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J11511-001

Kozhin D.O., Alekminskii D. E., Evgrashin V.V., Baranov Yu.N.

FACTORS DETERMINING THE DANGEROUS ACTION OF THE DRIVER WHILE DRIVING

FGBOU VPO "State University - ESPC"
Orel, Moskovskaja 77, 302033

Abstract. Investigations of biotechnical system "Man-Machine" in terms of psychophysiological factor, based on the process of human adaptation to the vehicle in order to improve driver safety arepresented in the article.

Keywords: vehicle, driver, adaptation, system, security system, skills.

The current situation with the security in the exploitation of vehicles requires the development of new methodological approaches, based on specific measures which are directed on increasing of safety.

System "man - machine - environment" (H-M-C), which is a single package designed to perform specific functions got prevalence for the qualitative and quantitative analysis of hazards with technical objects. System H-M-C combines hardware, people and the environment interacting with each other. The main components of this system are: a man, machine, environment and complex processes occurring between the main components, need to be managed.

The study of states and their mutual influence on each of the three levels allows identifying the main tasks with human security in the "H-M-C." Considering the matrix the depth of study of safety measures in each case can be determined. For example, if the reliability of elements of system in their parameters is achieved on the level of warning (abandoned) safety and on the same level interference from technology and organization of work is excluded, that the goal - the safe operation of the system will be achieved. But, as in the real world the absolute reliability of the element is not achievable, we have to create a reliable system of unreliable elements [1].

During the main operation of the system "man-machine-environment" the most prolonged in time and throughout its duration, changes are observed as with separate elements, and the system as a whole. For example, people in addition to physical aging, gradually accumulate experience in dealing with the elements of the system, at certain stages accumulate new knowledge, and on the other forget previous studies and so on.

Environment during the main system operation also has different stages of the condition, which depend on the zonal features of the objects, the time of year, day, weather changes, and changes in the state of machines that support environment parameters and so on.

The problem of providing of safe and healthy working conditions of drivers covers the range of issues at the intersection of economic, legal, technical, biological, psychological and medical sciences as well as in itself a vehicle driving involves the joint operation of a biological level - HUMAN and technical means of production - MACHINES that performs in a specific production environment, which is partly formed by natural processes, and partly the product of human industrial activity (technical condition of the means of production, the state of roads, bridges, etc.) [2].

In the operational period the whole system "Man-machine-environment" is provided for achieving socio-economic objectives. The way to achieve the aim is defined by technology, and the driving mechanism of the system is the organization of labor and skills of the driver.

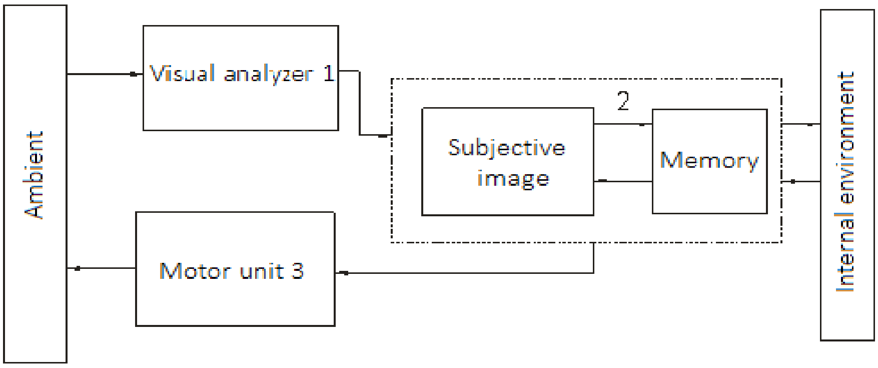
Each element involved in the process of production, must meet certain specific requirements. Technical requirements refer to the car; the driver professional requirements refer to the driver. Requirements are made to fuel, spare parts, equipment for repair, the production environment, the organizers of production, etc. All the elements without exception must comply with the safety requirements. Security of the system in common can be achieved only in the case of compliance with safety requirements of each of its elements [3].

A distinctive feature of the transport process is that it is performed in a constantly changing working environment parameters that the majority of industrial production is considered a serious technological violation [4].

At the same time the possibility of adapting the means of production to fluctuations in the parameters of the production environment: fuel quality, road conditions, weather conditions are very limited. A mismatch between the individual elements of the process, and dramatically increasing number of technical and technological failures, forced the driver to compensate for additional costs, which inevitably leads to an increased level of accidents and professional morbidity among drivers [5].

There are three links in the reflex act allocated by physiologists. The first one is the so-called sensory (perceived sensors) link that allows feeling irritated, transmitting information about it into the brain, collating irritating signal with its image in memory, and aware of it. Physiological systems providing perception are called analyzers. Each analyzer consists of receptors (cells that perceive irritation), the pathways by which the signal about irritation is transmitted into the brain, and the center in the cerebral cortex of the brain.

The second link of the reflex chain refines the perceived information, decision making, organizing the executive command and the transfer of this command into those areas of the cerebral cortex, which form and coordinate certain purposeful movements. This unit organizes the decision process (pic.1).



Pic.1. The scheme of visual-motor response:
1-perception of information; 2-deciding 3-motor response

Deciding the driver not only analyzes the information about the external environment, incoming currently on various analyzers and compares it to the prior knowledge and experience, stored in the memory. It assesses the significance of incoming information for this situation, as well as conducting forecast of possible further developments. The final decision is also influenced by the status and internal environment. For example, when the driver is tired or he has health problems in some cases, he makes the decisions different from such with the feeling of vitality and physical comfort.

The third link of the reflex circuit implements accepted decisions. This is actuator. It begins in the cells of the motor cortex area of the brain, including neural structures leading motor impulses in the brain, spinal cord and peripheral nerves and ends in muscles. Due to this link certain movement or complex motor act in accordance with the decision performs.

All conscious human activity, as well as production activities of the driver, at its core is the realization of complex conditioned reflexes. Any working activity provides all three described the reflex chain link, but depending on the type of activity and the specific situation in each of these units lays burden of varying intensity.

All three links function among vehicles drivers with constant voltage. Since kind of their profession they have to make quick decisions and to implement them in a timely manner with the help of vision and hearing constantly monitoring the rapidly changing field or traffic conditions.

Developing work skills is the formation of a conditioned reflex, as well as any other human adaptation to the conditions of existence. It starts by explaining and showing the labor action. Skill is fixed by achieving useful outcome relevant to such person.

Cortex receives and analyzes the signals from the environment, develops and strengthens conditioned reflexes in the form of labor movements, inhibits excessive reflex connections and integrates reflexes in single reflex activity - a dynamic stereotype aimed at achieving the perceived goal of human labor by development of skills.

It is known that the improvement in movements by exercise manifested in the exclusion of superfluous inappropriate movements for such activity. During the exercises motor activity is automating, its performance is achieved with minimal consciousness and intense attention. The more difficult to learn the skill (reception), the more repetitions required academic work at mastering.

Besides inherent in human memory information an important role plays intuition, which is very significant impact on the decision. All elements of the man-machine form a tightly coupled system, functioning as a unit. Purposeful changing of individual elements called adaptability or adaptation.

Among the elements of the analyzing system man possesses the greatest ability to adapt. Using their physical and mental capabilities and changing the course of operations performed by them, the person is able to largely compensate inaccuracies in car design, primitive working conditions, and sometimes incorrect task.

However, a person's ability to adapt, although are large, but not unlimited. If a person puts in front of requirements that do not correspond to his possibilities, it leads to disruption of the normal course of the process that affects both the results of their labor, and the labor human ability, and sometimes even his health.

When a rational approach to the organization of technological processes on the transport of passengers and goods should strive not only to the adaptation by training human to drive, but also to maximize the adaptation of work equipment to the possibilities of human. In system Human-machine operation of the machine depends on the actions of a person (the driver), as well as human actions depend on the possibilities inherent in the design of the machine.

Man must learn to maintain the car safely, but it is needed to learn how to design car so that the man could serve it with minimum energy expenditure.

Therefore, the development of safe techniques of performing various technical and technological operations (driving, maintenance, car repairs, etc.), and primarily the acquisition of safe behavior in extreme conditions should be constantly given the priority in preparation of driving personnel in specialized educational institutions.

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Научный руководитель: д.т.н., проф. Баранов Ю. Н.

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Imangulov A.R., Filkin N.M.

INVESTIGATION OF DYNAMIC PROCESSES OF THE HYBRID CAR POWERTRAIN

Kalashnikov Izhevsk State Technical University
Izhevsk, Studencheskaya 7, 426069

Abstract. The dynamic and mathematical models for calculation of dynamic loads that occur in the powertrain of the parallel hybrid car are examined in the article. The dynamic model reflects inertial, elastic and dissipative properties of the powertrain. The mathematical model is obtained by means of Lagrange equation and includes seven generalized coordinates. By computer simulation in Simulink / Matlab environment the statement that during transient processes dynamic loads in a car powertrain can be several times greater than the maximum torque of power plant is proved. Dynamic loading of the test hybrid car was evaluated by dynamic factor.

Key words: hybrid car, hybrid energy-power plant, powertrain, dynamic loading, simulation, dynamic factor.

Introduction. At present one of the leading directions for reducing transport negative influence on the environment is designing hybrid energy-power plants consisting of internal combustion engines (ICE) and electric motors (EM). In these energy-power plants electric and thermal energy is more effectively used, consequently fuel efficiency is improved by 30-50 %, a noise level is decreased, and environmental safety of vehicles is considerably increased.

Analysis of previous works in the field of research of cars with the hybrid energy-power plants shows that the majority of them are focused on the development of methodologies validating power parameters and characteristics of power plants, on searching for optimal parameters of the hybrid energy-power plant, on modeling factors of operational properties of machines and on other issues closely connected with problems of improving traction properties and fuel efficiency of the hybrid car.

However, studies of the dynamic processes that occur in transmissions have always attracted attention of many researchers. It’s known that these dynamic processes can be divided into two types: *steady-state* processes and *transient* processes. When transient processes (e.g. clutch engagement and disengagement, gear shifting, braking, motor start etc.) take place, transmission dynamic loads can be several times greater than the maximum engine torque, which has a negative influence on the functionality of the machine.

The irregularity of the torque causes the irregularity of changes in the shaft angular velocity, i.e. acceleration or deceleration of rotation. As the shaft has elasticity and masses are located on it, each section of the shaft will have its own degree of irregularity. It is so because masses pass different angles concurrently and therefore move with different velocities. The latter generates variable twists in shaft sections, which determines shaft structural strength. Thus alternate torques cause alternate stresses. The latter can be great and exceed an endurance limit, which leads to fatigue failure [1].

Since at present there is no general approach to the determination of driveline dynamic loads, it is evident that there is a need for theoretical and experimental research into dynamic processes occurring in machine transmissions. This makes it possible to validate the choice of technical decision and to search for the most rational design when there is no experimental model yet.

Survey of literature. Peak dynamic transmission loads occur in such adverse but quite real operating conditions as taking off by sudden engagement or a "kick" of the clutch, getting a stuck car by means of swinging etc. According to experiments and calculations powertrain loads during clutch "kicks" can be taken as peak loads in real operating conditions. So this mode can be used for the assessment of powertrain parts strength [2].

The authors [3, 4, 5] suppose that maximum moments in the driveline occur in the absence of driving wheels slipping.

In accordance with [6] during schematization transmissions are presented in the form of oscillating systems with discrete parameters. In the systems reduced to a discrete form all the parts are replaced by elements, each of which has only one property: inertial, elastic or dissipative. Meanwhile it is supposed that all the rest properties of the element don't have any significant effect on the calculation results.

It's known that the structural-kinematic scheme of a machine assembly includes a lot of various links. To simplify mathematical formulation the elements of the equivalent mechanical oscillating system must be reduced to one shaft (i.e. to one angular velocity) or in some cases to several shafts. During this reduction the equality of kinetic energies of reducible and reduced masses, the equality of potential energies of deformation of system's elastic links and the equality of dissipation energy on system's reducible and reduced elements must be retained.

The rational dynamic model of four-by-two hybrid car powertrain for the investigation of dynamic processes is given in [7, 8].

Input data and methods. The structural scheme of the hybrid energy-power plant is presented in Fig. 1 and includes the following flyweights: J_{em} – the inertia moment of the rotational parts of EM; J_{ice} – the inertia moment of rotational parts of ICE and the flywheel; J_{bd} – the inertia moment of the belt drive of the matching reducer and the driving parts of the clutch. The torsional rigidity c_{em} and the damping coefficient K_{em} reflect elastic and dissipative properties of the EM drive. The element simulating the clutch operation is also included to the structural scheme. The characteristic of this element is the friction torque M_c, acting on the driven parts of the clutch J_1.

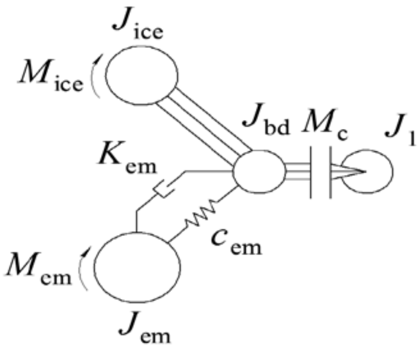

Fig. 1. The structural scheme of the car hybrid energy-power plant

Impact of hybrid energy-power plant on the powertrain elements when car takes off can be presented as the clutch friction torque M_c. So the dynamic model shown in Fig. 2 can be used for calculation of dynamic loads appearing in the powertrain when the four-by-two hybrid car takes off. The dynamic model shown in Fig. 2 has the following components: J_1 –the inertia moment of the driven parts of the clutch, J_2 – the inertia moment of the gearbox elements, J_3 – the inertia moment of the cardan drive elements, J_4 – the inertia moment of the cardan and final drive elements and the differential, J_5 – the inertia moment of the differential axles and driving wheels, J_6 – the inertia moment of the driving axle beam relative to the rotation axis of the driving wheels, J_7 – the inertia moment of the flywheel equivalent to the translating mass of the car; c_d – torsional rigidity of the torsional damper, c_1 – torsional rigidity of the primary shaft, c_2 – torsional rigidity of the secondary shaft, c_3 – torsional rigidity of the cardan and final drives, c_4 – torsional rigidity of the differential axles, c_5 – torsional rigidity of the driving wheel tires, c_6 – torsional rigidity of the suspension elastic elements in torsion. K_1, K_2, K_3, K_4, K_5, K_6 are damping coefficients of the corresponding elastic-damping sections. The clutch friction torque M_c (when the clutch is slipping) is imposed on the mass J_1. The moment of resistance to motion M_ψ is imposed on the mass J_7.

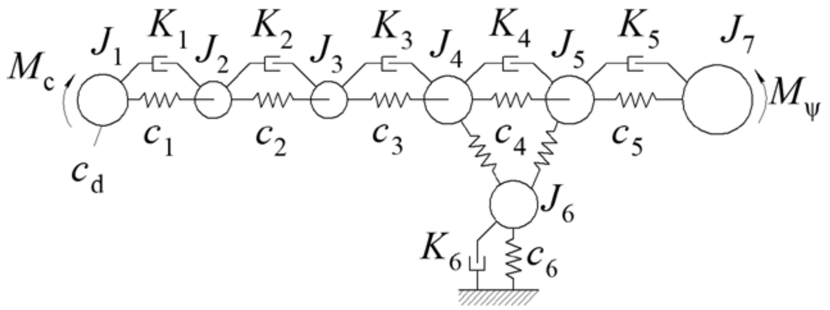

Fig. 2. The dynamic model for the calculation of dynamic loads that occur in the powertrain when the car takes off

The system of differential equations of operation of the parallel hybrid car powertrain with elastic-damping links can be deduced by means of the Lagrange equation [9]:

$$\frac{d}{dt}\left(\frac{\partial E_k}{\partial \dot{q}_i}\right)-\frac{\partial E_k}{\partial q_i}+\frac{\partial E_p}{\partial q_i}+\frac{\partial \Phi}{\partial \dot{q}_i}=Q_i\,, \quad (1)$$

where E_k, E_p are kinetic and potential energy of the system respectively; Φ is dissipative function; Q is a generalized force acting along the generalized coordinate q_i.

The dynamic loads that occur in the transmission elements of machines can be characterized by means of the following moments:

$$M_i = c_i \cdot \varepsilon_i + K_i \cdot \dot{\varepsilon}_i\,, \quad (2)$$

where M_i is moment on the corresponding elastic-damping section, c_i is the torsional rigidity of the corresponding section, ε_i is angular deformation of the elastic link, K_i is the damping coefficient of the corresponding section.

On the basis of the Lagrange equation the system of differential equations of a mechanical system operation shown in Fig. 1 can be presented in the following form:

$$\begin{cases} J_1 \cdot \ddot{\varphi}_1 = M_c - c_1^* \cdot (\varphi_1 - \varphi_2) - K_1 \cdot (\dot{\varphi}_1 - \dot{\varphi}_2), \\ J_2 \cdot \ddot{\varphi}_2 = c_1^* \cdot (\varphi_1 - \varphi_2) + K_1 \cdot (\dot{\varphi}_1 - \dot{\varphi}_2) - c_2 \cdot (\varphi_2 - \varphi_3) - K_2 \cdot (\dot{\varphi}_2 - \dot{\varphi}_3), \\ J_3 \cdot \ddot{\varphi}_3 = c_2 \cdot (\varphi_2 - \varphi_3) + K_2 \cdot (\dot{\varphi}_2 - \dot{\varphi}_3) - c_3 \cdot (\varphi_3 - \varphi_4) - K_3 \cdot (\dot{\varphi}_3 - \dot{\varphi}_4), \\ J_4 \cdot \ddot{\varphi}_4 = c_3 \cdot (\varphi_3 - \varphi_4) + K_3 \cdot (\dot{\varphi}_3 - \dot{\varphi}_4) - c_4 \cdot (\varphi_4 - \varphi_5 - \varphi_6) - K_4 \cdot (\dot{\varphi}_4 - \dot{\varphi}_5 - \dot{\varphi}_6), \\ J_5 \cdot \ddot{\varphi}_5 = c_4 \cdot (\varphi_4 - \varphi_5 - \varphi_6) + K_4 \cdot (\dot{\varphi}_4 - \dot{\varphi}_5 - \dot{\varphi}_6) - c_5 \cdot (\varphi_5 - \varphi_7) - K_5 \cdot (\dot{\varphi}_5 - \dot{\varphi}_7), \\ J_6 \cdot \ddot{\varphi}_6 = c_4 \cdot (\varphi_4 - \varphi_5 - \varphi_6) + K_4 \cdot (\dot{\varphi}_4 - \dot{\varphi}_5 - \dot{\varphi}_6) - c_6 \cdot \varphi_6 - K_6 \cdot \dot{\varphi}_6 . \\ J_7 \cdot \ddot{\varphi}_7 = c_5 \cdot (\varphi_5 - \varphi_7) + K_5 \cdot (\dot{\varphi}_5 - \dot{\varphi}_7) - M_\psi , \end{cases} \tag{3}$$

where

$$c_1^* = \frac{c_d \cdot c_1}{c_d + c_1}. \tag{4}$$

For the assessment of dynamic loads in the powertrain the friction torque M_c can be given as exponential dependence [10]:

$$M_c = M_{c\max} \cdot \left(1 - e^{-k \cdot t}\right), \tag{5}$$

where $M_{c\max}$ is a static moment of fully engaged clutch, k is a constant characterizing the rate of clutch engagement, t is simulation time.

For automotive clutches

$$M_{c\max} = \beta_c \cdot M_{e\max}, \tag{6}$$

where β_c is a clutch safety factor, $M_{e\max}$ – maximal torque of hybrid energy-power plant.

The ICE and EM of the test hybrid car developed on the basis of the car Izh-2126 run on one output shaft of the power plant and are connected by the belt reducer with the reduction ratio 1.4. According to this scheme both motors accelerate the car at the moment of taking off. The maximum torque of low-powered ICE of VAZ-1111 is 46 N·m, and maximum torque of EM PT-125-12 is 49 N·m.

The curves of the clutch friction torque M_c with different time of clutch engagement that is for a normal getaway (t_c = 0.4 s) and for an abrupt getaway or when the clutch is “kicked” (t_c = 0.1 s) are presented in Fig. 3.

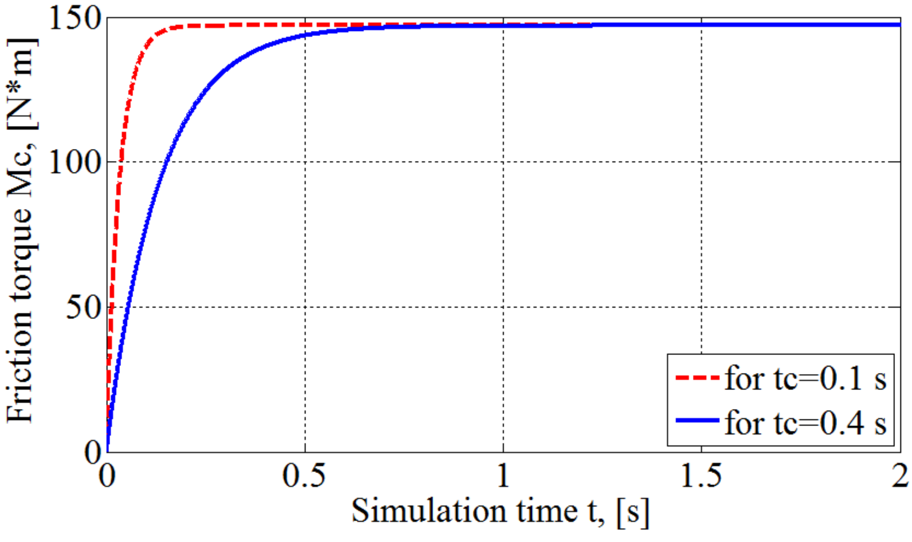

Fig. 3. Curves of the clutch friction torque

The system of differential equations (3) has no solution in an analytical form. So it was solved in Simulink / Matlab. The function ode4 was chosen as a numerical method of ordinary differential equation solution. Ode4 is based on the explicit Runge-Kutta 4th order method. This function is the most convenient for the solution of various problems.

Results. Discussion and analysis. The curves of moments on the primary shaft of the gearbox are shown in Fig. 4. It is easy to see that the faster clutch engagement the more dynamic loads appear on the elements of the powertrain.

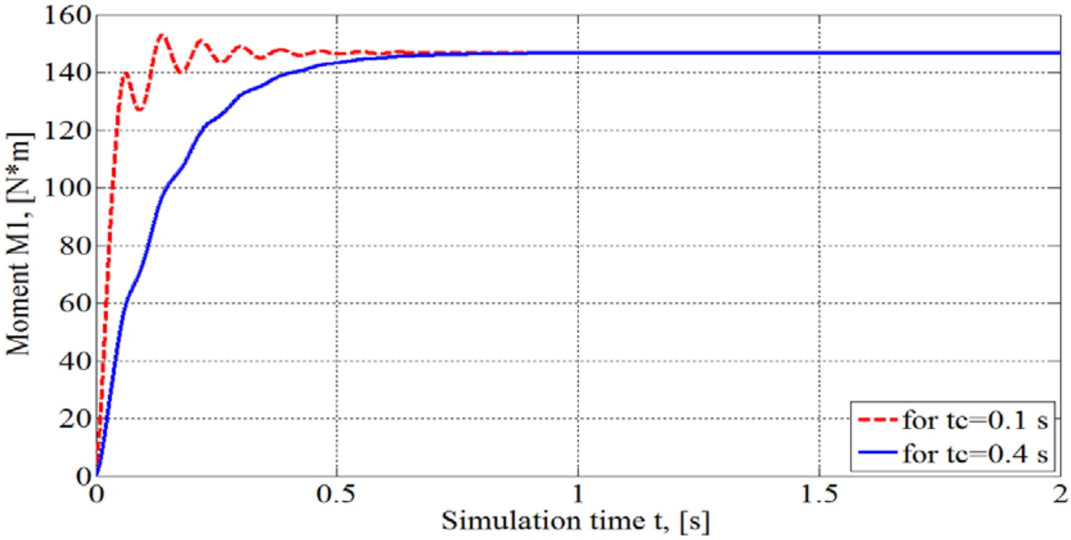

Fig. 4. The curves of moments on the primary shaft of the gearbox

It is convenient to estimate dynamic loading by means of the dynamic factor k_d [10] which is defined as the following ratio

$$k_d = \frac{M_{i\max}}{M_{e\max}}, \tag{7}$$

where $M_{i\max}$ is the maximal moment reduced to the primary shaft of the gearbox that occurs on the powertrain element; $M_{e\max}$ is the maximal torque of the power plant reduced to the primary shaft of the gearbox according to its external characteristic.

Maximum values of moments occurring on the various elements of the powertrain for normal and abrupt getaway are given in Table 1.

Table 1

Maximum values of moments on the various elements of the powertrain

Moments	Maximum values of moments for different times of clutch engagement	
	t_c = 0.4 [s] (normal getaway)	t_c = 0.1 [s] (abrupt getaway)
$M_{1\max}$	146.6496	152.9093
$M_{2\max}$	146.5182	155.9537
$M_{3\max}$	146.4668	157.1004
$M_{4\max}$	146.3967	158.6415
$M_{5\max}$	145.3193	158.9105
$M_{6\max}$	146.3967	167.5769

In accordance with the calculation results given in Table 1 it can be asserted that the powertrain of given car has approximately the same dynamic loading on each elastic-damping section. The dynamic factor for these powertrain elements is equal to 1.6 approximately. It is also necessary to note that the dynamic factor k_{d6} for the link corresponding to the elastic elements of suspension system is equal to 1.7 approximately.

Also during investigation the question of influence of such powertrain parameters as the torsional rigidity and the damping coefficient of the section corresponding to the torsional damper and the primary shaft of the gearbox on maximum values of moments on the transmission sections was examined. Dependence of maximum moment on the damping coefficient and the torsional rigidity of this section is shown in Fig. 5. The analysis of the results has indicated that ranges of coefficients K_1 = [0.1…3.5] N·m·s/rad and c_1 = [100…5100] N·m/rad are of interest for further research.

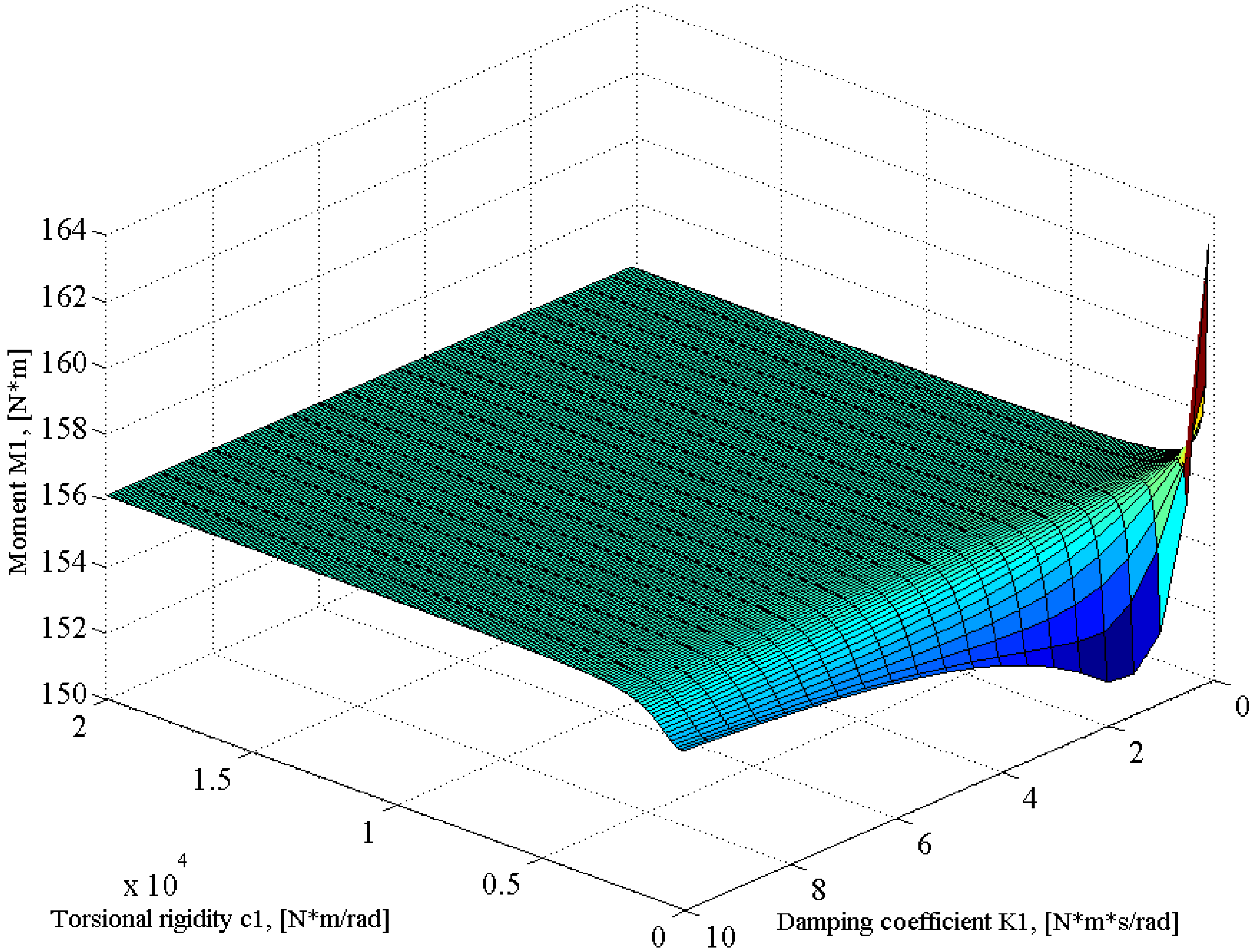

Fig 5. Dependence of maximum moment of elastic-damping section corresponding to the torsional damper and the primary shaft on the damping coefficient and the torsional rigidity of this section

Conclusion and summary. According to the research results dynamic loads that occur in the parallel hybrid car powertrain during abrupt getaway can be 1.6…l.7 times more than the maximum torque of power plant, that, of course, leads to the reduction of durability of the driveline parts.

Thus, it can be assumed that selecting optimal values of coefficients of torsional stiffness and damping coefficients of the powertrain parts it is possible to achieve the reduction of dynamic loads that occur in any transmission system.

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Куликов А.В., Фирсова С.Ю.

ОЦЕНКА ЭФФЕКТИВНОСТИ РАБОТЫ АВТОМОБИЛЬНОГО ТРАНСПОРТА ПРИ ПЕРЕВОЗКЕ СТРОИТЕЛЬНЫХ ГРУЗОВ

Волгоградский государственный технический университет, Россия, 400005, Волгоград, пр. им. Ленина, 28

Firsova SY, Kulikov AV

PERFORMANCE EVALUATION OF ROAD TRANSPORT WHEN TRANSPORTING CONSTRUCTION CARGOES

Volgograd State Technical University, Russia, 400005, Volgograd, Lenin pr., 28

Аннотация. В статье рассмотрен вероятностный характер описания элементов и этапов перевозочного процесса. Определены суммарные издержки обращения системы материально технического обеспечения в жилищном строительстве. Приведена оценка эффективности перевозки строительных грузов автомобильным транспортом.

Ключевые слова: автомобильный транспорт, грузовые перевозки, организация перевозок, технология перевозок, элементы и этапы перевозочного процесса, строительные грузы, инерционность транспортного процесса, транспортные затраты, экономический эффект, эффективность, коэффициент эффективности перевозочного процесса.

Abstract. The paper considers a probabilistic nature of elements description and stages of transport process. The paper defines the total costs of circulation of logistical support in housing construction. The paper presents performance evaluation of road transport when transporting construction cargoes.

Key words: road transport, cargo transportation, transport organization, transportation technology, elements and stages of the transport process, construction cargoes, sluggishness of the transport process, transportation costs, economic effect, effectiveness, effectiveness ratio of the transportation process.

Introduction.

The main task of road transport is timely, quality and full satisfaction of customer. The organization of transport is the organization of activities related to the preparation for loading, loading, transportation to destination, unloading of various cargoes. The task of organization of transport is the effective linkage between stages of the transportation process.

The paper uses a systematic approach to the organization of transportation of building cargoes. The operations, which make up the transportation process, are presented in the form of process scheme of building cargoes transportation using one mode of transport or several modes of transport. The cost structure of circulation system of logistical support in housing construction is considered. The paper presents ways to reduce the transport component in the construction of residential facility.

The paper considers the organization schemes of the cycle of transport process of transportation of building cargoes and schemes of linkage and possible states of the elements of stage of loading (unloading) of building cargoes. The probabilistic nature of elements description of the transportation process is considered. The factors influencing the duration and regularity of distribution of residence time of vehicle at the point of loading (unloading) are found. The paper examines stage characteristics of loading of construction cargoes (concrete products and bricks).

This paper presents minimal costs related to downtime of loading mechanisms and vehicle. The paper proposes the methods of selecting rational transportation and technological scheme of transportation of building cargoes.

The paper considers the economic indicators to assess the effectiveness of the transport process in the building industry. The paper analyses the impact of conditions of transport organization on the effectiveness of road transport during transportation of construction materials.

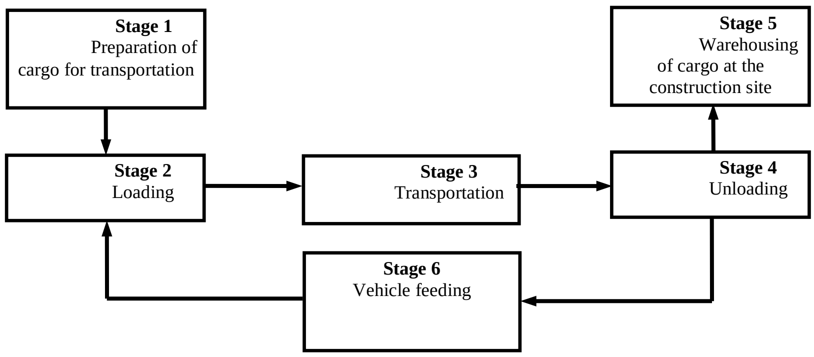
Main text.

The transportation of building cargoes starts at the point of production and finishes at the point of consumption. The transportation process starts with the process of cargo preparation for transportation (storage, packaging, labeling, etc.). The accumulation process (for example, at the factory or construction warehouse) is necessary to get the right amount of cargo forwarded to one consumer. The process of loading and delivery from the supplier to the construction site using road transport follows previous stage.

Transportation of building cargoes is a complex process of sequential, interconnected and cross operations, regulating all steps to transport materials from their production site to place of consumption.

The method of delivery is defined as transport and technological scheme, which is a set of sequential process steps and complex of technical means, ensuring the fulfillment of these operations and established procedure of transportation of cargo using optimal scheme [3]. The rational shipping method is considered to be one, which is the most effective in accordance with the optimality criterion [2]

The process operations, which make up the process of transportation, are heterogeneous and differ greatly in their duration. Some operations form certain stages of the transport process, when they are combined, all of which performs a specific task. The process schemes of transportation of building cargoes are shown in Fig. 1.



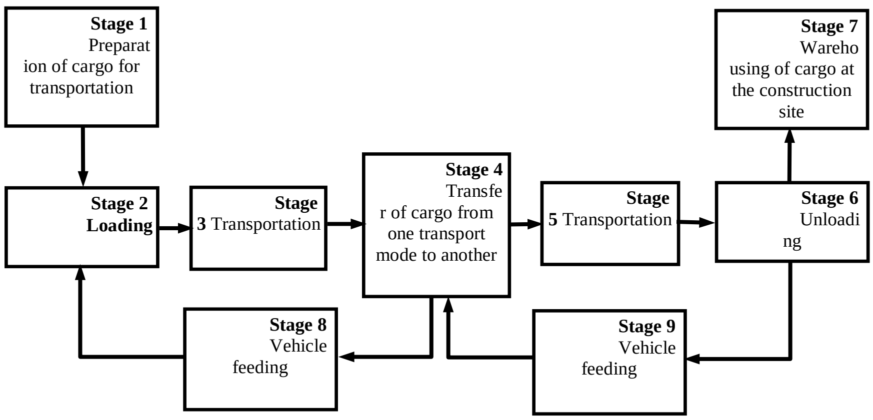


Fig. 1. The process schemes of transportation of building cargoes: a) one mode of transport; b) several modes of transport

The transportation volumes of building cargoes in housing construction are based on cost estimates for the construction of residential buildings. Planning of traffic volumes of building cargoes is carried out in technological order in accordance with the schedule of construction of a particular object. The role of road transport is to provide transportation of necessary construction materials within fixed time limits, in proper amounts and to the "right" price.

The transportation costs are an important component, which forms the cost of construction. Improving transportation technology of building materials will allow reducing transportation costs. Development of technological schemes of transportation of building materials provides a coherent work of transport and cargo handling facilities, thereby reducing production losses [10, 12].

The total costs of circulation of the system of logistic support in construction are defined by the following formula [5, 7, 8]:

$$\sum Cls = C_{proc} + C_{mtr} + C_{tr} + C_{track} + C_{stor} + C_{scar}, \quad (1)$$

where C_{proc} – order placement and order processing costs; C_{mtr} – cost of material and technical resources; C_{tr} – transport costs; C_{track} – costs of material resources tracking; C_{stor} – storage costs; C_{scar} – costs associated with resource scarcity.

There is a difference between "effect" and "efficiency". The effect is the result of production activity, the efficiency is not the result itself, but ratio of result to cost, i.e. efficiency is the ratio of useful effect (result) to expenses to obtain it.

The economic effect from optimization of the volume of a single shipment is defined by the following formula:

$$\Delta E_{tr1} = C_{п} \cdot T_{н} \cdot Д_{рг} \cdot M_{х} - C_{п} \cdot T_{н} \cdot Д_{п} \cdot M_{х} \cdot n - (З_{пр} + \Delta C_{а}) \cdot n, \quad (2)$$

where ΔE_{tr1} – economic effect, rub.; n – number of transported consignments during construction period; $D_{р}$ – duration of delivery of one consignment, days.

The optimal volume of transported consignments is calculated according to the formula:

$$W_{с} = \sqrt{\frac{2 \cdot G \cdot Q \cdot (O_{ст} + \Delta C_{а})}{S_{х} \cdot (G - Q)}}, \quad (3)$$

where $W_{с}$ – optimal volume of consignments, t; G – capacity of the plant which supplies material, t; Q – material requirements, t; $O_{ст}$ – fixed costs related to the order rub. /consignment; ΔC_a – costs of transport organizations, which are related to switching the vehicle to another work, rub. /consignment; S_X – prime cost of stock holding, rub/t.

The economic effect from changes in regularities of distribution of service time of vehicle at the point of loading is determined by the formula:

$$\Delta E_{mp2} = (t_1 - t_1') \cdot C_{а} \cdot A_x, \quad (4)$$

where t_1 – waiting period at the point of loading of vehicle with an exponential distribution of service time, h; t_1' – waiting period at the point of loading of vehicle with Erlangian or regular distribution of service time, h.

The economic effect from optimization of the number of vehicles running with loading mechanism is defined by the following formula:

$$\Delta E_{tr3} = E_{tl} - E_{tl}^{\min} \quad (5)$$

where ΔE_{tr3} – effect from optimization of the number of vehicles running with loading mechanism, rub/h; $З_{tl}$ – losses connected with downtime of loading mechanisms and vehicle due to non-uniformity of their work, rub/h; $З_{tl}^{\min}$ – minimum losses related to downtime of loading mechanisms and vehicle due to non-uniformity of their work, rub/h.

The economic effect of the choice of optimal type of vehicle and cargo-handling mechanisms is defined by the following formula:

$$\Delta E_{tr4} = \left(C_l^{cur} \cdot M_x^{cur} + C_v^{cur} \cdot A_x^{cur}\right) - \left(C_l^{opt} \cdot M_x^{opt} + C_v^{opt} \cdot A_x^{opt}\right), \qquad (6)$$

where ΔE_{tr4} – economic effect of the choice of optimal type of vehicle and cargo-handling mechanisms, rub/h; C_l^{cur} – prime cost of using the current loading mechanism, rub/h; C_v^{cur} – prime cost of using the current vehicle, rub/h; C_l^{opt} – prime cost of using the selected loading mechanism, rub/h; C_v^{opt} – prime cost of using the selected vehicles, rub/h; A_x^{cur} – number of used cars, u; M_x^{cur} – number of used loading mechanisms, u; A_x^{opt} – optimal number of vehicles, u; M_x^{opt} – optimal number of loading mechanisms, u.

The expected economic effect of transportation with the highest values of technical speed can be calculated by the formula [5]:

$$\Delta E_{тр5} = \sum_{i=1}^{\kappa}\left[\frac{n_{ei} \cdot l_{ег} \cdot C_a}{V_{T_{1i}}} - \frac{n_{ei} \cdot l_{ег} \cdot C_a}{V_{T_{2i}}}\right], \qquad (7)$$

where ΔE_{tr5} – economic effect of transportation with the highest values of technical speed, rub; κ – recommended number of time periods per day, which provides speed increase, u; n_{ei} – number of haulages over time period, u; $l_{ег}$ – length of haulages with a cargo, km; C_a – prime cost of vehicle usage, rub/h; $V_{T_{1i}}$ – technical speed in the current time interval of shipments, km/h; $V_{T_{2i}}$ – technical speed in the proposed time interval of shipments, km/h.

A rationalized method of delivery in relation to specific customers, transport network, possible forms of transport service and types of construction cargoes reduces the transport costs in the construction based on the feasibility studies in compliance with system, structural, technological and organizational requirements. According to our evaluations, the transport costs are reduced from 25% to 15% of the total cost of housebuilding.

The transport process can be considered based on operations with vehicle and operations with objects of transportations. The main element of the transport process includes cargo relocation, loading transportation and unloading.

The cycle duration of the transport process is formed under the influence of factors, which can be grouped into the following stages: feeding of the vehicle for loading, loading, transportation and unloading.

These stages consist of elements-technological operations. Inclusion or removal of any element from the stage changes the ratio between all the other elements, influencing parameters of the transport process as a whole, reducing or extending the cycle duration of the transport process.

The whole variety of transportations of building cargoes, which are performed using road transport, can be summarized under three schemes (Fig. 2) [4]:

1. One loading point – several unloading points.
2. Cargoes from many points of loading are delivered to one point of unloading.
3. Entire cargo is delivered from one point of loading to one point of unloading.

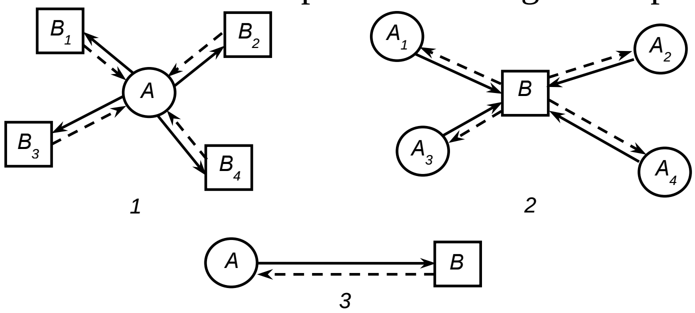


Fig. 2. The organization scheme of the cycle of transport process of road transportation of construction cargoes

The incoming flow is a regularity, which subjects the arrival of vehicle units at the point of loading or unloading over time. In the vast majority of works on the queuing theory, we consider the simplest case of flow, when the probability of receiving P_n within the time interval t equals n requests. It is defined by the formula:

$$P_n(t) = \frac{(\lambda t)^n}{n!} e^{-\lambda t}, \tag{8}$$

where n – average number of requests received per time unit.

With regard to the transport process, the incoming flow of vehicles in the points of loading and unloading of cargo can be Poisson, Erlangian and regular.

If the arrival of vehicles at the point of loading is distributed randomly and the probability that n vehicles arrive per time unit is defined by the Poisson law, than the distribution of interval duration between the adjacent vehicles has a density:

$$f(t) = \lambda e^{-\lambda t}, \ (0 < t < \infty). \tag{9}$$

Parameter λ is calculated based on experimental data:

$$\lambda = \frac{n}{T}, \tag{10}$$

where n – number of vehicles arrived at the point of loading; T – period of observation; λ – intensity of the incoming flow of vehicles.

The pattern of distribution of the incoming flow depends primarily on the organization of vehicle work. The incoming flow is Poisson`s or close to it when organizing vehicle work using schemes *1* and *2* (Fig. 2). When organizing transport using Scheme 3, the incoming flow of vehicles at the point of loading is distributed by the Poisson law or the Erlang law. The pattern of distribution depends on the length of haulage with cargo and the number of working vehicles. The larger the distance of haulage with cargo and the greater number of working vehicles, the less the aftereffect and the flow is described by the Poisson distribution. Reducing the length of haulage with cargo leads to self-regulation of vehicle traffic and the incoming flow is distributed according to the Erlang law.

Stages such as loading and unloading are connected with all the works on loading and unloading of road transport vehicles and all the delays of vehicles at the points of loading and unloading regardless of the reasons. Numerous operations making up the process of loading works can be grouped into the following four elements [4]: t_1^{p} – waiting for loading; t_2^{p} – maneuvering of vehicle; t_3^{p} – loading; t_4^{p} – execution of documents.

Connection schemes of possible states of the elements of loading stage (unloading) are shown in Fig. 3. The analysis of these schemes shows that the execution of shipping documents can be performed sequentially (after loading and unloading) and simultaneously (concurrently with the loading and unloading). Other elements of this stage are performed sequentially. At this stage, time of loading is necessary element according to the technology, and the other elements have a negative effect on loading point capacity, increasing the cycle time of the transport process.

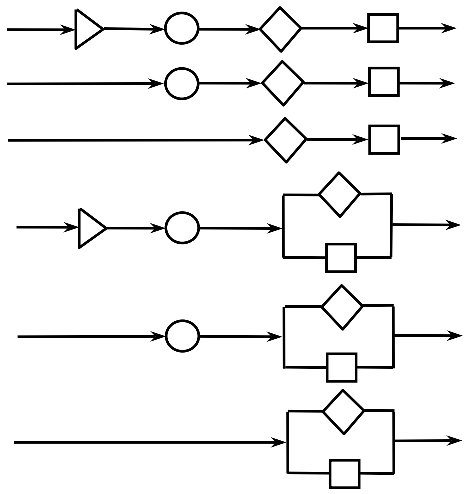


Fig. 3. Connection schemes of possible states of the elements of loading stage (unloading): 1 – waiting for loading (unloading); 2 – maneuvering; 3 – loading (unloading); 4 – execution of documents

In the general case, it is unknown how long a certain vehicle will be at the point of loading (unloading). Downtime of the vehicle during loading (unloading) is determined by the formula:

$$t_{\text{p}} = t_1^{\text{p}} + t_2^{\text{p}} + t_3^{\text{p}} + t_4^{\text{p}}, \quad (11)$$

or

$$t_{\text{p}} = t_2^{\text{p}} + t_3^{\text{p}} + t_4^{\text{p}}, \quad (12)$$

when the element “waiting for loading (unloading)” is missing. In the case when the execution of documents is done concurrently with the process of loading (unloading),

$$t_{\mathrm{p}} = t_2^{\mathrm{p}} + t_3^{\mathrm{p}} . \qquad (13)$$

The time during which any specific vehicle is serviced: maneuvering and loading (unloading), and the execution of documents, considered to be the duration of the service, ie

$$t_{\mathrm{s}}^{\mathrm{p}} = t_2^{\mathrm{p}} + t_3^{\mathrm{p}} + t_4^{\mathrm{p}} , \qquad (14)$$

where $t_{\mathrm{s}}^{\mathrm{p}}$ – the duration of service at the point of loading (unloading).

Total period at the point of loading (unloading) of vehicle is the sum of the waiting time and service time:

$$t_{\mathrm{p}} = t_1^{\mathrm{p}} + t_{\mathrm{s}}^{\mathrm{p}} . \qquad (15)$$

Duration and regularity of the distribution of stay duration of vehicle at the point of loading (unloading) are due to duration and regularity of distribution of elements, included in the stage [4].

The duration of element "maneuvering" depends on the organization of the loading point. The most rational way to organize work of dump trucks in the transportation of bulk building cargoes is the so-called ring - workflow of the vehicles. In this case, there is no oncoming traffic of vehicles. Maneuvering time is minimized under such an arrangement.

Average time of vehicles maneuvering at the point of loading ranges within one minute, and the distribution regularity of duration of this element is described by exponential law:

$$f\left(t_2^{\text{п}}\right) = \lambda_2 e^{-\lambda_2 t} . \qquad (16)$$

The duration of element "loading" depends on the type of cargo and type of vehicle and loading equipment. Thus, downtime of dump trucks under loading when transportating bulk building materials depends on the capacity of excavator bucket, ie it depends on the number of buckets, which are loaded into the truck body on every haulage. The larger the capacity of the excavator bucket, the lower the average downtime of vehicle under loading. In this case, the average downtime under loading is determined by:

$$\bar{t}_3^{\mathrm{p}} = t_{\mathrm{ce}} m_{\mathrm{b}} , \qquad (17)$$

where $\bar{t}_3^{1}$ – average downtime under loading; t_{ce} – execution time of one cycle of loading by excavator; m_{b} – number of buckets of cargo loaded into the vehicle.

The coefficient of variation for such cases of loading has little value, and distribution regularity of the duration of loading is described by normal law:

$$f\left(t_3^{\text{п}}\right) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{\left(t_3^{\text{п}} - \bar{t}_3^{\text{п}}\right)^2}{2\sigma^2}\right] . \qquad (18)$$

When loading reinforced concrete slabs, bricks and other cargoes, in the case when loading of these cargoes is associated with stacking in the truck body, securing of cargoes, etc., the coefficient of variation of the duration of loading approximately equals to one and distribution regularity of the duration of loading is described by exponential law:

$$f\left(t_3^{\text{п}}\right)=\mu_3 e^{-\mu_3 t}. \tag{19}$$

When loading viscous cargoes (mortar, concrete mix and other) distribution regularities of the duration of loading is described by Erlang distribution:

$$f_k\left(t_3^{1}\right)=\frac{\lambda(\lambda t)^k}{k!}e^{-\lambda t}. \tag{20}$$

The duration of execution of documents depends on the organization and technological process of loading operations, and distribution regularity of this element is determined by Erlang distribution. In individual cases, when there is no checkpoint at the loading point, when combining execution of documents and loading, the duration of execution of documents is distributed by the exponential law:

$$f\left(t_4^{1}\right)=\mu_4 e^{-\mu_4 t}. \tag{21}$$

The duration of service and distribution pattern depend on the relevant parameters - elements of loading stage (unloading). The distribution of service duration and actual service duration depend on the organization of loading operations. For example, during transportation of soil and inert materials from the excavator, when elements of stages such as maneuvering and execution of documents are not available or do not take a long time during service period, the distribution of service duration is determined by a normal distribution:

$$f\left(t_s\right)=\frac{1}{\sigma\sqrt{2\pi}}\exp\left[-\frac{\left(t_s-\bar{t}_s\right)^2}{2\sigma^2}\right] \tag{22}$$

or Erlang distribution of large order

$$f_k\left(t_s\right)=\frac{\lambda(\lambda t)^k}{k!}e^{-\lambda t}, \tag{23}$$

where $k>4$.

In the case where the duration of the elements such as stages “maneuvering, loading and execution of documents” is distributed according to the exponential law, the duration of service has the same regularity:

$$f\left(t_o\right)=\mu_o e^{-\mu_o t}. \tag{24}$$

The example of characteristics of some random variables included in loading stage is presented in Table 1, Table 2.

Table 1

Characteristics of loading stage of concrete products

Elements of loading stage	Mathematical expectation, $\mu(t)$	Dispersion, $D(t)$	Pearson criterion, χ^2	Function
Waiting for loading	8,09	76,75	2,325	$f(t)=0{,}124e^{-0{,}124t}$
Loading	20,76	37,34	5,302	$f(t)=\frac{1}{6{,}11\sqrt{2\pi}}\times\exp\left[-\frac{(20{,}76-t)^2}{74{,}68}\right]$
Execution of documents	16,45	69,39	0,94	$f(t)=\frac{0{,}182(0{,}182t)^3}{3!}\times e^{-0{,}182t}$

Table 2

Characteristics of loading stage of bricks

Elements of loading stage	Mathematical expectation, $\mu(t)$	Dispersion, $D(t)$	Pearson criterion, χ^2	Function
Waiting for loading	52,65	240,68	0,834	$f(t) = 0{,}019e^{-0{,}019t}$
Maneuvering	2,56	2,27	1,84	$f(t) = 0{,}39e^{-0{,}39t}$
Loading	39,6	12,60	0,454	$f(t) = \frac{1}{3{,}55\sqrt{2\pi}} \times \exp\left[-\frac{(39{,}6-t)^2}{25{,}2}\right]$

Knowing the regularity distribution of incoming flow and service time, we can define a vehicle's waiting period of loading (unloading) operations. If the arrival of vehicles at points of loading or unloading is described as a Poisson random process with a parameter λ, and service time has random distribution with the intensity of service μ_o, than the average waiting time t, according to Pollaczek-Khinchin formula, is determined by the following formula [1, 4]:

$$t_1 = \frac{\lambda}{\mu_o^2}\left[\frac{\mu_o^2 D(t_o)+1}{2(1-\rho)}\right], \qquad (25)$$

where $D(t_o)$ – dispersion of service time; ρ – reduced density of the incoming flow of vehicles.

Taking into account constant service time $D(t_o) = 0$, in the case of Erlang distribution $D(t_s) = 1/(k\mu_s^2)$ and in the case of exponential distribution – $D(t_o) = 1/\mu_o^2$.

Thus, the average waiting time for loading and unloading is determined by the following formula:

- in the case of constant service time

$$t_1 = \frac{\rho^2}{2\lambda(1-\rho)}, \qquad (26)$$

- in the case of Erlang distribution of service time

$$t_1 = \frac{\rho^2(1+k)}{2\lambda k(1-\rho)}, \qquad (27)$$

- in the case of exponential distribution of service time

$$t_1 = \frac{\rho^2}{\lambda(1-\rho)}. \qquad (28)$$

For any distribution of the incoming flow of vehicles in the points of loading or unloading and any regularity of service time duration of the element "waiting for loading (unloading)" is determined by the exponential distribution [11].

Minimum costs related to downtime of loading mechanisms and vehicle due to non-uniformity of their work are determined according to the formula:

$$M_x \cdot C_n(1-\rho) + C_a \cdot A_x \cdot \frac{\lambda}{\mu_s^2}\left[\frac{\mu_s^2 \cdot D(t_s)+1}{2(1-\rho)}\right] \Rightarrow \min, \qquad (29)$$

Calculations to determine costs related to downtime of loading mechanisms and vehicle due to non-uniformity of their work during transportation are presented in Table 3 and Fig. 4.

Table 3

Costs related to downtime of loading mechanisms and vehicle

Number of cars, u	Density of the incoming flow	Performance of transportation complex, t/h	Average latch wait time loading, h	Cost of the loader, rub./h	Vehicle cost, rub./h	Total cost, rub./h
1	0,05	1,61	0,01	5329,01	8,04	5337,05
2	0,10	3,19	0,03	5059,49	33,78	5093,28
3	0,14	4,73	0,04	4791,65	80,02	4871,68
4	0,19	6,21	0,06	4525,75	150,13	4675,88
5	0,24	7,59	0,07	4262,10	248,17	4510,27
6	0,29	8,88	0,09	4001,07	379,13	4380,20
7	0,33	10,03	0,12	3743,10	549,09	4292,19
8	**0,38**	**11,05**	**0,14**	**3488,74**	**765,51**	**4254,25**
9	0,42	11,92	0,17	3238,63	1037,61	4276,23
10	0,47	12,62	0,21	2993,54	1376,74	4370,28
11	0,51	13,14	0,24	2754,41	1796,90	4551,31
12	0,55	13,49	0,29	2522,31	2315,22	4837,54
13	0,59	13,67	0,34	2298,53	2952,49	5251,02
14	0,63	13,67	0,40	2084,46	3733,49	5817,94
15	0,66	13,53	0,47	1881,63	4687,01	6568,64

When transporting soil, minimal costs related to downtime of loading mechanisms and vehicle due to non-uniformity of their work amounts to 4254,25 rub/h (Table 3) [7, 8].

The effectiveness of stages of cargo transportation and feeding of vehicle for loading is connected with haulage and vehicle speed.

Each stage of cycle of the transport process has quantitative characteristics and it is described by a certain distribution. These factors fit together and influence the regularity and characteristics of the distribution of cycle duration of the transport process. Average cycle time of the transport process is derived from the sum of the residence time of each unit of vehicle in various stages [4]:

$$t_c = t_{vf} + t_l + t_t + t_u, \tag{30}$$

where t_c – average cycle time of the transport process; t_{vf} – average duration of the stage “feeding of the vehicle for loading”; t_l – average duration of the loading stage; t_t – average duration of the stage “transportation”; t_u – average duration of the unloading stage.

In general, the duration of cycle of the transport process will be determined by the following formula [4]:

$$t_c = \frac{L_x}{V_т} + t_1^l + t_2^l + t_3^l + t_4^l + \frac{L_{er}}{V_t} + t_1^u + t_2^u + t_3^u + t_4^u. \tag{31}$$

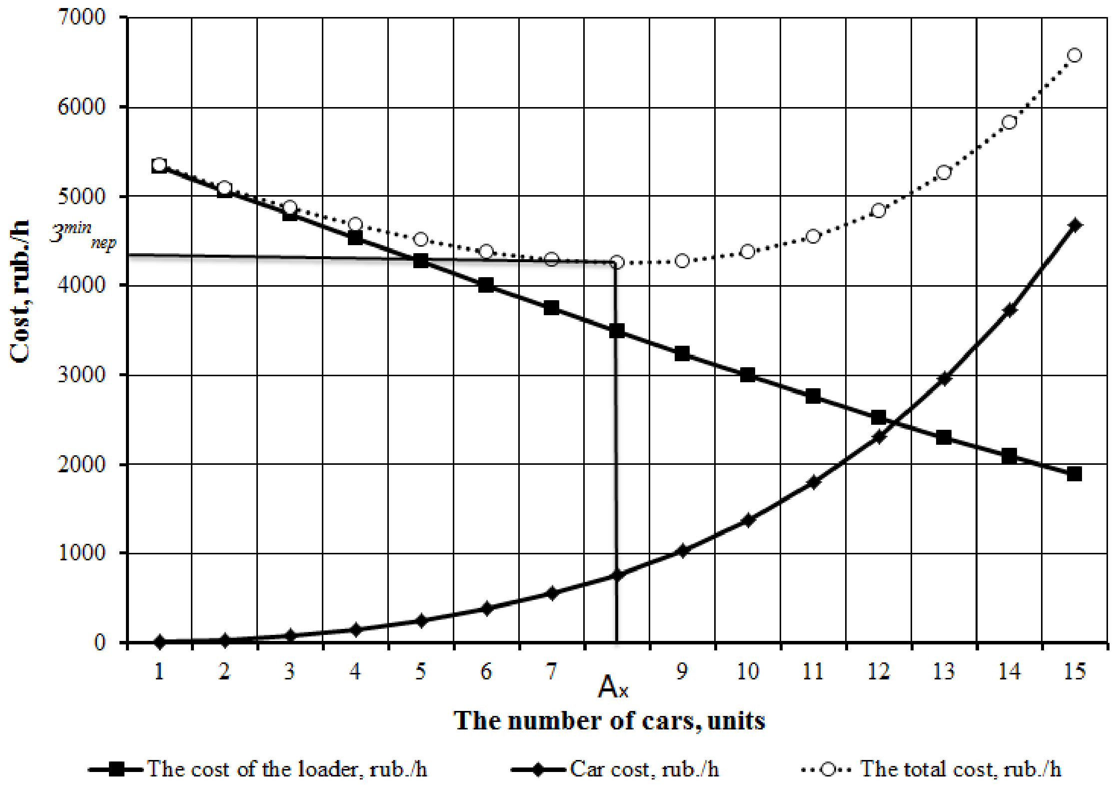


Fig. 4. The influence of the number of vehicles on the costs related to downtime of loading and unloading mechanism and vehicle

When transporting main building materials such as soil, clay, filter and inert materials, mortar, ready-mixed concrete, asphalt mass, brick, and other building cargoes, there is no preparation of the cargo for shipment and operations of the stage “cargo storage” or they have a small duration and low costs, i.e.,

$$T_1^t = 0; \quad T_5 = 0. \tag{32}$$

For road transportation of this range of cargoes delivered from the place of manufacture to the point of consumption over one transport cycle, costs and duration of the shipping process are identical to the transport process and therefore, the efficiency of the shipping process is identical to the efficiency of the transport process. Currently, there are many such transportations, and raising the effectiveness of transport has a significant impact on transport costs.

When organizing transportation of building cargoes, various technological schemes are used. Each of them is characterized by a combination of a number of typical process operations at the point of loading and unloading point (construction site), on transport.

When selecting transportation scheme of building cargoes, it is necessary to consider features of the product and its production, transportation factors, etc. Optimization of the system involves the cost minimization of the entire system. A set of material elements at all stages of transportation of building cargoes – warehouses, transport, loading and unloading equipment, as well as stocks of goods are the technological structure of delivery systems of building materials.

Design of the scheme and technology of organization of transport requires the development of a set of questions: choosing mode of transport and vehicle; development of packaging designs, identifying needs for it, etc. [9]. Selection of transport and technological scheme is an essential element of development of the technology of cargo transportation.

When selecting transport and technological scheme, it should be understood that different options of the technological scheme could be applied to transport the same cargo, equivalent from the standpoint of technological requirements for transportation, but with significant differences in technical and economic parameters.

Optimal transport and technological scheme should be selected based on a feasibility analysis of all possible alternatives. Sum of reduced costs shall be taken as an optimization criterion [4].

If there are two or more comparable options of transport and technological schemes with approximately equal reduced costs, the preference is given to option, which provides certain conditions: increasing the turnover of current assets by reducing delivery time; reducing direct labor costs and material resources; possibility to use an automated process control of transportation; flexibility of the transport process and its ability to be reorganized taking into account sudden change in conditions (destination, environmental factors); constancy during transportation, which is suitable for load unit; elimination of hard physical labor; a higher level of mechanization and automation of loading, unloading and storage operations, safety of working conditions; better safety of transported building cargo.

Selection of transport and technological scheme includes: the analysis of technical and economic parameters of the process and transport and technological characteristics of cargo; selection of connection type (direct, mixed) and modes of transport; type of transportation, type and establishment of the optimum dimensions, weight and technological characteristics of load unit (container, package); choice of means of mechanization of loading, unloading and storage operations at shipper, consignee and at transfer points from one transport mode to another; feasibility analysis of selected alternatives and the final selection and design of transportation and technological scheme [3].

Transport costs are an important part, which forms the cost of construction. One of the methods to reduce transport costs is to improve transportation technologies. The development of technological scheme of transportation of construction materials minimizes production losses. The task of technology is to reduce the duration, labor input of cargo transportation by reducing the number of operations and the stages of the transportation process, remove unnecessary operations from the shipping process, and make it more purposeful. Transportation of concrete products and bricks refers to mass transport.

There are three commonly used technological schemes of transportation of concrete products and bricks from the factory to the construction site [8]: towing vehicles with semitrailers, using the "mounting wheels", exchange of semitrailers.

The cost of each operation can be estimated based on the duration of its implementation and the prime cost of vehicle and use of loading and unloading mechanisms per unit time.

The efficiency of road transport is predetermined by the choice of optimal routes and correct selection of the most suitable vehicles for the specific conditions. The optimal route of transportation of building cargoes should include such vehicle traffic, which will ensure the execution of planned volumes of transportations in minimum period. In addition, each vehicle, truck, trailer or semi-trailer should be used efficiently. It is characterized by utilization ratio of its capacity.

The economic indicators are important elements. They reflect economic interests of the construction sector and they should be systematically upgraded.

As noted by prof. Velmozhin AV, the efficiency of use of vehicle may be determined by perfection of its design and compliance with the operating conditions as well as the organization of transport.

As the main purpose of transportation process is to move a certain amount of cargo over a certain distance, transport volumes must be specific in time and space. Therefore, freight capacity of the transport complex could be estimated using tonne-kilometers or tons.

Experience in the performance evaluation of road transport vehicles shows, that the indicator "tonne-kilometer" has serious drawbacks. True tonne-kilometers, which define the amount of transportation work, are the product of weight and haulage distance. Therefore, each tonne-kilometer individually characterizes a single unit of work regardless of the conditions of transportations and labor costs for their implementation. As a wide range of transportations are performed by road transport, differing by the nature of cargo and distance of transportation, and so forth, one unit of work, expressed by one tonne-kilometers, can cover different amounts of labor costs in the specific conditions of transportation. True tonne-kilometer does not characterize the utility and customer value of the work performed, as well as the amount of labor costs, which are socially necessary for the work. True tonne-kilometer does not establish a link between the transportation process and the national economy.

As the indicator of road transport vehicle tonne-kilometer does not stimulate the struggle for reducing the number of transported tons and distance of their transportation. This indicator is ill suited to assess the effectiveness of the transportation process.

The indicator for assessing the effectiveness of the transportation process such as "ton" also has disadvantages. It defines only the amount of transported cargo and does not characterize the economic costs associated with moving it.

The effectiveness indicator should combine the efficiency of the transport complex and the impact of cargo transportation on the activities of the companies serviced.

Proper accounting of the costs associated with the shipping process is important not only for the transport industry, but primarily for industries and businesses served by transport.

When determining the costs related to implementation of the transportation process, it is necessary to take into account: technical and economic parameters of the vehicle; transportation distance; costs associated with loading and unloading, damage and loss of cargo, delay in delivery of cargo.

The linear graph of the transportation process (Fig. 5) shows the cost structure, interconnection between the components of the transportation complex, and also between the transport system and the medium [2, 3, 4].

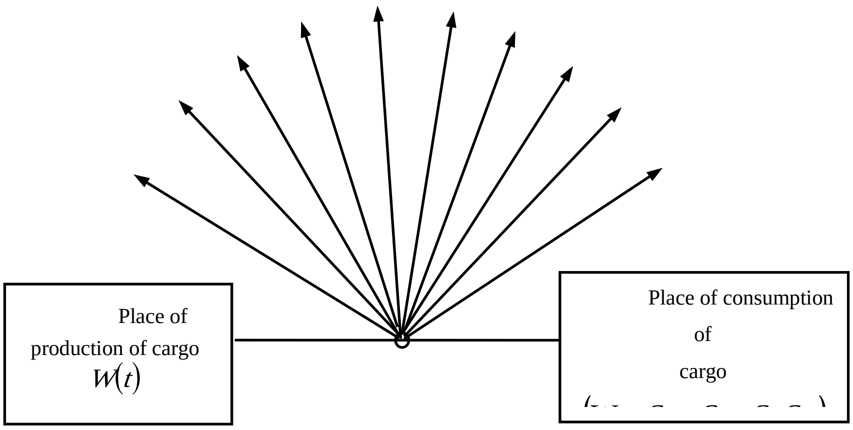


Fig. 5. The linear graph of the transportation process

Notations in Fig. 4: $W(t)$ – cargo flow, t; W_Q – volume of transport products, t; S_{cp} – prime cost of cargo preparation for transportation, rub/t; S – prime cost of transportation, rub/t; S_{lu} – prime cost of loading and unloading, rub/t; S_s – prime cost of cargo storage, rub/t; R_1 – costs related to increasing distance of transportation of cargo, rub; R_2 – costs due to mismatch between vehicle and nature of cargo, sort of cargo, rub; R_3 – costs related to damage and loss of cargo, rub; R_4 – costs associated with additional loading and unloading operations, rub; R_5 – costs associated with additional cargo storage, rub; R_6 – costs related to the inertia of the transportation process, rub; R_7 – costs associated with the increase in the cost of transportation, rub; R_8 – costs associated with the increase in the cost of loading and unloading operations, rub; R_9 – costs associated with the increase in the prime cost of preparing cargo for transportation, rub; R_{10} – costs related to the increase in the prime cost of storage of cargo, rub.

The values of individual additional costs of the transportation process, are determined by the equation [2, 3, 4]:

$$R_1 = \frac{L_{hca} - L_{hc}}{q\gamma_c \beta_e}\left(C_{пер} - \frac{C_п}{V_т}\right)W_Q, \tag{33}$$

where L_{hc} – planned haulage distance with cargo, km; L_{hca} – actual haulage distance with cargo, km; W_Q – volume of transported production, t.

$$R_2 = \frac{1}{\beta_e}\left\{\frac{1}{q'\gamma'_c}\left[C'_{пер}L_{hc} + \frac{C_п}{V'_t}\left(L_{hc} + t'_{пр}V'_t\beta'_e\right)\right] - \right. \\ \left. - \frac{1}{q\gamma_c}\left[C_{пер}L_{hc} + \frac{C_п}{V_t}\left(L_{hc} + t_{пр}V_t\beta_e\right)\right]\right\}W_Q, \tag{34}$$

where q; γ_{c}; V_{t} – planned performance indicators; q'; γ'_{c}; V'_{t} – actual performance indicators.

$$R_3 = Z\delta_{\text{c}} W_Q, \tag{35}$$

where Z – percentage of loss and damage of cargo during transportation; δ_{c} – cost of unit weight of cargo, rub/t.

$$R_4 = bS_{\text{lu}} W_Q, \tag{36}$$

where b – coefficient, which takes into account the additional loading and unloading operations; S_{lu} – prime cost of loading and unloading operations, rub/t.

$$R_5 = S_{\text{s}} T_{\text{s}} \frac{(Q_{\text{ew}} - Q_{\text{exw}})}{2}, \tag{37}$$

where S_{s} – prime cost of the storage of unit weight of cargo per unit of time, rub/(t·h); T_{s} – duration of storage, h; Q_{ew} – amount of cargo entered the warehouse over period of time $t_1 - t_0$, t Q_{exw} – amount of cargo exported from the warehouse over a period of time $t_1 - t_0$, t.

$$R_6 = \delta\left[W(t) - W_k\right], \tag{38}$$

where δ – costs caused by delay in the receipt of cargo of the enterprise, served by transport, rub/t.

$$R_7 = \Delta S W_Q, \tag{39}$$

where ΔS – increase in the cost of transportation of cargo, rub/t.

$$R_8 = \Delta S_{\text{lu}} W_Q, \tag{40}$$

where ΔS_{lu} – increase in the prime cost of loading and unloading operations, rub/t.

$$R_9 = \Delta S_{\text{pr}} W_Q, \tag{41}$$

where ΔS_{pr} – increase in the prime cost of cargo preparation for transportation, rub/t.

$$R_{10} = \Delta S_{\text{s}} W_Q, \tag{42}$$

where ΔS_{s} – increase in the prime cost of storage of the cargo, rub/t.

If during the time interval $(t_1 - t_0)$ transport products equals to W_Q, the costs associated with meeting the needs of enterprises in the transportation, will be equal to

$$(S_{\text{lu}} + S_{\text{pr}} + S + S_{\text{s}})W_Q. \tag{43}$$

Actual costs will consist of the following components:

$$(S_{\text{lu}} + S_{\text{pr}} + S + S_{\text{s}})W_Q + R_1 + R_2 + R_3 + R_4 + R_5 + R_6 + R_7 + R_8 + R_9 + R_{10}.$$

(44)

Most fully, public utility of transportations will be reflected by the efficiency factor of the transportation process, which is the ratio of the costs associated with meeting the needs of enterprises served by transport in the transportation to the actual costs [4]:

$$K_{\mathrm{et}} = \frac{\left(S_{\mathrm{lu}} + S_{\mathrm{pr}} + S + S_{\mathrm{s}}\right)W_Q - R_3}{\left(S_{\mathrm{lu}} + S_{\mathrm{pr}} + S + S_{\mathrm{s}}\right)W_Q + R_1 + R_2 + R_4 + R_5 + R_6 + R_7 + R_8 + R_9 + R_{10}}, \quad (45)$$

where K_{et} – effectiveness ratio of the transportation process.

These factors have a differential impact on the efficiency of road transport. To identify the most important factors and their influence on the coefficient of transportation process, it is necessary to analyze influence of the conditions in the organization of transport on efficiency of the transportation process.

The analysis of influence of the conditions in the organization of transport on the efficiency of transportation process ranks the main parameters which influence the efficiency coefficient. Indicators such as safety of cargoes transported, technical readiness coefficient of vehicle, inertia of the transportation process, technical speed and downtime of the vehicle during loading and unloading operations per haulage, load capacity of the vehicle have the greatest impact on the efficiency of road transport (Table 4).

Table 4

The main parameters influencing K_{et}

Parameters	Unit of measurement	Change limits	Value of K_{et} when the parameter changes by 10%
1. Cargo traffic of the transport complex	t/h	No limits	–
2. Damage and loss of cargo	%	0–25	Can be negative
3. Technical readiness coefficient	–	0,72–0,94	0,69
4. Inertia of the transportation process	%	5–18	0,65
5. Technical speed	km/h	15–35	0,78
6. Downtime of the vehicle during loading and unloading operations	h	0,117–1,0	0,88
7. Load capacity of the vehicle	t	1,5–20	0,87
8. Transportation distance	km	1–32	0,92
9. Prime cost of transportation	rub/t	8,5–21,6	0,96

The effectiveness coefficient of the transportation process varies in a wide range in practice (0,32–0,84) and characterize quality of the transportation process (Table 5).

Table 5

Actual efficiency of the transportation process

Parameters	Unit of measurement	Clay		Concrete	
		Actual value	Planned value	Actual value	Planned value
1. Volume of traffic	kilotons	58,238	–	24,7	–
2. Prime cost of transportation	rub/t	52,4	68	74,6	90,2
3. Prime cost of loading and unloading	rub/t	35	42	–	–
4. Additional costs due to the mismatch of the vehicle	rub/t	7,2	–	11,4	–

Parameters	Unit of measurement	Clay		Concrete	
		Actual value	Planned value	Actual value	Planned value
5. Additional costs due to cargo damage	rub/t	–	–	1,1	–
6. Additional costs due to inertia of the transportation process	rub/t	2,3	–	–	–
7. Additional costs due to increased prime cost of transportation	rub/t	–	–	6,07	–
8 Additional costs due to increased prime cost of loading and unloading	rub/t	1,07	–	–	–
9. Effectiveness coefficient of the transportation process	–	0,61	–	0,68	–

Summary and Conclusions.

The paper considers a systematic approach to transport of building materials. The operations, which make up the transportation process of building materials, should be considered as a process flow schemes of transportation. These schemes include the following stages: preparation of cargo for transportation; loading; transportation; transfer of cargo from one mode of transport to another; unloading; storage of cargo at the construction site.

The paper considers the structure of distribution costs of logistical support in housing construction. The transportation costs in the construction of a residential facility can be reduced through: optimization of the volume of one shipment; changing the regularities of distribution of vehicle service time at the loading point; optimizing the number of vehicles operating with one loading mechanism; choosing the optimal type of vehicle and loading and unloading mechanisms; organization of transportation with the highest values of technical speed.

All schemes of cycle of transport process of road transportations of construction materials can be divided into three groups: cargo is transported from one point of loading to several unloading points; cargoes are delivered to one unloading point from several points of loading; the entire cargo is transported from one point of loading to one unloading point.

At the loading stage, time of loading is a technologically necessary element for building cargo, and the other elements (waiting, maneuvering, and execution of documents) have a negative effect on the cargo throughput of the loading point and increase the duration of the transport cycle.

The article reveals the probabilistic nature of the description of elements of the transportation process of building cargo. Knowledge of the characteristics of duration distribution of the random variables allows organizing the transportation process with a certain reliability taking into account the execution time. The main factors influencing the duration and regularity of distribution of residence time of vehicle at the point of loading (unloading), are regularity of distribution of the incoming flow of vehicle, waiting for loading (unloading); maneuvering time; loading (unloading) time; time of execution of documents. The article defines the probabilistic characteristics of the loading stage of building cargoes (concrete products and bricks).

The paper defines the minimal costs associated with downtime of loading mechanisms due to the non-uniformity of their work when transporting soil (4254,25 rub/h).

It is necessary to carry out the feasibility analysis of selected alternatives, when choosing the rational transport and technological scheme of transportation of building materials. Sum of reduced costs is taken as the optimization criterion.

The paper analyzes the impact of the conditions of the organization of transport on the efficiency of road transport when transporting building cargoes.

To evaluate the effectiveness of the organization of transportation process of construction cargoes, it is proposed to use effectiveness coefficient of the transportation process. This coefficient is the ratio of costs, associated with meeting the needs of serviced construction projects in the transport of cargoes, to the actual costs.

The article defines the dependence of effectiveness coefficient of the transportation process of construction cargoes from external and internal factors of transport organization (Table 4, 5). The following factors have the greatest influence on the coefficient: damage and loss of cargo during transportation, technical readiness coefficient of vehicle, inertia of transportation process and technical speed.

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