Виконано математичну постановку задачі форму- вання міських вантажних перевезень. Розроблено струк- туру системної інформаційної моделі, яка враховує матеріальний, енергетичний та інформаційний потоки. Представлено математичні вирази для розрахунку кри- терію вибору раціональних маршрутів – добротність маршруту. Критерій враховує можливості логістичного центру (його інформативність), масу перевезеного ван- тажу, завантаженість маршруту (затори), відстань перевезення й реальний час доставки вантажу. Його осо- бливою рисою є те, що він визначається в онлайн-режимі і враховує динаміку завантаженості маршрутів впро- довж робочої зміни.

Розроблено динамічну модель затримок у прийнятті рішень у логістичних ланцюгах міських вантажних пере- везень. Модель дозволяє розрахувати час обробки заявок на транспортне обслуговування і час на саме транспорт- не обслуговування. Показано, що сумарний час доставки вантажу складається із часу знаходження транспорт- ного засобу на маршруті, з урахуванням опору маршру- ту і часу затримок у всіх логістичних ланцюгах системи.

Розроблено математичну модель оцінки надійності вантажних міських перевезень з урахуванням завантаже- женості вулиць. Модель функціонує в онлайн-режимі та дозволяє визначати параметри транспортного процесу, які враховують наявність заторів на вулицях міста.

Запропоновано критерій оцінки надійності логістич- ної системи вантажних міських перевезень – коефіцієнт надійності. Критерій враховує час проходження тран- спортним засобом маршруту і час затримок у прийнят- ті заявок на обслуговування в логістичному центрі, а також час затримок на транспортному підприємстві. Показано, що при відсутності затримок у логістичних ланцюгах коефіцієнт надійності дорівнює одиниці, при наявності затримки – коефіцієнт надійності менше оди- ниці. Визначено фізичний зміст критерію надійності – це частка невиконання заявок на транспортне обслугову- вання точно в строк

Ключові слова: вантажні перевезення, коефіці- єнт надійності, добротність маршруту, міські затори, вулична мережа

MODELING OF RELIABILITY OF LOGISTIC SYSTEMS OF URBAN FREIGHT TRANSPORTATION TAKING INTO ACCOUNT STREET CONGESTION

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1. Introduction

The problem of forming the routes of the urban network of freight transportation refers to the problems of stochastic programming, because input data for solving an optimization problem (flow of requests, range of transportation, volume of transportation, etc.) are random functions of time. Decision-making on the formation of urban routes of cargo delivery is carried out by an employee of the logistics center of the transport company in the process of online operational management of requests. In this case, the efficiency of route selection is determined, on the one hand, by a set of princi- ples and methods used to solve a transport problem or its varieties, on the other hand, using modern Internet resourc- es available online. The latter are effective means of making management decisions to date.

The relevance of this study is confirmed by the fact that at this stage there are Internet resources that allow collect- ing information about the need for freight transportation. At the same time, for modeling and forecasting traffic flows in the urban transport network, special modules for dynamic modeling of cargo transfer in real time, taking into account congestion (traffic jams) on transportation routes, are re- quired. Such modeling modules for urban freight transporta- tion have to complement existing Internet resources, operate on their basis, using the systems of information gathering, shortest route selection, determination of highway conges- tion and the presence of traffic jams on routes.

Proceeding from the above, the main argument of such research is finding solutions to improve the efficiency of urban freight transportation. The methods of such a search are the development of a mathematical model that interacts with modern Internet resources and allows choosing an optimum route, taking into account congestion of highways and streets at different times of the working day. The practical significance of such a study is to reduce the time and cost of transport services within the city.

2. Literature review and problem statement

In [1], the results of the formalization of the process of functioning of various production transport systems, providing for the accumulation, temporary storage, loading and transportation of goods, are presented. It is shown that to solve such problems it is necessary to apply a logistic approach, which is a methodological aspect in freight transportation technology. In [2], the mathematical model of the logistics system is presented, which allows rationalizing the work of interconnected enterprises on the basis of a complex of technological and management decisions. The analysis of the presented works [1, 2] shows the prospects of using the logistic approach in the development of freight transportation models. But they did not provide any methodical or methodological approaches to constructing models that are problematic components in transport reliability modeling.

In [3], the analysis of the process of functioning of a transport-storehouse complex is carried out and the efficiency criterion is formalized. This indicator represents specific costs of cargo handling and takes into account the expenses of the freight owner related to the downtime of vehicles waiting for service. The conducted study demonstrates the relevance of using criteria estimates of different logistics systems in the process of their functioning. In [4], the analysis of trends of urban freight transportation development is performed and the criterion of economic feasibility is elaborated. The method of estimating urban freight transportation based on information about freight flows is presented. Thanks to the creation of the information matrix, freight rates are justified. The results are presented, which make it possible to state that the economic criterion is appropriate when choosing urban routes.

The analysis of [3, 4] allows drawing a conclusion about application of the criteria approach in them. But it is advisable that the criteria are dimensionless. This allows for a generalized assessment of reliability, which is also a problem component in transport reliability modeling.

Concerning the characteristics of transport information service products, the paper [5] considered four stages of forming system estimates. The information model is developed on the basis of artificial neural networks. The results of modeling show that the availability of information and communication systems is an important component of urban freight transportation. This affects the efficiency of transport services. But the mechanism of using information systems according to selected criteria is not disclosed.

The paper [6] also shows that the development of information technologies provides new opportunities to traditional urban transport. The concept of intelligent transportation as a new generation of transport systems is introduced, which will allow building a reasonable transport infrastructure. It is noted that exchange of information about the density and volume of traffic on city streets will allow increasing the level of transport services. However, there are many problems in collecting, storing and using intelligent vehicles. The papers [7, 8] present the results of forecasting the time of cargo delivery in the city network. It is pointed out that the majority of models are designed for passenger transportation, which cannot be used in freight transportation forecasting. Also, the conclusion about the promising use of GPS technologies is made. The prospects of IT systems are substantiated in [9]. It is proved that such an approach increases the informativeness of monitoring and allows forecasting transport services. From the analysis of [6–9], we can draw a conclusion about the promising use of GPS technologies in transport. But their presentation and use in mathematical models as components or parameters that assess the reliability and efficiency of the investigated process are problematic.

The papers [10, 11] are devoted to reliability assessment of transport services. On the basis of the analysis of transport networks, the authors found that it is expedient to evaluate them by comparing the reliability criterion. The methodology for calculating the criterion, which is determined by the degree of congestion of city streets, is presented in the study. However, these works do not address the issue of determining the congestion of city streets at certain hours of the day. This makes the use of the above methodological approach problematic for determining the congestion criterion of streets.

The papers [12, 13] deal with modeling urban traffic flows on the basis of the revealed analogies in the patterns of processes in electric circuits. In them, the concept of "road resistance" in a separate section of the street is used. This approach allows developing a mathematical model of vehicle speed reduction in certain areas of city streets with traffic jams. In these works, in addition to the identified problem of congestion accounting, a promising approach to calculating the road resistance of a vehicle is shown.

Further development of such an analogy is obtained in [14]. The mathematical model of urban freight transportation is developed, the main difference of which is real-time operation. By means of Internet resources, the congestion of road sections or the presence of traffic jams is determined. But the developed model does not consider the congestion dynamics of city streets and does not allow assessing transportation reliability, so completion is required.

The problem of identifying a dynamic mathematical model of delays in decision-making at a logistics center and transport company when receiving a transportation request is reduced to the definition of the model operator. The "model operator" means a dynamic mathematical model in the form of second-order linear differential equations. A similar approach in the modeling of freight transportation during harvesting is used in [15]. The presented methodical approach is promising. It allows modeling delays in transport services. This will allow determining reliability indicators that can be presented in the form of dimensionless criteria.

Methods of modeling dynamic flows of urban freight transportation, taking into account street congestion in real time, based on the use of available Internet resources, need further development and improvement. The obtained forecast will allow justifying a rational cargo delivery route in real time (for the next 30...60 min.), thus increasing delivery reliability.

3. The aim and objectives of the study

The aim of the study is to develop a mathematical model for assessing the reliability of urban freight transportation, taking into account street congestion in online mode, and justify the reliability criterion of urban freight transportation.

To achieve the aim, the following objectives were set:

– to substantiate the methodical approach to the study of reliability of urban freight transportation taking into account street congestion;

– to substantiate the process parameters of urban freight transportation, considering traffic jams on city streets;

– to carry out mathematical modeling of reliability of transport services for urban freight transportation.

4. Methodical approach to the study of urban freight transportation taking into account street congestion

As a methodical approach to the study, mathematical models in the form of second-order differential equations were chosen. Such equations have proven themselves well in technical fields and have a well-grounded solution apparatus. The chosen method allows studying processes that are functions of time.

The objective function of choosing rational routes for intra-city freight transportation is to increase the reliability of cargo delivery (on time) and reduce transportation costs. The factor that changes in the decision-making process is the congestion on city streets, which will be taken into account by the parameter of route resistance R_r. The mathematical model is a second-order differential equation, the solution of which will allow predicting delays on the route, taking into account route resistance.

Considering the system model of urban freight transportation in the most general view, we distinguish three input flows: matter, energy, information. "Matter" means the volume of cargo to be moved from the consignor to the consignee. The cargo (material) flow, under the influence of information (logistics center) and energy (transport company), turns into a transport service.

When considering such a model of the transport process, the central issue should be description of the information flow, which is primary, and material and energy flows as secondary. Therefore, the process of urban freight transportation can be represented as a chain. The first stage is the preparation of information using Internet resources and dynamic modeling software. The second stage is the transfer of information in the form of rational routes to the transport company, which performs freight transportation at a given time. In order to increase the reliability of cargo delivery (on time) and reduce delivery expenses of the transport company, the mathematical apparatus of cybernetics and system engineering is used.

Difficulties in choosing rational city routes, taking into account the actual congestion of city highways, are due to the fact that such tasks do not have formal methods of solution to date. For example, the classic transport task allows defining the shortest route. However, the shortest route is not always rational in the city conditions because of uneven congestion of highways. On the shortest route there may be traffic jams, which will reduce vehicle speed and increase delivery time and costs.

The process of "manual" route selection among the options considered and analyzed in the logistics center by search and comparison takes into account the quantitative rather than qualitative aspect of the process. Therefore, modeling, forecasting and effective management of urban freight transportation require formalization of the problem in the form of a dynamic mathematical model.

5. Results of studies of urban freight transportation processes

5. 1. Parameters of the urban freight transportation process, taking into account traffic jams on city streets

The procedure for modeling urban freight transportation processes can be broken down into the following steps.

The first stage of modeling allows choosing a route with the minimum resistance and determining the time of freight delivery t_d, that is, travelling time, as well as route quality factor Q_r. The physical significance of the route is given in [14].

To determine the running speed of the vehicle on a route, the calculation formula of route resistance is used [14]:

$$R_t = \frac{\upsilon_t^2}{J} = \frac{l_t^2}{t_t \cdot m \cdot \sqrt{IR}}, \ \frac{\text{km}^2}{\text{T} \times \text{h}}, \tag{1}$$

where υ_r is the vehicle speed on a route without traffic jams, determined using the Google Maps Internet resource, km/h; J is the logistics system performance per unit time, t/h; l_r is route length, km; m is cargo weight, t; t_t is vehicle travelling time, h. The travelling time on the chosen route t_t is determined using the Google Maps Internet resource; IR is the Internet resource, which takes into account traffic jams in online mode, dimensionless value.

If there are no traffic jams, the route in this Internet resource is displayed in green and $IR=1$. If there are delays in movement, the color of the route turns yellow, then red and brown. So, $IR=0.9...0.7$. For $IR=0.6$, speed decreases to 5 km/h.

The informational content of the logistics center L_{LC}, which is part of the logistics system of urban freight transportation, characterizes the ability to create an information field that causes the movement of material flows. The informational content can be calculated according to the formula proposed in [14]:

$$L_{LC} = R_r \cdot t_t = \frac{l_t^2}{m \cdot \sqrt{IR}}, \ \frac{\text{km}^2}{\text{T}}. \tag{2}$$

Then, the running speed of the vehicle on a route, taking into account traffic jams, is determined by the formula:

$$\upsilon_{run} = \upsilon_r - \upsilon_{ab}, \tag{3}$$

where v_{ab} is the value of speed reduction due to traffic jams, determined by the formula:

$$\upsilon_{ab} = \sqrt{\upsilon_r^2 - J \cdot R_r}, \ \text{km/h}. \tag{4}$$

Using the estimated value of the running speed of the vehicle v_{run}, it is possible to determine the time of cargo delivery t_d from the consignor to the consignee, taking into account traffic jams in the online mode:

$$t_d = \frac{l_r}{\upsilon_{run}}, \ \text{h}. \tag{5}$$

The resulting value of cargo delivery time t_d allows determining the route quality factor according to the formula given in [14]:

$$Q_r = \frac{L_{LC} \cdot m \cdot \sqrt{IR}}{l_r^2 \cdot t_d}, \; \frac{1}{h}. \tag{6}$$

This allows choosing the optimum value $Q_r \rightarrow \max$ from the three presented routes with the help of the videoprobki.ua Internet resource. For example, a route with a minimum value of l_r will not always be optimal due to traffic jams (low IR) or low informational content of the logistics center L_{LC}.

The route quality factor Q_r, calculated by (6), can serve as a criterion for choosing an optimum route for urban freight transportation, since it takes into account material, information and energy flows. The route is selected based on the information of Google Maps and videoprobki.ua Internet resources. The criterion takes into account the capabilities of the logistics center (its informational content), weight of cargo transported, congestion, transportation distance and actual time of cargo delivery.

The feature of the proposed criterion Q_r in comparison with known, is that it is determined online. So, the criterion Q_r takes into account congestion dynamics during the working day or at the time of cargo delivery. For this purpose, it is necessary to add reverse information communication of the vehicle with the logistics center in the scheme of the information model.

The second stage of modeling takes into account the lag effect of the system in the process of decision-making and movement on a route, which allows determining the time of delays in the logistics system (LS).

The sum of delivery and delay time determines the total time of the transport service order:

$$t_\Sigma = t_d + t_{dl}, \; h, \tag{7}$$

where t_Σ is the time of request fulfillment, h; t_{dl} is the delay time in the LS, h.

The author of [16] obtained a second-order differential equation, which allows representing the transient process in the logistics system of urban freight transportation from receipt of the transportation request until freight delivery to the customer. Let's represent the equation without the procedure for receiving it:

$$T_{LS} \frac{d^2 m}{dt^2} + 2 d_{LS} Q_r T_{LS} \frac{dm}{dt} + \frac{m}{K_{LC} K_{TC}} + m \cdot K_{ls} = J. \tag{8}$$

The time constant of the logistics system T_{LS}, characterizing the lag effect of the system, is determined by the expression:

$$T_{LS} = \sqrt{\frac{T_{LC} \cdot T_{TC}}{K_{LC} \cdot K_{TC}}}, \; h, \tag{9}$$

where T_{LC} is the time constant of the logistics center (LC), which takes into account the lag effect (delays) in request processing, h; T_{TC} is the time constant of the transport company (TC), which takes into account the lag effect (delays) in the receipt of transportation requests, h; C_{LC} is the coefficient of sensitivity of the logistics center to the receipt of requests; C_{TC} is the coefficient of sensitivity of the transport company to the receipt of transportation requests from the logistics center.

For the coefficient d_{LS}:

$$d_{LS} = \frac{(T_{LC} + T_{TC})}{2 T_{LS} \cdot K_{LC} \cdot K_{TC}}. \tag{10}$$

The obtained coefficient d_{LS} characterizes the absence or presence of the oscillatory process in the LS. In accordance with the accepted methods of the theory of identification of dynamic objects, for $d_L < 1$, oscillations are present in the system, for $d_{LS} > 1$ – absent.

The right member of the equation (8) is the input signal in the LS – logistics system performance, t/h. The left member of the equation is the response of the LS to the input signal J. The increase in the number of time constants T_{LC} and T_{TC} makes the process less sensitive (less susceptible) to the input influence of J. The time of request processing and cargo delivery increases.

The gain factors of T_{LC} and T_{TC} characterize the sensitivity of the LC and TC to the receipt of requests.

The solution for the above differential equation (8) is the expression:

$$m(t) = m \left[1 - \exp\left(-\frac{d_{LC} Q_r}{T_{LC}} \cdot t \right) \cdot \cos ft + A \sin ft \right], \tag{11}$$

where $m(t)$ is the time function of delivery of the specified mass of cargo; t is the current time, h; f is the frequency of oscillations, determined by the expression:

$$f = \frac{1}{T_{LS}}, \frac{1}{h}. \tag{12}$$

A is the amplitude of oscillations, determined by the expression:

$$A = \frac{1}{d_{LS}}. \tag{13}$$

The importance of the time constant T_{LS} suggests that the logistics center and the transport company have a significant lag effect in the receipt of requests and, as a result, will have a large delay time.

5. 2. Results of mathematical modeling of reliability of transport services for urban freight transportation

The results of dynamic modeling of the cargo delivery process on urban routes, formula (11) with the change in cargo weight $m = 5 \div 15$ tons and traffic jams on a route $IR = 1.0 \div 0.7$ are shown in Fig. 1, 2.

From the analysis of the results, it follows that cargo weight is a significant parameter and increases the delay time in the LS 3.11–3.23 times. When changing traffic jams on a route, IR decreases from 1.0 to 0.7, hence, the delay time increases 2.42 times.

This result affects the total transport service time, formula (7), which increases 1.32–1.42 times.

The above modeling results suggest that the dynamic model allows determining the total time of transport services, taking into account various factors. The model works online and interacts with Google Maps and videoprobki.ua resources. This is the difference of the developed model from earlier known.

The value of the total transport service time t_Σ is given by the joint use of the developed models. The first one can determine the travelling time of the vehicle, taking into account the route quality factor t_q. The second one allows determining delays in making service decisions.
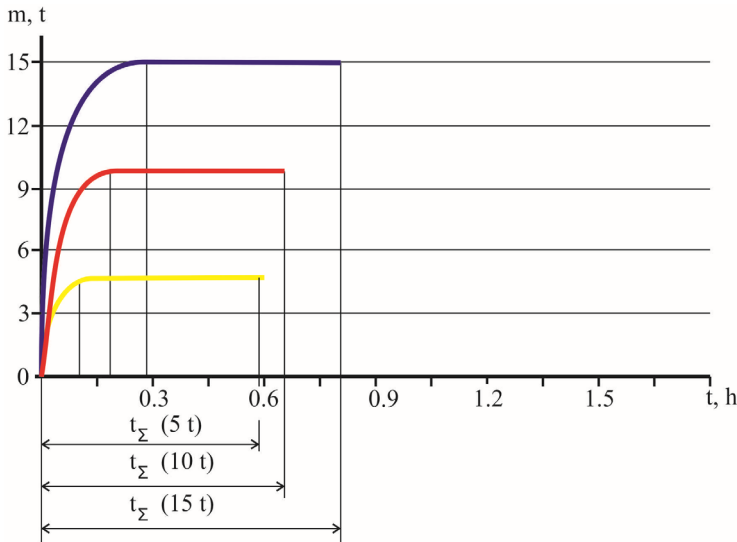
m, t

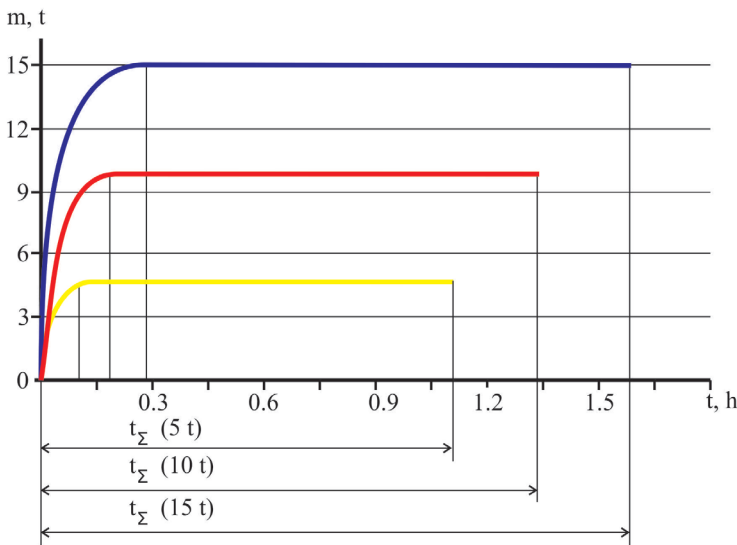Fig. 1. Transitional process of cargo delivery time t_Σ of the logistics system with different cargo weights m for IR=1.0

m, t

Fig. 2. Transitional process of cargo delivery time t_Σ of the logistics system with different cargo weights m for IR=0.7

5. 3. Justification of the reliability criterion of transport services for urban freight transportation

The above values t_q, t_d, t_Σ allow determining the reliability of the logistics system of urban freight transportation. According to [15], it can be argued that the reliability of the *LS* of freight transportation is estimated as the ratio of the following process indicators. In the numerator – service time expectation. In the denominator – total service and delay time expectation.

In accordance with the formulated definition, we write down the expression to assess the *LS* reliability when fulfilling a single request *i*, which was performed in the *LS*:

$$C_{R,i} = \frac{t_{d,i}}{t_{d,i}+t_{dl,i}} = \frac{t_{d,i}}{t_{\Sigma,i}}. \tag{14}$$

For *n* requests performed in the *LS* during the working day, the coefficient C_R is determined by the expression:

$$C_R = \frac{\sum_{i=1}^{n} t_{d,i}}{\sum_{i=1}^{n} t_{d,i} + \sum_{i=1}^{n} t_{dl,i}}, \tag{15}$$

where *n* is the number of transportation requests.

Based on (15), the reliability factor is less than unity and acquires a value equal to unity only when total delays are zero. Even in the presence of insignificant delays, C_R is less than unity.

The resulting dimensionless parameter C_R, which has the physical significance of the share of request fulfillment on time, can be a criterion that estimates the reliability of the logistics system.

The maximum value of unity, C_R can acquire in the absence of delays, i. e. t_d=0. If there are delays in the LS, t_d>0, C_R will be less than unity. The higher the value of C_R, the more reliable the transport process.

The dependences of the reliability coefficient of urban freight transportation with changes in cargo weight and in the presence of traffic jams on a route are presented in Fig. 3.
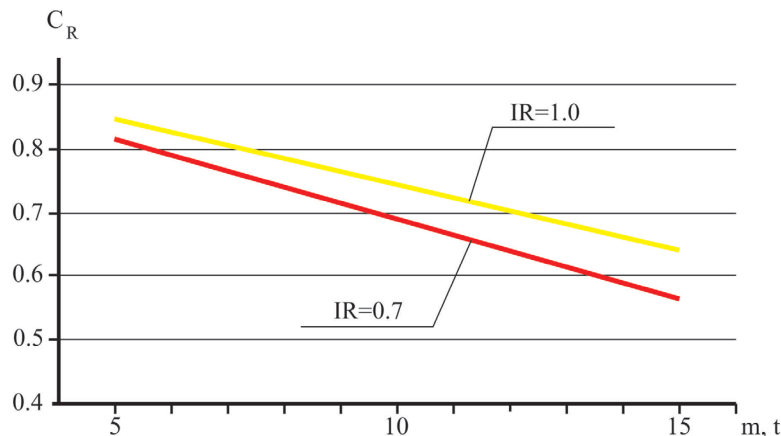
C_R

Fig. 3. Dependences of the reliability coefficient C_R of the logistics system with different weights of cargo transported *m* and in the presence of traffic jams on a route *IR*

From the analysis of the dependences presented in Fig. 3, it follows that the increase in cargo weight reduces the value of the reliability factor from 0.84 to 0.64 while the presence of traffic jams on a route, $IR=0.7$, further reduces the value of C_R to 0.57.

The presented modeling results confirm the above conclusion that the reliability factor C_R can be a dimensionless criterion that predicts the reliability of the transport service.

6. Discussion of the results of the study of urban freight transportation processes

The parameters of the transport process such as road resistance and route quality factor are substantiated. Their numerical values allow choosing an optimum route, which is a practical significance of this work. The route quality factor takes into account the capabilities of the logistics center (informational content), cargo weight, congestion (traffic jams), transportation distance and actual time of cargo delivery. This is the difference of the proposed parameter from previously known. A special feature is that it is determined online and takes into account congestion dynamics during the work shift. This allows obtaining numerical estimates and comparing their values.

The parameters of the transport process were determined in the form of dependences of delays on cargo weight, route length and traffic jams on city streets. The scientific result of the study are the dependences, which allow calculating the time of delays in transport services. Their difference from the known models is that they take into account the dynamics of the transport process and interact with Internet resources through GPS technologies. It is found that cargo weight is a more important parameter and increases the delay time in the LS 3.11–3.23 times.

The criterion of reliability of the logistics system of urban freight transportation, namely reliability coefficient, is proposed. It is provided by the block of mathematical modeling of delay time and takes into account a number of criteria. Among them: travelling time of the vehicle, delay time in the receipt of transportation requests at the logistics center, delay time at the transport enterprise. The analysis of the modeling results suggests that in the absence of delays in logistics chains, the reliability coefficient is equal to unity, in the presence of a delay the reliability coefficient is less than unity. The physical significance of the reliability criterion is defined. It is the share of non-fulfillment of transportation requests on time.

The disadvantage of the proposed method for assessing the reliability of logistics systems of transport services is the mechanism of determining delays in all system components, which can be the subject of further research. The restriction of the developed reliability criterion is its applicability only for urban freight transportation.

7. Conclusions

1. As a result of the research, the mathematical model for assessing the reliability of urban freight transportation is developed, taking into account street congestion. The model operates online and allows determining the process parameters of urban freight transportation (road resistance and route quality factor). It takes into account traffic jams on city streets, which distinguishes this model from previously proposed. Thus, it is possible to calculate the reliability criterion for different routes and choose a route with its maximum value.

2. The dynamic model of delays in decision-making in the logistics chains of urban freight transportation is developed. According to the input data (cargo weight, route length, traffic jams on a route), the model allows calculating the processing and implementation time of transportation requests. Data on the presence of traffic jams on routes are obtained using Internet resources (GPS technology). It is shown that the total time of cargo delivery consists of the travelling time of the vehicle, taking into account the road resistance and delay time in all logistics chains of the system.

3. The reliability criterion of transport services for freight transportation within a city is offered. It is shown that the reliability criterion varies from 0.84 to 0.64 while the presence of traffic jams on a route, $IR=0.7$, further reduces the value of C_R to 0.57. It is concluded that the reliability coefficient C_R can be a dimensionless criterion, predicting the reliability of transport services, which makes the practical significance of this work.

References

1. Shramenko, N. Y. (2017). The methodological aspect of the study feasibility of intermodal technology of cargo delivery in international traffic. Scientific Bulletin of National Mining University, 4 (160), 145–150.

2. Shramenko, N. Y. (2018). Mathematical model of the logistics chain for the delivery of bulk cargo by rail transport. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 5, 136–141. doi: https://doi.org/10.29202/nvngu/2018-5/15

3. Shramenko, N. Y. (2015). Effect of process-dependent parameters of the handling-and-storage facility operation on the cargo handling cost. Eastern-European Journal of Enterprise Technologies, 5 (3 (77)), 43–47. 2015. doi: https://doi.org/10.15587/1729-4061.2015.51396

4. Zhang, R. M., Huang, L. (2017). Application of the freight rate on freight flow forecast. Advances in Transportation Studies, 3, 61–68.

5. Yuan, Y., Zhao, Q. Y., Wan, X. Y. (2018). Evaluating transportation information service products through artificial neural networks. Advances in Transportation Studies, 3, 59–68.

6. Sun, S., Liu, C. (2016). Application of improved storage technology in Intelligent Transportation System. Advances in Transportation Studies, 3, 51–60.

7. Wang, Z., Goodchild, A., McCormack, E. (2016). Freeway truck travel time prediction for freight planning using truck probe GPS data. European journal of transport and infrastructure research, 16 (1), 76–94.

8. Combes, F., Tavasszy, L. A. (2016). Inventory theory, mode choice and network structure in freight transport. European Journal of Transport and Infrastructure Research, 16 (1), 38–52.

9. Meyer, A., Sejdovic, S., Glock, K., Bender, M., Kleiner, N., Riemer, D. (2017). A disruption management system for automotive inbound networks: concepts and challenges. EURO Journal on Transportation and Logistics, 7 (1), 25–56. doi: https://doi.org/10.1007/s13676-017-0108-5

10. Gao, J., Sun, J., Shi, Q. Z., Liu, F. S. (2015). A comparative reliability evaluation method for transportation network planning and design. Advances in Transportation Studies, 3, 55–64.

11. Mishra, S., Tang, L., Ghader, S., Mahapatra, S., Zhang, L. (2018). Estimation and valuation of travel time reliability for transportation planning applications. Case Studies on Transport Policy, 6 (1), 51–62. doi: https://doi.org/10.1016/j.cstp.2017.11.005

12. Danchuk, V. D., Kryvenko, V. I., Oliynyk, R. V., Taraban, S. M. (2010). Elektrotekhnichna model doslidzhennia transportnykh potokiv. Visnyk Natsionalnoho transportnoho universytetu, 21 (2), 28–32.

13. Danchuk, V., Kryvenko, V., Oliynyk, R., Taraban, S. (2015). Electric simulation of urban road traffic flows. Visnyk Natsionalnoho tekhnichnoho universytetu «Kharkivskyi politekhnichnyi instytut». Seriya: Novi rishennia v suchasnykh tekhnolohiyakh, 46, 109–114.

14. Kutiya, O. V. (2019). Development of a mathematical model of urban freight transportation. Technical service of agriculture, forestry and transport systems, 15, 203–212.

15. Vojtov, V., Berezchnaja, N., Kravcov, A., Volkova, T. (2018). Evaluation of the Reliability of Transport Service of Logistics Chains. International Journal of Engineering & Technology, 7 (4.3), 270–274. doi: https://doi.org/10.14419/ijet.v7i4.3.19802

16. Kutiya, O. V. (2019). Development of a dynamic model of decision-making delays in the logistics chains of urban freight traffic. Technical service of agriculture, forestry and transport systems, 16, 37–47.