. Sulym, P. Khozia, O. Fomin, M. Khara, O. Burlutskyy. New Approach to Determining the Rational Parameters of the On-Board Capacitive Energy Storage for a Metro Train 733

J. Jelinek, B. Kopilakova, P. Stodola, J. Stodola. Threat and Risk Management 739

G. Boyko, M. Kovtanets. Increasing Efficiency of the Pad Brake Operation 747

D. Juodvalkis, M. Mažeika. Research of Electric Vehicle Charging from AC Power Supply 750

O. Fomin, O. Kozynka, A. Klymash, O. Tymoshchuk. The Control Analysis of the Current Receivers Interaction (Including Composites) with the Contact Wire 755

R. El Banna, S. Kilikevičius, A. Fedaravičius. Transportation of Microparticles Applying Dynamic Dry Friction Manipulations 761

O. Ischuka, D. Lomotko, M. Lomotko. Choosing the Optimal Variant for Shunting Operations Using the Logistic Approach at Marshalling Station 766

V. Nozhenko, M. Kovtanets, M. Morneva, Y. Velychkovska, I. Medvediev, T. Kovtanets. On the Dissemination of Vibration Energy from the Wheel and Rail Contact Surface into Adjacent Structures 772

P. Lukášik, V. Kadlub. Run-in and Long-Term Operation of Ceramic Brake Pads on Wheeled Vehicles 775

Proceedings of 27th International Scientific Conference. Transport Means 2023.

Research of the Main Criteria for Planning Multimodal Routes

D. Lomotko[1], H. Prymachenko[2], O. Shkurenko[3], M. Perepichko[4]

[1]*Ukrainian State University of Railway Transport, Feuerbach Square 7, 61050, Kharkiv, Ukraine, E-mail: den@kart.edu.ua*
[2]*Ukrainian State University of Railway Transport, Feuerbach Square 7, 61050, Kharkiv, Ukraine, E-mail: gannaprymachenko@kart.edu.ua*
[3]*State University of Infrastructure and Technology, Kyrylivska str., 9, 04071, Kyiv, Ukraine, E-mail: dondyy@ukr.net*
[4]*Odessa National Maritime University, Mechnikova str., 34, 65029, Odessa, Ukraine, E-mail: samojlovskaamaja@gmail.com*

Abstract

The main criterion when planning multimodal routes is the cost of cargo transportation, this indicator, according to the basic principle of logistics, always tends to the minimum. The paper formulates the objective cost function for the transportation of containers in multimodal transportation. It is taken into account that in multimodal transportation, one operator and, accordingly, it is he who formulates the final cost, which tends to the minimum. Also, an important criterion when carrying out multimodal cargo transportation is the cargo delivery time, which according to the principles of logistics should have a minimum value. An important quantity that characterizes the flow of cargo movement on a multimodal route is the function of the probability of movement of a certain number of transport units on it during a given time interval. All these parameters are relevant for the transport systems of European countries.

KEY WORDS: *multimodal route, logistics, transportation operator, freight transportation*

1. Introduction

The identification of the structure of the cargo movement system in multimodal transportation and the relationships between the elements of the structure itself and with other movement systems with which interaction can occur was carried out on the basis of the methodology of the system approach, which allows finding the optimal solution to the problem of forming multimodal routes as a system. Based on the postulates of the general theory of systems [1], it is known that every system is integral, but it can be divided into a number of subsystems, each of which can be considered as an integral system and vice versa. Indicators of system integrity and divisibility indicate that the elements that make up a multimodal freight transportation system function only within the framework of this multimodal transportation system. At the same time, it is necessary for each of the elements to have a certain quantitative and / or qualitative parameter value in order to achieve the general goal of the functioning of the multimodal system. Outside of a given multimodal system, elements exist by themselves, just as they can form other systems. In fact, the multimodal system itself functions due to the functioning of a certain set of elements, and not each element separately. During the physical movement of material flows on a multimodal route, certain elements of transport systems interact. In particular, the participation of two or more types of transport, the operator of multimodal transport and other possible participants, which together with the work of infrastructure elements of transport systems ensure the movement of cargo in multimodal transport communications. At the same time, a multimodal transport system is a technologically interconnected system of vehicles, transport communications, transport infrastructure regardless of the form of ownership, and a system for regulating their interaction [2]. Thus, it is the transport systems of various types of transport that are the physical (material) basis for the formation of multimodal routes, as a set of interconnected elements of transport systems that interact with each other to ensure the movement of material flows. In this case, the object of movement is a material flow or cargo. Vehicles of various types of transport and infrastructure facilities involved in the multimodal route determine the presence of a "technical-infrastructural" subsystem in the multimodal system of movement of material flows. In the case of multimodal transportation of goods with the participation of railway transport, the key elements are stations and tracks as infrastructure objects and locomotives with wagons as technical means, sea transport - respectively ports, sea routes and fleet, automobile - bus stations, highways and trucks. Accordingly, the multimodal route as a system is characterized by the presence of an "information-providing" subsystem, the elements of which are the subjects of the transport services market, such as carriers, the operator of multimodal transportation, terminal owners and possible third parties involved in the movement of material flows along the multimodal route. The number of them in the delivery system depends on the complexity of the system being formed - the number of elements included in it and the relationships between them. Formation of a multimodal route is a process of selection and arrangement in a chronological sequence of elements of transport systems and relevant subjects of the market of transport services [3]. The complexity of the multimodal system of movement of material flows depends on the number of elements of transport systems included in it and the number of involved subjects of the transport services market. The functioning of the technical-infrastructural subsystem of the multimodal system of movement of material flows is ensured by the subjects of the market of transport services - the information-providing subsystem, and the number of such subjects is determined by the complexity of the formed system.

2. Mathematical Modelling

The multimodal transport system can be studied as a stochastic multi-stage transport problem. Then, under the given conditions and designations, the economic-mathematical model of the *d*-stage transport problem for determining the amount of costs (z) at each moment of time from the beginning of the route to various points of its duration takes the form:

$$z=\sum_{i=1}^{m}\sum_{k=1}^{p}s_{ik}\cdot x_{ik}+\sum_{k=1}^{p}v_{k_1k_p}\cdot w_{k_1k_p}+\sum_{k=1}^{p}\sum_{j=1}^{n}t_{kj}\cdot y_{kj}\to min\ ; \tag{1}$$

$$\sum_{k=1}^{p}x_{ik}\le a_i,\quad i=\overline{1,m}\ ; \tag{2}$$

$$\sum_{k=1}^{p}y_{kj}=b_j,\quad j=\overline{1,n}\ ; \tag{3}$$

$$a_i\ge\sum_{k=1}^{p}w_{k_1k_p}\le b_j\ ; \tag{4}$$

$$\sum_{k=1}^{p}x_{ik}=\sum_{j=1}^{n}y_{kj}\le c_k,\quad k=\overline{1,p}\ ; \tag{5}$$

$$x_{ik}\ge 0,\ i=\overline{1,m},\quad k=\overline{1,p}\ ; \tag{6}$$

$$w_{k_1k_p}\ge 0,\quad k=\overline{1,p}\ ; \tag{7}$$

$$y_{kj}\ge 0,\quad k=\overline{1,p},\quad j=\overline{1,n}\ , \tag{8}$$

where s_{ik}, $v_{k_1k_p}$, t_{kj} - costs for transporting a transport unit from the i-th customer of a multimodal transportation service ($i=\overline{1,m}$) to the k-th intermediate point on a multimodal route ($k=\overline{1,p}$), costs for transporting a transport unit between intermediate points of a multimodal route, costs from the k-th intermediate point to the j-th consignee $(j=\overline{1,n})$, respectively, um. unit; x_{ik}, $w_{k_1k_p}$, y_{kj} - the number of transport units on the section of the multimodal route from the i-th customer of the multimodal transportation service to the k-th intermediate point on the multimodal route, between the intermediate points of the multimodal route, from the k-th intermediate point to the i-th consignee, respectively, units; a_i- the available stock of transport units at the i-th customer of the multimodal transportation service, units; b_j- demand of the j-th consignee for transport units, units; c_k- capacity of each k-th intermediate point on the multimodal route, unit.

To solve the problem, you can apply the simplex method or reduce it to a classic one-stage transport problem and solve it using the potential method. The conditions for the existence of a solution to the problem are as follows:

1) the total stock of products of all customers of the multimodal transportation service allows to satisfy the aggregate demand of all consignees:

$$\sum_{i=1}^{m}a_i\ge\sum_{j=1}^{n}b_j\ ; \tag{9}$$

2) the throughput capacity of all intermediate points is sufficient to process the total flow of cargo in the multimodal transport network:

$$\sum_{j=1}^{n}b_j\le\sum_{k=1}^{p}c_k. \tag{10}$$

Such formulation of the transport problem is classical. The constraints in the problem are presented in the form of inequalities, so it is open. If the constraints have the form of equalities, it is called closed. If we take the demand for transportation as a variable value, that is, the demand of consignees for transport units, then the restriction will take the form:

$$P\left[\sum_{k=1}^{p} y_{kj} = b_j(\omega)\right] \ge a_j, \quad \omega \in \Omega_j, \tag{11}$$

where Ω_j – is the set of events ω, namely, the number of multimodal transportations that ended with delivery to consignees; $b_j(\omega)$ – is a random variable of the demand of consignees and has a mathematical expectation $\overline{b_j(\omega)}$ and a mean square deviation σ_j, then:

$$P\left[\sum_{k=1}^{p} y_{kj} = b_j(\omega)\right] = P\left[\frac{b_j - \overline{b_j}}{\sigma_j} = \frac{\sum_{k=1}^{p} y_{kj} - \overline{b_j}}{\sigma_j}\right] = \Phi\left[\frac{\sum_{k=1}^{p} y_{kj} - \overline{b_j}}{\sigma_j}\right] \ge a_j; \tag{12}$$

$$\frac{\sum_{k=1}^{p} y_{kj} - \overline{b_j}}{\sigma_j} \ge \Phi^{-1}(a_j), \tag{13}$$

where Φ – is the distribution function of the demand of cargo receivers for transport units.

$$\begin{aligned}\sum_{k=1}^{p} y_{kj} &= \overline{b_j} + \Phi^{-1}(a_j)\cdot\sigma_j = \int_{t_0}^{\tau} b_j \cdot P'(b_j)\,db + \Phi^{-1}(a_j)\cdot\sigma_j = \\ &= \int_{t_0}^{\tau} b_j \cdot P'(b_j)\,db + \Phi^{-1}(a_j)\cdot\left|\sqrt{\int_{t_0}^{\tau}\left(\left[b_j - \int_{t_0}^{\tau} b_j\cdot P'(b_j)\,db\right]^2 \cdot \Phi' b_j\right)db}\right|.\end{aligned} \tag{14}$$

If the variable value is the offer of customers of the multimodal transportation service, that is, formula (2) changes:

$$P\left[\sum_{k=1}^{p} x_{ik} \le a_i(\nu)\right] \le b_i, \quad \nu \in \Omega_i, \tag{15}$$

where Ω_i – is the set of events ν, namely, the number of multimodal transportations that started as shipment of cargo units from customers of multimodal transportation services; $a_i(\nu)$ – random variable of the offer of customers of multimodal transportation services and has a mathematical expectation $\overline{a_i(\nu)}$ and a mean square deviation σ_i, then:

$$P\left[\sum_{k=1}^{p} x_{ik} \le a_i(\nu)\right] = P\left[\frac{a_i - \overline{a_i}}{\sigma_i} \le \frac{\sum_{k=1}^{p} x_{ik} - \overline{a_i}}{\sigma_i}\right] = F\left[\frac{\sum_{k=1}^{p} x_{ik} - \overline{a_i}}{\sigma_i}\right] \le b_i; \tag{16}$$

$$\frac{\sum_{k=1}^{p} x_{ik} - \overline{a_i}}{\sigma_i} \le F^{-1}(b_i), \tag{17}$$

where F – is the distribution function of the offer of multimodal transportation service customers.

$$\begin{aligned}\sum_{k=1}^{p} x_{ik} &\le \overline{a_i} + F^{-1}(b_i)\cdot\sigma_i \le \int_{t_0}^{\tau} a_i \cdot P'(a_i)\,da + F^{-1}(b_i)\cdot\sigma_i \le \\ &\le \int_{t_0}^{\tau} a_i \cdot P'(a_i)\,da + F^{-1}(b_i)\cdot\left|\sqrt{\int_{t_0}^{\tau}\left(\left[a_i - \int_{t_0}^{\tau} a_i\cdot P'(a_i)\,da\right]^2 \cdot F'(a_i)\right)da}\right|.\end{aligned} \tag{18}$$

In order to assess the necessity and relevance of the study of the system of multimodal transportation as the transportation of transport units of containers, a statistical analysis of transported containers over the period of the last 14 years was carried out (Fig. 1). A trend towards an increase in container transportation was obtained in the forecast for the period from 2009 to 2021 with an accuracy of almost 80%. The year 2022 in Ukraine showed a sharp decrease in container transportation, which is associated with military actions and, accordingly, a significant impact on the transport industry, but even then, there is a trend towards a projected increase in container transportation with a probability of 74,7%.

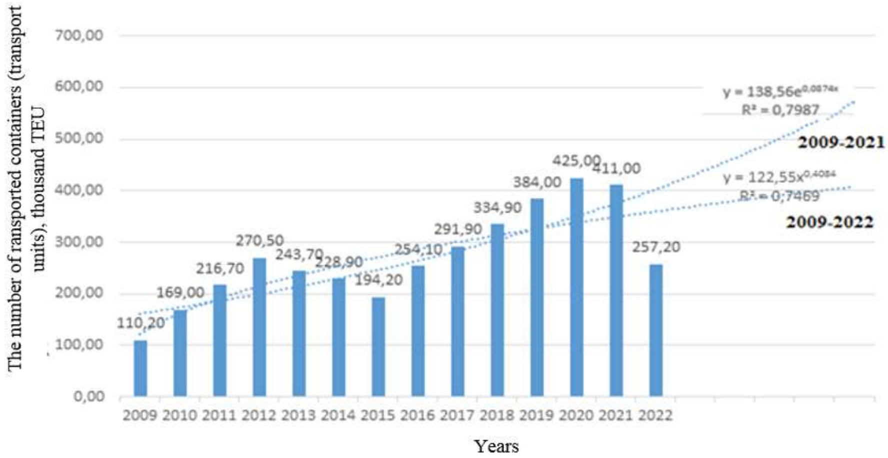

Fig. 1 Histogram of the number of transported containers for 2009-2022 with an exponential trend line [4, 5]

The main criterion when planning multimodal routes is the cost of cargo transportation, this indicator, according to the basic principle of logistics, always tends to the minimum. In [6], the objective function of costs for the transportation of one container was formulated for intermodal transportation, but for multimodal transportation, one transportation operator and, accordingly, that it is he who formulates the final cost, which tends to the minimum.

If the objective function is formulated in the form of costs per transport unit for multimodal transportation, then it will have the following form:

$$Z(A,t_0)=\left(z_{doc.}+N\cdot\sum_{\gamma=1}^{\#A}\left(L_{a_\gamma}\cdot z_{a_\gamma}+z_{a_\gamma}^{add.1}+z_{a_\gamma}^{add.2}+\theta\cdot\left(\left|T_{a_\gamma}-T_{a_{\gamma+1}}\right|\right)\cdot z_{s_{a_\gamma}^{fin.},s_{a_\gamma}^{st.}}+\left(z_{s_{a_\gamma}^{st.}}^{wh.}+\chi\cdot z_{s_{a_\gamma}^{st.}}^{vert.}\right)\cdot\tau_{s_{a_\gamma}^{fin.},s_{a_\gamma}^{st.}}^{del.}\left(t_0\right)\right)\right)/n\rightarrow$$
$$\rightarrow min, \qquad (19)$$

where A – is an ordered variable vector (set) of arc numbers corresponding to the cargo movement route on the graph of possible elements of multimodal routes; t_0 – the moment of starting the implementation of the multimodal route, min.; $z_{doc.}$ – costs for processing transport documents, um. unit; N – the volume of the cargo lot, reduced to the capacity of the transport unit, units; $\#A$ – the power of a set of elements of a variable vector A; L_{a_γ} – the length of the section of the route corresponding to the γ – th element of the set a, km; z_{a_γ} – specific costs for moving a transport unit in the section corresponding to arc a_γ, um. unit; $z_{a_\gamma}^{add.1}$ – additional expenses on arc a_γ related to the cargo (fee for additional fastening, overloading, packaging, etc.), um. unit; $z_{a_\gamma}^{add.2}$ – additional expenses on arc a_γ, related to the specifics of moving the vehicle (court fee, fee for ice passage of the vessel, seasonal surcharge to the tariff, etc.), um. unit; $z_{s_{a_\gamma}^{fin.},s_{a_\gamma}^{st.}}$ – specific costs associated with the unloading of a transport unit at the final terminal of the arc a_γ, movement and loading at the terminal of the arc $a_{\gamma+1}$, um. unit; $z_{s_{a_\gamma}^{st.}}^{wh.}$ – specific cost of guarding the container in the terminal warehouse, which is located at the initial vertex of the arc $a_{\gamma+1}$ during the waiting period, um. unit; $z_{s_{a_\gamma}^{st.}}^{vert.}$ – the specific cost of guarding the container in the terminal warehouse, which is located at the initial vertex of the arc $a_{\gamma+1}$ during the waiting period, um. unit; χ – a boolean variable that takes the value 1 if protection is required and 0 otherwise; T_{a_γ} – type of transport connection on arc a_γ; $\tau_{s_{a_\gamma}^{fin.},s_{a_\gamma}^{st.}}^{del.}(t_0)$ – the time interval of the delay during the transition between arcs a_γ and $a_{\gamma+1}$ (when changing one mode of transport to another or performing operations with trains at railway stations, customs operations, etc.), which depends on the time of the start of the route t_0; $\theta(a)$ – the Havisside function takes the value 0 at $a \le 0$ and 1 at $a \succ 0$; n – number of transport units in a multimodal shipment, units.

Also, an important criterion when carrying out multimodal cargo transportation is the cargo delivery time, which according to the principles of logistics should have a minimum value:

$$T(A,t_0)=\sum_{\gamma=1}^{\#A}\left(\left(L_{a_\gamma}/v_{a_\gamma}\right)\cdot k_{a_\gamma}^{del.}(t_0)+\tau_{s_{a_\gamma}^{fin.},s_{a_\gamma}^{st.}}^{del.}(t_0)\right)\to min, \tag{20}$$

where v_{a_γ} – is the average speed of movement along the arc a_γ; $k_{a_\gamma}^{del.}(t_0)$ – is the delay factor when moving along the arc a_γ, which depends on the moment of the start of the implementation of the multimodal route t_0.

In order to obtain an adequate solution to the given task, certain restrictions are imposed on the control variables of the model:

$$\begin{cases} t^{st.r.}\le t_0\le t^{fin.r.}; \quad l_{a_\gamma}^{k}=l_{a_{\gamma+1}}^{n}, \quad \gamma=1,2...\#A, \\ l_{a_1}^{n}=l^{n}; \quad l_{a_{\#A}}^{k}=l^{k}; \quad n\le M_{a_\gamma}(t_0), \ \gamma=1,2...\#A; \end{cases} \tag{21}$$

where $t^{st.r.}, t^{fin.r.}$ – are, respectively, the initial and final limits of the interval of the possible start of the implementation of the multimodal route, which are usually determined by the customer of the multimodal transportation service; l^{n}, l^{κ} – numbers of vertices of the transport network graph, which correspond to the starting and ending points of the multimodal route, respectively; $l_{a_\gamma}^{k}, l_{a_{\gamma+1}}^{n}$ – the number of the final vertex of the arc a_γ and the number of the initial vertex of the arc $a_{\gamma+1}$, respectively; $l_{a_1}^{n}, l_{a_{\#A}}^{k}$ – the number of the starting vertex of the first arc of the multimodal route and the number of the final vertex of the last arc of the multimodal route, respectively; $M_{a_\gamma}(t_0)$ – the number of free seats for each transport unit (slots on board a container ship or fitting platforms for loading containers, etc.) at the time of starting the movement of cargo along the arc a_γ, depending on the time of starting the implementation of the route t_0.

The first constraint in formula (21) ensures the search for an optimal solution, in which the moment of starting the implementation of the multimodal route is within a certain time interval that corresponds to the conditions of the customer of the multimodal transportation service; the second - ensures the continuity of the multimodal route due to the coincidence of the final vertex of the previous arc and the initial vertex of the next arc; the third and fourth - ensure the selection of only those options of multimodal routes connecting the vertices of the transport network, which are specified by customers of the multimodal transportation service as the initial and final points of cargo movement; fifth - ensures the selection of only those multimodal routes that ensure the availability of a sufficient number of free cargo spaces to ensure the possibility of moving a consignment of cargo in full along the entire multimodal route [7, 8]. Thus, in such a setting, the task of choosing the optimal multimodal transportation plan is a task of multi-objective or vector optimization.

Another important quantity that characterizes the flow of cargo movement on a multimodal route is the function of the probability of movement of n transport units on it during a given time interval $[t_0,\tau]$:

$$P(n,[t_0,\tau])=1-exp\left(-\int_{t_0}^{\tau}\lambda\sum(t)dt\right)\cdot\sum_{q=1}^{G(S,n)}\prod_{f=1}^{S}\frac{\left(\int_{t_0}^{\tau}\lambda f(t)dt\right)^{q_{gf}}}{q_{gf'}}, \quad \sum f\cdot q_{gf}\prec n, \ q_{gf}\in B, \tag{22}$$

where $\lambda f(t)$ – is the intensity of the flow of transport units of multiplicity f, as a function of time; q_{gf} – the number of events of the flow of multiplicity f in the time interval $[t_0,\tau]$ in the g-th version of the development of events; S – the maximum multiplicity of the flow at the p-th intermediate point; $G(S,n)$ – the power of the set of probabilistic cases of the development of events at the given values of S and n, when the case is understood as one of the possible implementations of the flow characterized by the set $\{q_{g1},q_{g2},...,q_{gS}\}$ of the flow at the p-th intermediate point; $\int_{t_0}^{\tau}\lambda f(t)dt=\int_{t_0}^{\tau}\lambda\sum(t)dt$ – "leading flow function", i.e. the cumulative total flow intensity of all multiples as a function of time.

3. Conclusions

The multimodal transportation system is studied as a stochastic multistage transportation problem. This made it possible to formulate an economic-mathematical model of the d-stage transport problem under the given conditions and designations to determine the cost of multimodal transportation of transport units at each moment of time from the beginning of the route to various points of its duration. This approach makes it possible to choose in advance the most acceptable multimodal route option for the customer of the multimodal transportation service, because the main criterion when planning multimodal routes is the cost of cargo transportation. Therefore, the objective function of the research was chosen as costs per transport unit in multimodal transportation, and the second criterion in the implementation of multimodal transportation of goods - the time of delivery of goods. And the question of choosing a multimodal route is reduced to the problem of multi-objective or vector optimization. And the value characterizing the flow of cargo movement on a multimodal route was chosen as the function of the probability of movement of a certain number of transport units on it during a given time interval, which made it possible to bring the obtained mathematical models closer to the realities of the movement of material flows in space. The obtained results indicate the relevance and theoretical effectiveness of the active development of the system of multimodal transportation with the participation of railway transport and, accordingly, the need to study the main criteria of their planning and organization. And the determination of such factors as the cost of transportation, the time of finding material flows on the road are the main criteria for the effectiveness of the functioning of multimodal transport systems.

References

1. **Orlovskij, P.N.** 1996. System analysis (basic concepts, principles, methodology), Kyiv, 360 p. [in Ukraine].
2. Model law on transport activities from 31.10.2007. № 997_i37 [online cit.: 2023-05-05]. Available from: https://zakon.rada.gov.ua/laws/show/99_i37.
3. **Onyshenko, S.P.; Кoskina, Ju.** O. 2019. The essence, specificity and formation of the cargo delivery system, Bulletin of Vinnytsia National Polytechnic University 3(144): 86-95. doi.org/10.31649/1997-9266-2019-144-3- 86-95 [in Ukraine].
4. Transportation of goods in containers for 2022 amounted to 257.2 thousand TEU [online cit.: 2023-05-05]. Available from: https://cfts.org.ua/news/2023/01/26/ukrzaliznitsya_oprilyudnila_obsyagi_vantazhnikh_perevezen_za_2022_rik_73519 [in Ukraine].
5. Transport book 2021 [online cit.: 2023-05-05]. Available from: https://cfts.org.ua/transport-book-2021.
6. **Shapatina, O.O.** 2020. Formation of the automated technology of management of intermodal transportation / Qualifying scientific work on the rights of the manuscript. Dissertation for obtaining the scientific degree of candidate of technical sciences in the specialty 05.22.01 – "Transport systems" (275 - Transport technologies). – Ukrainian State University of Railway Transport, MES of Ukraine, Kharkiv, [online cit.: 2023-05-05]. Available from: https://kart.edu.ua/wp-content/uploads/2020/10/dis_shapatina.pdf
7. **Lomotko, D.V.; Prymachenko, H.O.; Kovalova, O.V.; Shkurenko, O.V.; Hryhorova, Y.I.** 2021 Use of modern logistics technologies in terms of saving resources, IOP Conference Series: Materials Science and Engineering 1021(1): 012041.
8. **Lomotko, D.V.; Prymachenko, H.O.; Hryhorova, Y.I.** 2019. The role of Ukrainian railway transport in modern logistic processes, Scientific Journal Science and Progress of Transport. Bulletin of the Dnipropetrovsk National University of Railway Transport, Dnipro: Dnipro National University of Railway Transport named after Academician V. Lazaryan 5(83): 43-51. DOI: https://doi.org/10.15802/stp2019/184487.