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Ptytsia Natalia
Kharkiv National Automobile and Highway University, Kharkiv, Ukraine

MODELING OF ADDITIONAL TIME COSTS IN THE ROAD TRANSPORT SYSTEM AT THE LAST MILE STAGE

The article addresses the problem of optimizing loading and unloading operations in road transport as a key element of the transport and logistics process that significantly affects the overall efficiency of freight delivery. It has been established that considerable time expenditures during the execution and waiting for loading and unloading operations lead to increased operating costs and reduced fleet productivity. An analysis of the regulatory framework showed that the existing regulations were developed under the conditions of a centralized economy and do not correspond to modern market requirements.

The necessity of updating these standards has been substantiated, taking into account contemporary conditions and the characteristics of vehicles, types of packaging, as well as the specifics of goods and organizational approaches to logistics operations. The use of regression models has been proposed to formalize the dependencies between the duration of loading and unloading operations and the key parameters of the process. The obtained values of time parameters can be incorporated into the construction of linear and regression models, which will ensure greater accuracy in predicting time expenditures and in developing recommendations for improving the efficiency of transport and logistics systems. The integration of regulatory, mathematical, and digital approaches to the optimization of loading and unloading operations in last-mile retail logistics is identified as a necessary condition for enhancing the effectiveness of logistics processes under current market conditions.

Keywords: loading and unloading operations, road transport, logistics processes, transportation efficiency, regression modeling, time expenditures, last mile.

INTRODUCTION

Loading and unloading operations in road transport represent one of the most resource-intensive and critically important components of the transportation process, significantly affecting its overall efficiency. Considerable time expenditures for performing or waiting for loading and unloading operations lead to prolonged vehicle downtime, which results in higher operating costs and reduced turnover of the rolling stock.

The main causes of such time losses include: insufficient mechanization of operations, outdated technical equipment, lack of unified logistical coordination among participants in the transport process at transshipment points, as well as inefficient organization of preparatory and accompanying operations [1, 2].

Within the framework of the modern logistics approach, optimization of loading and unloading operations involves a comprehensive review and streamlining of operations at points of cargo dispatch and receipt, particularly at warehouses, logistics terminals, and consolidation centers.

The foundation for improving efficiency lies in ensuring the prior readiness of cargo for shipment: formation of consignments taking into account the technical parameters of vehicles (load capacity, dimensional restrictions), packaging of cargo into transport containers, precise identification of cargo location within storage zones, as well as timely preparation of mechanization equipment (forklifts, conveyors, cranes, etc.) for operation. The packaging of small-batch and piece cargoes has become particularly relevant, as it minimizes the number of operations and reduces the impact of the human factor [2, 3].

LITERATURE REVIEW AND PROBLEM STATEMENT

The regulation of vehicle downtime during loading and unloading operations is governed by normative documents, in particular the «Unified Time Standards», which establish baseline values for first-class cargo per ton. For second-, third-, and fourth-class cargoes, adjustment coefficients are applied that account for the actual coefficient of vehicle load capacity utilization, taking into consideration full loading within permissible dimensions (including volumetric limitations) [3–5].

Modern research confirms the significant variability in the actual duration of loading and unloading operations, which is determined by cargo characteristics, vehicle parameters, the level of mechanization, and personnel qualifications. To refine these dependencies, the use of regression models is proposed, as they make it possible to formalize the relationship between processing time and key process parameters [5–9]. For example, calculations have shown that additional time expenditures for documentation amount to approximately 0.24 hours, while the standard time for loading and unloading operations per ton of cargo is 0.07 hours, which confirms the necessity of accounting for these factors in practical planning.

In a broader context, the literature review [3–9] indicates that the problem of optimizing vehicle servicing at cargo handling points extends far beyond the purely technical aspects of loading and unloading operations. It encompasses:

– optimization of vehicle service sequencing as a task of minimizing total costs;

– implementation of information technologies to enhance the efficiency of logistics systems;

– strategic planning of logistics processes and rational use of resources;

– application of mathematical models — from the classical vehicle routing problem (VRP, PVRP) to modern methods of fuzzy logic and queuing theory;

– digitalization and automation using blockchain, cloud services, and artificial intelligence.

Particular importance is attached to the integration of these approaches into practical solutions that focus not only on minimizing downtime but also on incorporating loading and unloading operations into the overall management of transport and warehouse flows.

Thus, loading and unloading operations optimization serves as a fundamental element in improving vehicle service systems at logistics terminals and provides a foundation for the development of more advanced digital and mathematical management models.

PURPOSE AND OBJECTIVES OF THE STUDY

The purpose of this article is to substantiate the necessity of considering additional time expenditures for loading and unloading operations and documentation processing in the organization of road transportation of small consignments.

The objective of the study is to develop an approach to formalizing these factors within a mathematical model, which enhances the accuracy of logistics cost assessment and supports effective managerial decision-making.

RESEARCH RESULTS

However, the existing regulations were developed under conditions of centralized economic management and were primarily oriented toward typical processes, which no longer fully correspond to the realities of modern market-oriented logistics.

In connection with the transition to a decentralized economic management system, the increasing role of private carriers, and the implementation of flexible logistics strategies, there arises a need to update and adapt the regulatory and methodological framework.

Modern logistics planning requires a revision of the regulations regarding the duration of individual stages of loading and unloading operations, taking into account changes in vehicle characteristics (body types, level of automation, platform parameters), new types of containers and packaging, as well as the specific features of the cargo being handled.

The time for loading and unloading is determined either by regulatory standards or by the dependency (1), which has the following form:

$$t_{\text{н/р}} = 2 \cdot \left(t_{\text{д}} + q_{\text{н}} \cdot \gamma_{\text{ст}} \cdot \tau_{\text{н–р}} \right), \qquad (1)$$

where $t_{\text{д}}$ – additional time for documentation processing, h;

$q_{н}$ – nominal vehicle load capacity, t;

$\tau_{н-р}$ – standard time for loading or unloading 1 ton of cargo, h/t;

$\gamma_{\text{ст}}$ – coefficient of static load capacity utilization.

According to current regulations, the average duration of procedures related to the documentation of cargo operations is 15–20 minutes [1–3]. The normative time expenditures for performing loading and unloading operations per ton of cargo generally amount to about 3 minutes. However, the results of modern empirical studies demonstrate significant variability in these indicators depending on the specific conditions of logistics operations. This variability is determined by a number of factors, in particular: the physical and mechanical properties of the cargo (volume, weight, shape, fragility), the type of transport used, the level of mechanization, the organizational structure of the logistics operation, and the qualifications of the personnel.

Considering the substantial dispersion of actual loading and unloading operations duration values, there is an objective need for an in-depth analysis of the functional dependencies between time expenditures and the parameters that determine them. Such an approach makes it possible not only to adapt existing regulations to modern conditions but also to develop recommendations aimed at improving the efficiency of logistics operations through rational planning of resources and time.

This issue becomes particularly relevant in the context of organizing the “last mile” stage in retail logistics systems [5]. The delivery of small-batch cargoes to the end consumer is generally carried out by light and medium-duty vehicles, which results in higher frequency of loading and unloading operations while reducing the volume of individual shipments.

At the same time, even when using the same method of performing cargo operations (for example, with a manual hydraulic trolley), the level of efficiency largely depends on such factors as the infrastructural characteristics of the delivery point (availability of ramps, elevators, access roads), time of day, road traffic density, and the workload of logistics personnel.

DISCUSSION OF RESEARCH RESULTS

To refine the recommended data, it is necessary to study the functional dependencies of the corresponding performance indicators on various factors. The specific feature of the last mile stage in retail logistics systems is that the delivery of small-batch cargo is carried out by vehicles of different load capacities, while the same method and organization of loading and unloading operations are applied. These dependencies are predominantly linear in nature [10], therefore, the time expenditures for their execution can be represented by the corresponding linear model:

$$Y = a_x + b_x x\,, \tag{2}$$

where $Y = t_{\text{н-р}}$ – time for loading and unloading cargo, h;

$Y = t_{\text{н-р}}$ – additional time for documentation processing, h;

$b_x = 2\tau_{\text{н-р}}$ – standard time for loading or unloading 1 ton of cargo, h/t;

$x = q_{\text{н}} \cdot \gamma_{\text{ст}} \cdot$ – product of the nominal vehicle load capacity and the coefficient of static load utilization, t.

For conducting calculations and approximating the dependence of loading and unloading operations duration on its components, regression analysis is applied. To obtain the coefficient values, field observation data on the time vehicles spend at loading and unloading points during cargo delivery by vehicles of different load capacities are used [5, 10].

The coefficients of the regression models obtained in the course of calculations, as well as the verification of their statistical significance, are presented in Table 1.

Table 1 – Calculation results and verification of regression model coefficients

Indicator	Value	Standard error	*t*- criterion for coefficients of regression equations	*p* – null hypothesis probability values for regression equation coefficients
$a_x = 2t_{\text{д}}$	0,483289	0,0228	21,1181	$2{,}23 \cdot 10^{-9}$
$b_x = 2\tau_{\text{н-р}}$	0,13466	0,0232	15,789	$2{,}19 \cdot 10^{-10}$

The correlation coefficient for calculating the duration of loading and unloading operations is 0,91, the standard approximation error amounts to 0,6. The adjusted multiple correlation coefficient is 0,87 and the probability value of the null hypothesis (F-test) equals 0.000001.

As a result of the performed calculations, it was established that the additional time expenditures associated with the preparation of accompanying documentation amount $t_{\text{о}}$ =0.24 h, while the duration of loading and unloading operations for 1 ton of cargo is $\tau_{\text{н-}}$ =0.07 h.

CONCLUSIONS

The obtained quantitative values should be taken into account when formalizing the mathematical model that describes the structure and dynamics of logistics costs associated with small-batch cargo delivery at the final stage of the logistics chain. Their inclusion in the model makes it possible to adequately account for time expenditures accompanying logistics servicing, particularly vehicle downtimes caused by administrative and technological procedures.

This, in turn, ensures greater accuracy in forecasting total costs and supports the adoption of well-founded managerial decisions in route planning and resource provision for logistics operations.

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Птиця Н.В. **Моделювання додаткових витрат часу в системі автомобільних перевезень на етапі last mile**

У статті розглянуто проблему оптимізації навантажувально-розвантажувальних робіт на автомобільному транспорті як ключового елементу транспортно-логістичного процесу, що суттєво впливає на загальну ефективність перевезень. Встановлено, що значні часові витрати під час виконання та очікування навантажувально-розвантажувальних робіт зумовлюють підвищення експлуатаційних витрат і зниження продуктивності рухомого складу. Аналіз нормативної бази показав, що чинні регламенти були розроблені за умов централізованої економіки та не відповідають сучасним ринковим умовам. Обґрунтовано необхідність їх оновлення з урахуванням сучасних умов та характеристик транспортних засобів, видів тари і упаковки, а також специфіки вантажів і організаційних підходів до логістичних операцій. Запропоновано використання регресійних моделей для формалізації залежностей між тривалістю навантажувально-розвантажувальних робіт та ключовими параметрами процесу. Отримані значення часових параметрів можуть бути включені у побудову лінійних і регресійних моделей, що забезпечить точність прогнозування витрат часу та формування рекомендацій для підвищення ефективності транспортно-логістичних систем. Інтеграція нормативних, математичних та цифрових підходів до оптимізації навантажувально-розвантажувальних робіт при забезпеченні «last mile» у роздрібній логістиці є необхідною умовою підвищення ефективності логістичних процесів у сучасних умовах.

Ключові слова: вантажно-розвантажувальні операції, автомобільний транспорт, логістичні процеси, ефективність перевезень, регресійне моделювання, часові витрати, остання миля.

ПТИЦЯ Наталія Василівна, кандидат технічних наук, доцент кафедри транспортних систем і логістики, Харківський національний автомобільно-дорожній університет, Харків, Україна, e-mail: nataliya.ptitsa@gmail.com. https://orcid.org/0000-0002-4559-7651

PTYTSIA Natalia, Ph. D. of Engineering, Associate Professor at the Transport Systems and Logistics Department, Kharkiv National Automobile and Highway University, Kharkiv, Ukraine, e-mail: nataliya.ptitsa@gmail.com. https://orcid.org/0000-0002-4559-7651

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