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LOGISTICS MANAGEMENT OF MOTOR VEHICLE TERMINAL OPERATIONS AS A QUEUING SYSTEM

The article analyzes calculating the motor vehicle terminal operations as a queuing system and determining the effectiveness of proposed methods for optimizing terminal operations based on logistic approaches. The research assesses the feasibility of implementing a control system at a humanitarian aid warehouse that would ensure the collection and storage of data on vehicle locations at loading areas, the status of loading and unloading mechanisms, and decision-making regarding their use, as well as to transmit commands to drivers to enhance the efficiency of road transport operations during humanitarian cargo delivery. The core principle of the terminal's operations is optimal logistics management of cargo flows. Goods are sorted by priority and destination, ensuring minimal delays and rapid delivery of humanitarian aid to those in need. Calculations have been made for the operation of the motor vehicle terminal as a queuing system, specifically focusing on vehicle downtime during unloading at the humanitarian warehouse. The effectiveness of the proposed terminal optimization methods based on logistic approaches was also evaluated. The vehicle idle time during cargo operations was determined for traditional technology and for the implementation of a regulation system for truck arrival at loading fronts. Furthermore, the annual cost savings achievable through the organization of an optimal regulation system for truck arrivals at terminal loading fronts were calculated. It is proposed to develop the integrated decision support within the terminal system's functional cycle as an automated system. The main objective of this method is to eliminate the 'human factor,' as automation is intended to enhance data quality, streamline the processing of cargo owner information, and optimize technological processes. The primary challenges for humanitarian aid terminals include ensuring cargo security, preventing delays, and maintaining operational responsiveness to changing conditions. At the same time, investments in advanced technologies and infrastructure improvements can significantly increase the operational efficiency of such terminals.

Key words: *motor vehicle terminal, queuing system, loading front, humanitarian cargo, terminal system.*

Музикін М. І., Нестеренко Г. І., Бібік С. І., Баркалова Н. О. Логістичне управління роботою автомобільного терміналу як системи масового обслуговування

Статтю присвячено розрахунку роботи автомобільного терміналу як системи масового обслуговування та визначенню ефективності запропонованих методів оптимізації роботи терміналу на основі логістичних підходів. Дослідження спрямоване на визначення доцільності впровадження на складі гуманітарної допомоги системи контролю, яка б забезпечувала збір та збереження інформації про місцезнаходження автомобілів на вантажних ділянках, стан навантажувально-розвантажувальних механізмів та прийняття рішень щодо їхнього використання, а також передачу команд водіям з метою підвищення ефективності автотранспортних операцій при перевезенні гуманітарних вантажів. Основний принцип роботи терміналу базується на оптимальному логістичному управлінні потоками вантажів. Вантажі сортуються за пріоритетом та місцем призначення, що забезпечує мінімальні затримки та швидку доставку гуманітарної допомоги тим, хто її потребує. Проведено розрахунки роботи автомобільного терміналу як системи масового обслуговування та простій автомобілів під розвантаженням на складі гуманітарної допомоги. Також розраховано ефективність запропонованих методів оптимізації роботи терміналу на основі логістичних підходів. Встановлено простої автомобілів під вантажними операціями при традиційній технології і при впровадженні системи регулювання підведення вантажних автмобілів до вантажних фронтів. Також розраховано річну економію, яку можливо досягти шляхом організації оптимальної системи регулювання підведення автомобілів до вантажних фронтів терміналу. Формування інтегрованої інформаційної підтримки прийняття рішення в функціональному циклі термінальної системи пропонується зробити у виді автоматизованої системи. Головною задачею цього методу є виключення «людського фактору», оскільки автоматизація має вдосконалити якість отриманої інформації, обробку інформації про вантажовласників та оптимізувати технологічні процеси. Основними викликами для терміналів гуманітарної допомоги є забезпечення безпеки вантажів, уникнення затримок та оперативне реагування на зміну умов. Водночас, інвестиції у новітні технології та покращення інфраструктури можуть значно підвищити ефективність роботи таких терміналів.

Ключові слова: *автомобільний термінал, система масового обслуговування, вантажний фронт, гуманітарні вантажі, термінальна система.*

Problem statement. With the onset of the russian federation's full-scale aggression, effective logistics has become a key factor in ensuring the timely delivery of food, medical supplies, clothing, and other vital resources to those who need them most.

Humanitarian aid motor vehicle terminals play a crucial role in delivering essential resources to crisis-affected areas. These terminals function as queuing system nodes, ensuring efficient and prompt distribution of cargo. They possess a complex structure, including zones for reception, storage, and dispatch of goods. Each zone is designed to handle specific types of cargo (food and non-food items), which allows for the optimization of loading and unloading processes.

Analysis of Recent Research and Publications. Having analyzed the research of scientists on this issue, we obtained the following. Article [2] analyzes the largest humanitarian crisis in Europe since the Second World War, which arose as a result of the full-scale military aggression launched in the territory of Ukraine in February 2022. The increase in the level of conflict led to a significant increase in humanitarian aid; however, supply and distribution face difficulties due to the destruction of transport and communication infrastructure. The article proposes the use of the ArcGIS system to develop a software product that will plot the optimal and safe route for humanitarian cargo delivery in real-time, avoid risks, and reduce human factor interference. The application of geographical data from various sources, such as GPS, aerospace, and satellite images, as well as information from local websites, will allow the creation of a map of the status situation and ensure effective humanitarian aid management. It also considers using the Hierarchy Analysis Method to define optimization criteria and select the optimal route. This approach considers partial criteria, such as route length, travel time, vehicle brand, and others, to determine new routes under military conflict conditions. The provided recommendations and methods make it possible to create an innovative tool for effective humanitarian aid management in military conflict conditions, ensuring the safety and efficiency of delivery in Ukraine. The development of such a tool will not only facilitate the supply of humanitarian aid but also help prevent threats to workers and aid recipients, contributing to the provision of necessary resources in an emergency.

The aim of the paper [3] is to analyze the current state of the humanitarian situation in Ukraine under military aggression and to develop ways to improve this situation by creating new and developing existing transport hubs located both on the western border of the country and in the central regions. In the research, the authors used methods of analysis and synthesis to study available information on the current state and trends in the further development of logistics and humanitarian hubs both on the western border and within the country. Aggregation and intelligent data analysis were used to identify promising directions for the development of the logistics network.

Results. The uncertain situation currently facing the operation of seaports compels the state to seek alternative routes for the export and import of raw materials and finished products. To address this issue, it is also advisable to develop a network of transport hubs near the western border. To date, 31 regional humanitarian aid hubs have been established in Ukraine. The leading regions include Zaporizhzhia with 5 hubs, followed by Kyiv and Ivano-Frankivsk with 2 hubs each. The remaining regions have 1 hub each. The number of hubs in border areas remains insufficient, especially considering the sharp change in the directions of main cargo flows –specifically, grain and metal. As of March 2022, the average daily demand for transportation towards the EU reached 8,000 wagons;

therefore, it is urgent to resolve the issue of developing both the existing bogie exchange system and additional transshipment infrastructure.

Scientific Novelty. The authors have aggregated and systematized information regarding the existing system of transport hubs to support current and future volumes of both humanitarian and industrial export-import cargo.

Practical Significance. The results obtained provide a scientific basis for the concept of creating and developing a system of humanitarian and logistics hubs to increase the efficiency of cargo flow movement.

Analysis of the key challenges in international transportation shows that establishing a rational delivery scheme is essential for resolving these issues and improving freight efficiency. Analysis of the selection criteria for a rational delivery scheme indicates that total delivery costs provide the most comprehensive measure of efficiency, while timeliness remains a critical factor in international transportation.

The article [4] discusses the topical issues of the transformation of logistics flows in wartime conditions in Ukraine. The classification of humanitarian aid goods, sources of their receipt are considered, and the monitoring of logistical problems that arose in the country with the beginning of the full-scale russian invasion is carried out. The essence of the concept of humanitarian logistics and its main tasks are determined, the difficulties of working with humanitarian cargo are described, and ways to prevent untimely delivery of humanitarian cargo are proposed. It is noted that poorly established coordination between various participants in the logistics chain leads to a slowdown in the dispatch and delivery of humanitarian cargo. Attention is focused on the important role of domestic companies in the processes of delivering humanitarian cargo. Prospects for the restoration of logistics in the post-war period are outlined, which will allow Ukraine to integrate into the European system.

The article [5] analyzes the state of legal regulation in the transportation of humanitarian aid cargo and identifies vectors for improving the relevant legislation. It is emphasized that under martial law, the possibilities of the national economy to function are significantly limited, logistics chains within the country are disrupted. This has necessitated changes in established approaches to the organization and implementation of transport activities, the reorientation of the transport services market from commercial cargo transportation toward the transportation of humanitarian aid goods, the priority use of road transport for the transportation of goods due to restrictions on transportation by other modes of transport. It is emphasized that modern challenges require consideration at the legislative level. A comparative analysis of the general and simplified procedures for the import of humanitarian aid cargo into the territory of Ukraine is carried out. It is noted that under martial law, the transportation of humanitarian cargo has undergone gradual simplification at the legislative level. The stages of development of legislation in terms of simplifying the import of humanitarian aid cargo are highlighted. Attention is paid to the features of the transportation of humanitarian aid cargo by rail under martial law by JSC «Ukrzaliznytsia». It is concluded that the transportation of humanitarian cargo as a type of economic (foreign economic) activity is characterized by certain features: 1) a special (simplified in the conditions of martial law) procedure for customs clearance and customs control; 2) a special subject composition (direct participants: donors, recipients, purchasers, transport organizations (carriers); indirect participants (authorized state authorities, etc.); 3) a specific object of transportation (humanitarian aid goods). The features of the transportation of humanitarian cargo in the conditions of martial law are highlighted. The expediency of considering the features of concluding and executing contracts for the transportation of humanitarian cargo in the special transport legislation of Ukraine, in particular, the Rules for the Transportation of Cargo, is substantiated.

In [6], a concept for the creation and development of humanitarian hubs in Ukraine is presented. To reduce costs and reduce the time for putting such hubs into operation, it is advisable to locate them based on existing facilities – border railway stations, transshipment complexes, railway bogie interchange points, etc. In addition, it is necessary to develop a terminal network within the country in several echelons – strategic, tactical, and operational. When creating hubs of the two lower levels, close coordination between military and civilian administrations is mandatory, which has proven its effectiveness since 2014. Hubs created on the western border should be adapted to perform both a humanitarian function and to ensure export-import transportation of agricultural and industrial cargo. Even with the partial or complete restoration of seaports, transportation of goods by rail and road, both in the direction of Ukraine and in the opposite direction, to the countries of the European Union will remain relevant. Thus, the establishment and development of a logistics hub network is currently a top priority for Ukraine. However, implementing such large-scale infrastructure projects is impossible without attracting significant investment through public-private partnerships (PPP).

The paper [7] examines the main factors that influenced the change in logistics services in Ukraine. A special problem for logistics during this period is the road infrastructure. Stable logistics chains have been destroyed. Routes have become longer – it is necessary to bypass dangerous areas, and alternative roads are not adapted to the movement of oversized trucks. Without studying new logistics routes, it is quite difficult to predict the duration of delivery. The principle by which companies transporting humanitarian cargo operate is reduced to the following formula: there is a truck in which the necessary goods that must be delivered are required. Usually, the cargo does not occupy the entire cargo space, but only part of it, so it would be advisable to use several orders in parallel, which in turn will reduce fuel consumption due to its shortage, optimize costs, and reduce the number of trips by car, which are now quite dangerous due to broken roads and mined territories. It is also considered that the delivery of humanitarian goods in international traffic has a number of features. Specifically, under current regulations, importing humanitarian aid requires only a single document – a declaration containing all necessary details regarding the consignor, consignee, and the goods. Additional innovations include the abolition of the restricted list of goods classified as humanitarian aid, the exemption of Ukrainian carriers from foreign road tolls, and streamlined border crossing procedures.

Given that deliveries directly to aid recipients consist of small-batch shipments, they must be executed rapidly between periods of shelling while maintaining maximum stealth to avoid enemy detection.

Study [10] proposes a classification of methods for solving small-batch cargo routing problems. These route-planning methods focus on identifying the shortest paths; however, they do not account for client prioritization or specific service strategies. Most often, vehicle routing tasks are carried out using simple and effective heuristic methods that allow you to quickly find the desired solution. However, it does not guarantee finding the optimal solution. Currently, methods are being developed that combine the flexibility of heuristics with the precision of linear programming models, enabling the achievement of optimal or, at the very least, provably better solutions [11].

In previous research [12] it was determined that the optimal strategy for servicing cargo owners in conditions of uncertainty with constantly changing demand is service by periods of the day, which leads to an increase in the quality of transport services and the formation of a flexible tariff policy of transport enterprises aimed at more fully meeting the requirements of cargo owners.

Reference [13] proposes a formalization of costs associated with small-batch cargo transportation. The research develops a model for selecting rational vehicle capacity in small-batch operations, depending on the average shipment size and the number of consignors served.

Reference [14] outlines a methodology for organizing international transportation. However, this approach does not account for transit time costs. The criteria lack a detailed description of the freight process and fail to consider potential customs delays.

The author's research [15] is aimed at improving the organization of the transportation of small-batch cargo by the method of forming delivery routes with variable demand for transportation. For this, the probabilistic nature of the demand for transportation is calculated, and attention is also paid to determining the number of arrivals. The parameters of the transport process are considered deterministic.

In [16], it is noted that any transportation process begins with identifying consumer demand for products. The accuracy of determining the batch size directly affects the time required to find a suitable vehicle, compliance with delivery deadlines, the maintenance of safety stocks at consumer warehouses, vehicle utilization efficiency, and overall storage costs.

The authors of research [17] discuss the method of terminal transportation, where the main task is to organize an effective cargo delivery system. The following methods were considered for comparing the terminal and end-to-end delivery schemes and forming an integrated information automated decision support system in the functional cycle of the terminal system.

The purpose of the article is to calculate the performance of a motor vehicle terminal as a queuing system and to determine the effectiveness of the proposed logistics-based optimization methods. The research aims to determine the feasibility of implementing a control system at a humanitarian aid warehouse that would ensure the collection and storage of information on vehicle locations in loading areas, the status of loading and unloading mechanisms, and decision-making regarding their utilization, as well as transmitting commands to drivers to enhance the efficiency of motor transport operations during humanitarian cargo delivery.

Statement of basic materials. Terminal transportation is conducted via dedicated terminals and is primarily used for **consolidated cargo**. An alternative technology is **through-delivery** (end-to-end), which involves transporting goods using a single vehicle without changing drivers. The effectiveness of the schemes is assessed by indicators: delivery speed, costs, and time. The main difference between the two schemes is the ability to consolidate small shipments due to cargo storage at the terminal, which smooths out irregularities in the terminal system, while through-delivery schemes do not have such an opportunity due to the short period of selection of the required amount of cargo. The formation of integrated information support for decision-making in the functional cycle of the terminal system is proposed to be done in the form of an automated system. The main task of this method is to eliminate the "human factor", since automation should improve the quality of the information received, the processing of information about cargo owners, and optimize technological processes. It focuses on the automation of workstations for consignors, consignees, motor transport dispatchers, and logistics center operators, all of which are integrated with a modeling unit and a decision-making module. The primary disadvantage of the integrated decision support method is the high cost of technology implementation, whereas the main drawback of terminal transportation schemes is the significant time consumption.

The main principle of the terminal operation is based on optimal management of cargo flows. Cargo is sorted by priority and destination, which ensures minimal delays and rapid delivery of humanitarian aid to those who need it.

For the effective operation of terminals, modern technologies are used, such as warehouse management systems (WMS), automated cargo sorting and tracking systems. This allows to increase in the accuracy and speed of cargo processing.

The main challenges for humanitarian aid terminals are ensuring cargo safety, avoiding delays, and responding promptly to changing conditions. At the same time, investments in the latest technologies and infrastructure improvements can significantly increase the efficiency of such terminals.

Calculating the service indicators of a multi-channel queuing system (QS). [14]

Converting the request flow intensity per hour:

$$\lambda = \frac{N}{24}. \quad (1)$$

Service flow intensity:

$$\mu = \frac{t}{n}. \quad (2)$$

Load intensity

$$\rho = \lambda \cdot t_{обс}. \quad (3)$$

Load intensity shows the degree of consistency between the incoming and outgoing request flows of the service channel and determines the stability of the queuing system.

Probability that the channel is free (proportion of channel downtime)

$$p_0 = \frac{1}{\sum \frac{\rho^k}{k!} + \frac{\rho^{n+1}}{n!(n-\rho)}\left(1 - \left(\frac{\rho}{n}\right)^m\right)}. \quad (4)$$

Probability that the channel is under service:

$$p_n = \frac{\rho^n}{n!} p_0. \quad (5)$$

Probability of failure (probability that the channel is busy) (portion of requests that were rejected).

$$p_{відм} = \frac{\rho^{n+m}}{n^m \cdot n!} \cdot p_0 \quad (6)$$

Probability of requesting service (probability that the client will be served).

In systems with failures, failure and service events form a complete group of events; therefore:

$$p_{відм} + p_{обс} = 1. \quad (7)$$

Relative throughput:

$$Q = p_{обс}. \quad (8)$$

Average number of channels busy with service (average number of busy channels).

$$p_{обс} = 1 - p_{відм}. \quad (9)$$

Average number of channels busy with service (average number of busy channels).

$$n_3 = \rho \cdot p_{обсл}. \quad (10)$$

Average number of idle channels.

$$n_{пр} = n - n_3. \quad (11)$$

The channel utilization factor.

$$K_3 \frac{n_3}{n}. \quad (12)$$

Absolute throughput (Intensity of the outgoing flow of serviced requests).

$$A = p_{обс} \cdot \lambda. \quad (13)$$

Average idle time of the QS (per hour).

$$t_{пр} = p_{відм} \cdot t_{обсл}. \quad (14)$$

Average channel idle time (per hour).

$$t_{пр.к} = \frac{t_{обсл} \cdot (1 - p_{відм})}{p_{відм}}. \quad (15)$$

Probability of queue formation.

$$p_{черги} = \frac{\rho^n}{n!} \cdot \frac{1-\left(\frac{\rho}{n}\right)^m}{1-\frac{\rho}{n}} \cdot p_0. \quad (16)$$

Average number of requests in the queue.

$$L_{черги} = \frac{\rho^{n+1} \cdot \left(\frac{\rho}{n}\right)^m \cdot \left(m+1-m \cdot \frac{\rho}{n}\right)}{n \cdot n! \cdot \left(1-\left(\frac{\rho}{n}\right)\right)^2} \cdot p_0. \quad (17)$$

Average idle time of the QS (the average waiting time of a request in the queue).

$$T_{прост} = \frac{L_{черги}}{A}. \quad (18)$$

Average number of requests being served.

$$L_{обсл} = \rho \cdot Q. \quad (19)$$

Average number of requests in the system (i.e., requests are already being served and those waiting in the queue).

$$L_{СМО} = L_{черги} + L_{обсл}. \quad (20)$$

The average time a request spends in the QS.

$$T_{СМО} = \frac{L_{СММ}}{A}. \quad (21)$$

The calculation results are given in Table 1.

Table 1

Results of QS calculations.

No.	Indicator	Indicator	Value
1	Request flow intensity per hour, cars/hour	λ	2.2
2	Service flow intensity	μ	2.143
3	Load intensity	ρ	1.027
4	Probability that the channel is free	P_0	0.327
5	Probability of failure	P_{fail}	0.00614
6	Average number of channels busy with service	n_b	0.815
7	Average number of idle channels	n_{idle}	1.02
8	The channel utilization factor	K_u	0.5
9	Absolute throughput	A	2.187
10	Average idle time of the QS	t_{idle}	0.00286
11	Average idle time of the channel	$T_{id.c}$	347.086
12	Probability of queue formation	P_{queue}	0.341
13	Average number of requests in the queue	L_{queue}	0.327
14	Average idle time of the QS	T_{idle}	0.15
15	Average number of requests being served	L_{serv}	1.02
16	Average time a request spends in the QS	T_{QS}	0.616

The purpose of this part in the research is to determine the feasibility of implementing a control system at a humanitarian aid warehouse that would ensure the collection and storage of information on vehicle locations in loading areas, the status of loading and unloading mechanisms, and decision-making regarding their utilization, as well as transmitting commands to drivers to enhance the efficiency of motor transport operations during humanitarian cargo delivery. Unloading at the humanitarian aid warehouse is carried out by two teams in two sections of the warehouse. Motor transport operates for 72 hours. According to the results of statistical research, the arrival of vehicles at the warehouse is a random process following the Poisson distribution with an intensity of 2.2 vehicles/hour. The vehicle service time at the warehouse section is normally distributed with a mean of 28 minutes and a standard deviation of 6 minutes.

The capital investment required to implement the control system amounts to 5,000 c.u. (conditional units), while additional annual operating costs are 4,000 c.u. The absence of such a system leads to situations where vehicles remain idle at some loading areas while others remain free. Implementing the control system will reduce unproductive vehicle downtime and increase the productivity of loading areas. However, as the implementation requires additional expenditures, the feasibility of transitioning to the new technology must be determined through a technical and economic analysis.

$$Є_a + E_н \cdot K_a \leq \Delta Є + E_н \cdot \Delta K_a, \tag{22}$$

where $Є_a$, K_a – operating costs and capital investments required to implement a system for regulating the delivery of vehicles to the loading fronts; – operating costs savings in the "motor transport – cargo front – warehouse" system:

$$\Delta Є = 365 \cdot e_{a-г} \cdot \Delta T_a, \tag{23}$$

$e_{a-г}$ – the cost of one vehicle-hour; ΔT_a – the reduction in vehicle downtime per day as a result of regulating vehicle arrivals; ΔK_a – capital investment in rolling stock.

To calculate the parameters included in formula (22), it is necessary to establish the idle times of vehicles during cargo operations using traditional technology and the implementation of a control system. Given the probabilistic nature of transport processes, this can be done as completely as possible using the simulation modeling method.

First, let us establish the random nature of the flow of vehicles arriving at the cargo fronts.

If the flow intensity is described by a Poisson distribution, then the intervals between arriving vehicles are described by the dependence

$$P\left(I > I_a\right) = e^{-\lambda_a I_a} \quad \text{or} \quad P\left(I \leq I_a\right) = 1 - e^{-\lambda_a I_a}, \quad I_a = -\frac{1}{\lambda_a} In\, R_i, \tag{24}$$

where R_i are random numbers with their uniform distribution in the interval from 0 to 1; I_i is the interval between consecutively arriving vehicles.

Now, let us simulate the intervals between vehicles in the following sequence.

1. We obtain R uniformly distributed random numbers in the interval from 0 to 1. The number of interval simulations

$$R \geq \frac{x^2}{4\varepsilon^2}, \tag{25}$$

where x is a value taken from the table of probability integral values depending on the value of P: $x = 1.96$ at $P = 0.95$; ε is a permissible error.

2. Using expression (24) and the extracted random numbers, we determine the intervals between the vehicles. For example, the interval between the first and second vehicles:

$$I_{12} = -\frac{24}{2,2} \cdot In\left(0,227\right) = 40 \text{ min};$$

$$I_{23} = -\frac{24}{2,2} \cdot In\left(0,176\right) = 47 \text{ min};$$

$$I_{34} = -\frac{24}{2,2} \cdot In\left(0,252\right) = 37 \text{ min}.$$

We will determine the duration of the cargo operation using arbitrarily defined normal random deviations.

Previously, it was assumed that the driver selects a warehouse section at random. The process of selecting a warehouse section is simulated using a table of random numbers. If there are two sections in the warehouse and the random number falls within the interval from 0 to 0.5, then the vehicle is directed to the first section, if in the interval from 0.5 to 1.0, then to the second one.

Similarly, we simulate the structure of the vehicle fleet that performs the pickup (delivery) of cargo from the warehouse.

With the regulated vehicle delivery, each subsequent vehicle arrives at the cargo front that is free from service, or at the one where the vehicle service ends earlier than the others.

With different disciplines of the driver's choice of the warehouse and a normal distribution of fluctuations in the duration of the cargo operation, the simulation results obtained are given in Table 2.

Analysis of the data obtained in Table 2 allows us to draw the following conclusions:

1. Minimal idle time of vehicles ensures optimal regulation of their delivery to the cargo fronts.

2. The second most effective control procedure is the sequential passage of arriving vehicles to the warehouse sections.

Using the data of Table 5.2 and assuming the cost of 1 vehicle-hour equal to 4 UAH, the annual savings in operating costs in the «motor transport – cargo front – warehouse» system with optimal regulation in the delivery of vehicles to the warehouse will be:

$$\Delta Є = 365 \cdot 4\left(\frac{1514-360}{60}\right) = 28\,080.$$

As a result of reducing the idle time of vehicles at the cargo fronts, capital investments for the purchase of vehicles are eliminated:

$$\Delta K_a = \frac{\Delta \sum MH}{t_p} C_a, \tag{26}$$

$\Delta\Sigma MH$– daily savings, vehicle-hours; t_p – average duration of vehicle operation during the day, hours; C_a– cost of the vehicle, c.u.; for example, for a DAF FX105 vehicle, 672 thousand UAH.

Savings in capital investments for the purchase of vehicles:

$$\Delta K_a = \frac{(1514-360)\cdot 672\,000}{60\cdot 12} = 1\,077\,066.$$

Substituting the calculated data into formula (4.1), we find:

164 000 + 0,125 · 205 000 < 28 080 + 0,125 · 1 077 066;

189 625 < 192 731,25.

Table 2

Simulation results.

Discipline of warehouse selection	Number of serviced vehicles, pcs.	Waiting time for service, min	Vehicle downtime while waiting for service, vehicles, min.
Random selection	188	11.08	4542
Sequential selection	188	6.27	1311
Optimal regulation	188	5.19	1080

Thus, at the selected warehouse, it is effective to use both sequential selection (in the form of a traffic light) and optimal regulation (using a dispatcher).

The approach of vehicles to the warehouse sections can be regulated by a dispatcher. The effect of dispatching:

$$\Delta Є = 365 \cdot 4 \cdot \left(\frac{1514-360}{60}\right) + 0,125 \cdot \frac{672\,000\cdot(1514-360)}{60\cdot 12} = 162\,713,3.$$

Conclusions. Calculations were made for the motor vehicle terminal operations as a queuing system and for vehicle idle time during unloading at the humanitarian aid warehouse. The efficiency of the proposed methods for optimizing the terminal's operation based on logistics approaches was also calculated. This includes the creation of sequential regulation (installing a traffic light system to distribute vehicles among service channels). Based on the obtained calculations, we can conclude that organizing an optimal system for regulating the delivery of vehicles to the cargo fronts makes it possible to achieve annual savings of 162,713.3 UAH. Therefore, the sequential vehicle routing procedure is highly effective, as its implementation at this cargo front does not require additional capital or operating costs.

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