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# РОЗРОБКА МОДЕЛІ ПРОЦЕСУ ДОСТАВКИ ВАНТАЖІВ У МІЖНАРОДНОМУ СПОЛУЧЕННІ

*Запропонована математична модель процесу доставки вантажів у міжнародному сполученні, основою якої є модель марківських ланцюгів. Розглянуті моделі базисних систем поставки, що використовуються на автомобільному транспорті. На базі створених математичних моделей проведений імітаційний експеримент. На підставі регресійного аналізу результатів імітаційного експерименту визначені залежності витрат на доставку вантажів від параметрів попиту на перевезення.*

**Ключові слова:** *міжнародні автомобільні перевезення, математична модель, марківські ланцюги, регресіний аналіз.*

## 1. Introduction

The pace of economic development of the world economy contributes to the intensification of international relations and increases the trade volume. That determines the growth of international cargo transportation. Due to an increase in requirements to the international carriers and competition level in the market of international road transport there is a need to develop and implement more efficient methods of transportation processes management.

In the conditions of growing level of competition and transportation volumes, the task of the assessment of demand parameters impact on carriers expenses becomes particular important when choosing the optimal technological schemes. At the same time the random nature of the transportation process and the limitations imposed by existing laws and acts regulating international road transport should be taken into account in the mathematical model.

## 2. Analysis of published data and problem statement

In European Commission publication [1] it is pointed that existing methods of rationalization of cargo delivery process have some disadvantages due to which their use in the conditions of transport enterprises at the contemporary market is inefficient. The majority of existing methods and models for rationalization of the delivery schemes [2–4] do not consider the probabilistic characteristics of transport process parameters, and that reduces the efficiency of managerial and organizational decisions. As the most advanced models, which consider stochastic nature of transportation process, should be noted the multi-agent approach to delivery problem with uncertain demand information [5] and the real-time model of control of freight forwarder transportation networks [6]. The perspective directions of researches in this field are to improve models which consider the transport process as a process with a finite number of cargo and rolling stock states (models of Markov processes), and to adapt them to the conditions of the enterprises in the modern market of transport services taking into account the basic terms of international cargo delivery (according to INCOTERMS — International Commercial Terms).

The researches of flow parameters of requests for cargo transportation, i. e. of parameters of transportation demand, have been carried out by the author in [7] and used for solving a bunch of practical problems: e. g., definition of the optimal strategies of transportation market participators [8], estimation of the efficiency of freight forwarder participation in the process of transportation [9], and others. Each request is proposed to be characterized by such indicators as the volume of cargo, the interval of request receiving, delivery distance and total zero mileage. But for the conditions of international deliveries, zero mileage could be ignored, because its value is much smaller than the distance of delivery. In addition, the interval of request receiving as a demand parameter, that determines the frequency of requests receipt and their number during the modeling period can also not be taken into account because of the peculiarities of documents processing and technological process in international transport. The last statement is determined by the fact, that the request servicing in international transport often takes several days, and the transport process model should be considered for performing of a single request, not of their set.

## 3. Research object, purpose and tasks

As the research object, the process of international cargo delivery is considered in this paper.

The research aims to develop for the process of international cargo delivery such a model, which considers stochastic nature of transport demand and the technological process of transportation.

In order to achieve the purpose of the research, the following objectives are set:

1. To develop graph-models for basic conditions of international cargo delivery with the use of road transport.
2. To conduct numerical simulations with the developed models for the stochastic characteristics of demand on transport services.

3. To analyse simulations results in order to determine dependencies of transportation process efficiency from the demand parameters.

## 4. Simulation model for evaluation on freight forwarders risk to entry the transportation market

As the investigated parameter, which characterizes the efficiency of the transport process, the operating costs are proposed to be used:

$$C_{op} = t_d \cdot \sum_{i=1}^{n} C_i \cdot p_i, \quad (1)$$

where $C_{op}$ — the operating costs, \$; $t_d$ — duration of delivery, hrs; $n$ — number of elementary operations; $C_i$ — self costs for the $i$-th operation, \$/hrs; $p_i$ — the probability of $i$-th operation implementation.

The analysis of the basic supply conditions INCOTERMS [10] allows identifying of three main terms — «Delivered At Frontier» (DAF), «Free Carrier» (FCA) and «Ex Works» (EXW), which are used for the international delivery of goods. Delivery duration for the main basic conditions is calculated respectively as follows:

$$t_d^{DAF} = t_l + t_{ins} + t_{pack} + t_{move} + t_{drive} + t_{cust}, \quad (2)$$

$$t_d^{FCA} = t_l + t_{ins} + t_{pack} + t_{move} + t_{drive} + t_u + t_{cust}, \quad (3)$$

$$t_d^{EXW} = t_l + t_{pack} + t_{move} + t_u + t_{cust} + t_{search}, \quad (4)$$

where $t_l$ — duration of loading operations, hrs; $t_u$ — duration of unloading operations, hrs; $t_{ins}$ — duration of insurance operations, hrs; $t_{pack}$ — duration of packaging checking operations, hrs; $t_{move}$ — duration of the cargo moving operations, hrs; $t_{drive}$ — duration of driving to the loading point operations, hrs; $t_{cust}$ — downtime in the customs point, hrs; $t_{search}$ — downtime due to reverse loading search, hrs.

The process of international cargo delivery could be represented as a sequence of separate operations, where the transition from $i$-th to $j$-th state is characterized by the density of transition probability $\lambda_{ij}$. At Fig. 1 the marked graph of states for the delivery process according to the basic terms of «Delivered At Frontier» is shown.

To determine the probabilities of operations performance for the graph, the proper equations system of Kolmogorov should be performed:

$$\begin{cases} \dfrac{dp_1}{dt} = (\lambda_{12} + \lambda_{13} + \lambda_{14}) \cdot p_1 - \lambda_{51} \cdot p_5, \\ \dfrac{dp_2}{dt} = \lambda_{24} \cdot p_2 - \lambda_{12} \cdot p_1, \\ \dfrac{dp_3}{dt} = \lambda_{34} \cdot p_3 - \lambda_{13} \cdot p_1 - \lambda_{53} \cdot p_5, \\ \dfrac{dp_4}{dt} = \lambda_{45} \cdot p_4 - \lambda_{14} \cdot p_1 - \lambda_{24} \cdot p_2 - \lambda_{34} \cdot p_3, \\ \dfrac{dp_5}{dt} = (\lambda_{51} + \lambda_{53}) \cdot p_5 - \lambda_{45} \cdot p_4. \end{cases} \quad (5)$$

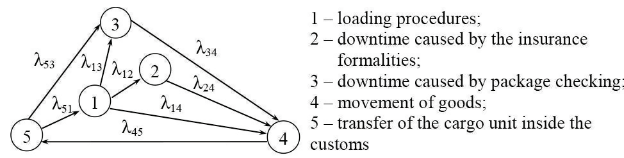


**Fig. 1.** The graph of the explored system states (the «Delivered At Frontier» term)

To solve equations (5), $A_{ij} = \int \lambda_{ij} dt$ should be defined. If the density of transition probability is the ratio of the duration $t_i$ of the respective $i$-th operation to the total time of delivery, then:

$$\lambda_{ij} = \frac{t_i}{t_d} = 1 - \frac{t_d - t_i}{t_d}. \quad (6)$$

Integrating (6) with respect to $t_i$, we obtain:

$$A_{ij} = t_i - (t_d - t_i) \cdot \ln t_d. \quad (7)$$

Thus, taking into account (7), $A_{ij}$ for the respective probability densities of the graph at Fig. 1 can be defined in the following way:

$$\begin{cases} A_{12} = t_{ins} - (t_d - t_{ins}) \cdot \ln \cdot t_d, \\ A_{13} = t_{pack} - (t_d - t_{pack}) \cdot \ln \cdot t_d, \\ A_{14} = t_l - (t_d - t_l) \cdot \ln \cdot t_d, \\ A_{51} = t_{drive} - (t_d - t_{drive}) \cdot \ln \cdot t_d, \\ A_{24} = t_{move} - (t_d - t_{move}) \cdot \ln \cdot t_d, \\ A_{34} = t_{move} - (t_d - t_{move}) \cdot \ln \cdot t_d, \\ A_{53} = t_{cust} - (t_d - t_{cust}) \cdot \ln \cdot t_d, \\ A_{45} = t_{move} - (t_d - t_{move}) \cdot \ln \cdot t_d. \end{cases} \quad (8)$$

Then the system of equations (5) can be written as follows:

$$\begin{cases} p_1 = (A_{12} + A_{13} + A_{14}) \cdot p_1 - A_{51} \cdot p_5, \\ p_2 = A_{24} \cdot p_2 - A_{12} \cdot p_1, \\ p_3 = A_{34} \cdot p_3 - A_{13} \cdot p_1 - A_{53} \cdot p_5, \\ p_4 = A_{45} \cdot p_4 - A_{14} \cdot p_1 - A_{24} \cdot p_2 - A_{34} \cdot p_3, \\ p_5 = (A_{51} + A_{53}) \cdot p_5 - A_{45} \cdot p_4. \end{cases} \quad (9)$$

Since $\sum_{i=1}^{n} p_i = 1$, this equation can be included in (9) instead of any other; the equation with the biggest number of summands should be replaced, namely — the fourth equation of the system:

$$\begin{cases} (A_{12} + A_{13} + A_{14} - 1) \cdot p_1 - A_{51} \cdot p_5 = 0, \\ -A_{12} \cdot p_1 + (A_{24} - 1) \cdot p_2 = 0, \\ -A_{13} \cdot p_1 + (A_{34} - 1) \cdot p_3 - A_{53} \cdot p_5 = 0, \\ -A_{45} \cdot p_4 + (A_{51} + A_{53} - 1) \cdot p_5 = 0, \\ p_1 + p_2 + p_3 + p_4 + p_5 = 1. \end{cases} \quad (10)$$

Solving the system (10) using one of known methods (e. g., the method of Cramer or the method of Gauss), we find the value of probabilities $p_i$.

The graphs of states, shown at Fig. 2 and Fig. 3, correspond to the terms of delivery «Free Carrier» and «Ex Works» respectively. The mathematical models of delivery costs determining for these terms are analogous.

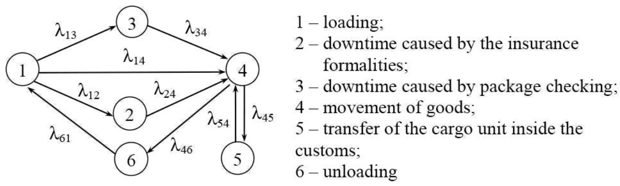


**Fig. 2.** The graph of the explored system states (the «Free Carrier» term)

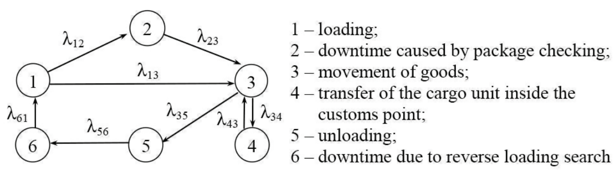


**Fig. 3.** The graph of the explored system states (the «Ex Works» term)

The proposed mathematical models allow us to take into account the random nature of the process of international cargo delivery, if the appropriate statistical data on time parameters $t_i$ and speed of the vehicle are available.

## 5. Numerical results of the simulations based on the proposed models

To obtain the numerical results using the developed model the experimental studies were conducted on the basis of KAMAZ-Transservice Ltd. (Rivne, Ukraine) for the Renault Premium HD-440 vehicle model. As a result the dependencies of operating costs from the delivery distance are obtained for shipment volumes of 10 tons, 15 tons and 20 tons (Fig. 4–6).

The verification of the reproducibility of experimental results confirms the hypothesis about the homogeneity of series' variances of the response function (estimated values of Cochran criterion are less than the corresponding tabulated criterion values). This led to the conclusion that the performed experiment is reproducible.

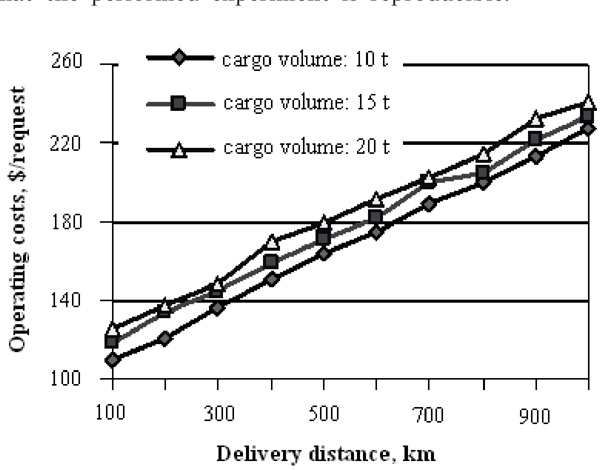


**Fig. 4.** Dependence of the costs from the delivery distance (the «Delivered At Frontier» term)

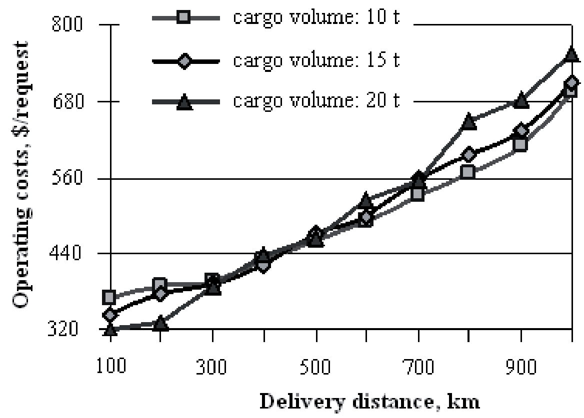


**Fig. 5.** Dependence of the costs from the delivery distance (the «Free Carrier» term)

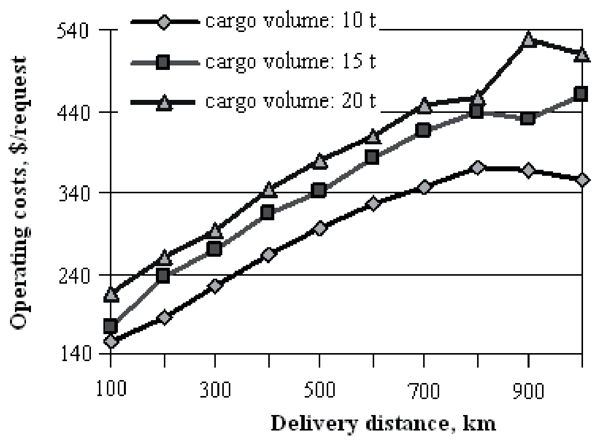


**Fig. 6.** Dependence of the costs from the delivery distance (the «Ex Works» term)

## 6. Results of regression analysis for the conducted simulation experiment

As a result of regression analysis conducted using the built-in tools of MS Excel, the following relevant dependences from $L$ and $Q$ demand parameters are obtained for the terms «Delivered At Frontier», «Free Carrier» and «Ex Works»:

$$C_{op}^{DAF} = 82 + 0{,}13 \cdot L + 1{,}59 \cdot Q, \quad (11)$$

$$C_{op}^{FCA} = -383 + 0{,}37 \cdot L + 27{,}4 \cdot Q, \quad (12)$$

$$C_{op}^{EXW} = 295 + 0{,}40 \cdot L, \quad (13)$$

where $Q$ — the shipment volume, $t$; $L$ — the distance of delivery, km.

The values of the determination coefficients for the obtained regression models are in the range from 0,93 to 0,98. These results confirm that the accuracy of dependencies is high enough.

Using appropriate Fischer criteria, it's determined, that the models (11)–(13) are characterized by the information ability and adequacy.

## 7. Conclusions

The proposed model based on Markov chains under certain conditions is an effective tool for studying the transport process. In particular — the models of operating costs dependence from the demand parameters for the basic term were obtained using this model.

Proposed approach allows defining the impact of stochastic demand parameters on operating costs of the transport firm and, as a result, — choosing the appropriate rational schemes of transport servicing.

Analyzing the experimental results, it could be noted that for the «Ex Works» term the value of shipments has no effect on operating costs. It also should be noted, that for the shipment value of 15 tons the extremum exists in the range of distance delivery from 800 to 1000 km, where the operating costs have their minimum possible value.

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#### РАЗРАБОТКА МОДЕЛИ ПРОЦЕССА ДОСТАВКИ ГРУЗОВ В МЕЖДУНАРОДНОМ СООБЩЕНИИ

Предложена математическая модель процесса доставки грузов в международном сообщении, основой которой является модель марковских цепей. Рассмотрены модели базисных систем поставки, используемые на автомобильном транспорте. На базе разработанных математических моделей проведен имитационный эксперимент. На основании регрессионного анализа результатов имитационного эксперимента определены зависимости затрат на доставку грузов от параметров спроса на перевозку.

**Ключевые слова:** международные автомобильные перевозки, математическая модель, марковские цепи, регрессионный анализ.

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# ИССЛЕДОВАНИЕ И РАЗРАБОТКА ИЗМЕРИТЕЛЯ НИЗКОЧАСТОТНЫХ ВИБРАЦИЙ ДЛЯ СИСТЕМЫ КОНТРОЛЯ НОРМИРОВАННЫХ ПАРАМЕТРОВ ПРОИЗВОДСТВЕННЫХ ФАКТОРОВ

*Разработан измеритель низкочастотных вибраций для системы контроля нормированных параметров производственных факторов на основе биморфного пьезоэлемента для частот не более 1 Гц. Проведено компьютерное моделирование устройства с целью исследования происходящих процессов, оптимизации параметров и оценки частотных свойств. Данное исследование позволило определить временные параметры алгоритма управления, реализуемого микроконтроллером, частоту изменения управляющего воздействия и максимальную частоту измеряемых вибраций.*

**Ключевые слова:** *низкочастотные вибрации, биморфный пьезоэлемент, фотоприемник, измерение, контроль, нелинейность, компенсация, моделирование.*

## 1. Введение

Известно, что вибрация, и, особенно, низкочастотная вибрация является одним из высокоактивных факторов, воздействующих на человека в производственных условиях. Патологическое воздействие низкочастотных вибраций проявляется в общих вегетативных расстройствах с периферическими нарушениями, преимущественно

 