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May, 28-29, 2019, Ternopil, Ukraine

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Comparative study of level-of-service determination based on VISSIM software and Highway Capacity Manual as exemplified by T-shape and partial cloverleaf interchanges

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Abstract: This paper presents a comparative analysis of the level-of-service (LOS) determination based on the VISSIM simulation software and technique described in Highway Capacity Manual (HCM). The methodology used in the analysis is that of the level of service determination for road transport network as exemplified by T-shape intersection and partial cloverleaf (parclo AB3) interchange in the city of Kryvyi Rih. The Department of Road Safety of the National Patrol Police of Ukraine set the task to determine the vehicles queuing length on the bridge if traffic lights at the T-shape intersection are installed. To conduct the project, the VISSIM simulation model of the intersection was developed according to site data collection on workdays and at weekends. LOS criteria were determined by using both traffic management assessment methods. The scenario of traffic lights installation at the intersection was elaborated. It was determined that with traffic signalization adjustment the average travel speed would be about 40% of the free flow speed for a street class. The two assessment methods vary significantly regarding traffic flow density criterion (35.1%). The conclusion is that flow density criterion is not reliable for the node LOS definition. By way of application value of the research findings the recommendations have been prepared for T-shape intersection traffic management that dismissing the project of traffic lights installation at the intersection needs to be considered.

Keywords: road network, VISSIM, HCM, level-of-service, microsimulation model, intersection.

1. Introduction

The network assessment is a basic and necessary element of civil engineering, specifically site plans, network routing patterns, traffic management layouts. Thus, the assessments methods and criteria are one of the most important parts of road network design and operation procedures. At the same time, there is no generally recognized method of road network assessment which is laid out as appropriate specifications and design guidelines in Ukraine. Not only the publication review shows that the specialists in city planning and road traffic management use principally different approaches to decision-making processes. Design of road traffic management is based on traffic flow theory and detailed modelling and characterized by various mathematical tools. In city planning, at the stage of site plans and network routing pattern development, sketchy solutions of road network are accepted. More elaborated design of the road network is performed at the stage of detailed project planning. However,

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in this case, an accurate calculation of highway capacity is not carried out. Therefore, the road network assessment is formalistic. As such, parameters like network density and values of line capacity for streets of various categories are used for finding solutions in road network design. However, except for the presented partial criteria, there are other approaches to road network assessment when the integrated criterion is obtained as the main assessment value. It is a so-called level-of-service (LOS) criterion specified in Highway Capacity Manual (HCM) [1] applied at various stages from planning and design to operation of the road network. The recent edition of HCM has been changed significantly: LOS criterion for almost all road network elements have been included in it, the performance of pedestrian and bicycle traffic and quality of public transport services have been considered. For further analysis and the most efficient decision-making (in terms of safety, road capacity, etc.) it is possible to use traffic microsimulation. In general, improvement of road network assessment methods which would be based on the results of traffic microsimulation and determination of LOS criterion for case-study of traffic management in Ukrainian cities is viewed as a pressing task for transport modellers and civil engineers.

2. Materials and Methods

Traffic simulation models are used by numerical techniques on a digital computer to create a description of traffic behaviour over extended period of time for a given transportation facility or system [2-8]. As compared to empirical and analytical models, simulation models predict performance iteratively tracking events as the system status unfolds. Time can be continuous or discrete, and a status of a system is a technical term that is determined effectively by current conditions. Empirical models predict system performance on the basis of relationships developed through statistical analysis of site data, whereas analytical models express relationships among system components on the basis of theoretical considerations being tempered, validated, and calibrated by site data [8].

The advantages of simulation models are presented in HCM [1]. In such case other analytical approaches are not appropriate, there are as follows:

– they can experiment off-line without using on-line trial-and-error approach;
– they can experiment with new situations which do not exist today;
– they can yield insight into what kinds of variables are important and how they are interrelated;
– they can provide time and space sequence information as well as means and variances;
– they can study system in real time, compressed time, or expanded time;
– they can conduct potentially unsafe experiments without any risk to system users;
– they can replicate base conditions for equitable comparison of improvement alternatives;
– they can study the effects of changes on the operation of a system;
– they can handle interacting queuing processes;
– they can transfer unserved queued traffic from one time period to the another;
– they can modify demand over time and space,
– they can model unusual arrival and service patterns which do not follow more traditional mathematical models.

At the same time, it should be noted that the simulation model has several shortcomings, namely: it may be easier ways to solve the problem; simulation models require considerable input characteristics and data, which may be difficult or impossible to obtain; simulation models may require verification, calibration, and validation; development of simulation models requires knowledge in a variety of disciplines, including traffic flow theory, computer programming and operation, probability theory, decision making, and statistical analysis; simulation model may be difficult for analysts to use due to a lack of documentation or need for unique computer facilities; results may vary slightly each time a model is run [1, 2].

In this table it is presented the classification of road traffic situations for which microsimulation would be more acceptable in comparison with HCM technique 1 [6].

Table 1. The list of road traffic situations.

Road network element	HCM technique
Interrupted traffic flow (signalized and unsignalized intersections)	Saturation flow analysis (except signalized intersections), bus operation, street parking, special using of lane, queuing, pedestrians/ cycling interactions
Urban streets	Coupled control efficiency, traffic lights modes, impact from branch roads, impact from bottlenecks which appear on sections of roads, the design of traffic lights control
Signalized intersections	Geometric shift intersections, vehicles arrivals values, the shift of phase control, pedestrians' routes, the design of traffic lights control
Unsignalized intersections	Left turns from a two-laned road, delay before sign "Yield road"
Pedestrians	Pedestrian traffic impact
Bicyclists	Interrupted traffic delay
Transit flow	Interrupted traffic delay
Conditions of traffic interruption	Bottlenecks, saturation flow analysis, temporary transport demand, non-balanced using of lanes, special constraints to lanes using/use, transport service of work areas
Two-lined freeways	Interconnection of traffic and landscape conditions
Multiline freeways	Interrupted traffic delay
High-speed lanes	Lanes for cargo transport
Reference road section	Interrupted traffic delay
Ramps and its connections	Ramps measurement

Currently, one of the most commonly used solutions for traffic microsimulation is a VISSIM software package from PTV VISION Group [8]. The results of the comparative study of the road network evaluation criteria which can be obtained from HCM technique and from VISSIM simulation study are shown in Table 2. So, the value of traffic flow density, delay, volume to capacity ratio are computational parameters that cannot be defined directly through a simulation model analysis.

Table 2. The fusion of road network evaluation criteria which can be obtained from HCM technique and VISSIM simulation model.

Evaluation criteria for LOS defining	HCM technique	VISSIM simulation model
Speed	+	+
Travel time	+	+
Queuing length	+	+
Travel time	+	+
Flow density	+	-
Vehicle delay	+	+
Pedestrian delay	+	+
Volume of capacity	+	-
Public transport schedule	+	-
Vehicles emissions analysis	-	+

The volume to capacity (v/c) ratio [1, 6] isn't calculated through microsimulation in VISSIM due to a stochastic nature of this value. It is necessary to argue in favour of the fact that the capacity of road sections is a result of deterministic approach. Although the capacity could be determined in any moment of simulation time, this value could not be the same in other moments in the simulation process while complying to the components that define the capacity variance. The simulation study responds to the following questions:

- What will happen in real conditions if road congestion exceeds the node capacity?
- What values of traffic speed, flow density, vehicle inputs, traffic delay will be obtained?
- How these values can impact the road network status? [1].

Public transport schedule is the input data in VISSIM. Optionally VISSIM can determine the value of vehicles delay but this value is not HCM compliant [6]. VISSIM directly measures the total delay, which consists of control delay, stopped delay, and other delay incurred in the vicinity of the traffic control device, such as vehicles slowing down for turn movements [8]. Properly calibrated microscopic simulation models will produce delays that more accurately reflect field operations related to the given network geometry, multimodal volumes, and control strategies than deterministic equation based on methods like those included in HCM. VISSIM explicitly models vehicle-vehicle (vehicle-pedestrian, auto-transit, etc.) interactions, queue interactions, freeway and signalized arterial interactions, arterial actuated signal control operations, events (e.g., railroad preemption), ramp metering, etc., unlike the deterministic approaches [3].

In HCM, delay is considered as control delay and vehicles stop. It is determined as follows [1]:

$$d = d_1(PF) + d_2 + d_3, \tag{1}$$

here d_1 –control delay, veh/s; *PF*– adjustment factor for the traffic light; d_2 – additional delay for casual arrivals and queuing saturation which are adjusted according for an analysis period and a type of traffic light; d_3 – start delay of queuing which causes subsequent delay of all analyzed vehicles.

The first and second values are defined as follows:

$$d_1 = \frac{0,5 \cdot C \cdot (1 - g/C)^2}{1 - \left[g/C \cdot \min(1, X) \right]}, \tag{2}$$

$$d_2 = 900 \cdot T \cdot \left[(X-1) + \sqrt{(X-1)^2 + \frac{8 \cdot k \cdot I \cdot X}{c \cdot T}} \right], \tag{3}$$

here T – duration of the analysis period, h; C – cycle length, s; k – delay factor that depends on traffic light settings; I – filtration adjustment factor; c – capacity of a signal group (veh/h); X – saturation rate.

Saturation rate is:

$$X_c = \frac{Y_c \cdot C}{C - L}. \tag{4}$$

The capacity is defined with retaliation to adjustment saturation flow for the appropriate lane:

$$c = s_i \cdot \frac{g}{C}, \tag{5}$$

here g – green time signal, s; C – control time, s; s_i – saturation flow, veh/h.

In HCM [1] the set of adjustment factors is presented for an accounting additional impacts on the basic value of saturation flow:

$$s = s_0 \cdot N \cdot f_w \cdot f_{HW} \cdot f_g \cdot f_p \cdot f_{bb} \cdot f_a \cdot f_{LU} \cdot f_{LT} \cdot f_{RT} \cdot f_{Lpb} \cdot f_{Rpb}, \tag{6}$$

here s_0 – base saturation flow, (vh/h/ln); N – number of lanes, N; f_w – lane width adjustment factor; f_{HW} – heavy-vehicle adjustment factor; f_g – grade adjustment factor; f_p – parking adjustment factor; f_{bb} – bus blockage adjustment factor; f_a – area type adjustment factor; f_{LU}– lane utilization adjustment factor; f_{LT} – left-turn adjustment factor; f_{RT} – right-turn adjustment factor; f_{Lpb} – left-turn ped/bike adjustment factor; f_{Rpb} – right-turn ped/bike adjustment factor.

Thus, capacity ratio and saturation flow are the main factors for additional delay definition. LOS is defined just from the additional delay. Ultimately travel time just has the main influence on the average traffic speed ST:

$$ST = T_r + d. \tag{7}$$

Despite that T_r is defined, depending on free flow speed and street category it is retrieved from the data specified in the table. This seriously decreases the accuracy of HCM method.

For traffic management analysis in real conditions, it is viable to provide 8-step procedure which consists of the determination of project scope, goals and obtained results, site data collection, simulation model development, input data calibration, assessment of simulation results, LOS criteria definition, and alternative scenarios analysis.

The research aims to develop the methodology of road network LOS determination is based on VISSIM microsimulation evidence from the case-study of traffic lights expediency at the T-shape intersection which transits to a bridge.

3. Results

3.1. Project description

This research was conducted for the road conditions of the city of Kryvyi Rih, a large industrial centre of Ukraine. Its transportation system is strategic for numerous mining and manufacturing enterprises. Initially, urban agglomeration and specificity of urban development aimed to meet the needs of the industry. That's why the urban transportation system is characterized by great haulage distances due to remote locations of isolated industrial facilities (more than 50 km).

The VISSIM-based simulation study of the transportation system of the city of Kryvyi Rih has been worked out by the efforts of the members of Automobile Transport Department (Kryvyi Rih National University) since 2016 for developing appropriate practical recommendations and further decision-making. During this time the critical for social safety areas of road network were detected. The visual observing for quantity and quality of traffic flows and pedestrian flow rates were provided for these urban areas. Based on the results of the site data collection, for the first time the set of microsimulation models of black spots were created in VISSIM. There are 3 urban areas in Central district of the city which include cloverleaf interchange, 9 intersections in Metallurgical district, 11 interchanges in Saksahanskyi and Pokrovskyi districts. The results of computer experiments were used to analyze the impacts of various traffic management options on the transportation system capacity and vehicle/pedestrian safety [10].

The case-study is devoted to expediency of traffic lights at the T-shape intersection of Bykova and Ivana Avramenka streets which transits to the bridge.

The Department of Road Safety of the National Patrol Police of Ukraine has set the task to investigate the possibility of queuing on the bridge in Bykova street if the traffic lights at the intersection of Bykova and Ivana Avramenka streets are installed. Moreover, the intersection is characterized by the parameters which should not be taken into account when calculating via pure HCM technique. They are: a bus stop; traffic concentration; intersection's inclination impact; some road capacity limiting (the confined bridge); overload of urban intersection with traffic flows.

The Bypass (Obyizna street) adjoining to the intersection of Bykova and Ivana Avramenka streets is a parclo AB3 interchange (a partial cloverleaf interchange) [11]. One-lane road at Bykova street from the side of Vechirnyi Boulevard overpasses Obyizna street and pass into Symonova street. Obyizna street has two lanes for each way and an additional lane for Bykova street. The interchange scheme and directions of the traffic flows are presented in Figure 1.

The public transport routes # 15, 201, 210, 293, 295, 306 are transit on the interchange. The closest bus stops are situated in Ivana Avramenka and Symonova street. The interchange is a node for transport service of Vechirnyi Boulevard district and Schidnyi-1 residential area. A primary school, METRO Cash & Carry wholesaler and Epicenter hypermarket are situated near the intersection.

The proposed program of lights control (project CB-04/1-18-EH) and their designed locations are shown in Figure 2.

3.2. Site data collection

In case of traffic lights control adjustment on the T-shape section of the intersection, it is important to determinate the traffic flows values and directions accurately. According to this, the traffic flow 1 in Bykova street splits on two left-turn flows before the bridge and to Ivana Avramenka street, and also on the straight traffic in Symonova street. The flows from the latter street were fixed from the two points: before (flow 8) and after (flow 5) the bridge that allows collecting vehicle inputs data more accurately. The ramp from Symonova street is performed in two routes to Vechirniy Boulevard (flow 2) and across the bridge to Schidnyi-1 residential area (flow 4).

The lengths of the routes are shown in Figure 1, they define microscopic simulation model boundaries. The measurements of vehicles inputs are provided in various periods of time at the weekend and on workdays with 15-minute interval for each route. The traffic flow mix value was assumed with 13% average ratio of heavy vehicles. A clear trend to traffic load increasing at certain periods at weekend as well as on workdays can be traced from the collected data. So, there are the clear peak hours in interchanging. The collected site data of the traffic and pedestrian inputs are used for microsimulation model development in VISSIM software with static vehicles routes assignment.

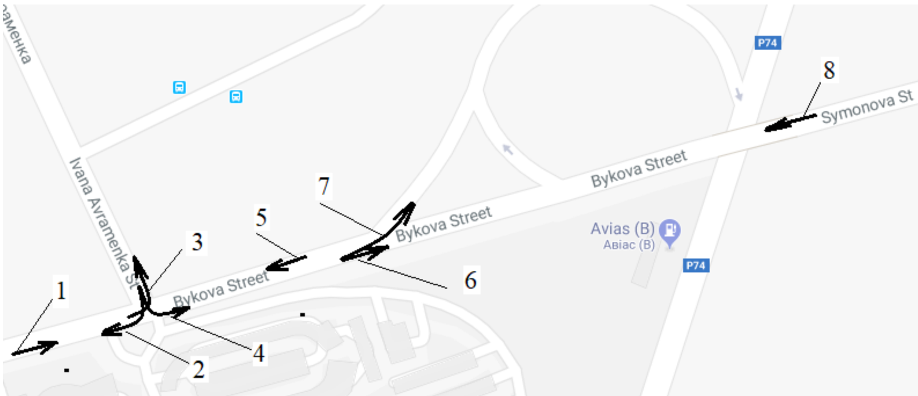


Figure 1. The input traffic flows and lengths of their routes: *1* – traffic from Epicenter hypermarket straight to Bykova street (366 m); *2* – right-turn traffic from Ivana Avramenka street to Bykova street (283 m); *3* – traffic from Bykova street to Ivana Avramenka street (290 m); *4* – left-turn traffic from Ivana Avramenka street to Bykova street (232 m); *5* – straight traffic from the bridge to Epicenter hypermarket (112 m); *6* – traffic on road section from the T-shape intersection to the bridge toward Schidnyi-1 residential area (115 m); *7* – left-turn traffic from Bykova street (113 m); *8* – ramp from Symonova street to Bykova street (270 m).

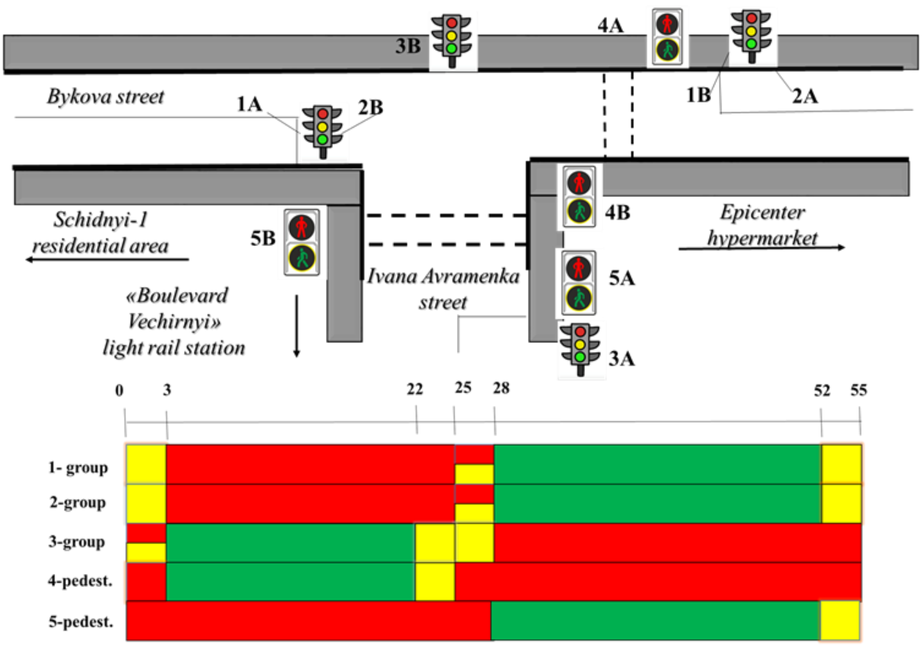


Figure 2. The proposed timing program and traffic lights locations (Project CB-04/1-18-EH).

3.3. Simulation results analysis

VISSIM defines the priority rule of conflict points via conflict areas assignment [2, 8]. The conflict areas were determined following traffic management: at ramp from Symonova street and before roundabout of parclo the yield sign has been installed. VISSIM traffic control block requires setting signal groups of lights control. For this purpose, the proposed program of traffic signalization was implemented in VISSIM model.

The VISSIM-simulation results show that queuing is absent for the unsignalized intersection option. It is also proved by the data obtained during investigation of traffic flows on the interchanging. These data were also used as input values of simulation model calibration.

The average value of vehicle travel time for various vehicles routes (Figure 3) are determined based on the microsimulation results for traffic management provided that traffic lights are installed according to the scheme (Figure 2).

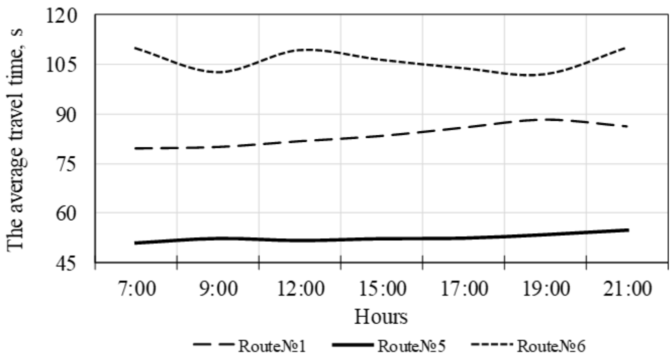
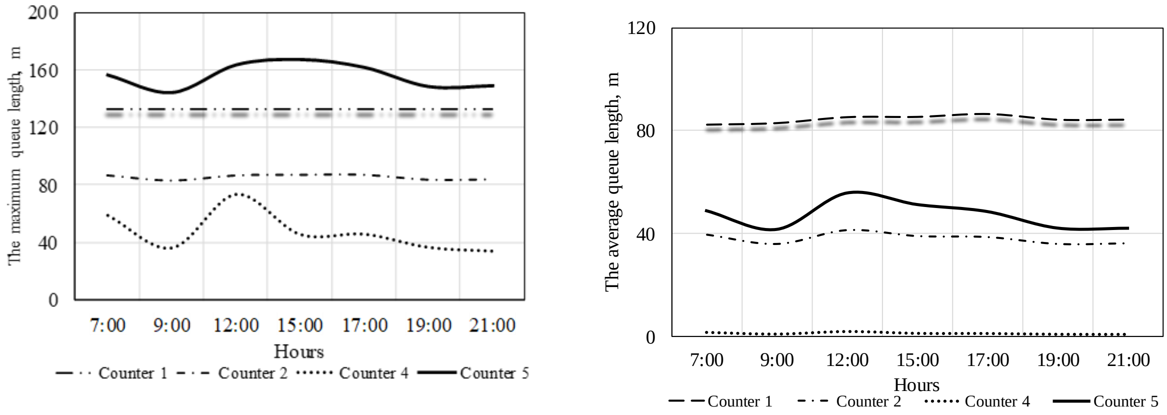


Figure 3. The average travel time for the most loaded routes: №1 – from Epicenter hypermarket towards Bykova street; №5 – left-turn ramp from Bykova street; №6 – ramp from Symonova street to Bykova street.

It was found that maximum travel time is spent for straight traffic. The value of travel time from T-shape intersection to the bridge towards Schidnyi-1 residential area is 106.3 s, from the bridge in Bykova street towards Epicenter hypermarket is 83.6 s, on the side of Epicenter hypermarket in Bykova street is 52.4 s.

The distribution of queue lengths obtained from the appropriate counters (Figure 4) is shown in Figure 5. Standard deviations of average queue length value during a day are 1.4 m, 2.4 m, 0.4 m, and 5.3 m for the routes pass through 1, 2, 4 and 5 counters respectively. But for the counter 3, the queue is absent. The major queue values are on the counters 1, 2, 5 through which individual transport routes with numbers 1, 4, 5, 6 are transited. Thus, the values of vehicle travel time are verified by created queues.

Figure 4. The location of queue counters: 1 – ramp from Bykova street to intersection; 2 – ramp from the bridge to Bykova street; 3 – straight traffic towards Symonova street; 4 – left turn ramp from the bridge; 5 – ramp from the Bypass to the bridge.



(a) (b)

Figure 5. The vehicle queue lengths: (**a**) The maximum value; (**b**) The average value.

If traffic signalization is installed, the average queue length of 84.4 m before the intersection will be on the ramp from Bykova street, 38.1 m before T-shape intersection at the same street at ramp from the bridge, 47.3 m from the ramp on the side of Symonova street. It should be noted, that there are peak traffic loads (peak-hour-factor – PHF [1, 6]) in the period from 11 to 13 p.m. Inequality of peak loads distribution is proved by variation of peak hour factor for different traffic routes where the maximum values of this parameter are associated with 1 and 8 routes presenting straight traffic on the bridge (Table 3).

Table 3. PHF determination for the vehicle routes.

	Routes							
	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***
PHF	0.92	0.68	0.79	0.75	0.77	0.79	0.59	0.87

It can be noticed that the road section length from the T-shape intersection in Bykova street to the bridge aside Schidnyi-1 residential area is 115 m. This fact implies that about a half of the bridge length traffic queue is possible.

3.4. Node LOS determination

The next stage of analysis is the node LOS determination. For this purpose, the parameters from VISSIM were used, namely the value of delay and average control delay, and average traffic speed. For the node LOS calculation, the user defined attributes (UDAs) were used in VISSIM [12]. There were four UDAs: attribute LOS to calculate the average node LOS, attribute WorstLOS to determine the worst LOS of all time intervals and simulation runs, attribute WorstMovLOS to calculate the worst traffic LOS, attribute NodeLabel to show the results in one label for current, previous interval and worst throughout all simulation runs and time intervals.

The values for UDAs were accepted according to HCM table for signalized intersections [1]. The programming code for the first UDA is as follows:

```
IF([TOTRES\VEHDELAY(...ALL)]≤10; “A”;
IF([TOTRES\VEHDELAY(...ALL)]≤20; “B”;
IF([TOTRES\VEHDELAY(...ALL)]≤35; “C”;
IF([TOTRES\VEHDELAY(...ALL)]≤55; “D”;
IF([TOTRES\VEHDELAY(...ALL)]≤80; “E”; “F”))))).
```

To calculate the worst node LOS the following code was used:

```
IF(NUMTOSTR([TOTRES\VEHDELAY(MAX, MAX, ALL)])=”;”;
IF([TOTRES\VEHDELAY(MAX, MAX, ALL)]≤10; “A”;
IF([TOTRES\VEHDELAY(MAX,MAX, ALL)]≤20; “B”;
```

IF([TOTRES\VEHDELAY(MAX, MAX, ALL)]≤35; "C";
IF([TOTRES\VEHDELAY(MAX, MAX, ALL)]≤55; "D";
IF([TOTRES\VEHDELAY(MAX, MAX, ALL)]≤80; "E"; "F")))))).

For estimation of the worst movement LOS we made use of the code:

IF(NUMTOSTR([MAX:MOVEMENTS\VEHDELAY(MAX, MAX, ALL)])=";";
IF([MAX:MOVEMENTS \VEHDELAY(MAX, MAX, ALL)]≤10; "A";
IF([MAX:MOVEMENTS \VEHDELAY(MAX,MAX, ALL)]≤20; "B";
IF([MAX:MOVEMENTS \VEHDELAY(MAX, MAX, ALL)]≤35; "C";
IF([MAX:MOVEMENTS \VEHDELAY(MAX, MAX, ALL)]≤55; "D";
IF([MAX:MOVEMENTS \VEHDELAY(MAX, MAX, ALL)]≤80; "E"; "F")))))).

To show the node label we used the code:

"Current node LOS:"=[LOS, CURRENT, CURRENT];
"Last interval LOS:"=[LOS,CURRENT, LAST];
"Worst node LOS:"=[WORSTLOS];
"Worst movements LOS:"=[WORSTMOVLOS].

So, LOS definition is obtained considering the average delay at the intersection, delay upstream the traffic light, and the average traffic speed. The comparison of the obtained parameters with the same ones determined via HCM technique is shown in Table 4.

Table 4. The node results.

Parameter	HCM	VISSIM	Deviation, %	LOS criteria	
				HCM	VISSIM
Average travel speed, km/h	28.1	24.57	11.0%	C	C
Traffic flow density, auto/km	280.1	430.8	35.1%	F	F
Average delay, s	37.1	47.0	21.0%	D	D
Control delay (ACD), s	34.1	27.3	20.0%	C	C

4. Discussion

The maximum deviations between the traffic management performance indicators in the intersection are obtained for such criteria as the flow density ratio and average delay. They are 35.1% and 21.0% respectively. HCM technique and VISSIM-model made such data as the average travel speed and the average delay differ by 11.0% and 20.0% respectively. The worst node LOS is F. It was obtained upon indication of flow density for the two assessment methods. This implies that the average speed at the interchanging is 25–33% of the speed in freeway conditions (FFS) for this urban street type and extensive delays and queuing are observed at the intersection. The VISSIM model versus HCM technique showed more similar scenario if decision on signal lights installation is made. Based upon the average travel speed which is dependent on the running speed and the amount of control delay incurred at signalized intersections, the interchanging was assigned LOS C. This value describes stable operations; however, ability to maneuver and change lanes in midblock locations may be more restricted than at LOS B, and longer queues, adverse signal coordination, or both may contribute to lower average travel speed of about 50% of FFS for the street class [1].

In general, due to the results of HCM technique and VISSIM model application, it has been determined that according to the average delay and ACD the interchanging has got LOS D. This implies that small increases in traffic flow may cause substantial increases in delay and decreases in travel speed. Node LOS D occurs due to adverse signal progression, inappropriate signal timing, high traffic volumes, or a combination of these factors. The average travel speed is about 40% of FFS.

5. Conclusions

The research presents the comparative study of the methodology of road network LOS determination which is based on VISSIM microsimulation results and HCM technique. To achieve this goal, it has been implemented that the project was aimed at determination of traffic lights installation viability at T-shape intersection of Bykova Street and Ivana Avramenka street in the city of Kryvyi Rih. In the course of the project the following results were achieved:

– the site data on vehicles and pedestrians' inputs were collected at the relevant week's time;

– the VISSIM-simulation model of the intersection was developed;

– based on the microsimulation results, it was determined that the traffic lights installation would rapidly increase queue origination;

– upon the average vehicles delay, ACD, flow density, average travel speed the appropriate node LOS criteria for the intersection were assigned via VISSIM and HCM technique;

– decision-making process was provided due to the determined LOS criteria; it is conceivable that if any signalized intersection with interrupted traffic stream is on the considered road area, the average travel speeds will be about 40% of FFS for the street class (node LOS D was obtained via HCM technique and VISSIM simulation);

– the developed recommendations for the intersection were considered by the Department of Road Safety of the National Patrol Police which was used as a reason to abandon the project of traffic management changing at the intersection.

It was found that the maximum deviations between the two methods of LOS determination were obtained for such performance criterion as traffic flow density (35.1%). This implies that the values received from this criterion are not adequate for the node LOS definition.

Further study will be focused on aggregation of modern measures of road network performance to quantitative and quality decisions making for social and economic safety of transportation system of the industrial city.

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A multi-criteria decision making approach for the evaluation of roads and streets system in Gniezno

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Abstract: The article presents the application of the MCDM methods, belonging to the PROMETHEE family, for the evaluation of potential solutions of the road system (RS) in the selected area located in Gniezno, historical capital of Poland. The proposed set of heuristics variants of RS were assessed by a coherent family of criteria taking into account different groups of stakeholders. The decision problem was defined as an issue of prioritising a finite number of variants of road-rail system reconstruction. The proposed model of decision-maker's preferences was developed based on the results of surveys conducted during public consultations with the residents of the area. The originality of the study consists in that the model became the basis for the final variants ranking that was subsequently compared with the results obtained using another MCDM method – ELECTRE III, where the decision-maker's preference model was developed on the basis of information obtained from independent experts.

Keywords: road and rail traffic, MCDM, sustainable transport, streets system, railroad crossings.

1. Introduction

The processes of urbanisation and de-urbanisation occurring in Poland, as well as the increase in the number of travels for various motivations entails the need to adapt and change the transport infrastructure. Significant for this fact is the growing number of motor vehicles in Poland, which almost doubled in 2017 as compared to 2003 (Table 1). This results in traffic congestion observed both in agglomerations and in smaller towns.

Table 1. Number of vehicles in Poland 2003-2017 [8].

Year	2003	2005	2007	2009	2011	2013	2015	2017
[millions vehicles]	15.90	16.82	19.47	22.02	24.19	25.68	27.41	29.63

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The above mentioned changes in infrastructure may concern both linear elements, including the construction or modernization of roads and railway lines or point elements, such as the construction/modernisation of fuel stations, public transport stops and stations, construction/ modernisation of road hubs, etc. The introduction of changes in the road system, especially in urban areas and due to different stakeholder groups, is a major challenge in many Polish local government units. This is due to the limited amount of funds allocated to such investments. Therefore, one of the possible solutions is to look for external sources of funding, including those from the European Union, for road and rail investments. The scale of the problem depends, on the one hand, on the size of the project (investment) itself, but also on its potential location where one may take into account geographical location (terrain, the existing infrastructure) or legal aspects – the location in relation to various local government units.

In view of the above, the authors defined a research problem involving the impact of evaluations obtained from public consultations on the choice of a variant of reconstruction of the road-rail system in the region of Gniezno, historically the first capital of Poland.

2. Road infrastructure investments and supporting the decision-making process

Making all investment decisions, including those relating to transport infrastructure, involves a large number of aspects. As in the case of complex socio-economic systems [1], a certain minimum set of criteria should be taken into account, e.g. the technical, economic, social, environmental and legal aspects [4, 5, 7, 11, 13, 14, 15, 17, 18, 19, 20].

Making investment decisions related to transport infrastructure is an issue that needs to be considered by numerous stakeholders [23]. The specific character of introducing certain changes into road systems requires that decision-makers have a broad and holistic approach to their task. As a consequence, it is advisable to apply a multi-criteria decision making (MCDM) methodology that takes into account many, frequently opposing, points of view [12, 21]. This approach is often used to tackle transport decision-making problems, including: those involving infrastructure [1, 9, 13, 14, 16, 24].

Project development process (PDP) related to transport infrastructure needs to account for numerous elements such as [18]:

1. Evaluation of alternative facility plans and policies (review of network – level plan).
2. Evaluation of alternative facility locations (project identification, mitigation, ROW studies).
3. Evaluation of alternative facility designs.
4. Evaluation of alternative project delivery practices (facility construction).
5. Evaluation of alternative operational policies and regulations.
6. Evaluation of alternative preservation practices.

Individual elements require, on the one hand, specific human resources, and tools and methods on the other. In this article, the authors, based on Sinha & Labi's [18] guidelines, presented a case study of transport infrastructure investment planning for a selected part of the town of Gniezno.

2.1. Gniezno case study. The characteristics of transportation problems

The region under consideration is located in the Wielkopolskie Voivodeship. It covers the south-western part of the Gniezno County (Figure 1) and, to be more precise, the urban area (the municipal commune – the city of Gniezno), as well as the rural area (the rural commune of Gniezno). The area of the county covers 1255 km^2 and the number of inhabitants as of the end of 2017 amounted to 145,333 [8]. The average population density of the area at the end of 2017 was almost 116 inhabitants per square kilometre, which is slightly lower than the Polish average of 123 inhabitants per square kilometre. In the case of the town of Gniezno, this figure is about 1700 inhabitants per square kilometre. In the central part of the district, both the national and international roads intersect (from Prague via Wrocław, Poznan to Bydgoszcz and Gdansk. Administratively, the Gniezno County is made up of 10 independent communes (Figure 1). The region is intersected by two railway lines (No. 353 Poznan East – Gniezno – Skandawa) Gniezno and No. 281 Olesnica – Gniezno – Milicz), which are crossed by county roads. The railway and road crossings considered (“I” and “II” Figure 2) in the analysed area are crucial for the transport system of both the City of Gniezno, the Gniezno Commune and, naturally, the Gniezno County. Due to their location, these railway crossings significantly limit the road capacity. This results in poor accessibility of the area and low level of safety for all inhabitants i.e.

obstacles for emergency services like fire brigade, etc. Due to the scale of the problem, the area of the analysis was additionally extended by several socio-economic conditions, which are closely related to Poznan, the capital of Wielkopolska, and the neighbouring county capitals.

Figure 1. Gniezno County with the area of potential changes in the road system ("X")

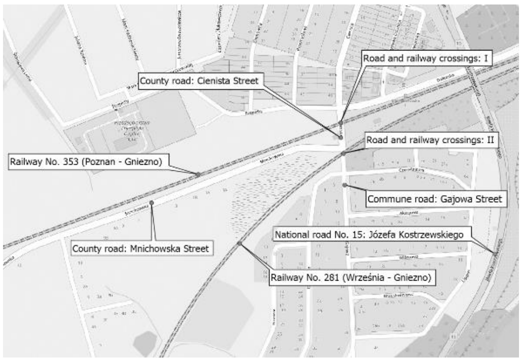

Figure 2. The current road system of the analysed part ("X") of the town of Gniezno.

According to the Polish regulations, the above mentioned road-rail crossings are classified as category A, which means that the traffic must be directed by authorized employees of the railway manager or railway carrier who have the required qualifications. At the same time, manual signals or systems or crossing devices equipped with gates closing the whole width of the road must be used (Figure 3, Figure 4). Taking into account the geographical location of the analysed area, it is a transit point for the inhabitants of the commune and the town of Czerniejewo who travel from or to Gniezno on the local road. This distance is less than 15 km, and the time needed varies from about 15 to about 30 minutes and it depends mainly on the day of the week, the time of day (during the peak traffic time decreases) and the time of raising the gates mainly rail-road crossing No.I (Figure 2). In the case of the residents of the town of Gniezno, or more precisely of the Dalki housing estate, the additional accessibility restriction is related to the latter of the above mentioned railway-road crossings. Due to the smaller use of line 281 for the needs of transport, the inconveniences related to closing the crossing are smaller. The measurements of traffic intensity showed that the average daily traffic at the railway-road crossing I varied between 6000 and 7000 vehicles per day – for most of the day, i.e.13-14 hours, traffic remained at the level of over 300 vehicles per hour. On the other hand, the average daily traffic of vehicles in the second crossing oscillated between 3000 and 4000 vehicles per day – on average during the greater part of the day there were about 200 vehicles per hour.

Figure 3. Railway and road crossing I.

Figure 4. Railway and road crossing II.

The analysed rail-road crossings play an important role, especially in journeys between the town of Gniezno and the communes of Gniezno and Czerniejewo. Taking into account the de-urbanisation processes of the town of Gniezno and comparing the individual years between 2013 and 2017, it is evident that in the selected areas the number of inhabitants of Dalki, Mnichowo and Skiereszewo increased significantly [7]. Therefore, in the authors' opinion, there is a high probability that in the coming years the number of people using level railway crossings will increase due to the expansion of areas intended for housing developments. Due to the increasingly frequent traffic congestion outside the strict centre of Gniezno as well as threats related to the impact of road transport on the environment, it was necessary to introduce changes to the existing infrastructure.

Stakeholders of the decision problem: In order to assess the proposed variants of changing the road system in the analysed area, it is necessary to define the participants of the decision-making process. The choice of the investment option as a compromise solution, according to the MCDM methodology, should take into account the interests of different stakeholders (Table 2). It should be stressed that the interests of a person may vary according to their current needs.

Table 2. Stakeholders of the decision problem.

Decision makers	Interveners
• Railway infrastructure manager – PKP PLK S.A. • Road infrastructure manager: ○ County Authorities in Gniezno (through Zarząd Dróg Powiatowych w Gnieźnie), ○ The Communal Authorities in Gniezno, ○ Municipal Authorities in Gniezno.	• Road users in the analysed region: drivers, passengers of public transport, cyclists and pedestrians. • Residents of the immediate vicinity of the analysed road system who, apart from using the possible changes, are also exposed to the negative impact of traffic, including the emission of noise and air pollution. • Enterprises (businesses) located in the analysed area and in its immediate vicinity • Railway carriers providing passenger and freight services in the area under analysis on lines No. 281 and No. 353 • Organizers and public transport companies using road infrastructure in the area under analysis. • Residents of neighbouring communes, e.g. Łubowo, Czerniejewo

Variants of road system: The analysis took into account the following four variants: alternative A0 – the current state and three other variants (alternative A1, alternative A2 and alternative A3), which were suggestions for potential changes. A number of conditions which were relevant from the point of view of major stakeholders were considered, including:

1. Eliminating a rail-road crossing on one of the railway lines.
2. Proposing a (rational) alternative road connection for motorised and non-motorised inhabitants of the area under consideration.
3. The technical feasibility of including the proposed changes into the existing road system.
4. Ensuring compatibility of the proposed road system solutions with local and regional planning documents.

The first of the investment options – alternative 1 (A1) involves (Figure 5):

1. The viaduct connecting the existing district road with the national road No.15.
2. A change in the route of the public transport line, i.e. public transport provided by Miejskie Przedsiębiorstwo Komunikacyjne Gniezno Spółka z o.o. (MPK Gniezno) buses and extra-municipal transport provided by regional carriers.

The elimination of the rail-road level crossing on railway line No.353, including the limitation of pedestrian and bicycle traffic.

Interestingly, alternative 1 has a number of disadvantages resulting from the location of railway lines No.353 and No.281 in relation to each other (these lines are connected under the national road No.15 railway viaduct and the distance between them is approximately 16 m). In addition, it is necessary to build another intersection at road No.15, which may reduce the capacity of this road.

Furthermore, it is essential to rebuild the energy infrastructure which is currently located along the viaduct next to road No.15 (Figure 6).

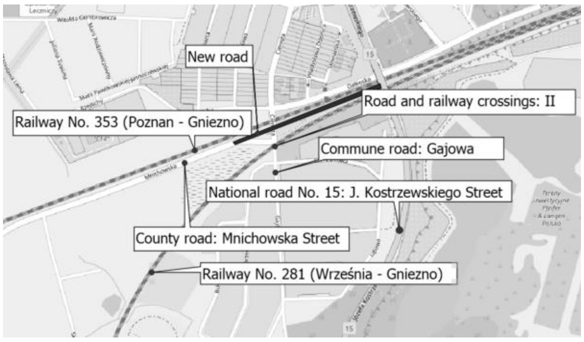

Figure 5. Alternative A1.

Figure 6. View of the energy installation near the railway viaduct – national road No. 15 over lines No. 353 and No. 281

The second investment variant, alternative 2 (A2), assumes the construction of a crossing under the railway line 353, which means closing the railway crossing on the line 353 and extending one of the local roads in the western direction parallel to the line 353, followed by a collision-free crossing under the tracks of the line 353 This alternative requires a change in the course of the public transport line and the buyout of land on which the road is planned, both on the northern and southern side of the railway line 353. The concept of solving the road system is presented in Figure 7.

The last alternative (A3) – Figure 8 is similar to alternative 2, assuming that the passage under the tracks would be located a bit further away. A characteristic feature of this variant is the location of a collision-free crossing under railway line no. 353 near the former railway-road crossing. At present, there is an unpaved road leading to the surrounding buildings on the southern side of the 353 railway line

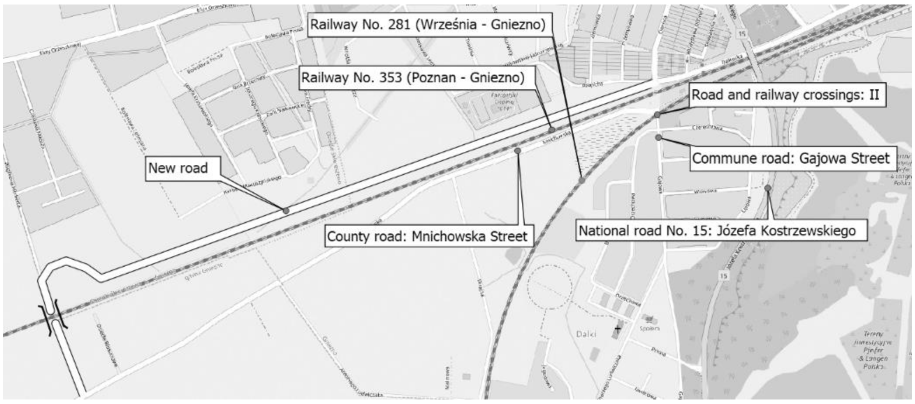

Figure 7. Alternative A2.

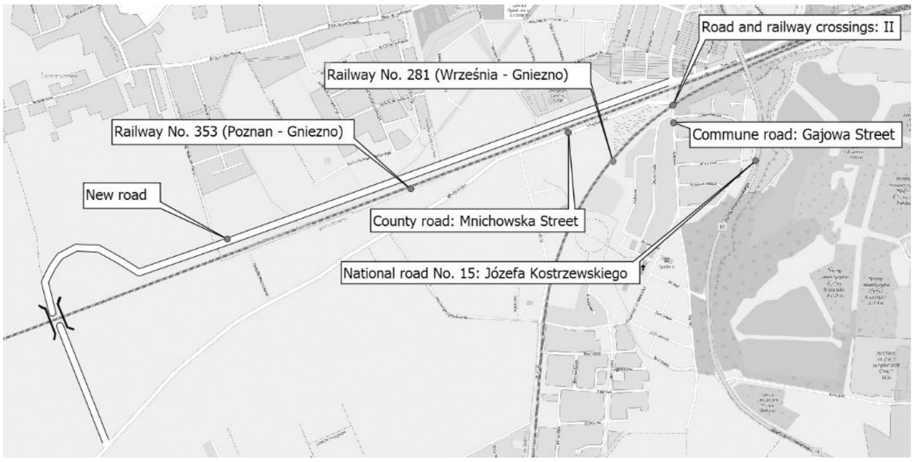

Figure 8. Alternative A3.

Choosing Criteria of Evaluation. The proposed variants were assessed by a coherent family of criteria taking into account different stakeholder groups, i.e. the inhabitants of the area, the entrepreneurs, the municipal and commune authorities, public transport, the investors. Thus, the following factors were taken into account [Kiciński et al., 2018]:

Criterion 1 – the costs of road system reconstruction. Within this criterion, the elements taken into account included carrying out design work, purchase of plots of land on which the new road system is to be built, construction work on roads, paths, pedestrian and bicycle paths of viaducts and culverts, as well as design work. This criterion expressed in PLN (4.25 PLN ≈ 1.00 Euro) is minimized.

Criterion 2 – average time of car ride. The method of determining this criterion takes into account the journeys between two selected starting points and four destinations. These points reflect the diversified directions of travel of the inhabitants of various communes of the Gniezno County, including those connected with access to
a hospital or a railway station. This criterion is expressed in minutes and it is minimised.

Criterion 3 – average distance between selected points of the city and municipality of Gniezno. This criterion takes into account the same set of starting points and destination points as when determining criterion 2. Only paved roads on which vehicles of at least 3.5 tonnes maximum permissible weight can be driven are included in the calculation. This criterion is expressed in kilometres and it is minimised.

Criterion 4 – the number of residential buildings located in the vicinity of the road. Only residential buildings located within 50 m from the edge of the roadway were taken into account in this criterion. This criterion is a measure of the disruption posed by the noise and pollution generated by traffic on this road. Nevertheless, it needs to be taken into account that the potential solutions of the road system do not affect the changes of the railway route. This means that the distance between the existing residential buildings and railway lines does not change. This criterion is expressed in units and it is minimised.

Criterion 5 – the size of changes in the transport work of rolling stock in a single course in regional and local public transport. When determining this criterion, the transport of the two largest public transport carriers operating in this region, i.e. MPK Gniezno (the urban public transport operator in Gniezno) and Przedsięborstwo Komunikacji Samochodowej w Gnieźnie Spółka z o.o. (the regional public transport company), was taken into account. The values were determined on the basis of business day data. It should be borne in mind, however, that in case of changes in the road system, the whole PTZ network may need to be adjusted, which was not considered in this criterion, as the very design of the public transport network is already a different decision-making problem. This criterion is expressed in vehicle-kilometres and it is minimised.

Criterion 6 – the changes in the length of bicycle or walking/cycling paths. It takes into account the interests of the most vulnerable road users – pedestrians and cyclists. This criterion is expressed in units of length (km) and it is maximised.

Criterion 7 – the accessibility of travels between selected points in the network. This criterion was defined for the time frame between 6 a.m. and 10 p.m. In this case, it was based on the closures of railway crossings, estimating the actual time of inability to cross the road-rail crossing of line 353. The criterion is maximized.

The matrix of assessments of all options on the basis of particular criteria is presented in Table 3.

Table 3. The matrix of assessments of the alternatives of road system.

No.	Name of criterion	Direction of preferences	Unit	Alternatives			
				A0	A1	A2	A3
1	The costs of road system reconstruction	Min	[PLN million]	0	19.2	23.5	25.3
2	Average time of car ride	Min	[min]	16	13	22	24
3	Average distance between selected points of the city and municipality of Gniezno	Min	[km]	9.5	9.2	10.3	11.4
4	The number of residential buildings located in the vicinity of the road	Min	[No.]	47	8	16	20
5	The size of changes in the transport work of rolling stock in a single course in regional and local public transport	Min	[vehicle-kilometres]	0	0.32	2.76	3.92
6	The changes in the length of bicycle or walking/cycling paths	Max	[km]	0	0.27	2	2.8
7	The accessibility of travels between selected points in the network	Max	[-]	0.67	1	1	1

Model based on decision makers' preferences. The way of defining the model of decision-makers' preferences in multi-criteria methods of prioritising variants depends on the method used. In this case, the multi-criteria methods of the Promethee family were used to determine the final rankings: I and II [2, 3, 10]. Similarly to the ELECTRE methods, they belong to the group of approaches based on the outranking relation. [12].

The model of the decision-makers' preferences, i.e. the values of indifference thresholds (q) of preferences (p) and the significance of the criteria were estimated on the basis of surveys conducted during public consultations. The set of questions presented to stakeholders included, among others [7]:

- the degree of inconvenience perceived in connection with the closure of level crossings;
- the most frequent motivation to travel when crossing railway lines;
- the frequency of use of railway crossing;
- the manner of crossing railway crossings.

The model of decision-makers' preferences adopted in the computational experiment is presented in Table 4.

Table 4. The model of decision-makers' preferences adopted based on public consultations.

No.	Name of criterion	Criterion relevance	thresholds *	
			q	p
1	The costs of road system reconstruction	5	0	19.2
2	Average time of car ride	10	16	13
3	Average distance between selected points of the city and municipality of Gniezno	10	9.5	9.2
4	The number of residential buildings located in the vicinity of the road	9	47	8
5	The size of changes in the transport work of rolling stock in a single course in regional and local public transport	3	0	0.32
6	The changes in the length of bicycle or walking/cycling paths	7	0	0.27
7	The accessibility of travels between selected points in the network	10	0.67	1
(*) q – indifference threshold, p – preference thresholds				

Computational experiments. The computational experiments were performed using Visual Promethee – version 1.4.0.0 [22]. The order of variants in the PROMETHEE I method is presented in Figure 9, where the so-called Phi+ output dominance flow and the Phi- output dominance flow are shown. Taking into account these rankings, it is possible to perform a final ranking of the variants from the best to the worst in terms of net dominance flows, which is presented in graphic form in Figure 10.

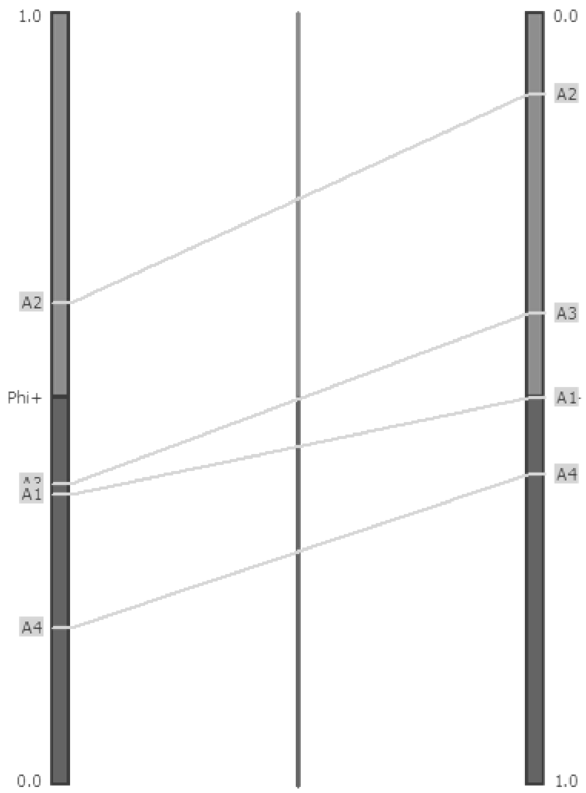

Figure 9. PROMETHEE I Partial Ranking

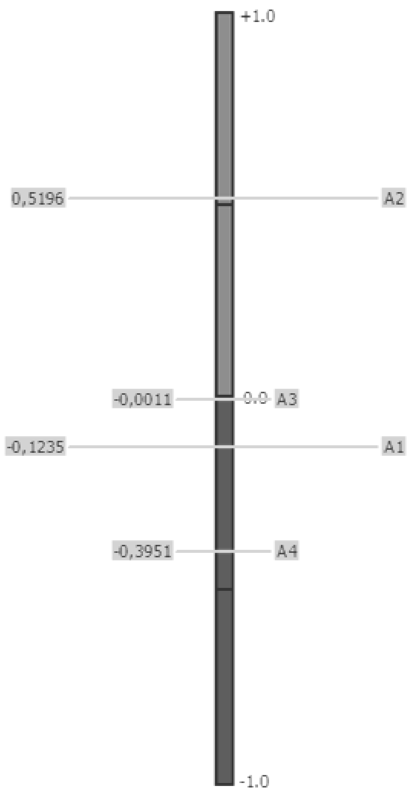

Figure 10. PROMETHEE II Complete Ranking

As can be seen from the adopted preference model, the highest ranked option is the option identified as alternative 1, which prevails over the others on four out of seven criteria. It is also characterised by the fact that it is not the worst in any of the other criterion functions.

3. Conclusions

The example of the approach to the problem of choosing a compromise investment option related to the reconstruction of railway and road infrastructure in the area of the city of Gniezno presented in this article confirms the usefulness of multi-criteria decision making methods. Comparing the approach described in the article Kiciński et al. [6], where another MCDM method – ELECTRE III – was used, it may be concluded that the direction of development of the road system in this part of the city should first consider alternative A1 which was the best alternative in both experiments. In both methods, despite the fact that preferences were expressed by different stakeholder groups:

1. PROMETHEE I and II: the inhabitants of the area (based on public consultations),
2. ELECTRE III: opinions of independent experts on transport and traffic organization,

the position of variant A1 in the rankings did not change. The situation was similar in the case of the worst option, i.e. alternative A3. As for the other options (alternative A0, alternative A2), the situation was no longer conclusive due to the discrepancies in the rankings observed when using particular methods.

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Improving financial conditions of ATEs in the city of Dnipro basing upon optimal assignment of vehicle fleet to the routes

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Abstract: The purpose of this paper is multifold: 1) to substantiate the topicality of the problem solution concerning optimal assignment of vehicles to municipal routes for auto-transport enterprises (ATE) in the city of Dnipro. 2) to present technological and economic evaluation of DATP 11255 PJSC enterprise, 3) to provide an overview of the available models to assign buses to routes with the determination of their sphere of use, specifying their key advantages and disadvantages, and 4) to propose a model for optimal assignment of buses to the routes-where target function is represented by maximization of ATE income, and the restriction is represented by non-exceedance of maximum admissible values of traffic interval and coefficients of bus capacity use. Passenger flow in terms of DATP 11255 PJSC routes during morning rush hour has been studied by means of table method. Basic technical-operational and economic parameters of the operation of DATP 11255 PJSC routes have been evaluated. Microsoft Excel SOLVER add-in has been applied to obtain optimal assignment of bus departures. The application value of the study is that it will make it possible to: 1) increase DATP 11255 PJSC income by 2.62 times (from 462.8 UAH/hour up to 1 211.8 UAH/hour); 2) improve quality of transportation process owing to the reduced maximum coefficient of the bus capacity use; and 3) ensure non-exceedance of maximum admissible bus traffic interval.

Keywords: target function, restriction system, optimal assignment, prime cost.

1. Introduction

Public municipal passenger transport (PMPT) is a complex multilevel system which studying requires using methods of system analysis; the methods include complex research of PMPT functioning problems and development of efficient tools for its improvement [1].

Despite certain budgetary support, under the conditions of financial crisis, being observed in the country, efficiency of PMPT operation in cities and towns is still low. Lack of funds to renovate (maintain) the vehicle fleet, random formation of route network, considerable uncontrolled competitiveness among official and illegal transporters result in unprofitability or weak profitability of the majority of ATEs, including ATEs in the city of Dnipro [2]. In this context, problem of rising and using "internal" ATE reserves, which basis is formed by the improvement of the technologies of passenger transportation process, is of special importance. Identification of those reserves along with their implementation is one of the main actions to improve economic and social parameters of the PMPT operation.

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Optimal vehicle fleet assignment to the routes is one of the possible technological measures aimed at improvement of ATE condition and quality of passenger transportation in terms of municipal bus routes. That assignment should include the following: possibility to obtain the required output information (results of passenger flow studies), stochastic nature of the transportation process; necessity to optimize two interrelated parameters – number and capacity of the route buses; and the available technological and social restrictions.

However, it should be noted that while solving the problem of optimal assignment, certain difficulties occur stipulated by the problem multivariance; that multivariance prevents form the problem solution by simple enumeration of possibilities. Moreover, majority of the available methodologies takes into account parameters of the passenger service quality but not the financial situation of ATE. Thus, in terms of modern conditions, a problem of vehicles assignment to the routes should be solved involving optimization methods, and target function (or its restriction) should consider needs and possibilities of all the participants of a transportation process.

2. Literature review

Solution of the problem of optimal vehicles assignment to the routes means the provision of equal satisfaction of the passengers' needs in term of their transportation on different routes taking into consideration a parameter of passenger service level, ATE costs, and technological restrictions (maximum traffic interval, bus stop capacity, number of buses etc.). In terms of its content, the problem belongs to the class of problems dealing with the production resources allocation aimed at reaching maximum efficient operation [3]. A method, in terms of which buses are assigned to the routes proportionally to the value of maximum passenger flows within the most loaded route section, is the most widely used one [4]. That method differs with its simplicity; however, it does not take into account quality of passenger service, effect of random factors, volumes and peculiarities of passenger flows within other (not so loaded) route sections, and structure of the fleet of vehicles being assigned.

Paper [5] represents different modifications of the assignment model [4] which propose to assign the routes proportionally to the volume of possible transport operation, proportionally to the transportation volumes, and proportionally to weighted average trip time. In term of the methods for bus assignment to the routes proposed in paper [6], bus traffic and passenger flow are analyzed with the consideration of random factors; probability of the fact that a passenger may not be allowed to board the bus on different routes is the criterion to assign buses. However, labour-consuming graphic constructions are required to obtain such solutions. That restricts the application of the methodology by the problems of research nature and complicates its use during short-time planning of transportation processes.

Thus, generalization of the analyzed assignment methodologies indicates that the models proposed in [4-6] are not optimization ones; correspondingly, the result, obtained with their help, is likely to be not optimal. However, main disadvantage of the majority of current assignment methodologies is in the fact that they were developed in 1970s-1990s before the changes in economic conditions on transport. Consequently, they do not take into consideration ATE interest in economic results of its activity.

3. Materials and methods

In recent years, numerous cities and towns in Ukraine have been demonstrating a tendency to the reduction in both volumes and quality of passenger transportation. That is the result of following factors: general economic crisis; reduced number of the vehicles due to their obsolete and technical depreciation; insufficient budgetary financing to cover losses due to the transportation of benefit-entitled passengers etc. All the mentioned factors result in unprofitability or low economic efficiency of the most Ukrainian ATEs.

While organizing ATE operation, one of the main tasks (having immediate effect upon the transportation efficiency) is the task to determine the route needs in the vehicle fleet [1,7,8]. That task consists of two sub-tasks: selection of bus capacity and number of buses as well as assignment of the buses to the routes. Both economic results of ATE operation and parameters of the passenger service (i.e. waiting interval, bus occupancy, possible denial for passengers to board the bus etc.) depends upon the qualitative and substantiated (involving current methods of system analysis) solution of those problems.

Unfortunately, insignificant attention is currently paid to the solution of problem concerning optimal assignment of vehicles to the routes. First of all, that fact is explained by insufficient professional qualification of ATE employees who tends to solve their economic problem at the expense of passengers; secondly, there are no unified criteria which would take into consideration the needs of both transporters and passengers. Thus, development of innovative models and methodologies (which will take into account current conditions of ATE operation) and obtaining optimal (rational) variants for bus assignment to the routes are rather burning issues.

DATP 11255 PJSC has been selected as the basic enterprise for the study. Currently, the enterprise services 6 municipal public routes. Passenger vehicle fleet includes 96 buses, 74% of which is accounted for Mercedes Sprinter and RUTA-22; the rest is accounted for BAZ A079, Bohdan A091, Bohdan A144, and Mercedes O345. Tables 1 and 2 represent assignment of buses to the routes and their basic characteristics respectively. Table 3 shows basic calculation categories for incomes and costs during the transportation process in 2018 (they were calculated on the basis of information represented in [9] as well as current route documents). Analysis of the data in Table 3 proves that nowadays *DATP 11255* PJSC is the unprofitable enterprise (at least, according to the released reports). Total amount of losses in 2018 was UAH 2 657 442. According to the employees of the AME operations department, problem of the bus assignment to the routes was of empiric nature without the use of optimization economic and mathematical methods and consideration of the majority of technical and operational parameters of the transportation process.

While organizing the operation of passenger transport, complexity of the approach while selecting optimal solutions is stipulated by internal contradictions of the parameters of ATE efficient operation and quality of passenger service. That is why, this problem is most often reduced to the problem with a single parameter, determining one (basic) criterion; other parameters are with the imposed restrictions.

Table 1. Current assignment of buses to *DATP 11255* PJSC routes.

Bus model	Passenger capacity	Route number						Total
		#33	#76	#76A	#79	#90	#156	
Mercedes Sprinter	18		16		11	8	18	53
Ruta-22	22	8		10				18
BAZ A079	40		10					10
Bohdan A091	50	4			5	2		11
Bohdan A144	80		2					2
Mercedes O345	92				2			2
Total		12	28	10	18	10	18	96

Table 2. Basic characteristics of the routes.

Parameter	Unit of measurement	Route number					
		#33	#76	#76A	#79	#90	#156
Tariff	UAH	7.0	7.0	7.0	7.0	10.0	7.0
Route length	km	17.4	19.6	18.7	16.1	26.4	20.7
Trip time	min	60	84	80	54	80	63
Operational speed	km/hour	17.4	14.0	14.0	17.9	19.8	19.7
Cruising speed	km/hour	24.4	19.6	19.6	25.0	27.7	26.8
Stops	unit	33	41	35	29	31	35

Table 3. Costs and incomes of *DATP 11255* PJSC in 2018.

Route number	#33	#76	#76A	#79	#90	#156	Total
Wages, UAH	2 289 925	4 298 158	1 930 958	2 148 883	1 736 134	2 017 257	14 421 318
Social deductions, UAH	915 970	1 228 045	508 147	920 950	631 322	1 100 322	5 304 757
Fuel and lubricants, UAH	6 106 467	10 745 394	3 760 286	5 986 173	5 208 403	7 702 256	39 508 988
Tyres, UAH	610 647	2 149 079	406 517	613 966	1 736 134	916 935	6 433 280
Amortization, UAH	1 221 293	1 842 068	813 035	1 074 441	1 420 474	1 467 096	7 838 409
Maintenance and repair, UAH	2 442 587	6 754 248	1 626 070	2 762 849	2 998 778	2 384 032	18 968 566
Other costs, UAH	1 679 279	3 684 135	1 117 923	1 841 899	2 051 795	2 750 806	13 125 840
Sum of costs , UAH	15 266 168	30 701 126	10 162 934	15 349 162	15 783 040	18 338 704	105 601 158
Total run, km	1 090 441	1 918 820	671 480	1 068 960	930 072	1 375 403	7 055 175
Trip time, hour	62 669	137 059	47 877	59 756	46 973	71 849	426 183
Number of trips	62 669	97 899	35 908	66 395	35 230	68 428	366 529
Anticipated income, UAH	16 875 323	31 953 326	12 756 845	16 566 482	16 693 314	25 027 515	119 872 806
Real income, UAH	14 681 531	30 355 659	9 950 339	14 578 504	15 357 849	18 019 811	102 943 694
Losses, UAH	584 637	345 467	212 595	770 658	425 191	318 893	2 657 441

Under conditions of complicated economic situation which is characteristic for the majority of ATEs (including the ones in Dnipro), optimality criterion should contain not only parameters of the service quality but also their economic efficiency. Taking into consideration all the aforementioned, the authors propose following structure for the model of optimal assignment of buses to the routes; in terms of the model, maximization of ATE income is the target function (depending upon the selected assignment variant), and restrictions are represented by non-exceedance of maximum admissible values of traffic interval and coefficients of bus capacity use:

$$\begin{cases} \sum_{i=1}^{m}\sum_{j=1}^{n} A_{ij} \cdot q_i \cdot D_{ij} \to \max & (1) \\ \gamma_j \le \gamma^{\max} = 1{,}2 & (2) \\ I_j \le I^{\max} = 15 \ \text{min}. & (3) \\ \sum_{j=1}^{n} A_{ij} = A_i & (4) \\ A_{ij} \ge 0 & (5) \end{cases}$$

where A_{ij} - is number of buses (taking into consideration specificity of obtaining input data at that stage, not the number of buses but number of departures) of i[th] model on j[th] route (assignment plan being developed); q_i - is capacity of i[th] bus model; D_{ij} - is income of ATE from the operation of a passenger unit of i[th] model on j[th] route; γ_j - is coefficient of bus capacity use in terms of the most loaded trip of j[th] route; $\gamma^{\max}$ - is maximum admissible coefficient of bus capacity use (taking into account control of transportation process quality, it is proposed to take $\gamma^{\max}$=1.20 for all routes); I_j - is bus traffic interval on j[th] route; $I^{\max}$ - is maximum admissible bus traffic interval (taking into account control of transportation process quality, it is proposed to take $I^{\max}$=15 min for all routes);

A_i - is available number of buses of i[th] model; m - is number of bus models being assigned; n - is number of routes being serviced.

Tables 1 and 2 represent basic parameters of the operation of DATP 11255 PJSC routes (operational velocity V_j, trip duration t_j, bus capacity q_i, fare T_j etc.) required to calculate constituents of the proposed models (1-5). Table 3 contains data on the constituents of prime cost of the transportation process required to calculate variable C_j^v and constant costs C_j^c for bus operation.

As for the data concerning values of the coefficient of passenger variation η_j, dynamic coefficients of bus capacity use γ_j^d, maximum values of passenger flows $H_j^{\max}$, and coefficients of capacity use in terms of the most loaded bus trip $\gamma_i^{\max}$, that information is possible to obtain only during the inspection of passenger flows.

Morning rush hour is the most important period for AME operation; thus, decision has been made to inspect passenger flows on all the routes of DATP 11255 PJSC from 8 a.m. to 9 a.m. (that is the period characterized by the greatest number of bus departures according to current bus schedules) only for direct route. To reduce labour consumption of the studies, recommendations from paper [10] were used as the substantiation of the sampling to guarantee sufficient accuracy of the obtained results. Basing upon recommendations [10] and current traffic interval, 21 bus trips are required to be studies in the context of the passenger flows inspection. Table 4 represents generalized information on the number of inspected trips, traffic intervals, and sampling percentage. Table 3 shows generalized results of the passenger flows inspection on DATP 11255 PJSC routes.

Basing upon the TEP data obtained during the inspection of passenger flows on DATP 11255 PJSC routes (Table 5), economic parameters of transportation process have been calculated which are required to obtain optimal bus assignment according to (1-5). Table 6 demonstrates the calculation results.

Problem of the vehicle fleet assignment to the municipal routes belongs to a special class of linear programming which are called transportation problems [1]. Special structure of a transportation problem helps apply following methods for its solution [11]: method of northwest angle, least-cost method, and Vogel's approximation method. According to the recommendations proposed in paper [7,10], it is appropriate to use Microsoft Excel SOLVER add-in while solving problems of mathematical programming with economic (technical) focus; that is a powerful auxiliary tool to perform complicated calculations including solution of the majority of mathematical programming problems.

Table 4. Substantiation of minimal number of trips for the inspection.

Route number		#33	#76	#76A	#79	#90	#156
Class I	Number of departures		1		1		
	Traffic interval, min		60		60		
	Selectivity, %		100%		100%		
	Number of inspections		1		1		
Class A	Number of departures	2	4		3	1	
	Traffic interval, min	30	15		20	60	
	Selectivity, %	50%	50%		67%	100%	
	Number of inspections	1	2		2	1	
Class B	Number of departures	4	5	4	6	3	9
	Traffic interval, min	15	12	15	10	20	7
	Selectivity, %	50%	40%	50%	33%	67%	33%
	Number of inspections	2	2	2	2	2	3
Departures, total		6	10	4	10	4	9
Inspections, total		3	5	2	5	3	3

Table 5. Basic technical and operational parameters of the routes serviced by *DATP 11255* PJSC during morning rush hour.

Parameter	Route number					
	#33	#76	#76A	#79	#90	#156
Number of the transported passengers	292	560	222	440	122	258
Proposed passenger capacity	188	330	88	350	104	162
Maximum passenger flow	182	428	158	328	93	216
Dynamic coefficient of the capacity use	0.63	0.88	1.21	0.63	0.72	0.86
Average duration of one passenger trip	7.0	10.2	8.9	8.0	16.2	11.2
Coefficient of variation	2.49	1.92	2.10	2.01	1.63	1.85

Table 6. Economic parameters of the operation of DATP 11255 PJSC routes.

Parameter	Bus model	Route number					
		#33	#76	#76A	#79	#90	#156
Tariff, UAH		7.00	7.00	7.00	7.00	10.00	7.00
Remuneration coefficient		0.91	0.93	0.91	0.92	0.90	0.89
Variablecosts, UAH/km		8.40	10.24	8.63	8.76	9.80	8.00
Constant costs, UAH/hour		97.44	80.64	91.28	100.18	83.16	105.14
Productivity, pas./seat		1.56	1.69	2.53	1.26	1.17	1.59
Income, UAH		9.92	11.03	16.14	8.12	10.53	9.91
Prime cost	Mercedes Sprinter	13.53	17.42	15.73	12.84	20.53	15.33
	Ruta-22	11.07	14.25	12.87	10.51	16.80	12.55
	BAZ A079	6.09	7.84	7.08	5.78	9.24	6.90
	Bohdan A091	4.87	6.27	5.66	4.62	7.39	5.52
	Bohdan A144	3.05	3.92	3.54	2.89	4.62	3.45
	Mercedes O345	2.65	3.41	3.08	2.51	4.02	3.00
Income	Mercedes Sprinter	-3.62	-6.39	0.42	-4.73	-10.00	-5.42
	Ruta-22	-1.16	-3.22	3.27	-2.39	-6.27	-2.64
	BAZ A079	3.83	3.19	9.07	2.34	1.29	3.01
	Bohdan A091	5.04	4.76	10.48	3.49	3.14	4.39
	Bohdan A144	6.87	7.11	12.60	5.23	5.91	6.46
	Mercedes O345	7.27	7.62	13.07	5.61	6.51	6.91

Output data for *SOLVER* add-in should be represented in the form of electronic table containing four range types:

- range of the problem variables;
- range of the specified problem parameters;
- range of the intermediate results;
- range of the target functions.

Range of the problem variables is the obligatory one; its configuration reminds a form of ATE fleet matrix *A* being assigned. Each box of the range corresponds to one element A_{ij} of matrix A which corresponds to the number of bus departures of i^{th} model operating on j^{th} route. Variable box should not contain any formulas.

Range of the specified problem parameters is the obligatory one containing constants preset by the problem condition. In terms of the problem of bus assignment to the routes, that range has four constituent parts:

- sub-range for income matrix $D = [D_{ij}]$;

- sub-range for the vector assigning number of buses of i^{th} model $K = [A_i]$ (at this stage, A_i means number of departures of i^{th} bus model within the time period being considered);

- sub-range for the vector of maximum admissible value of the coefficient of bus capacity use on j^{th} route $\gamma^{\max} = [\gamma_j^{\max}]=1.2$;

- sub-range for the vector of maximum admissible bus traffic interval on j^{th} route $I^{\max} = [I_j^{\max}]=15$ min.

Boxes of all the sub-ranges should not contain any formulas. All the output data should be entered into those sub-ranges before the beginning of the problem solving.

Range of the intermediate results contains formulas representing dependences between the table data being distributed within the three sub-ranges:

- sub-range of passenger-unit assignment to the routes $Q=[Q_{ij}]$ for the products of matrix *A* elements by corresponding elements of matrix *q*. Each box should contain a formula determining product $A_{ij} \cdot q_i$.

- sub-range of restriction functions of type (2) determining values of the coefficient of the vehicle fleet capacity use within the most loaded trip γ_j on j^{th} route. That is a mandatory range; each of its boxes contains following formula: $\gamma_j^{\max} = \dfrac{H_j^{max}}{\sum_{i=1}^{m} Q_{ij}}$.

- sub-range of the restricted-type functions (3) determining interval of bus trip I_j on j^{th} route. That is mandatory range; each of its boxes contains following formula: $I_j = \dfrac{60}{\sum_{i=1}^{m} A_{ij}}$.

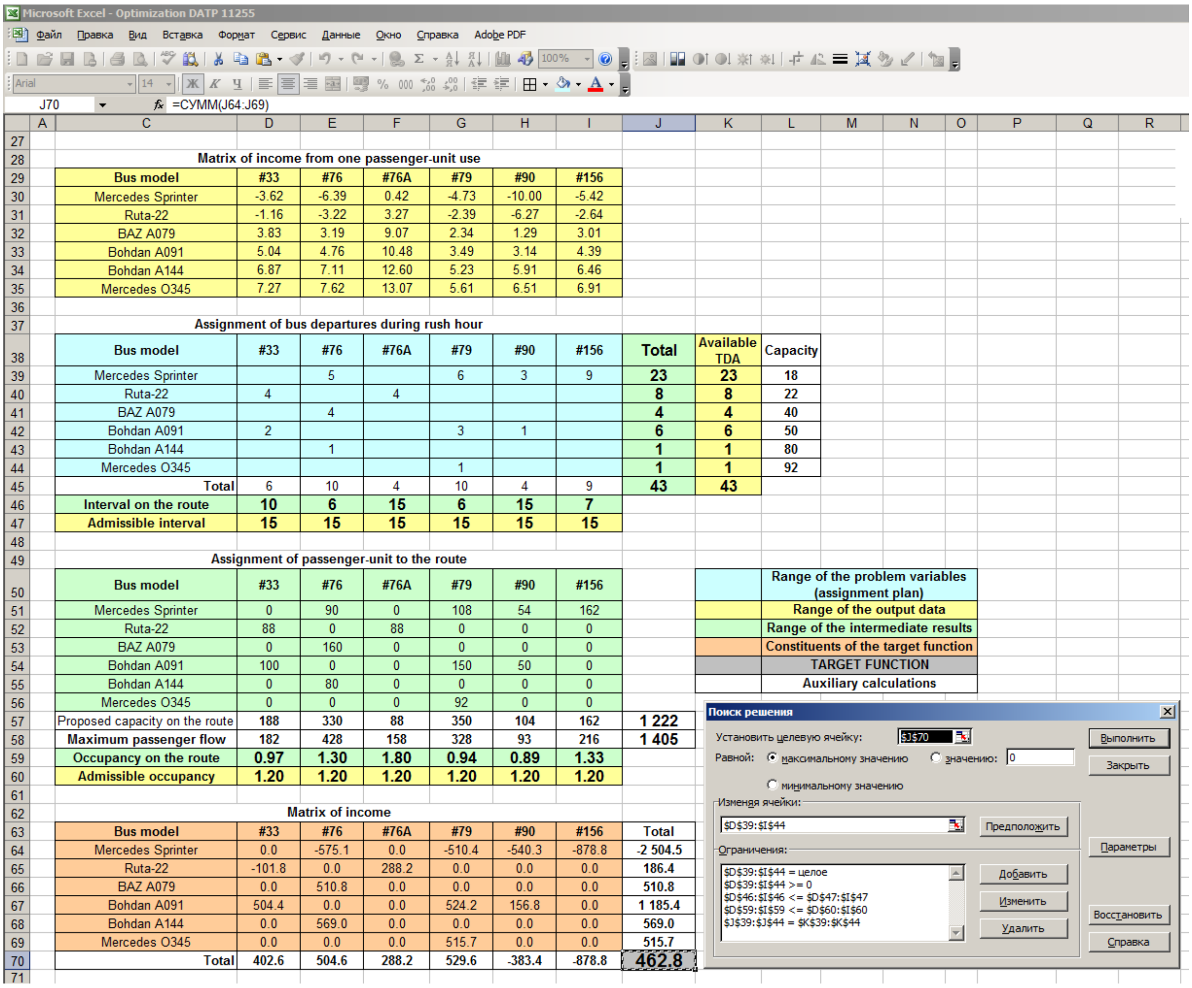
- sub-range of the restriction function of type (4) determining number of buses of i^{th} model being assigned on j^{th} route. That is a mandatory range; each of its boxes contains formula $\sum_{j=1}^{n} A_{ij}$.

Range of the target function F should consist one (and only one) box with the formula to determine criterion (1), i.e. formula of double sum $\sum_{i=1}^{m}\sum_{j=1}^{n} F_{ij}$.

To evaluate the efficiency of optimal vehicle fleet assignment to the routes, first of all, value of target function (1) in terms of the available organization of transportation process at *DATP 11255* PJSC should be determined.

Owing to the fact that technical and operational parameters of the routes operation (Table 5) were obtained during the passenger flow inspection during morning rush hour (8 a.m. – 9 a.m.), current bus assignment to the routes should be understood *not as the number of buses reserved for the routes* (Table 1), *but the number of their departures within the period being analyzed*. Figure 1 shows data concerning the number of departures of i^{th} bus model on j^{th} route. Those data are the range of problem variables. Each box of the range corresponds to one element A_{ij} of matrix A.

To determine value of target function (1), it is required to calculate matrix of the proposed passenger-units $Q_{ij} = A_{ij} \cdot q_i$ and matrix of the target function constituents $F_{ij} = D_{ij} \cdot Q_{ij}$. Results of calculated Q_{ij} and F_{ij} for current assignment are also represented in Fig.1. The obtained results prove that the proposed capacity of buses on the routes are less that its demand (1 222<1 405), i.e. transportation process is performed in terms of deficit being 183 passenger-units. Income of *DATP 11255* PJSC from 8 a.m. to 9 a.m. is UAH 462.8. Moreover, it should be noted that in terms of routes #76, #76A, and #156, maximum values of the coefficients of bus capacity is much higher than the admissible ones having negative effect upon the quality of passenger service.



Matrix of income from one passenger-unit use

Bus model	#33	#76	#76A	#79	#90	#156
Mercedes Sprinter	-3.62	-6.39	0.42	-4.73	-10.00	-5.42
Ruta-22	-1.16	-3.22	3.27	-2.39	-6.27	-2.64
BAZ A079	3.83	3.19	9.07	2.34	1.29	3.01
Bohdan A091	5.04	4.76	10.48	3.49	3.14	4.39
Bohdan A144	6.87	7.11	12.60	5.23	5.91	6.46
Mercedes O345	7.27	7.62	13.07	5.61	6.51	6.91

Assignment of bus departures during rush hour

Bus model	#33	#76	#76A	#79	#90	#156	Total	Available TDA	Capacity
Mercedes Sprinter		5		6	3	9	23	23	18
Ruta-22	4		4				8	8	22
BAZ A079		4					4	4	40
Bohdan A091	2			3	1		6	6	50
Bohdan A144		1					1	1	80
Mercedes O345				1			1	1	92
Total	6	10	4	10	4	9	43	43	
Interval on the route	10	6	15	6	15	7			
Admissible interval	15	15	15	15	15	15			

Assignment of passenger-unit to the route

Bus model	#33	#76	#76A	#79	#90	#156	
Mercedes Sprinter	0	90	0	108	54	162	
Ruta-22	88	0	88	0	0	0	
BAZ A079	0	160	0	0	0	0	
Bohdan A091	100	0	0	150	50	0	
Bohdan A144	0	80	0	0	0	0	
Mercedes O345	0	0	0	92	0	0	
Proposed capacity on the route	188	330	88	350	104	162	1 222
Maximum passenger flow	182	428	158	328	93	216	1 405
Occupancy on the route	0.97	1.30	1.80	0.94	0.89	1.33	
Admissible occupancy	1.20	1.20	1.20	1.20	1.20	1.20	

Matrix of income

Bus model	#33	#76	#76A	#79	#90	#156	Total
Mercedes Sprinter	0.0	-575.1	0.0	-510.4	-540.3	-878.8	-2 504.5
Ruta-22	-101.8	0.0	288.2	0.0	0.0	0.0	186.4
BAZ A079	0.0	510.8	0.0	0.0	0.0	0.0	510.8
Bohdan A091	504.4	0.0	0.0	524.2	156.8	0.0	1 185.4
Bohdan A144	0.0	569.0	0.0	0.0	0.0	0.0	569.0
Mercedes O345	0.0	0.0	0.0	515.7	0.0	0.0	515.7
Total	402.6	504.6	288.2	529.6	-383.4	-878.8	462.8

Figure 1. Work sheet of the prepared data for *SOLVER* add-in operation.

Optimal assignment of *DATP 11255* PJSC buses was performed with the help of *Microsoft Excel SOLVER* add-in. To perform the calculation, it is required:

- to call up *SOLVER* add-in: *Service →Solver*;
- to indicate target box (*J70*) – functional (1);
- to indicate optimization direction – maximum value;
- to indicate variable boxes (*$D$39:$I$44*) – assignment plan A_{ij} ;
- to enter restrictions: (*$D$59:$I$59<=$D$60:$I$60*) – restriction (2); (*$D$46:$I$46<=$D$47:$I$47*) – (3); (*$J$39:$J$44=$K$39:$K$44*) – (4) and (*$D$39:$I$44>=0*) – restriction (5);

Figure 2 represents the results of *Microsoft Excel* SOLVER add-in. Thus, optimal assignment of *DATP 11255* PJSC vehicles for morning rush hour has been obtained. Analysis of the information given in Figure 2 confirms that *DATP 11255* PJSC income may be increased by 2.62 times (from UAH 462.8 up to UAH 1211.8). In addition, improvement of the transportation process quality should be emphasized as all the mentioned values of maximum coefficient of the buses capacity use are not more than admissible value $\gamma_j < \gamma^{max}$ =1.20.

Microsoft Excel - Optimization DATP 11255

Matrix of income from one passenger-unit use

Bus model	#33	#76	#76A	#79	#90	#156
Mercedes Sprinter	-3.62	-6.39	0.42	-4.73	-10.00	-5.42
Ruta-22	-1.16	-3.22	3.27	-2.39	-6.27	-2.64
BAZ A079	3.83	3.19	9.07	2.34	1.29	3.01
Bohdan A091	5.04	4.76	10.48	3.49	3.14	4.39
Bohdan A144	6.87	7.11	12.60	5.23	5.91	6.46
Mercedes O345	7.27	7.62	13.07	5.61	6.51	6.91

Assignment of bus departures during rush hour

Bus model	#33	#76	#76A	#79	#90	#156	Total	Available TDA	Capacity
Mercedes Sprinter	4	2	3	11	2	1	23	23	18
Ruta-22	2				2	4	8	8	22
BAZ A079			1	1		2	4	4	40
Bohdan A091	1	3	1	1			6	6	50
Bohdan A144		1					1	1	80
Mercedes O345		1					1	1	92
Total	7	7	5	13	4	7	43	43	
Interval on the route	9	9	12	5	15	9			
Admissible interval	15	15	15	15	15	15			

Assignment of passenger-unit to the route

Bus model	#33	#76	#76A	#79	#90	#156	
Mercedes Sprinter	72	36	54	198	36	18	
Ruta-22	44	0	0	0	44	88	
BAZ A079	0	0	40	40	0	80	
Bohdan A091	50	150	50	50	0	0	
Bohdan A144	0	80	0	0	0	0	
Mercedes O345	0	92	0	0	0	0	
Proposed capacity on the route	166	358	144	288	80	186	1 222
Maximum passenger flow	182	428	158	328	93	216	1 405
Occupancy on the route	1.10	1.20	1.10	1.14	1.16	1.16	
Admissible occupancy	1.20	1.20	1.20	1.20	1.20	1.20	

Range of the problem variables (assignment plan)
Range of the output data
Range of the intermediate results
Constituents of the target function
TARGET FUNCTION
Auxiliary calculations

Matrix of income

Bus model	#33	#76	#76A	#79	#90	#156	Total
Mercedes Sprinter	-260.5	-230.0	22.4	-935.7	-360.2	-97.6	-1 861.5
Ruta-22	-50.9	0.0	0.0	0.0	-275.9	-232.0	-558.9
BAZ A079	0.0	0.0	362.6	93.6	0.0	240.7	696.9
Bohdan A091	252.2	714.0	524.0	174.7	0.0	0.0	1 665.0
Bohdan A144	0.0	569.0	0.0	0.0	0.0	0.0	569.0
Mercedes O345	0.0	701.4	0.0	0.0	0.0	0.0	701.4
Total	-59.2	1754.4	909.1	-667.4	-636.1	-89.0	1 211.8

Figure 2. Results of *Microsoft Excel SOLVER* add-in operation.

As previously stated, the obtained optimal distribution of buses to the routes (Figure 2) should be understood not as the number of buses reserved for the routes but as the number of their departures per period being analyzed. Thus, the obtained optimal plans of the departure assignments do not allow yet reserving all the vehicles of *DATP 11255* PJSC for municipal routes being serviced.

At the moment, 96 buses (Table 1) are operated on the routes of *DATP 11255* PJSC; assignment was performed for 43 vehicles (Table 1) as that is the amount of buses which is involved in transportation process for which TEP (Table 5) have been determined on the basis of passenger flows inspection.

Final reserving of *DATP 11255* PJSC vehicle fleet for the municipal routes being serviced require additional assignment of 53 buses more (96–43=53) so that following condition will be met:

$$\sum_{j=1}^{n} A_{ij}^{final} = A_i \,. \tag{6}$$

Final number of buses of i^{th} model which should operate on j^{th} route may be determined according to following dependence:

$$A_{ij}^{final} = A_{ij} + A_{ij} \cdot k_i \,, \tag{7}$$

where k_i is coefficient taking into account a degree of unassigned buses of *i*th model:

$$k_i = \frac{A_i - \sum_{j=1}^{n} A_{ij}}{\sum_{j=1}^{n} A_{ij}}. \quad (8)$$

Table 7 represents the results of calculation of the unassigned buses of *i*th model according to (8). Table 6 shows the results of calculations of final reserving of *DATP 11255* PJSC vehicle fleet for the routes (7).

Table 7. Calculation of the non-assignment degree k_i of *i*th model buses.

Bus model	$\sum_{j=1}^{n} A_{ij}$	A_i	$A_i - \sum_{j=1}^{n} A_{ij}$	k_i
Mercedes Sprinter	23	53	30	1.30
Ruta-22	8	18	10	1.26
BAZ A079	4	10	6	1.50
Bohdan A091	6	11	5	0.83
Bohdan A144	1	2	1	1.00
Mercedes O345	1	2	1	1.00
Total	43	96	53	

Table 8. Final optimal assignment of buses to *DATP 11255* PJSC routes

Bus model	**Passenger capacity**	**Route number**						**Total**
		#33	**#76**	**#76A**	**#79**	**#90**	**#156**	
Mercedes Sprinter	18	9	5	7	25	5	2	53
Ruta-22	22	5				5	8	18
BAZ A079	40			3	3		4	10
Bohdan A091	50	2	5	2	2			11
Bohdan A144	80		2					2
Mercedes O345	92		2					2
Total		16	14	12	30	10	14	96

4. Conclusions

Topicality of the solution of the problem concerning optimal vehicles assignment to the municipal routes in terms of ATEs of the city of Dnipro has been substantiated. The available models to assign buses to the routes has been analyzed with the specification of their area of application, basic advantages and disadvantages.

Structure of the model for optimal assignment of buses to the routes has been proposed; in terms of that structure, maximization of ATE income is a target function while restriction is represented by non-exceedance of maximum admissible values of traffic interval and coefficients of bus capacity use.

Microsoft Excel SOLVER add-in has been applied to obtain optimal assignment of buses departure making it possible the following: to increase *DATP 11255* PJSC income by 2.62 times (from UAH 462.8 up to UAH 1211.8); to improve quality of transportation process at the expense of decrease in maximum coefficient of bus capacity use to the limits of permissible value $\gamma^{\max}$ =1.20; to provide non-exceedance of maximum admissible traffic interval of buses $I^{\max}$ =15 min. Final reserving of *DATP 11255* PJSC vehicle fleet for the routes has been performed on the basis of the calculated coefficient k_i which takes into consideration a degree of unassigned buses of *i*th model.

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Constructional solutions for increasing the capacities of cable cars

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Abstract: Cableways have some potential to be used in urban public transportation, particularly uni-directional aerial cable cars with circulating cabins, called gondolas. They have several advantages, but two major problems must be solved: the capacity and the operating speed are not competitive when compared to other means of urban mass transport because of boarding procedures and slowing down and accelerating on intermediate stations. This paper presents constructional solutions that address these problems. It proposes that boarding takes place on at least two platforms; these could be on the same level or on separate levels. At intermediate stations certain cabins are diverted to an extra platform while the majority of cabins travel with unreduced speed. Following this constructional approach, the nominal capacity of gondolas could be doubled while increasing the operational travel speed on lines with lot of intermediate stops.

Keywords: gondola, public transport, dwelling time, platform, geometric modeling.

1. Introduction

Cableways are transport devices to carry passengers by rope, usually electrically powered, but are rarely used in urban areas. Cable car transport is carried out using aerial cable cars, surface lifts, and funiculars [1]. Ski lifts and funicular railways carry passengers on the ground level; with aerial cable cars, passengers are carried in the air. For this reason, aerial cable cars are more suitable for use in urban environments because they do not burden existing urban traffic routes.

According to operating principles, aerial cable cars are divided into aerial tramways and gondolas. Aerial tramways (jig-back ropeways, reversible aerial ropeways) transport passengers using one or two cabins that move back and forth on cables. Their maximum speed is 12 m/s or 43.2 km/h [2] and they have maximum capacities of up to 2,000 persons/h.

Gondolas are uni-directional aerial cable cars with circulating vehicles (cabins). They consist of several cabins that can carry up to 30 persons each and have greater capacities than aerial cars, up to 4,000 persons/h. The speed is slower than aerial cars, with a maximum of 7 m/s for bi-cable gondolas and a maximum of 6 m/s for monocable gondolas [2]. Passengers do not need to wait for the vehicles at the station, as the vehicles constantly come and go. The spans between the pylons are smaller than aerial tramways because there is more than one vehicle on the rope at a time and the lengths of gaps and precipices over which cabins can travel are smaller than for the aerial tramways. When at a station, cabins do not stand still but move slowly through the station, which can make it difficult for persons with disabilities and older adults to enter. Time of entry into the cabin is limited depending on the

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speed and length of the platform. Gondolas are more suitable for public passenger transport, which requires high capacity. The speeds of cable cars are low but, in the case of gondolas, the vehicles come constantly into stations and passengers do not need to wait for them.

The problem is that these cableways and gondolas do not have a large capacity for the transport of passengers. It is clear that the capacities of aerial cars are not competitive with the existing, more-used modes of passenger transport in urban centers. According to the Transport Research Board (2003), the types of public transport commonly used in urban centers have much higher capacities. Heavy rail can transport up to 49,000 persons/h, metro up to 36,000 persons/h and even light rail on streets (trams) can transport up to 11,800 persons/h. Buses on dedicated lines have a capacity up to 10,000 persons/h. These capacities may vary under different conditions of use, but they are much greater compared to the capacities of aerial cable cars.

The purpose of this article is to present new construction solutions for increasing the operational capacity of cableways, so that this mode of transport becomes more competitive compared to the other types of passenger transport in urban areas. The problem to be solved is actually how to increase the amount of entering and exiting passengers per time unit in the terminal and intermediate stations.

2. Overview of previous research

The uses of cable cars in non-urban environments, especially in mountainous areas and for tourism, have been well studied, but the use of these systems in urban areas and city centers as part of public transport networks have not. Technical solutions on cable cars are fairly well described in various books [1, 3]. The issue regarding the uses of different types of cable cars and comparisons with other transport systems in an urban environment is presented in a study by Clement-Werny et al. [4].

Aerial cable cars have several advantages compared with other transport modes. Routes are independent of surface characteristics (steepness, infrastructure barriers), and the need for extra land for transport facilities is limited. Cable cars are powered by electricity, and thus emit fewer CO2 emissions and exhaust emissions if renewable energy is used for electricity. Noise emissions are significantly reduced. The level of traffic safety is high and the transportation is comfortable (vibrations occur only when vehicles pass over the roller batteries) [5]. Despite their good characteristics, aerial cable cars also have certain limitations. The speed is limited and consequently the capacity is limited. Gondolas with intermediate stations are suitable only for distances up to 7 km. They are not wind resistant, and can normally handle winds up to 18 m/s (65 km/h), although bi-cable systems can handle up to 90 km/h. It is quite difficult to rescue people from aerial cable cars. Perhaps the most disturbing aspect is the negative visual impact of cable cars on urban landscapes [5].

In Medellin, aerial gondola lines were built for use in public transport. As Medellin is a representative example of the use of cable cars in public transport, this case has been discussed by many authors, including Heinrichs, Bernet, Brand and Dávila [6,7]. In other parts of the world, cable cars are used as parts of urban transport systems primarily for tourism purposes. The coexistence of people and the world of machines depends not only on technical possibilities, costs of technology implementation, legal regulations, but also on social acceptance and people's ability to coexist with technologies [11].

Dwell times for non-moving public transport vehicles (buses) were studied by Rexfelt [8]. The average dwell time when the validation of tickets is done before entering the platform for a bus for 10 people is around 22 seconds and for 30 people around 43 seconds.

3. Approach to the construction solutions

The existing system of entry and exit of gondolas (Fig. 1) should be reconsidered. The existing system for gondolas uses only one platform for boarding. The vehicle has a maximum speed of 0.5 m/s, and the minimum distance between vehicles in a station is 0.5 m [2].

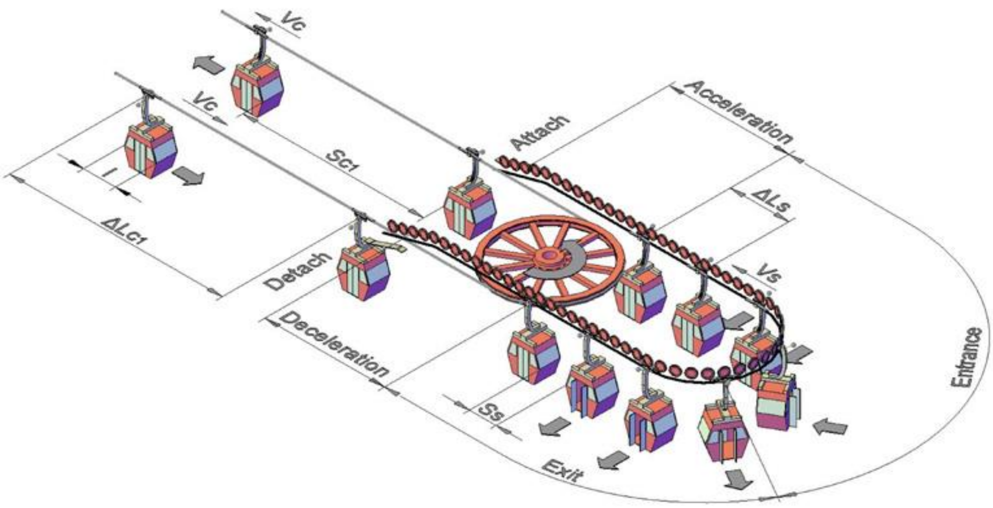

Figure 1. Existing system of gondolas – passenger entry and exit in station.

If a length of the vehicle is 3.0 m, the minimum pitch (distance between suspensions) between vehicles in the station is 3.5 m. On the base of the maximum speed of vehicles in the station (0.5 m/s) and minimum pitch between vehicles in the station, the minimum time interval between vehicles is 7 seconds. As only one platform is in use, the minimum time intervals between vehicles in the station and on the line are the same (7s).

Maximum capacity of the gondola lift depends of the minimum interval between vehicles and number of persons in the vehicle (n). If we take into account that the number of persons in the vehicle is 8, the theoretical capacity of gondola lift (Q_C) is:

$$Q_C = \frac{3600}{\Delta t_C} \cdot n = \frac{3600}{7} \cdot 8 = 4114 \quad (1)$$

However, in the practice the minimum time interval of 7 seconds is not applied. The gondola lifts with the largest nominal capacity have time intervals between vehicles of somewhere around 12 seconds. For example, the gondola lift in Medellin has a capacity of 3,000 persons/h with 10 persons in one vehicle and the interval between vehicles is 12 seconds [6].

The pitch between the vehicles on the line (Δl_C) depends on the relationship between the speed of the vehicles in the station and the speed on the line (V_C).

$$\Delta l_C = \frac{\Delta l_S}{V_S} \cdot V_C = \frac{3.5}{0.5} \cdot 6 = 42m \quad (2)$$

The calculated pitch between vehicles on the line of 42 meters is quite large. The existing gondola lifts, which have 12 seconds of interval between vehicles, have an even greater pitch between vehicles at 72 meters. The comparable distance between vehicles in road transport is much shorter. Also the time interval between vehicles on the line of ropeway, which is in the given case 7 seconds, is fairly large and is much greater than in transport by roads (2 seconds).

4. Construction solutions

The 7- versus 12-second time interval between two consecutive vehicles should be reduced. This can be achieved by the reconstruction of platforms.

4.1. Two platforms on one level

A system with two station platforms for gondolas is shown in Figure 2. Two platforms - one internal and one external - are placed at the same level. Each platform has a separate line for vehicle braking, transporting, and accelerating, and both platforms use the same zone for detaching and attaching grips on the rope. Cabin entry into the station for both platforms is at the same place, and when it detaches from the rope, it starts braking for the internal or external platform. Cabins alternate between the internal and external platforms.

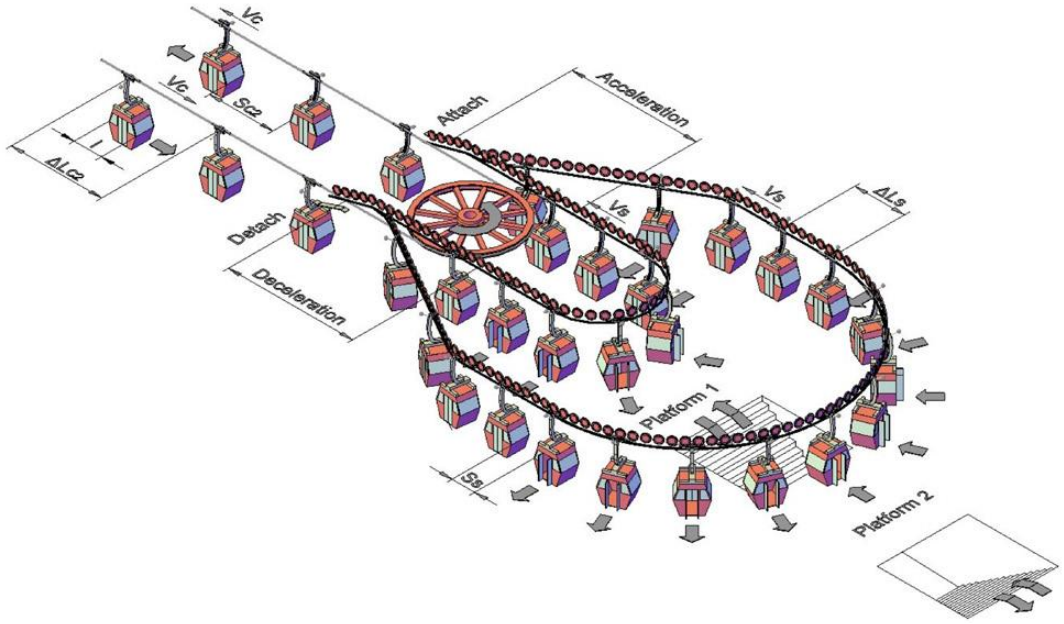

Figure 2. System of two gondola platforms on same level – passenger entry and exit.

The procedure of entry into and exit from slowly-moving cabins takes place separately at the internal and external platforms, where the acceleration of the cabins is separate. Only before the zone of attaching the grips onto the rope, where the cabin has the same speed as the rope (V_C), do the internal and external lines merge. All cabins leave the station at the same place. Passenger access to the internal platform runs through the underpass under the external platform.

This system could solve the problem of distances between vehicles that are too great on the line of the cable cars. In this case, vehicle speeds (0.5 m/s) and minimum distances between vehicles (0.5 m) in each of the two platforms in the station are the same as for the existing system of gondolas with one platform. It also has the same minimum time interval between vehicles in the stations' platforms (7 seconds). However, with the use of two platforms in the station, the minimum interval between vehicles on the line is reduced twofold to 3.5 seconds.

4.2. Two platforms on different levels

Weaknesses of the system with both platforms on the same level (Figure 2) could be removed by using two platforms on two different floors, as shown in Figure 3. Each floor would have separate lines for the braking, transporting, and acceleration of cabins. In this case, the surface of the ground plan in the station would be smaller.

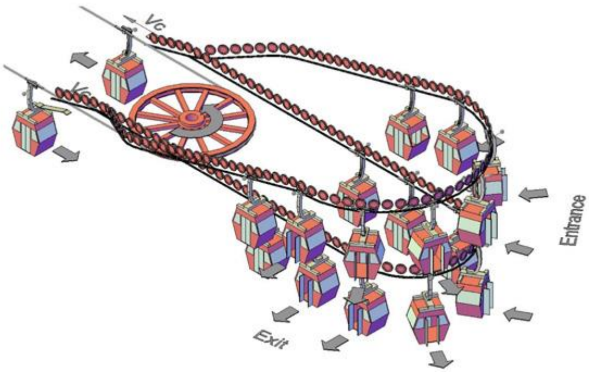

Figure 3. System of two platforms for gondolas on two different floors – passenger entry and exit.

4.3 Intermediate stations

Another advantage of gondolas is that they use small vehicles. This means that in the intermediate stations on the line, it is not necessary to stop all cabins, only those from which passengers exit. Special construction of intermediate stations, as shown in Figure 4, could allow this. Using this measure, passengers in other cabins could smoothly travel to other or final stations.

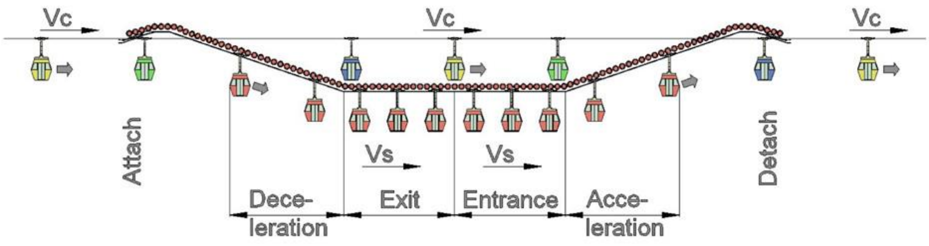

Figure 4. Existing system of gondolas – passenger entry and exit in station.

5. Analysis

With the use of two platforms in the station, the minimum time interval (Δt_{C2}) between vehicles on the line is cut in half to 3.5 seconds. The pitch between the vehicles (Δl_{C2}) on the line is reduced to 21 meters. The capacity of gondola lifts with two platforms in the station (Q_{C2}) shall be increased by two times and in this case is:

$$Q_{C2} = \frac{3600}{\Delta t_{C2}} \cdot n = \frac{3600}{3.5} \cdot 8 = 8228 \quad \text{persons/h} \tag{3}$$

Nominal capacities of gondolas with two platforms are much higher compared with other options of cable car transport, as shown in Figure 5.

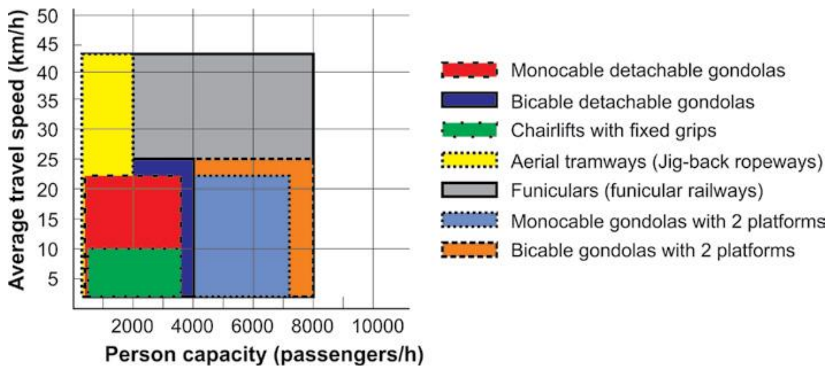

Figure 5. Comparison between gondolas with two platforms and other types of cable cars.

6. Conclusion

Cable car transport has many advantages compared with other modes of passenger transport, such as clean electricity, high levels of safety for passengers, and quiet operation. The most important characteristic is that cable car transport can be installed in the air over streets in urban areas, independent of congestion. However, cable cars, in spite of the advantages, still cannot achieve certain characteristics of other modes of transport, such as capacity or number of passengers per hour. This paper has demonstrated that cable car transport can become competitive with other types of passenger transport in urban areas. With additional platforms in gondola stations, it is possible to achieve reduced distance between vehicles on the line and increase capacity.

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Use of traffic calming measures in the Republic of Belarus

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Abstract: Traffic calming is one of the main approaches to ensuring safety in city streets and it is based on the concept of speed containment. The aim of this approach is to minimize passing transit flows through the streets of district importance, to ensure the safety of pedestrians and cyclists, as well as to impact the behavior of drivers in urban conditions. City streets should be designed taking into account the restriction of "extra" speed, in accordance with the category and purpose. It is necessary to have regard to the functionality of the street, the uniformity of the traffic flow, the appropriateness of the imposed limitations, and the predictability of the technical means used to organize traffic. The main criteria for the use of traffic calming measures can be: accident rate, speed through traffic, and specific traffic conditions. The article presents practical results of studies on traffic conditions in the pedestrian crossings areas equipped with humps. It discusses alternative measures of physical and psychological effects on the traffic participants in the context of the traffic calming approach.

Keywords: Speed Management, Traffic Organization, Speed Control Measures.

1. Introduction

The main problem of safety is speed. Anyway speed is connected with all road accidents. First, it is more difficult to react to sudden changes of traffic conditions and to prevent the accident at higher speeds. Secondly, speed affects the severity of the consequences. And first of all it concerns accidents with pedestrians. At a higher velocity, more energy is emitted, and a part of this energy is absorbed by an unprotected human body.

Various methods – road signs, humps, narrowings of a passable part, interruption of a direct trajectory, video control are applied to regulation of the high-speed mode on pieces of streets, more difficult for traffic participants. The limitation informs drivers on the safe speed of the movement under average traffic conditions. According to about 40–50% of drivers move quicker than the set limit. From them from 10 to 20% exceed the set limitation more than on 10 km/h [1]. Also it should be noted that drivers seldom correct towards reduction the allowed speed at temporary deterioration in weather or road conditions. The choice of speed is influenced by motives of the driver, its adoption of risk, the characteristic of the vehicle and the road environment.

It is more effective to apply an integrated approach to solve the problem of exceeding or selecting the wrong speed for existing conditions. A determinate combination of methods is necessary for each typical section of the road and road network. And the speed limits in a particular place should be

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justified and understandable to drivers. In addition, for violators, which will always be, we need video monitoring and more stringent legal measures. Highly effective and the use of intra-system auto-mobile technologies, which, when collecting data from technical means of organizing traffic, will additionally warn drivers or limit the speed in accordance with the settings. It is also highly effective to use in-system automotive technologies, which, when collecting data from technical means of organizing traffic, will additionally warn drivers or limit speed in accordance with the settings.

According to statistics [7], speed is the cause in more than 10% of accidents from the total number of reported road accidents and about 30% of fatal accidents. An increase in speed at 1 km/h in urban conditions entails an increase in accidents related to speed by 1-4%. Table 1 presents data on the distribution of accidents with victims, committed through the fault of the drivers, indicating violations of the requirements of the Traffic Regulations (Belarus).

Table 1. Distribution of accidents with victims for reasons (Belarus) (http://gaiminsk.by/statistika [date of request - 02.08.2018]).

Violations	Number of accidents (dead / injured)					
	2012	2013	2014	2015	2016	2017
speeding	830 (220/1010)	604 (114/711)	539 (132/612)	511 (103/611)	423 (75/485)	397 (111/463)
violation of the throughfare of a pedestrian crossing	659 (48/650)	691 (53/679)	689 (43/681)	630 (52/619)	573 (44/557)	541 (44/526)

2. The speed effect on the severity of the accidents consequences with pedestrians

There is a clear biomechanical relationship between the severity of accidents and high speed. With increasing speed, the amount of energy released increases and, in case of an accident, it will be absorbed by an object with a smaller mass. In the case of pedestrians, the difference in mass is enormous and there is absolutely no external protection to absorb excess energy. On this basis, Swedish scientist G. Nilsson has presented the following relationship between the speed and the number of road accidents [5]:

$$A_2 = A_1 * (V_2/V_1)^2 \tag{1}$$

A_2 – the number of accidents after speed changes, accidents; A_1 – the number of accidents before speed changes, accidents; V_2 – the average speed after the introduction of changes, km/h; V_1 – the average speed before the introduction of changes, km/h.

At the same time, the dependence of the severity of the consequences on the change in speed was determined by the following formulas:

$$I_2 = I_1 * (V_2/V_1)^3 \tag{2}$$

I_2 – the number of accidents with injured after a change in speed, accidents; I_1 – the number of accidents with injured before the change in speed, accidents; V_2 – the average speed after the introduction of changes, km/h; V_1 – the average speed before the introduction of changes, km/h.

$$F_2 = F_1 * (V_2/V_1)^4 \tag{3}$$

F_2 – the number of accidents with fatalities after a change in speed, accidents; F_1 – the number of accidents with deaths before the change in speed, accidents; V_2 – the average speed after the introduction of changes, km/h; V_1 – the average speed before the introduction of changes, km/h.

These dependencies were refined [2] – the severity of the consequences depends on the initial velocity.

Of course, it is necessary to take into account that in urban conditions it is necessary to maintain a reasonable speed and take into account mobility. But considering only the effect of speed changes on the severity of the consequences and the number of accidents, we obtain the following data (see Table 1).

Table 2. The impact of speed changes on the severity of consequences from accidents.

V_2,km/h	80	70	60	50	40	30	20
A_2,accidents	17,8	13,6	10	6,9	4,4	2,5	1,1
I_2,accidents	23,6	15,9	10	5,8	2,9	1,3	0,4
F_2, accidents	31,6	18,5	10	4,8	2,0	0,6	0,1

Note: conditionally A_1 = 10 accidents, I_1 = 10 accidents, F_1 = 10 accidents, V_1 = 60 km/h - permitted speed according to the Traffic Rules.

3. The system approach to speed management in pedestrian crossing areas

Traffic calming measures have been applied for a long time. The range of technical methods and means of calming is extremely wide. It includes: channelization; chicanes; gateway treatments; intersection diverters; on-street parking; round-a-bouts; speed humps; speed tables; street closures; street design alterations; street narrowing; traffic controls; vehicle size restrictions and etc, including combinations.

However, it should be noted that Belarus is still taking the first steps to streamline the application of these measures and the calming zones development. For example, in Belarus there is only one ring of a small radius (the Vostochnaya street in Minsk).

There is no universal solution when we are choosing a safe speed. Effective speed control requires a comprehensive, systematic, step-by-step approach. The following combination of measures is most often used in the areas of pedestrian crossings [4,6].

Step 1. Setting limitations. Speed limits should take into account specific characteristics of the road network, be logical and understandable to road users.

Step 2. Informing about speed limits. Appropriate road signs and markings are used to implement this stage. Information on speed limits must be reliable and available under all road conditions.

Step 3. Application of measures of physical and psychological impact. To reduce the level of the conflicts danger between the traffic participants and reduce the speed apply some measures of physical impact in the approach to traffic calming:

- humps and bumps of various types and elevated sections of the carriageway (see Fig. 1);

Figure 1. The typical example of the hump's installation in Minsk, Belarus.

- dividing lines, street-refuges, narrowings of the carriageway, side reserve strips (see Fig. 2);

Figure 2. The typical example of the street-refuge's installation in Minsk, Belarus.

- zigzags and small-radius roundabouts (see Fig. 3);

Figure 3. The typical example of the small-radius roundabout's installation in Minsk, Belarus.

- combination of speed control measures.

Step 4. Application of video control and legal measures. Any restrictions should be monitored, and in case of intentional violations it is necessary to apply sanctions in accordance with the law.

Step 5. Informing drivers about the reasons for imposing limitations. Any limitations should be logical for each specific section of the road network and correspond to its characteristics. The introduction of measures from steps 1-4 to reduce the speed should be made available to the traffic participants, and it is also desirable to inform the drivers about it after the implementation of certain results.

3.1. The setting the speed limits

Until recently, the general approach for the introduction of speed limits, including pedestrian crossings, was the introduction of the V85 limit. V85 is a speed that does not exceed 85% of vehicles. In recent years, when choosing speed limits, we are based not only on the choice of the driver, but also on the analysis of the traffic situation and the characteristics of transport and pedestrian flows, especially on the biomechanical constraints of road users.

In Australia and the USA, the X-LIMITS approach is used to select the limit of speed limits. It consists in collecting data on the parameters of the carriageway, the characteristics of the transport and pedestrian flow (intensity, density, speed, intervals between groups of vehicles and pedestrians, etc.) and features of the site. Further, the obtained data is entered into the computer program and the recommended limit for the speed is calculated.

In Europe, the Vision Zero approach is used [8], [9]. It assumes that the upper the speed limit will be such that it is possible to exclude accidents with the dead and significantly reduce the number of accidents with the injured.

However, it is necessary to balance the safety, mobility and environmental impact of speed on the state of the environment. Speed should also reflect the function of the road. Table 3 presents comparative safe speed data for various sections of the road network in Sweden and Belarus.

Table 3. The speed at various sections of the road network.

Road type/traffic situation	Safe speed in Sweden (km/h)	Safe speed in Belarus (km/h)
Roads with potential conflicts between cars and unprotected road users	30	40 (20 for dwelling zone)
Intersections with potential side impacts between cars	50	60
Roads with potential head-on conflicts between cars	70	70
Roads where head-on and side impacts with other road users are impossible	≥100	90(120 for highway)

3.2. The informing about speed limits

First, any information on the limitation must be available to the driver under any road conditions. Secondly, any limits must be justified.

Traffic signs and markings are commonly used to inform about speed limits. Also, innovation systems can be used.

3.3. The application of physical and psychological impact measures

The speed of the road must match the category of street or road. In certain places - residential areas, pedestrian crossings, etc. - measures of physical and psychological influence are applied – humps or bumps, narrowing, street-refuges, rings of small radius, portal constructions, etc. Most European countries for such sites apply a speed limit of 30 km/h [11,12].

Physical impact measures are applied when entering a low-speed zone to adapt drivers to the proposed traffic conditions. Measures of psychological impact give the feeling to drivers that they enter the territory with special conditions.

Table 4 shows the relationship between the installation of unevenness in the pedestrian crossing zone and accidents.

It is known that the use of humps provides a reduction in the number of accidents both with victims and with material damage [3,10].

However, in the course of the research it was found an increase in accidents of varying consequence. This circumstance can be explained by the following reasons.

Firstly, there is no strict division into the local (residential, low-speed) and city-wide (trunk, high-speed) networks in many cities of Belarus. Many residential streets are used for transit, high-speed traffic - the differentiation of the road network is conditional. Because of this, the displacement of transit traffic from residential streets and its redistribution to high-speed streets (including continuous traffic) does not occur. It should be noted that the city streets are being reconstructed rather slowly. This does not provide a reduction in the accidents number with an increase in intensity.

Secondly, in some city where the streets have heavy traffic and the passenger traffic it has been achieved a sufficient reduction only for cars. In some cases, not only passenger transport did not reduce the traffic speed on humps, but also cars at the same time, studies have found that 6–10% of drivers do not make decisions on reducing their driving speed when driving through humps.

Thirdly, in some cases, humps are applied on highways with four or more lanes, where their use is clearly in contradiction with the fundamental tasks of road transport - improving the quality and reducing the cost of transport services, as safety, efficiency, environmental friendliness and sociology, but not only on safety. There were also cases of an increase in the accident rate due to a sharp deterioration in traffic conditions after a comfortable, high-speed traffic to the humps zone. It should be noted that today we are looking for other ways to improve safety, including reducing speed in certain places, within the required limits and at the right time, for example, with the help of flexible traffic light control with mandatory automatic video monitoring.

Table 4. The accident data on pedestrian crossings with humps (Belarus)

Locations	Years of the installation	the number of accidents	
		before the installing	after the installing**
		with injured / without injuries*	
2-lane streets			
Beloruskaya st., 15	2004	-	0/4
2nd Velosipedny lane, 30/2	2007	-	0/4
Yakubova st., 48/1	2009	-	3/3
Chervyakova st., 20	2011	0/0	2/4
Internationalnaya st., 25	2013	0/2	0/2
4-lane streets			
Ulyanovskaya st., 31	2010	-	1/4
Karastoyanova st., 21	2010	0/1	3/1
Kiseleva st., 4	2011	0/0	1/2
Promishleny lane, 12	2011	0/2	0/2
Angarskaya st., 12/1	2014	1/0	0/0
4-lane streets with a wide dividing strip (more than 10 m)			
Tukhachevsky st.- Zhilunovicha st.	2011	0/8	0/3
Komsomolskaya st. - K. Marx st.	2010	-	3/13
Shevchenko blvd., 18	2012	0/0	1/0
Kuleshova st., 2	2013	2/3	0/0
Centralnaya st., 1	2014	1/3	0/0
6-lane streets			
Plekhanova st., 72	2004	-	2/4
Gorodski Val st., 4	2007	-	1/3
Yakubova st., 58	2015	1/0	0/1
Selitskogo st. – Elnitskaya st.	2011	3/9	1/32
Varvasheni st. –Altaiskaya st.	2014	0/1	0/1

*- statistics for 3 years; **- statistics after the installing to 01.01.2018.

In addition, on such streets with medium and high load, there was an additional specificity associated with the formation and resorption of bloking before humps. This is due to the fact that the saturation flown on humps is significantly less than on a flat surface, respectively, 0.33 and 0.55 v/sec. When driving through the hump of dense packs of cars, the arrival interval of which is close to 2 second, and the departure interval is 3 second blocking is started. And in the presence of an unregulated pedestrian crossing near artificial irregularities, for the same reason queues are formed and grow noticeably faster, and they dissolve much more slowly. It causes traffic delays and additional stops (from a speed of about 20 km / h). There have been cases when a transport-pedestrian overload occurred on humps, causing the formation of long non-dissolving vehicle queues (from 10–15 minutes to several hours). These features exacerbated the process of interaction between traffic and pedestrian flows.

Fourthly, the hump forces drivers under the threat of loss of controllability or car breakdowns to forcibly and constantly reduce speed, regardless of the traffic situation. This causes objective disturbance of drivers and passengers, i.e. "Social" costs. In addition, the vigilance of drivers is dulled.

Fifthly, there are difficulties associated with the lack of an unequivocal priority of pedestrians when crossing the roadway through an unregulated pedestrian crossing. The transition of the roadway at a pedestrian crossing in the unregulated mode consists of three parts (stages) - the exit to the roadway, the intersection itself and the end of the crossing. The current Rules of the Road give pedestrians an advantage in two phases out of three, namely, in the actual transition and at the end of the transition. At the same time, a pedestrian can begin the transition of the roadway only when he is convinced of the safety of the exit, i.e. if he does not force the driver of the approaching vehicle to slow down or stop. Many pedestrians simply ignore this.

And in conclusion, it should be noted that it was established that the use of humps in historical trends in the reduction of accident rates was not secured.

3.4. The application of video control and legal measures

The video monitoring contributes to reducing the number of potential violators and has proven itself in many countries. When using the video control system, police control and the application of legal measures are intended to be used only in cases of intentional violations of limitations.

3.5. The informing drivers about the reasons for imposing restrictions

The effective way to reduce the speed in emergency sections of the road network is to inform the road users about the reasons for the limitations and the effect obtained from the measures taken. The explanation of the introduction of countermeasures helps to reduce the amount of intentional violations.

4. Conclusion

The traffic calming use provides of reduces the accidents level. In some cases, an increase in accidents was established due to various organizational and managerial causes in the Belarus conditions. There is also a need to assess the effectiveness of speed control measures, taking into account the traffic specifics in order to improve the overall traffic quality (safety, efficiency, ecological compatibility and sociology).It is necessary to exclude the use of humps on highways using alternative solutions. Also it is necessary to develop proposals for improving the Rules in terms of transferring priority from a pedestrian to the driver and vice versa.

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Investigation of tram movement indicators in general structure of traffic flow

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Abstract: In the work, the average operating speed of the tram is investigated on the sections with the high density of the road network. Such peculiarities are inherent to the cities where its configuration has developed historically, and trams move in the general structure of traffic flow which is predetermined by the absence of traffic capacity reserves in the old, as a rule, central part of the city. It frequently causes the reduction of the whole traffic flow speed of movement, in particular on the intersections and within public transport stops. Determination of the mutual impact of automobile movement and trams is topical because, on the one hand, trams, taking into account their dynamic and technological movement peculiarities, worsen traffic flow indicators, and on the other hand, vast traffic intensity causes downtime of the trams rolling stock in the queues before the intersection that decrease passenger transportation quality. As a result of the research reported in this paper it was managed to determine the amount of change of the average tram operating speed for different methods of traffic flow control for different times of day.

Keywords: traffic flow, traffic intensity, traffic composition, urban public transport, speed of movement, tram priority

1. Introduction

Combining of movement of automobile transport and trams on a common roadway cause significant reduction of speed of the last in comparison with their technic-operational characteristics and taking into account worn-out state and track facilities, the effectiveness of passenger transportation by them on such sections is quite low. For the old historical cities, the solving of this problem is the topical task because the development of electric transport network provides opportunity also to reduce environmental pollution of city air pool and, simultaneously, provide massiveness of passenger transportation.

With the aim to avoid the negative phenomena during the designing of road network elements where trams move in general structure of traffic flow and to improve the level of service on their junction sections (intersections), special attention is paid to: minimization of delays in tram movement, increase of safety and improvement of access to tram stops; minimization of delay for the other vehicles in mixed traffic [1-4]. Quite often the attention is paid to the reduction of signal delay and the diversity of priority traffic signal control [5]. Besides, to avoid problems with delays in traffic flow movement, in which trams move, such approaches are using as investigation of existing places of crowding of vehicles; determination of optimal configuration of tram network; investigation and analysis of

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forecasted delay of traffic light signals in transport systems with tram movement; analysis of maneuvers and conflict science on traffic lanes where trams move, optimization of tram stops location; optimization of traffic light control phases on controlled intersections and pedestrian crosswalks [1, 6–9]. As only base transport model which describes movement of trams in traffic flow is determined, it is necessary to have clear vision about the possible frequency of their appearance and distribution of other types of vehicles on the lanes of passing and oncoming traffic [10].

General delay before traffic lights on the routes of tram movement is connected with two separate phenomena. Firstly, traffic light delays are simple delays that appear because of big amount of vehicles which use the same lane as tram and connected with intersection capacity [1, 5, 11–13]. Secondly, delays can appear due to temporary crowding on tram lanes the other urban public transport (buses) that can have joint stops for boarding and alighting passengers [11–15]. From the results of research, increase of tram speed and reduction in delay on controlled intersections is maximum restriction of manoeuvres on lanes with their movement.

Priority traffic light control can take one of two forms – passive or active [7, 14, 16–18]. Passive traffic light control – is development of such control systems, where the direction (street or road) that serves tram movement always is given more green time in comparison with other conflicting directions. Such actions cause increase in movement of the whole traffic flow that move in given direction [16, 19]. During the active control or regulation in real time regime the phase of traffic light on direction that serves trams changes during its approaching to the stop-line.

Control systems in regime of real time that change traffic light signal depending from traffic intensity have high level of effectiveness on those directions where traffic flows have significant level of unevenness [20, 21]. The essence of the work of such systems is based on the mechanisms of determination of vehicle (in our case tram), i.e. its identification by detector during approaching to intersection. If the detector detected it during permissive (green) time than such time continues, if the time was restrictive (red) than traffic light makes a switch from red to green earlier than it is provided by control regime.

Important element for provision the reliability of traffic light system control with adaptive control systems is constant collection of initial information about traffic flow condition and based on this issuance of the final decision (control algorithm) [22, 23].

Such control is especially effective on arterial sections of the road network that serve intensive traffic flows with significant heterogeneity. Also, it is necessary to note that neither passive nor active control forms cannot be used on those sections of city streets and roads where coordinated control of traffic flow movement is functioning, because adaptive change of algorithm on one of intersections cause the destruction of principle of unhindered movement of traffic flow during the passing by it the other intersections that are connected in such system [13, 16, 24].

Under any circumstances if the increase the speed of intersection passage, where most often appear traffic flow delays, can be reached, then it can be argued that increase of effectiveness of transport system functioning is happen [25, 26].

2. Materials and Methods

One of the main factors which were measured in this research is the real-time of tram movement on the routes and its change due to created (planned) schedules.

For the investigation of existing movement conditions such methods were used:

- field research during the determination of traffic flow indicators and tram movement characteristics using surveillance cameras (carried out on the base of Center of traffic movement control of Lviv municipal enterprise “Lvivavtodor”);

- documentary research during analysis of reporting and statistical data received with the help of program software MicroGIS (carried out on the base of Center of traffic movement control of Lviv municipal enterprise “Lvivavtodor” and Lviv municipal enterprise “Lvivelectrotrans”);

- simulation of intersection passage with the help of program software PTV VISSIM for the analysis of existing state on the routes and creation the simulation model of road situation for the different time periods, when the change of traffic intensity takes place.

For determination of the effectiveness of pointed algorithms, application the investigation of tram movement indicators on the routes of the transport network of Lviv city is carried out. For this purpose, two types are chosen where:

- passage of controlled intersections is happening in result of traffic light cycle operation with the fixed time program control;
- passage of controlled intersection is happening in result of traffic light cycle operation with the fixed time program control with the use of tram search algorithms in traffic flow.

Field research on determination of effectiveness of traffic flow intensity were carried out during working days of the week (Monday, Wednesday and Friday) on the streets where tram routes are mapped with the aim of determining the change of this indicator during the day and also traffic flow composition (share of public transport, in particular trams).

During the documentary research, which was carried out simultaneously with the field research, the time of passage by trams the sections of the chosen route is determined which is received from statistical data that came to the Center of traffic movement control from GPS-receiver, and also the deviation from established schedules on every control point is determined

Traffic simulation was that into program software VISSIM the primary indicators of traffic intensity, traffic composition and speed of movement were entered that were determined during the field research with the aim of receiving the indicator of delay on route sections in the current state. Also, the situation of determining the change of possible time losses during the change of these primary indicators was simulated. Separate scientific approaches to the traffic flow simulation in the composition of which are trams are reviewed in the work [27]. Besides, using the methods of traffic simulation it can be possible to achieve high precision of delay minimization results in traffic flows.

3. Results

Let's carry out short analysis of the tram routes network in Lviv city (Table 1).

Table 1. Characteristics of tram routes network in Lviv city.

№ of the route	Initial stop	Final stop	Type of route	Length, m	Number of routes	Time in movement, min
1	Railway station	Saksahanskogo St.	Circular	7896	19	49
2	Konovaltsia St.	Pohulianka St.	Linear	14266	32	65
3	Soborna Sq.	Aquapark	Linear	11019	21	45
4	Promyslova St.	Arts Academy	Linear	9752	23	49
5	Aquapark	Promyslova St.	Linear	16151	35	76
6	Railway station	Mykolaichuka St.	Linear	11469	32	60
7	Tatarbunarska St.	Pohulianka St.	Linear	15054	30	68
8	Soborna Sq.	Vernadskoho St.	Linear	13981	57	29
9	Railway station	Center	Circular	8541	18	49
10	Railway station	Pohulianka St.	Linear	10343	29	64
11	Railway station	Center	Circular	10413	21	62

Routes №2 and №8 were taken into consideration. They differ by the mode of arrangement of tram tracks relative to the roadway, the number of trams on the route, time of work. Tram route №2 in general (approximately 80%) is laid out in such way that the trams move in general composition of traffic flow, at the same time on the tram route №8 nearly 70% from its length tramcars move separately from the rest of the flow. Such two routes were chosen with the aim of comparison travel time between the stops due to the established schedules, choose the main indicators which impact on speed regime, analysis of received indicators of the average speed etc.

During the carrying out of these research one of the main tasks was to collect information about existing condition of transport network; investigate the influence of general traffic flow on tram movement on the routes №2 and №8; determine the quality of service provision which includes the evaluation of operation performance indicators on sections of pointed routes, execution of daily transportation plan and provision the precision in movement. Also, the important task is to investigate how the operation of algorithms of the automated system of traffic flow control impacts on indicators of effectiveness of transport system functioning from the principle of optimization for the criteria of delay minimization by the way of comparing these indicators for tram routes №2 and №8.

According to research results, carried out in program software MicroGIS, it is received “stadiums of movement” which allow carrying out tram movement indicators monitoring as on the separate route sections and on the whole its duration. Typical appearance of such “stadium of movement” for the route №2 is given on Figure 1. Using this data, it is determined the planned and actual arrival time to the stopping point with the determination of deviation in schedules; speed and time of movement between stops. Together with available information about traffic flow intensity in which moves the tram, the number of junction points (intersections), which it passes, and the way of traffic light system control (fixed-time or adaptive) on them, and also fixed size of passenger flow for the determined period, it can be determined factors which mainly impact on tram movement regimes.

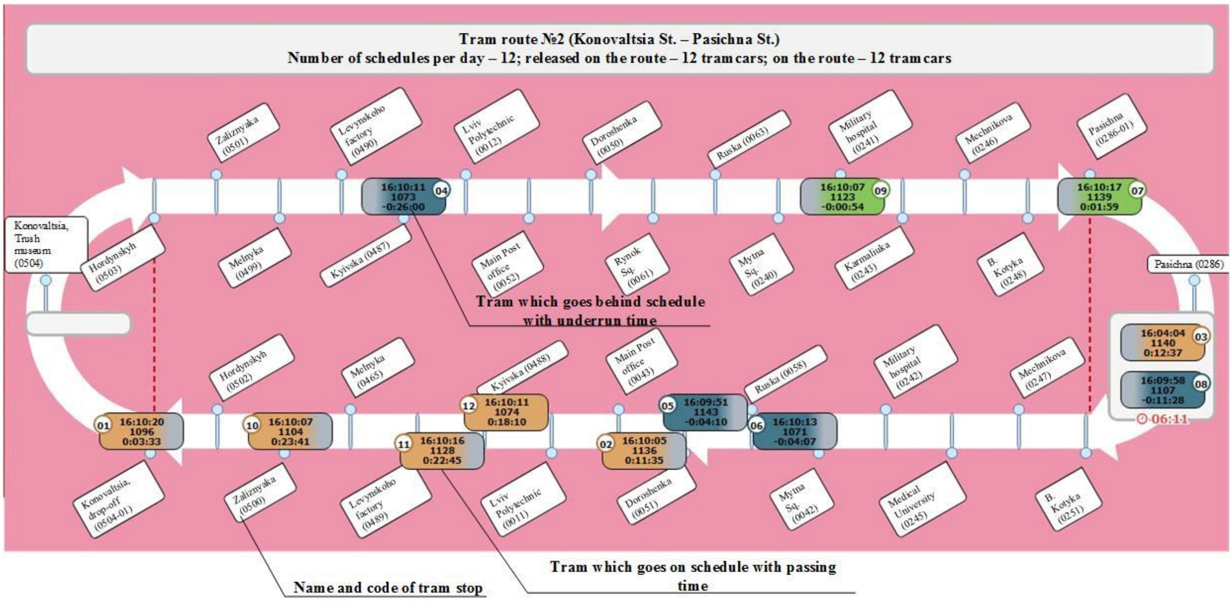

Figure 1. General view of interface in specialized program software “Ukrainian geoinformational systems”, where monitoring of “stadiums of movement” is performed.

Such specialized program software is designed for improvement of visual monitoring of trams movement on the route where by the green color are marked trams that move due to established schedule, by the brown color – move with slight deviation from the schedule with pointing the time of such deviation; by the blue color – move with significant deviation (time of deviation also points). If to the color of those trams that late relative to the established schedule grey background is added, then this means that tram moves in a special regime. The special regime can be used in cases when city events are held, traffic accidents occur, repair works are being carried out on the lines etc.

Important practical value of program software MicroGIS is in the fact that the final specified results of monitoring are displayed on ultimate consumers (citizens, tourists etc.) on the means of cellular communication.

Results of monitoring were recorded into research protocol that looks like Table 2.

Table 2. Protocol for recording the monitoring results of tram movement indexes on the route.

№ of record	Name of stopping point (its number in database of ASCTM)	Distance between stopping points, m	Time of movement between stopping points, min	Speed between stopping points, km/h	Arrival time on stopping points		Deviation	
					planned	real	passing	underrun
1								
2								
…								
n								
Average value of index								

Observation for realization the transportation by urban public transport (UPT) (in our case it is tram) and its control performs the Department of operational response. According to received information it is carried out its processing and making a decision due to the situation which is on the route. The key tasks of the Department are service of traffic light objects in Lviv city which are on balance of the enterprise and monitoring the UPT and formation of daily work reports.

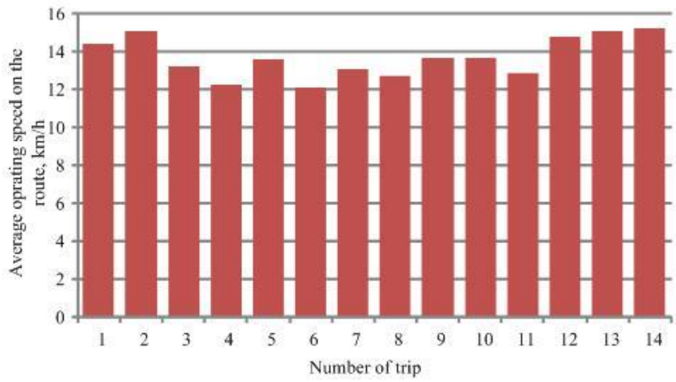

Figure 2. Change of the average operating speed of movement during the day on tram route №2.

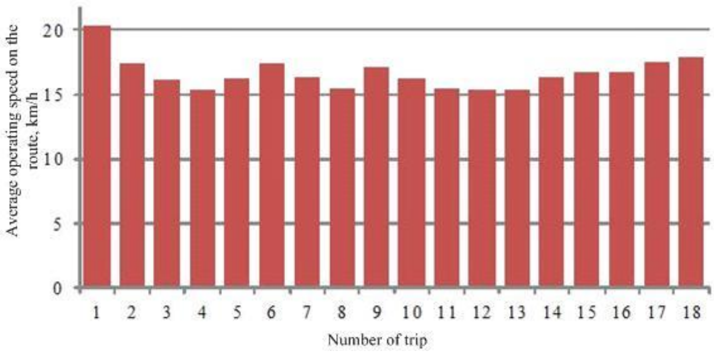

Figure 3. Change of the average operating speed of movement during the day on tram route №8.

Having processed the data of measurement the average operating speed of movement on the chosen tram routes during the workday, it is received such their distribution for every trip of routes №2 (Figure 2) and №3 (Figure 3).

On the tram route №2 the average operating speed during the day is about 12 km/h. The highest its value in the trip is observed in the morning period from 06:30 to 08:20 and in the evening period 20:10 to 22:27 that is nearly 15 km/h. General speed fluctuations during the work of the route ± 3–4 km/h.

Average operating speed during the day on the tram route №8 is about 16 km/h and its maximum value is observed from 06:08 to 06:40 and is about 20 km/h. The lowest average operating speed in 15 km/h is recorded in the period of the morning and evening peak hours. General fluctuations of the average operating speed during the work of the route ± 4–5 km/h.

Based on this, it can be said that the general increase in the average operating speed of tram providing the construction of tramway separately from the roadway gives the increase of its value in 4-5 km/h even in the case when all intersections, through which lays the route, are in one level. Such a conclusion takes into account the fact that the passenger flow on both routes has not been measured but the time of tram at the stop was nearly the same.

Also, it was managed to carry out the monitoring of the average operating speed of movement depending from the length of the section (distance between the stops) on both investigated routes, results of which are given on Figure 4 and 5.

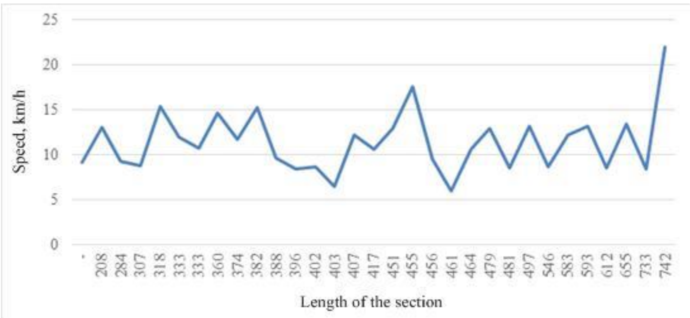

Figure 4. Change of the average operating speed from the length of the section on tram route №2.

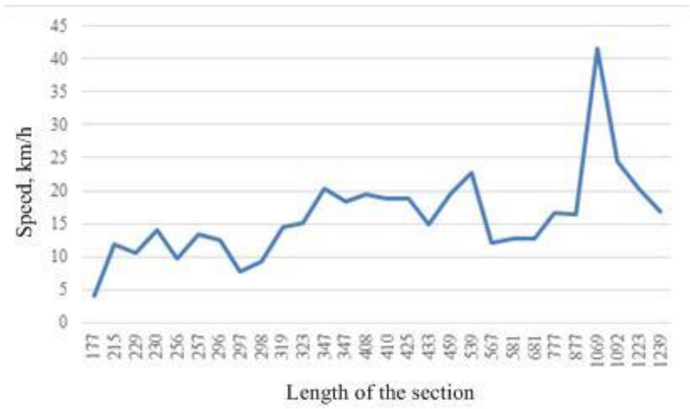

Figure 5. Change of the average operating speed from the length of the section on tram route №8.

From the given figures it can be made a conclusion that providing trams movement in general structure of traffic flow (Figure 4) its average operating speed almost has not some typical tendency of change than in the case when trams move separately by allocated tramway (Figure 5). These graphs represent the amount of mutual influence of tram and traffic flow.

4. Discussion

During the documentary research, the data was received about the average operating speed of trams on tram route №2 before implementation the system of automated control of movement (adaptive control on controlled intersections with the provision of tram movement priority) and compare them with analogical values of its indicator in conditions of operation such system. Distributions of these speeds are given on Figure 6.

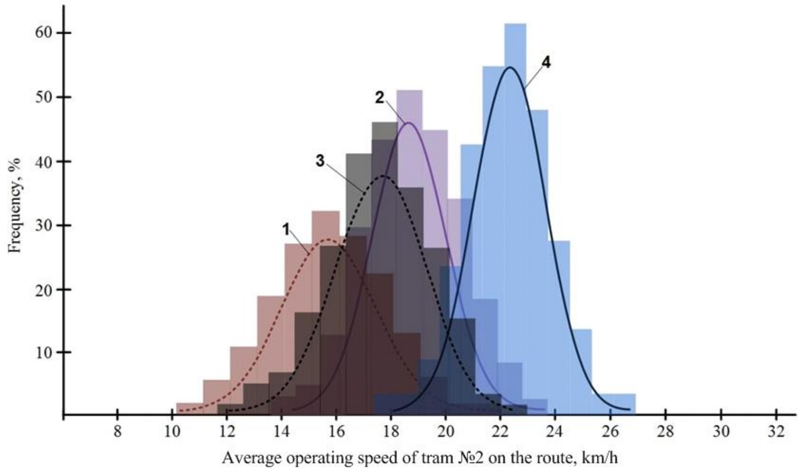

Figure 6. Distribution of average operating speed on tram route: 1 – operation of route in peak period before ASCTM implementation; 2 – operation of route in off-peak period before ASCTM implementation; 3 – operation of route in peak period after ASCTM implementation; 4 – operation of route in off-peak period after ASCTM implementation.

Research results certify that difference in average operating speed for peak and off-peak periods is 17–26%. Taking into account the fact that before implementation ASCTM and after such a difference is almost the same, we can receive the impact of change of traffic volume on tram operation index. Besides, general effect from implementation ASCTM gives growth of average operating speed on the route approximately on 13% for peak and approximately on 22% for off-peak periods. Based on this, conclusion can be made that during observance the certain constant interval in movement on the route implementation of ASCTM provides opportunity to release some amount of motive power of trams, and general effect for streets on which goes the route is increase of capacity because for such their (streets) parameters (1x1 lane) vehicles follow behind tramcar.

During the simulation 4 sections on city streets with 1x1 lanes were chosen, on which tram route №2 goes, with the possibility to pass the tram from the right side, that is tramways are laid on the axis of the street. Percentage of UPT in the flow on pointed sections was on section 1 – 7%; on section 2 – 5%; on 3 – 6%; on 4 – 5%. Trams share in traffic flow composition was about 2%. All other vehicles are automobiles. On all sections in specialized program software PTV VISSIM simulation of change the average connection speed for all vehicles was carried out for the condition that the share of UPT increased in comparison to existing on 5, 10, 15, 20 and 25%. Results of simulation are given on Figure 7.

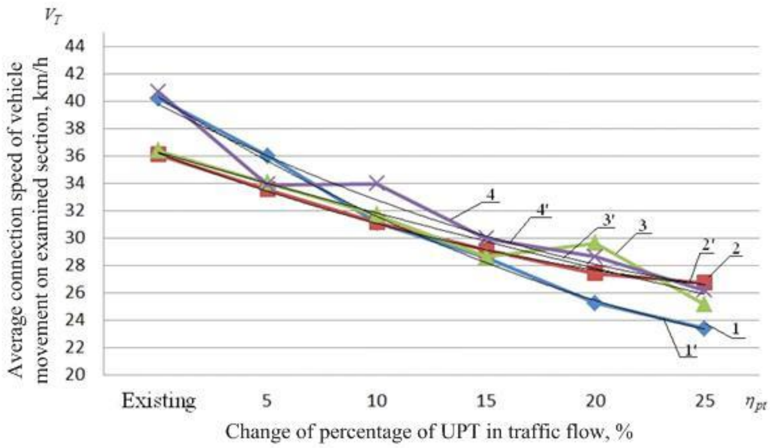

Figure 7. Change of the average connection speed of vehicle movement on investigated sections depending from increase of UPT share in traffic flow composition.

On given figure, under numbers 1, 2, 3, 4 simulation results, which were get in software environment VISSIM for examined sections, are marked, and 1', 2', 3', 4' are trend lines of these results change.

5. Conclusions

For the results of the investigation it is determined changes in time losses of tram movement on different sections of the road network, expressed by the change of the average operating speed and delay in traffic flows. Separated tram movement by the allocation of separated tramway gives the growth of the average operating speed on 4-5 km/h. Application of adaptive control on controlled intersections which operates by the principle of giving the priority in the movement to the tram increases the average operating speed on 3-4 km/h in comparison to fixed-time program control in conditions of its movement in the general structure of traffic flow.

On the other hand, increase of UPT share (including trams) by 25% causes sharp decrease of the average connection speed for all vehicles in the flow by 30-40%.

Such research can be the reasoning for redevelopment the routes of UPT, giving it the priority with the aim of increase the effectiveness of transport system functioning in historical cities.

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The analysis of influence of a nozzle form of the Bernoulli gripping devices on its energy efficiency

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Abstract: This article presents the advantages of using Bernoulli gripping devices in the transport and loading systems of the automated production. It provides the modeling of air flow dynamics in a nozzle and in a radial interval between the interacting surfaces of Bernoulli gripper and object of transportation. For this purpose we use averaging on RANS equation of dynamics of viscous gas, SST-model of turbulence and γ-model of laminar and turbulent transition. As a result of the study, this paper offers options of constructive improvement of a nozzle form and conditions for the analysis of energy efficiency of Bernoulli gripper. The theoretical contribution of this paper is that, as a result of numerical modeling in the program Ansys-CFX environment, the influence of the nozzle form in the Bernoulli gripping devices' on its carrying power, account characteristics, and energy efficiency has been determined.

Keywords: Bernoulli gripping device, object manipulation, nozzle, radial flow, industrial robot, RANS, SST-model of turbulence.

1. Introduction

In the transport and loading systems of the automated production of broad application devices which use power effect proceeding from a screened nozzle of air flow became widely used [1-7]. The nature of interaction of air flow with cargo depends on many parameters that allows to use positive effects of this interaction for various tasks: to hold cargos by means of an aerodynamic attraction; without contact to transport cargos on a pneumatic pillow; to use reactive force and force of viscous friction for orientation of objects of transportation. The combination of these effects of interaction allows to create essentially new devices for contactless gripping, orientation and transportation of objects of production. It is easy to integrate additional functions of pneumatic control of a number of parameters of objects of transportation into these devices.

Now the greatest distribution was gained by Bernoulli gripping devices (BGP), using aerodynamic effect of an attraction (Bernoulli's effect) [1-7]. The main difference of BGD from other grippers is the lack of mechanical contact (or the minimum contact piece) with surface of the object of manipulation (OM) that is important during the work from easy deformed, fragile, heated or objects with external coverings, unstable to attrition. Now BGD are widely used in the radio-electronic industry for manipulation of semiconductor plates, solar elements and printed circuit boards [8]. Application of BGD in polygraphy at production and the subsequent use of lithographic printing forms [9] is also known, in

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the food industry for manipulation of cut meat [10] and vegetable [11] plates, in the textile industry [12]. There is a wide prospects of application of BGD in pharmaceutical industry.

It is most of all investigated and introduced on production BGD with cylindrical or circular nozzle and vortex grippers. For the purpose of minimization of energy consumption of Bernoulli gripping device when performing handling operations by authors of the article the method of optimization of gripper orientation in the course of manipulation was developed. The method of optimization of Bernoulli gripping device orientation when performing transport operations on a rectilinear and arc trajectory is provided in the articles [13-14]. Influence of force of front resistance of Q1, Q2 on the minimum necessary lifting force is investigated in article [15]. The description of experimental installation and the analysis of the received experimental results on application of a method of optimization of Bernoulli gripping device orientation is described in the paper [16]. Gasdynamic analysis of the Bernoulli grippers interaction with the surface of flat objects with displacement of the center of mass carried out in [17-18]. Also authors in the article [19] deals with the topical issue of reducing energy consumption for transportation of industrial objects. The energy efficiency of the process of objects manipulation with the use of the orientation optimization method while gripping with the help of different methods has been studied. The economic efficiency of the use of the optimal orientation of Bernoulli gripping device while transporting the object of manipulation in comparison to the transportation without re-orientation has been proved. Influence of parameters of a gripping system on power expenses of the industrial robot during transportation is investigated in article [20]. The dynamics of the air flow between interacting surfaces of Bernoulli-Vacuum gripping device and object of manipulation is analyzed in article [21].

The analysis of publications shows that the problem of optimization of a design of Bernoulli gripping devices is relevant and expedient, considering expansion of the sphere of their use in productions. It is insufficiently studied and demand a further research of a condition and dynamics of a gas flow in a nozzle and in a radial interval between the interacting surfaces of BGD and OM, methods of increase in energy efficiency of these devices due to optimization of their design parameters.

In this article we will consider influence of a form of a nozzle of the BGD on its operational characteristics. For the solution of an objective we use approaches of hydrodynamics computation and information technologies for imitating numerical modeling by the finite element method (FEM). FEM allows to define distributions of pressure, speeds with high precision, to receive lines of a current and other parameters of flows.

2. Methodology

The principle of work of BGD consists in the following. Compressed air through nozzle 1 of the the Bernoulli gripping device (Figure 1) via nozzle 2 by radius rn follows into the camera between its face surface and the surface of OM 3. At the same time on r_n radius, at $h_c<r_n/2$, the stream experiences the biggest narrowing. In the place of the biggest narrowing, with excessive pressures of food of gripper by compressed air more than 30 kPa, the stream reaches critical speed, equal to acoustic speed for these conditions. As a result of further increase in the area of radial stream, its supersonic speed grows, and the static pressure upon surface of OM decreases to size smaller than atmospheric.

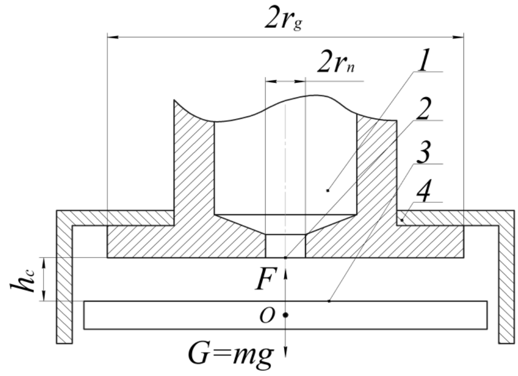


Figure 1. Constructive scheme of BGD.

At some distance from the center of nozzle there is hard braking of supersonic stream, to the subsequent its transition in subsonic that is followed by formation of pressure jump. As a result of further of times expansions the speed of subsonic stream falls, and static pressure in spacing slowly increases up to the size of atmospheric pa. Action of depression on surface of OM leads to its levitation. Side offset of OM prevent thrust blocks 4.

Key parameters which influence the most on power and account characteristics of the BGD are an air pressure in camera 1, nozzle radius r_n, outer radius of capture r_g and distance of h_c from edge of a nozzle to OM.

The mathematical model of course of air in radial interval between the interacting surfaces of BGD and OM is based on Navier-Stokes's (Reynolds averaged Navier-Stokes equations) equations (RANS) average according to Reynolds [22, 23]. For carrying out modeling the SST-model of turbulence [24] and γ-model of laminar and turbulent transition are used [25].

γ-model of laminar and turbulent transition is described by one differential equation for intermittency coefficient γ:

$$\frac{\partial(\rho\gamma)}{\partial t}+\frac{\partial(\rho V_j\gamma)}{\partial x_j}=P_\gamma-E_\gamma+\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\gamma}\right)\frac{\partial\gamma}{\partial x_j}\right] \tag{1}$$

where ρ - air density; t – time; x – coordinate; V – vector of air velocity; P_γ, E_γ - respectively generative and dissipation members of managing directors of laminar and turbulent transition; μ - molecular dynamic viscosity of gas; μ_t - turbulent dynamic viscosity of gas; $\sigma_\gamma=1.0$ - model constant.

In γ-model of transition use the modified equations of the SST-model:

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_j}(\rho V_j k)=\tilde{P}_k+P_k^{\lim}-\tilde{D}_k+\frac{\partial}{\partial x_j}\left((\mu+\sigma_k\mu_t)\frac{\partial k}{\partial x_j}\right) \tag{2}$$

$$\frac{\partial}{\partial t}(\rho\omega)+\frac{\partial}{\partial x_j}(\rho V_j\omega)=\alpha\frac{P_k}{\nu_t}-D_\omega+Cd_\omega+\frac{\partial}{\partial x_j}\left((\mu+\sigma_\omega\mu_t)\frac{\partial\omega}{\partial x_j}\right) \tag{3}$$

$$\tilde{P}_k=\gamma P_k \tag{4}$$

$$\tilde{D}_k=\max(\gamma,0.1)\cdot D_k \tag{5}$$

$$\mu_t=p\frac{a_1\cdot k}{\max(a_1\cdot\omega,F_2\cdot S)} \tag{6}$$

$$S_{ij}=\frac{1}{2}\left(\frac{\partial V_i}{\partial x_j}+\frac{\partial V_j}{\partial x_i}\right);\quad S^2=2S_{ij}S_{ij} \tag{7}$$

where k - kinetic turbulent energy; ω - the specific speed of dissipation of kinetic energy of turbulence; P_k, D_k - original generation and dissipation of the SST model; $P_k^{\lim}$ - the additional part, which provides the correct gain of turbulent viscosity in transitional area at very low level of turbulent viscosity of the running stream; ν_t - turbulent kinematic viscosity of gas; σ_k, α, a_1 - empirical constants of model.

The generative member in the equation (1) looks like:

$$P_{\gamma} = F_{length} \rho S \gamma (1-\gamma) F_{onset} \quad (8)$$

where F_{length} is empirical correlation which controls length of the transitional area (accept F_{length} = 100); F_{onset} is the function controlling the provision of the beginning of transition.

Dissipation member which is responsible for arelaminarization:

$$E_{\gamma} = c_{a2} \rho \Omega \gamma F_{turb} (c_{e2} \gamma - 1) \quad (9)$$

where c_{a2}=0.06, c_{e2}=50 – empirical constants; $\Omega = \sqrt{2\Omega_{i,j}\Omega_{i,j}}$ - invariant of the tensor of vorticity; $F_{turb} = e^{-\left(\frac{R_T}{2}\right)^4}$; $R_T = \frac{\rho k}{\mu \omega}$.

The provision of the beginning of process of laminar and turbulent transition is controlled by the following functions:

$$F_{onset1} = \frac{\mathrm{Re}_v}{2.2\,\mathrm{Re}_{\theta c}}, \quad \mathrm{Re}_v = \frac{\rho d_{\omega}^2 S}{\mu}; \quad (10)$$

$$F_{onset2} = \min(F_{onset1}, 2.0); \quad (11)$$

$$F_{onset3} = \max\left(1 - \left(\frac{R_T}{3.5}\right)^3, 0\right); \quad (12)$$

$$F_{onset} = \max(F_{onset2} - F_{onset3}, 0); \quad (13)$$

where d_{ω} - distance to the next wall.

The value of a critical Reynolds number of an impulse loss $\mathrm{Re}_{\theta c}$ is calculated with the help of an algebraic ratio with use of local variables [25]:

$$\mathrm{Re}_{\theta c} = f(TU_L, \lambda_{\theta L}). \quad (14)$$

Generation of P_k is counted by means of a formula Kato-Launder:

$$P_k = \mu_t S \Omega. \quad (15)$$

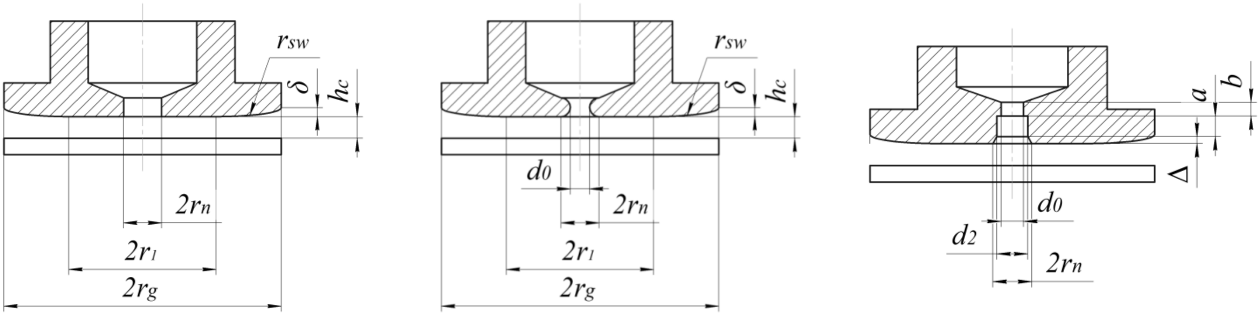
The additional member $P_k^{\lim}$ is defined as follows:

$$P_k^{\lim} = 5C_k \max(\gamma - 0.2, 0)(1-\gamma) F_{on}^{\lim} \max(3C_{SEP}\mu - \mu_t, 0) S\Omega;$$
$$C_k = 1.0, \quad C_{SEP} = 1.0; \quad (16)$$

$$F_{on}^{\lim} = \min\left(\max\left(\frac{\mathrm{Re}_V}{2.2 \cdot \mathrm{Re}_{\theta c}^{\lim}} - 1, \ 0\right), 3\right); \quad \mathrm{Re}_{\theta c}^{\lim} = 1100. \quad (17)$$

3. Results and discussions

The attractions of an object of manipulation by Bernoulli gripper are connected with a formation of object of depression zone on the surface. However, opposite to a nozzle the zone of the excessive pressure which is using the force on OM repellent is formed and leads to decrease in loading capacity of the BGD. Minimization of this force requires special profiling of a nozzle of the BGD. For this purpose, except a cylindrical nozzle, two cases of special configuration are considered, presented on Figure 2. Diameter of a bottleneck of the rounded-off or step nozzle should be chosen from a condition that the area of its section $\pi d_0^2/4$ was on 30... 50% are more than the area of critical section $S^* = 2\pi r_n h_c$.



a) b) c)

Figure 2. Options of design snuffled the JGD: a) cylindrical nozzle; b) rounded nozzle; c) stepped nozzle with a conic facet.

Unlike Figure 1 instead of a flat active surface of BGD the combination of a flat and toroidal surface is used. Such profiling of an active surface of the BGD will allow to reduce losses of energy of a flow by viscous friction in radial an interval and to increase extent of expansion of air flow. As a result, the size of a supersonic zone of depression will increase by surfaces of OM and depression size in a subsonic zone, will increase power characteristics of BGD on 50...70%. Generally attraction force power of Bernoulli gripping of an object of manipulation is defined by integration of distribution of depression $(p_a - p_r)$ in radial an interval:

$$F = 2\pi \int_0^{r_g} (p_a - p_r)\, r dr. \tag{18}$$

where p_r – an absolute air pressure in the radial gap of the radius r.

For definition of distribution of pressure upon surfaces of object of manipulation numerical modeling of the BGD with such geometrical parameters is carried out: external BGD radius r_g=30 mm, nozzle radius r_n=3 mm, diameter of the smallest section round and stepped of nozzle of d_0=2.5 mm, height of radial interval of h_c=0.2 mm, width round ache facets δ=0.3 mm, radius r_1=12 mm. For a stepped nozzle: d_2=4 mm, Δ=0.4 mm, a=3.6 mm, b=2 mm.

Numerical modeling was carried out in the environment of computing hydro-gas dynamics by Ansys-CFX with use of SST of γ-model of turbulence. For carrying out calculations means this program environments in settlement area have constructed unstructured final and differential grid. The total number of knots in settlement area makes 3 million. Knots of grid are united in volume elements (tetrahedrons and prisms). Total number of volume elements of grid it is equal to 7 million. The total number of tetrahedrons makes 3 million. As material are used air as ideal gas from libraries of the program. Boundary conditions for model of air flow are presented on Figure 3.

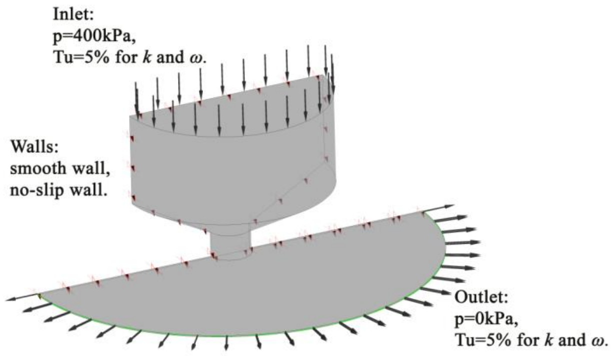


Figure 3. Extreme conditions for air flow model.

By the results of the executed calculations with use decisive the sonicTurbFoam module (for turbulent streams of the compressed gases moving with sound and supersonic speeds) schedules of distribution of pressure upon surfaces of OM have been constructed (Figure 4).

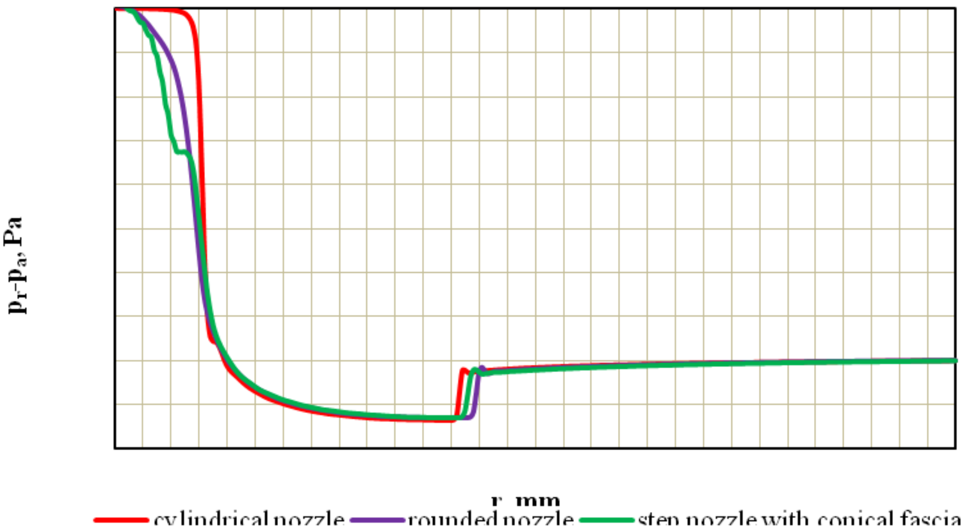


Figure 4. Schedules of distribution of pressure upon surfaces of object of manipulation for various options of design of BGD.

The fluid value of a radial interval h_c has more significant effect on distribution of pressure upon surfaces of an object of manipulation and resultant loading capacity of the BGD and also on a consumption of compressed air. For identification of nature of this influence modeling of dynamics of a flow for number of fixed values of radial gaps is carried out. Thus, here is obtained data on distribution of pressure upon surfaces of OM and a consumption of compressed air for various options of design of BGD at various values of radial gaps. It is carried out calculations of force of an attraction of an object of manipulation of Bernoulli gripper. Results of modeling and additional calculations are presented on Figure 5, 6.

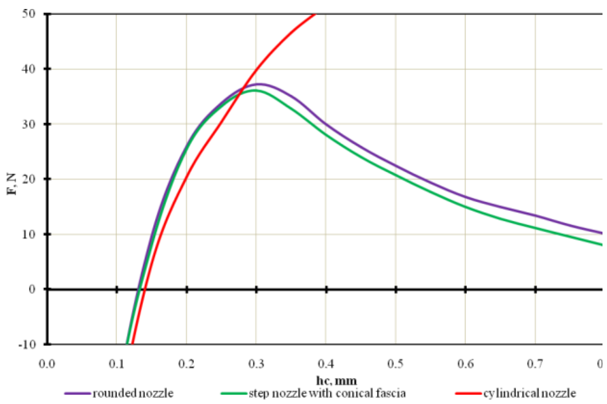


Figure 5. Dependence of the attraction force of an object of manipulation on the magnitude of the radial gap

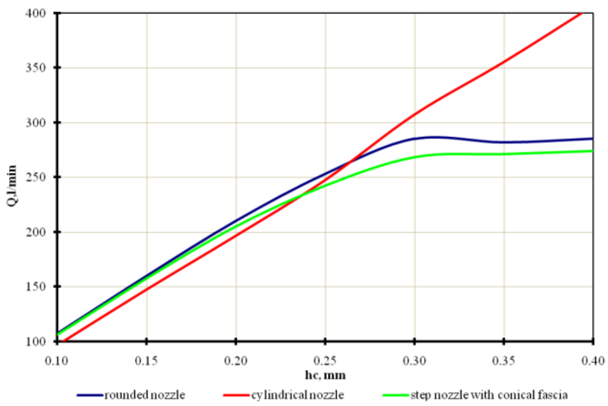


Figure 6. The dependence of the volumetric flow of compressed air on the size of the radial gap

The analysis of Figure 6, 7 proves the efficiency of the use of BGD with rounded and stepped nozzles in the range of radial gaps h_c=0.15...0.25 mm.

For a detailed analysis of the energy efficiency of the BGD in a static mode, when the object of manipulation is already gripped and occupies a fixed position, it is expedient to use the K_{ef} [N/W], which characterizes the ratio of the magnitude of the force of attraction F to the power consumption E

$$K_{ef} = F/E \tag{19}$$

$$E = p_a Q \ln\left(p_0 / p_a \right), [26] \tag{20}$$

where Q is the volume of air flow, brought to normal conditions; p_0 - excessive pressure of the BGD power supply.

The results of calculating the K_{ef} by the formulas (19, 20) and Figure 5, 6 is shown in Figure 7.

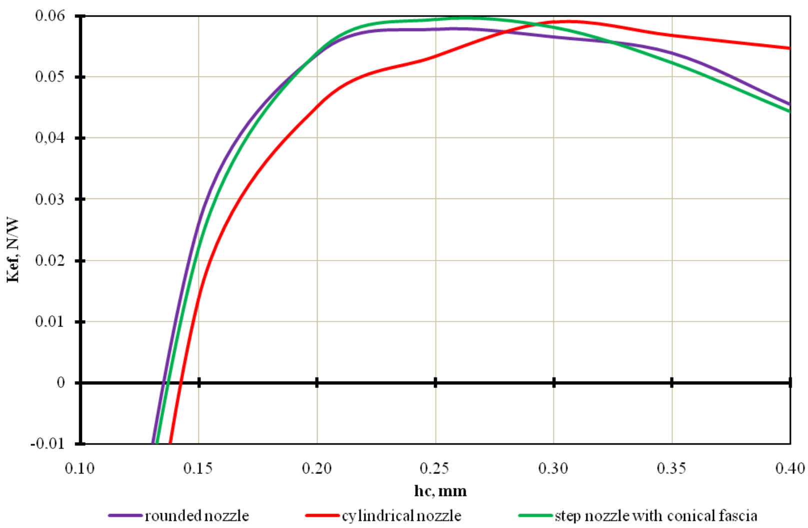


Figure 7. Dependence of K_{ef} on the magnitude of the radial gap for the BGD with different nozzle forms.

Thus, JGD with stepped nozzle and conical fissure reaches the highest energy efficiency in the range of radials hc=0.2...0.3 mm, the gripper with a rounded-off nozzle - at hc<0.2 mm, and a gripper with a cylindrical nozzle - at hc>0.3 mm. However, BGD with a cylindrical nozzle at hc>0.3 mm is inappropriate to operate due to the significant increase in the cost of compressed air. In addition, the highest stability of contactless holding of Bernoulli grippers of objects of manipulation is achieved when the equilibrium position of the trapped object corresponds to radial gaps hc=0.15...0.25 mm [17, 18].

Therefore, in order to increase energy efficiency of the BGD, it is necessary to minimize the energy loss of the air flow at the inlet to the nozzle, when the flow of the radial gap between the active surfaces of the gripper and the object held by it and the loss of the viscous friction in the radial gap is minimized.

4. Conclusions

The mathematical dependences for numerical simulation of the air flow dynamics in the nozzle of the Bernoulli gripping device and in the radial gap between its active surface and the surface of the object of manipulation are presented.

The variants of improvement of the shape of the Bernoulli nozzle gripping devices of industrial robots are offered. It is established that when using the Bernoulli gripper of a rounded or stepped nozzle with a tapered facet in the construction, the excess pressure on the surface of the object of manipulation in the area opposite the nozzle is reduced and the width of the supersonic zone of dilution increases. This allows you to increase the lifting capacity of the Bernoulli gripper by an average of 26%.

The dependences for calculating the energy efficiency of Bernoulli grippers in static mode are presented. It has been found that jet nozzles with rounded nozzle achieve the highest energy efficiency at radial intervals smaller than 0.2 mm, and grippers with a stepped nozzle and conical faces - in the range 0.2...0.3 mm. The highest stability of contactless gripping by Bernoulli grippers of objects of manipulation is achieved when the equilibrium position of the gripped object corresponds to radial gaps of 0.15...0.25 mm.

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Ensuring effectiveness in handling the movement of goods and passengers by enhancing information and communication technologies

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Abstract: The purpose of this paper is to propose measures for maximum practicable use of information and communication technologies in Ukraine while on cross-border movement of goods and means of transport. For today Ukraine has been intensively implementing the Single Window system, almost completely switched to electronic declaration as well as electronic submission of the documents and information required for official controls of goods belonging to entities or self-employed persons. A passenger declaration, filled out in advance and sent to customs authorities, for goods in accompanied/unaccompanied baggage or freight shipment can also significantly simplify procedures at a border crossing. The effectiveness of the measures proposed is proved using system analysis of well-structured problem by applying critical path method in a PERT diagram and Monte Carlo method for determining optimal time characteristics of handlings. Modeling alternative sequence scenarios of the process of customs clearance at the customs offices of departure and destination allows determining additive components of the total delivery time within customs territory of Ukraine. The scenarios include improvements in Single Window system, establishment of information and communication system for e-declaration of natural persons' goods and currency valuables. In this regard, first and foremost, experience of different countries on these issues as well as organisational, legal and technical difficulties are analyzed, and then directions for the development are outlined using mini-Delphi approach. In summary, the theoretical relevance of the research lies in the development of the mathematical model for the processes described, practical application of the improvements will reduce delays and additional delivery costs.

Keywords: passenger transportation, delivery of goods, border crossing, single window, e-declaration.

1. Introduction

According to the provisions of the Kyoto Convention «simplification and harmonization can be accomplished by applying maximum use of information technology» [1]. In Ukraine electronic declaring for goods is carried out using electronic customs declaration, certified by electronic digital signature, and other electronic documents or their details to the extent permitted by applicable law (paragraph 2, Article 257 of the Customs Code of Ukraine (CCU), 2012). By paragraph 4, Article 257 of the Code an accredited key certification centre has been set up in the system of the central executive body that ensures the formation and implementation of the state tax & customs policy. The centre provides all the necessary services, concerning electronic digital signature, free of charge to the territorial bodies at the regional and local levels and enterprises. The format of customs declarations submitted as electronic

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documents is based on international electronic data interchange standards (paragraph 5, Article 257 of the CCU). The additional information required for the identification of goods is filed into the electronic invoice, which is added to the customs declaration [2, 3].

Customs clearance begins at the moment a customs declaration is filed by a declarant, as well as documents for processing and the goods selves. In other words a local contract holder or his authorized representative makes a statement of accurate and reliable information about the goods, the purpose of crossing the customs border of Ukraine and other information necessary for customs supervision. The goods must be declared no later than within 10 days from the moment of their delivery to the customs office of destination or placed in a temporary storage warehouse (or customs warehouse) [2]. However, in practice, it is not all that simple. The customs clearance of each item of goods requires an individual approach, perfect knowledge of the customs, tax and currency legislation of Ukraine, the nuances of processing a range of documents, the ability to interact with customs and other regulatory bodies. Depending on the customs procedure, under which this or that product is placed, and special aspects of crossing the customs border of Ukraine the optimal pattern of its customs clearance, the procedures for filing and filling in documents, calculating customs payments, determining non-tariff regulation measures and the country of origin are defined. All the details of sales agreement are scrutinized. The customs authorities have to verify the accuracy of the customs declaration and preferential documents. For that purpose they may initiate a goods examination. One of the key tools for simplifying their task and facilitating cross-border trade is to harmonize the work of all government agencies that provide permits for the import and export operations. They are veterinary and sanitary agencies, phytosanitary agencies, state agencies monitoring compliance with food laws, certification authorities and so on [4, 5]. Moreover some products are subject to export or import licensing [6]. Licenses or approvals are issued by state bodies such as Ministry of Economic Development and Trade, Regional Administrations, State Service of Ukraine on Medicines and Drugs Control, Ministry of Agriculture and Food Industry, Ministry of Health and others [7]. A listing of documents required for customs clearance depending on transport mode is defined by Article 335 of the CCU. Also documents to determine the custom value of goods and additional documents specified by the applicable legislation of Ukraine have to be submitted. Because of the constant and swift changes of required documents, competent authorities, customs procedural formalities in Ukraine foreign exporters are advised to vest customs clearance as contract liabilities of the Ukrainian trading partner [8]. Obviously, the availability of exhaustive information on arrangements for a product import/export and the simplicity in submitting accompanying documents can significantly shorten transaction time. The research dwells upon the results of relevant initiatives in Ukraine and development of a model that allows estimating efficiency for improvements proposed by experts.

2. Materials and Methods

Analysing arrangements for the Single Window system in different countries. The World Trade Organization and the World Customs Organization comprehensively encourage the introduction of state control of goods on the basis of the Single Window principle, through which the trade operator can quickly obtain all the permits necessary for the movement of goods. Positive experience of implementing the Single Window system already exists in many countries [9-13]. A striking example of the early introduction of the Single Window is *Singapore*. Launched on Jan. 1, 1989 Singapore TradeNet System became the first national electronic trading document system in the world and linked several government agencies. In 2007 a new TradeXchange platform was introduced that facilitated the exchange of logistic and commercial information for parties from the public and private sectors and offered additional services for managing supply chains, filling out documentation, trade financing and insuring. For now all TradeXchange e-services have been migrated to the Networked Trade Platform [9]. The system is paid and based on monthly fees and transaction fees. Presently, 10 minutes after submission of documents, traders receive an electronic response describing the terms of obtaining the permit or the detailed reason for the refusal. About 9 million submissions for trade permits are processed per year (30 thousand per day).

The desire to make the port work in Hamburg more efficient launched the National Single Window system in *Germany*. It is currently managed and owned by a private company, which is divided into three parts by shareholders: one-third belongs to berth operators, one third to ship agents and owners, and the last one to freight forwarders. The system is mandatory only for dangerous goods and export goods subject to customs supervision. The main users of the system are freight forwarders, warehouses, logistics companies and departments of industrial and manufacturing businesses. System clients pay money for using it. They are provided with an individual code and password, and the data comes only to the specified addressee, registered in the system. One of the greatest achievements is the dramatic reduction in docflow and re-entering data due to the standardization [10].

Executive Order No13659 signed February 19, 2014 – Streamlining the Export/Import Process for America's Businesses – directs 47 *United States* Federal agencies with a role in trade to be ready to participate in electronic "Single Window" by December 2016. Now International Trade Data System is a part of U.S. Customs and Border Protection (CBP)'s Automated Commercial Environment. It connects the trade community to CBP and the other federal government agencies that regulate imported and exported goods [11].

The *Finnish* authorities have begun implementing the PortNet National Single Window system in the nineties. PortNet is a multifunctional single system for participants that deliver goods by sea. Since launch, PortNet has drastically reduced the need for filling and processing paper forms. The main lesson of Finnish success is that an effective system can be created with relatively little efforts and in a modern form, provided the state supports and the political will.

Korea's Single Window system uTradeHub was launched online in 2008 interconnecting the customs administration system and the systems of 56 public agencies. A lesson from Korea: it is necessary for countries that have established single windows to make full use of the procedural arrangements and technical instruments available to facilitate interagency coordination and participation of all stakeholders, including private sector representatives [12, 13, 14]. In 2018 the Korea Customs Service (KCS) launched the "Fourth Industrial Revolution and Smart Customs" programme. New platform, based on blockchain technology, will be established enabling all actors in the logistics chain (including manufacturers, exporters, transporters, government agencies, importers and consumers) to share reliable real-time information [15].

Analysis of some indicators that determine the effectiveness and level of comfort in doing business in the countries mentioned as examples of the good practice for trade facilitating is conducted on the basis of the data from the Logistics Performance Index (Figure 1-4). The World Bank Database gives an opportunity to measure the total burden of preparing the bundle of documents as well as to estimate time and cost for customs clearance and inspection procedures, conducted by other government agencies, and for handling that takes place at a port or a border crossing (Figure 5-6) [16,18].

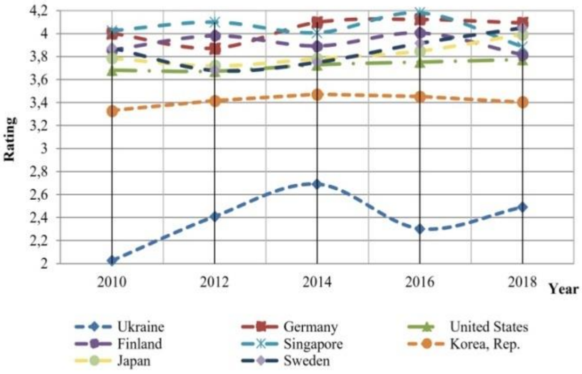

Figure 1. Efficiency of customs clearance process (1=low to 5=high)

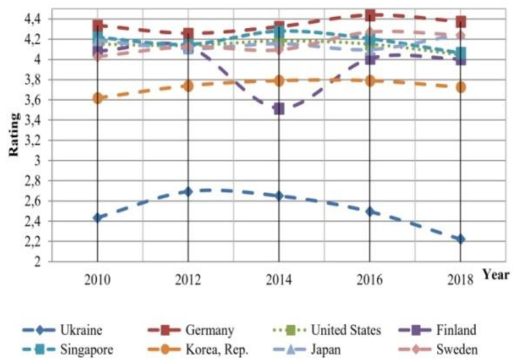

Figure 2. Quality of trade and transport-related infrastructure (1=low to 5=high)

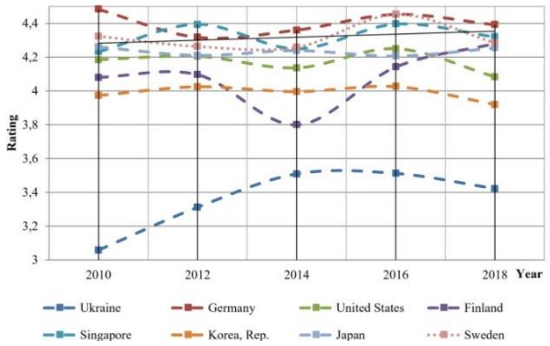

Figure 3. Frequency with which shipments reach consignee within scheduled or expected time (1=low to 5=high)

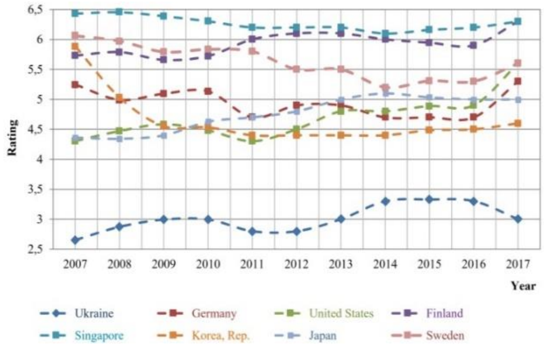

Figure 4. Burden of customs procedure (1=extremely inefficient to 7=extremely efficient)

Burden of customs procedure measures business executives' perceptions of their country's efficiency of customs procedures. The rating ranges from 1 to 7, with a higher score indicating greater efficiency. They are from the World Economic Forum's Executive Opinion Survey, conducted for 30 years in collaboration with 150 partner institutes [16].

Logistics professionals rate the level of satisfaction with customs higher than with other state bodies. In Ukraine customs authorities employ IT systems to process declarations and use risk management, consider international standards developed by the World Trade Organization and the World Customs Organization. But other agencies have not been modernized to the same extent, therefore interaction is not as fruitful as businesses would like. It is obvious that the level of comfort depends mainly on the economic and social development of the country.

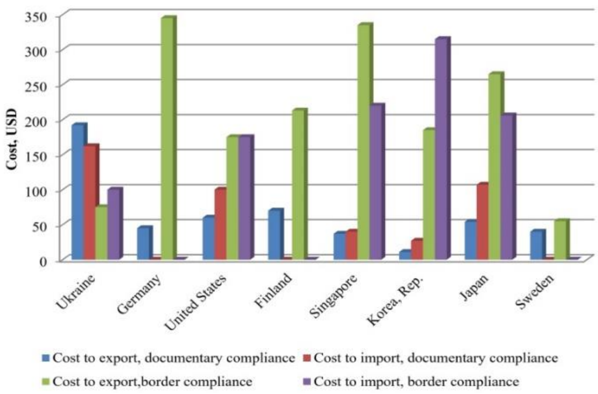

Figure 5. Cost to export/import, 2018

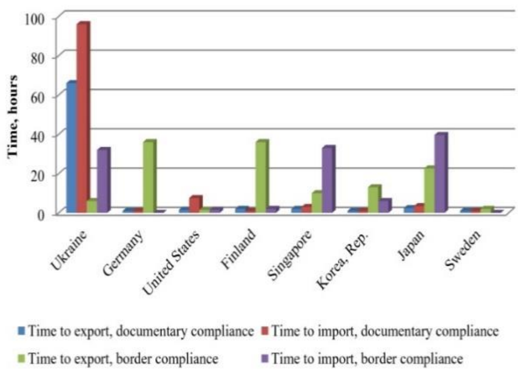

Figure 6. Time to export/import, 2018

The time and cost for documentary compliance include the time and cost for obtaining, preparing, processing, presenting (for example showing a port terminal receipt to port authorities) and submitting documents. The computation of border compliance time and cost depends on where the border compliance procedures take place, who requires and conducts the procedures and what is the probability that inspections will be conducted. If all customs clearance and other inspections take place at the port or border, the time estimate for border compliance will take this simultaneity into account. The border compliance time and cost could be negligible or zero in the cases of trade between members of the European Union or other customs unions. If some or all customs or other inspections take place at other locations, the time and cost for these procedures are added to the time and cost for those that take place at the port or border.

Currently Ukraine is also actively implementing the Single Window mechanism. In accordance with the Customs Code of Ukraine, this is a mechanism for interacting declarants, their representatives and other concerned parties with the customs agencies, other state bodies, institutions and organizations authorized to exercise licensing or control functions concerning the goods and vehicles for commercial use crossing the customs border of Ukraine. It provides for nonrecurring filing electronic documents and information with the state information web-portal "Single Window for International Trade" in order to meet the requirements of the laws and international treaties of Ukraine. This interaction is carried out with the use of the information and telecommunication system of customs authorities. In practice the main result of the Single Window implementation in Ukraine is the receipt of an electronic notification about the decision on the verification of goods crossing the customs border. It is assumed that the use of this mechanism will significantly reduce the time of customs control procedures, as well as financial costs and corruption by simplifying the documents flow and refusing paperwork. However, after the introduction of the Single Window in Ukraine, the declarants named a number of sticking points: the lack of clear rules for communication between customs, official control services and businesses; lack of awareness and limited experience of public officers in the use of the Single Window; inconsistency of work schedules of control agencies and customs offices, the requirements for submission of documents in paper form (in certain cases). Entities engaged in foreign economic activities also create difficulties because of outdated ways of filing documents or maintaining accounting records. In this case, an application is submitted to the customs authority with a request for the permanent execution of documents in paper form. Another drawback is considered to be difficulties that arise when it is necessary to make changes to the already issued additional or preliminary customs declarations or to cancel them, to withdraw funds reserve and so on.

Summarizing all above-mentioned problems and perspectives of the Single Window, enhancing information and communication technologies for customs supervision of legal entities and natural persons' goods received priority in Ukraine for now.

Table 1. Advantages and disadvantages of the electronic data exchange system in Ukraine (named by declarants).

Benefits of the Single Window	**Limitations of the Single Window**
It simplifies and reduces the number of customs formalities.	The need for additional amendments to the regulatory framework for electronic declaration of goods and other documents related to different types of inspection.
It reduces the time for certain customs formalities.	It does not guarantee shorter deadlines for obtaining permits than with a paper submission of documents directly to the inspector of the State Committee for Consumer Goods and Consumer Protection.
It minimizes the human factor in making decisions by customs officers and supervisory authorities.	There is still the subjectivity of some inspections regarding the targeted application for passing certain types of inspection.
It eliminates the corruption.	Despite the available supporting documents there is the need for inspection of wood packaging materials and proof of payment for this procedure.
It allows "covering a larger territory" for one customs office.	There is a lack of inspection officers for passing all necessary types of inspection at one customs office (for example, at a border crossing).
It promotes the development of international trade.	There is a lack of software and hardware tools.

Modeling alternative sequence scenarios for customs clearance procedure using project network. For the initial stage of the research organisational, legal and technical difficulties have to be analyzed, and then directions for the development are to be outlined using structured forecasting approach. Structured groups of exporters/importers or their authorized representatives and customs officers answer questionnaires in two rounds for revising their earlier replies in the light of common opinion of these two groups and for proposing new directions of the system development. As the result of face-to-face meetings, mini-Delphi technique is applied. Reduced scale Delphi studies provide more carefully considered viewpoints than the use of single round surveys [17]. The first round gives the following summarising problems prescribed by the group of declarants (Table 1).

According to the experts, the Single Window system has improved electronic declaring. The new regulations [5, 17] eliminate most of the gaps. However, declarants revealed the aspects that still delay passing different types of inspection and customs clearance. The results of the second round are to be summarized in a following article.

On the basis of regulatory provisions and experts description a customs clearance procedures sequence is depicted using network planning method. Network planning as a method of graphic modeling of operations has several advantages: it illustrates the sequence of the elements to be completed; it allows making up a business plan, computing float values and revealing hidden material resources. The program evaluation and review technique (PERT) are applied to optimize the network. To determine a critical path the longest sequence of dependent activities is to be identified and their completing time is to be estimated. It allows prioritizing activities for effective project management: to shorten the critical path of the project by pruning critical path activities; to perform more activities in parallel; to shorten the durations of critical path activities by adding material resources. The case studied in the course of supply chain for fabric rolls on wood pallets from Turkey (Figure 7). The network graph should be constructed so that there is no cycling of the process and the arrows (activities) do not overlap. However, for the process presentation in the article non-core canons are put aside.

Experts estimated time parameters of each milestone, therefore, this network shows not the early (late) start (finish) time of the events, but the minimum (t_{min}, optimistic), average (t_{av}, most likely) and maximum (t_{max}, pessimistic) time duration. According to this method the expected time for certain work is defined as $(t_{min}+4\ t_{av}+\ t_{max})/6$. For simulating model the Petri Net as programming tool is used (Figure 8, 9). However, to determine the durations of all the activities it is used not the estimated time, the calculation algorithm of which is shown above, but the Monte Carlo method. The principle of the method is to simulate a system operation as stochastic process. The simulation is carried out in the following steps: developing the chart flow for the process; programming the algorithm in VBA; generating input stochastic variables from specific distributions (Table 2) and repeating the experiment; statistical processing of simulation results.

3. Results

Hence overall time duration of critical path 1-2-4-5-7-10-11-12-13-14-15-16-17-18-19-20-21-22 is 132 hours.

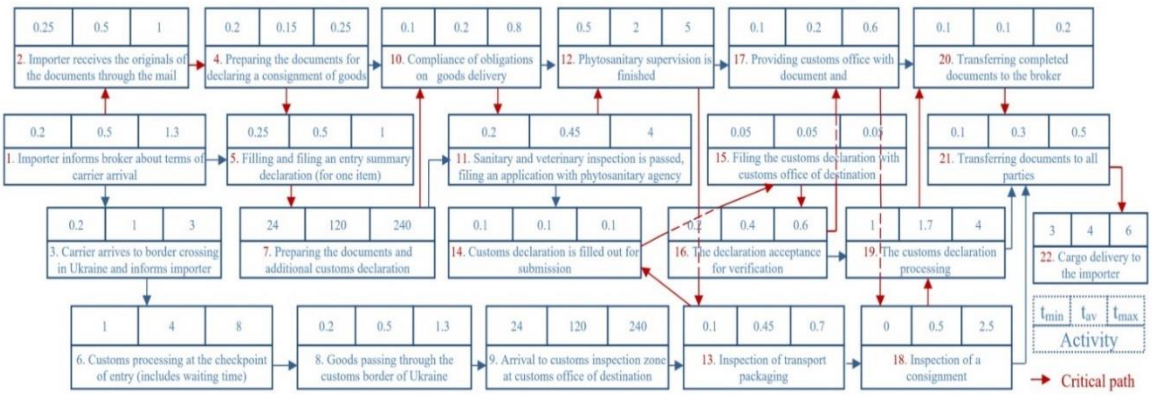

Figure 7. Simplified graph for customs clearance procedures in Ukraine: a case study.

If only a single form and single bill for services are submitted to specify the data necessary for different procedures related to phytosanitary inspection, then this value will be reduced by at least 2 hours.

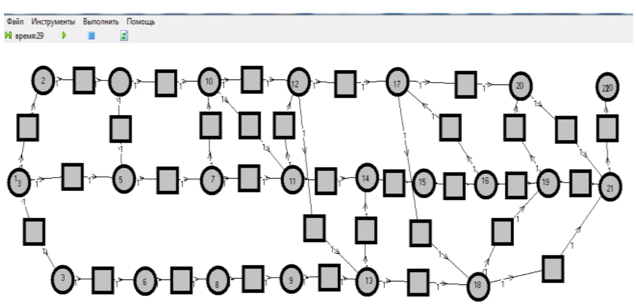

Figure 8. Petri net for modelling customs clearance procedures.

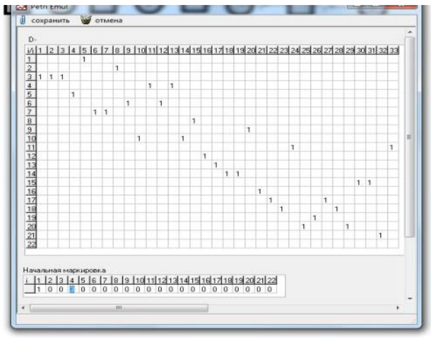

Figure 9. Matrix for Petri net.

Table 2. The data for generating input random numbers and calculating expected value of the whole process time duration (an extract from the research).

Variables of the graph	Distribution	A probability density function	Expected value	Standard deviation	Parameter k
...	...	...	...	...	...
6-1. Waiting time at the checkpoints, hours	Exponential	$f(t) = ke^{-kt}$	-	-	0,007
6-2. Time for customs processing at the checkpoints, hours	Normal (or Gauss)	$f(t) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(t-\bar{t})^2}{2\sigma^2}}$	0,67	+ - (0,2)	-
...	...	...	...	...	...

Another proposal of the focus group is to cancel a sale contract. The drafting takes a lot of time and efforts. When scrutinizing a declaration, the customs inspectors must read it, analyze it and make sure through payment documents that all of its provisions are met correctly. That slows down the customs clearance. Brokers must send scanned copies of the contract to all supervision agencies. Also it is necessary to provide a specification to the contract (which may not actually exist) for phytosanitary certificating. Banks constantly have problems regarding the interpretation and errors in contracts. Instead of a contract it is proposed an invoice.

A passenger declaration, filled out in advance and sent to customs authorities, for goods in accompanied/unaccompanied baggage or freight shipment can also significantly simplify procedures at a border crossing. For that purpose the Single Window system could be useful taking current technological horizons and digital mobility into account.

Also, one of the development trends for information and communication technologies could be the introduction of the well known "electronic reservation of a border queue place" technology, which significantly reduces the risk of delay at border crossings by booking a place in queue for a small fee. For today the coefficients of the variation of t standard deviation from the average waiting time at the border crossing points in Ukraine are rather high, indicating that the situation with regard to the queues is unpredictable. An electronic queue reservation will reduce the variation value from 40% to 10%, and the cargo owner will more accurately estimate the delivery time.

4. Discussion

Network planning of the procedure shows parallelism of the operations, which allows taking into account the significance of each improvement. Some improvements do not lie on the critical path and therefore they are not discussed in the article. Some considerations of experts were clarified during the survey; other comments were not taken into account, because of the difficulties to quantify their importance. Another round of focus-group survey is planned to revise the solutions. Since the operation time are only estimated regarding to 7 milestones of the process, further refinement is mapped out for both Single Window model and time characteristics of a wider set of operations with due account for potential risks.

5. Conclusions

Modern electronic systems and technologies can reduce the time for goods and documents to pass through customs. One of these systems is the Single Window, an electronic system for exchanging data at customs during import-export operations or transit, which is effectively used worldwide. The Singapore TradeNet system gives an electronic response about passing controls 10 minutes after filing documents. About 9 million submissions for trade permits are processed per year. PortNet is truly a multi-functional unified system in Finland for participants who deliver goods by sea. More than 99% of all forms for customs clearance of ship cargo are processed through the Single Window. In Ukraine, the Single Window system has not yet become so effective, but it has a number of advantages and, if finalized, it will lead to the development of international trade. Obviously, mobile applications and information resources comfort and facilitate our life, so new platforms, based on blockchain technology that make available various kinds of information for all participants of the delivery (including manufacturers, exporters, transporters, government agencies, importers and consumers), will provide an opportunity to analyze the situation and prevent errors.

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Possibilities of using bus rapid transit in cities with dense construction area

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Abstract: Bus rapid transit (BRT) is one of the most popular mass passenger transportation systems as it is cost-effective, comfortable and rapid during its use, hence it is widespread in developing countries. In the paper, the classification of urban public transport modes is highlighted and the main components of BRT system are given. Also, types of running ways on highways and other urban streets are classified and also measures aimed at giving the priority to public transport in mixed traffic are given.

Keywords: bus rapid transit, running ways, cities with dense construction area.

1. Introduction

In view of the rapid rate of motorization level growth many countries develop different strategies about transport systems development. These strategies cover legislative decisions and implementation of normative acts on the government level, organizational decisions on local levels and also engineering decisions about the construction of new roads and reconstruction of existing ones.

To the question of public transport operation improvement, a lot of publications are aimed recently. Particularly, authors [1-5] investigate the influence of transit ridership and passenger flows on the effectiveness of bus rapid transit functioning. Some publications emphasize on safety, capacity, and reliability of public transit systems [6-10, 15]. Special attention is paid to allocation of bus lanes [11] and giving the priority to public transit on intersections [12].

To the measures which are implemented in different large cities of the world for the development of effective transport infrastructure are related [12]:

- reconstruction and redevelopment of existing transport infrastructure;
- possibilities of parallel street usage;
- construction of transit highways;
- differentiation of traffic on local and highway;
- change of movement direction on lanes during the day;
- change of traffic management during peak periods;
- renewal of traffic light signal system;
- construction of new roads;
- restriction of entry to the city central part;
- creation of toll roads, increase of fines for a traffic violation;
- limitation of sold automobiles amount and complicated system of buying cars;
- creation of a car sharing system;

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- improvement of traffic management;
- implementation of restrictions for different modes of transport;
- usage of automobiles on even and odd days depending on the last number on license plates;
- usage of Intelligent Transportation Systems for traffic control and management.

The usage of one or the other organizational measures depends on country legislation. What concerns engineering measures, their implementation quite often is impossible because of the existing dense construction area. That is why in such cities it is necessary to use such transport systems in which preference is given to public transport, cycling and walking. To encourage citizens to use public transport, first of all, it is necessary to develop such a system which would be cost-effective for the city and also cheap and comfortable for usage by passengers.

To the public transport systems can be included bus, tram and trolley-bus transportation, subway, light rail transit and bus rapid transit and also suburban transportation. In Table 1 are given the main characteristics of public transport modes.

Among the most effective public transport systems can be highlighted subway, light rail transit and also BRT. Their main features are high transportation capacity, cost-effectiveness and also the existence of separated rights of way for vehicle movement which reduces travel time for passengers and increases the operating speed of vehicles. But construction of subway and light rail requires high economic costs and an area that is necessary for tram lanes allocation and also a big capital investment on underground lines construction. On the contrary, BRT is relatively cheap as they do not demand the construction of special pavement for bus movement that is why they are especially effective.

Table 1. General characteristics of public transport categories [14].

Public transport category	Typical location of public transport stops	Running ways	Service frequency	Buses/trams
Local	From 100 to 400 m, sometimes on request	Movement in mixed traffic	1…20 units per hour, depending from time of day	Local bus/tram
Local/ Express	The same as local but with small amount or without stops in express zones	Movement in mixed traffic in local connection, in express-zones possible full segregation from the rest traffic flow	The same as local but can serve only in peak periods as additional to local	Local bus/tram
Semi rapid	From 300 to 1000 m	Mainly partial separation from the rest traffic flow, possible full segregation from the rest traffic flow or movement in mixed traffic	4…8 units per hour, sometimes more	Typically articulated bus/high-capacity tram
Rapid	From 400 to 2000 m	Exclusively separated movement from the rest traffic flow	4…30 units per hour	Typically articulated bus/light rail (metro)
Rapid/ Suburban	As rapid in dense city areas; as suburban in all other cases	Exclusively separated movement from the rest traffic flow	4…8 units per hour on branches	Suburban bus/light rail (metro)
Suburban	More than 2000 m	Exclusively separated movement from the rest traffic flow	1…4 units per hour on branches	Suburban bus/suburban rail transport

The main difference between the urban tram system and BRT is that last can provide high-quality service of passengers with quite low costs, the price of which for the city can be from 4 to 20 times lower than light rail transit systems and from 10 to 100 times lower than subway [13].

Institute for Transportation and Development Policy gives the following definition of BRT: a high-quality bus-based transit system which carries rapid, comfortable and cost-effective urban transportation due to separated running ways, rapid and frequent operations and also excellent marketing and client service [15].

BRT system consists of such main components [16]:

- separated running ways;
- specially equipped stations;
- highly articulated vehicles;
- high-quality service;
- effective fare system;
- usage of Intelligent Transportation Systems.

In cities with dense construction area, the main problem is the allocation of separated running ways.

2. Materials and methods

Differentiate such types of running ways which can be implemented during the development of BRT system [17]:

- physically segregated ways for bus movement;
- highway lanes;
- urban streets.

Physically segregated ways for bus movement are effective during their usage because they totally separate bus movement from the rest of the traffic flow, moreover not only on sections between intersections and also on intersections. But their main drawback is that for construction of such running ways additional area is required which makes them impossible to use in cities with dense construction area.

Highway lanes can have such forms: median busways, high occupancy vehicle lanes and curbside bus lanes [17].

Considering urban streets, there the most spread forms are median busways, bus lanes and mixed traffic lanes [17].

Median busways are effective, but their usage is justified with bus intensity from 60 to 90 units per hour in one direction in peak periods with minimum bus volume 600 units. Besides, their implementation requires widening of existing roadway which is not always possible with high traffic intensity and existing dense construction area [18].

One more variant for giving the priority to public transport is the allocation of bus streets for bus movement. But such a decision is possible in the condition of existence parallel by-pass streets.

Table 2. Recommended bus volumes for bus lanes allocation [18].

Type of bus lane, located on the curbside	Minimum daily bus volume, units	Range of movement volume per hour on one direction in peak periods	
		Buses, units	Passenger, persons
Concurrent flow movement:			
in city central part	200	20-30	800-1200
outside city central part	300	30-40	1200-1600
Contra-flow movement:			
short segment	200	20-30	800-1200
extended segment	400	40-60	1600-2400

Bus lanes can be located on the curbside or in the lane which is adjacent to the curbside. The last case allows the placement of parked vehicles and also the arrangement of right turn without conflict with the bus movement. Also with the allocation of bus lanes in the curbside, it can be possible to arrange bus movement in concurrent and contra-flow directions. In Table 2 it is given recommended bus volumes for allocation the certain lane type.

The main condition for the allocation of separated bus lanes is the existence of enough number of lanes. Authors [19] note that the main factor which determines the possibility of bus lanes allocation is the number of persons who travel by public transport relative to the number of persons who use private transport. They propose such determination of bus lanes implementation possibility:

$$q_B \geq \frac{q_A}{N-1} x \,, \qquad (1)$$

here q_B and q_A – hourly bus and automobiles intensities relatively; N – the general number of lanes and x – average bus to automobile occupancy ratio.

In general, if the lane is allocated for buses and these buses carry the same amount of passengers as automobiles on adjacent lanes than bus lanes are warranted [19].

Author [20] indicated that in cities central parts advantages of allocation separated bus lanes are significant. Research in Thessaloniki city, Greece, shows that bus travel time reduced by 21.2% during the morning peak period and by 26.1% during the afternoon peak period. Fuel consumption reduced by 24.22% and 28.32% respectively during morning and afternoon periods. The average bus speed increased by 4.35% and 11.57% respectively for these periods. At the same time, the average speed of traffic flow reduced (respectively by 0.82% and 0.59%) and traffic delays increased (respectively by 1.71% and 0.06%).

Author [21] notes that on congested streets separated bus lanes can twice or three times increase bus speed (Figure 1).

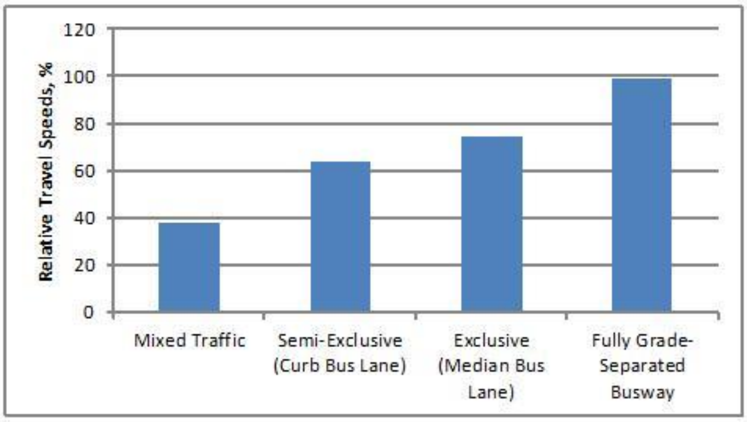

Figure 1. Relative bus speeds with a different implementation of running ways [21].

But, the negative moment is the approach of the bus lane to the city central part where there is no possibility for broadening the running way. Authors [17] name it "the last kilometer" when public transport from an existent bus lane is forced to flow into the general traffic flow. In such case, several variants are possible for allocation the temporary lanes for public transport movement: bidirectional bus lanes, reversible bus lanes and also separated bus lanes only in peak periods. Such variants are not optimal and can be used only in cases when other strategies are impossible to implement.

The other variant is the implementation of the so-called "dynamic" bus lane. Its essence lies in the fact that the lane can be used as common for traffic flow and buses, but on the edge of the lane are located special sensors which began to glow with the approaching of the bus and notify drivers that they should change the lane and give the way to buses. Such a strategy also is not optimal because, in places where traffic intensities are high, additional traffic delays can appear which can cause respectively public transport delay.

So, benefits for bus lanes allocation are evident, but the main problem is places where their usage is impossible. That is why in mixed traffic it is necessary to implement measures about giving the priority to public transport.

3. Results

During the movement in mixed traffic delays, in general, can appear on intersections. As Intelligent Transportation systems are an inevitable part of BRT system functioning, then determining the location of the bus using GPS is not a problem. That is why the urgent measure is giving the priority on intersections with the use of traffic light system during approaching to them public transport [22, 23].

Authors [25] highlight such strategies during public transport movement on intersections:

- firstly, differentiate active and passive priority. Active priority includes determining and regulation of transit transport passage in real time, while passive priority includes such measures as optimal traffic light cycle, green time distribution and coupled control usage;

- secondly, priority strategies can be classified as total, partial and relative priority. Under total priority control program tries to give the bus null delay. Under partial priority means extended or early green time. Under relative priority, buses receive priority in movement only when traffic intensities are low;

- thirdly, differentiate unconditional and conditional priority. Unconditional priority means that all buses are given the priority. For the determination of total, active and unconditional priority use the definition absolute priority. Conditional priority means that buses demand priority only when they are behind the schedule;

But the main condition for giving the priority to public transport on intersections is the creation such road conditions during which traffic jams in general traffic movement would not appear.

Authors [23] allocate 8 scenarios of active priority which are given on Figure 2, during the approach of public transport to the intersection on different stages of traffic light cycle duration.

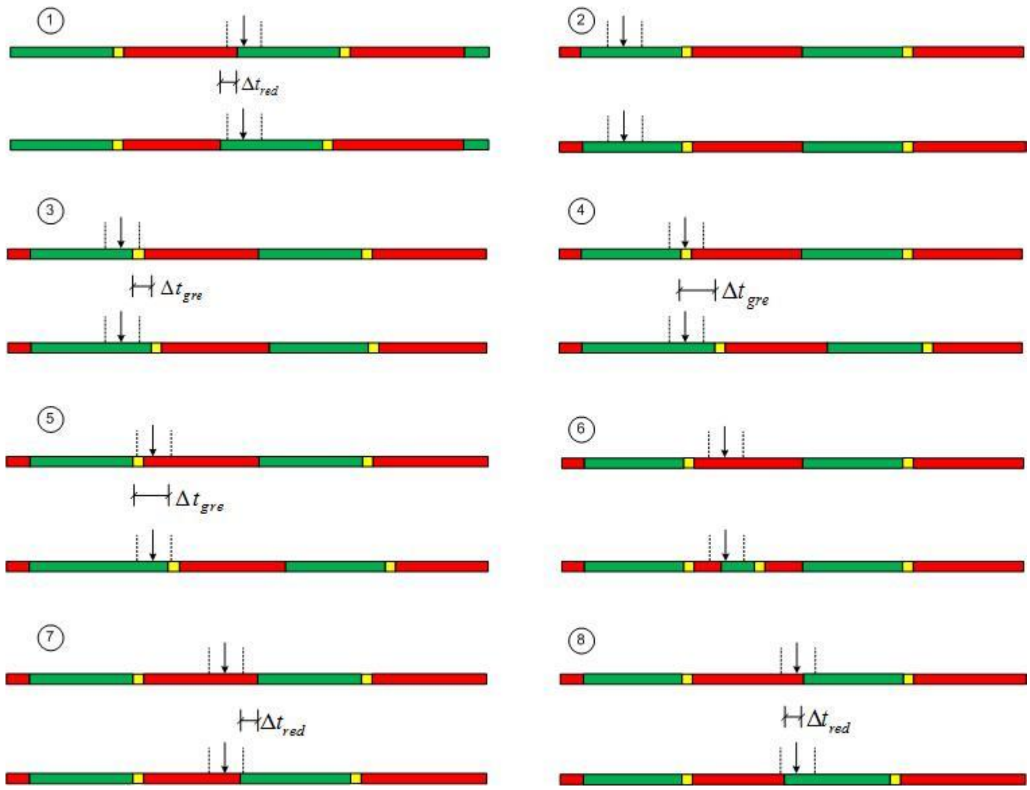

Figure 2. Scenarios of active priority for public transport on intersections [23].

Also to the measures about giving the priority to public transport on intersections can be related so-called by-pass lanes before intersections. Such lanes can be right turn lanes: at the moment when bus approaches to the intersection from this lane and the red traffic light signal is on, passengers board and alight. Then bus receives green before other vehicles for a few seconds. After that green traffic light signal turns on for the rest vehicles in the given direction (Figure 3, left). Another scenario is location the bus stop in the far side. When the bus approaches to the intersection, the green light turns on and bus passes the intersection a few seconds earlier than other vehicles, and then passengers board and alight on the bus stop (Figure 3, right) [18].

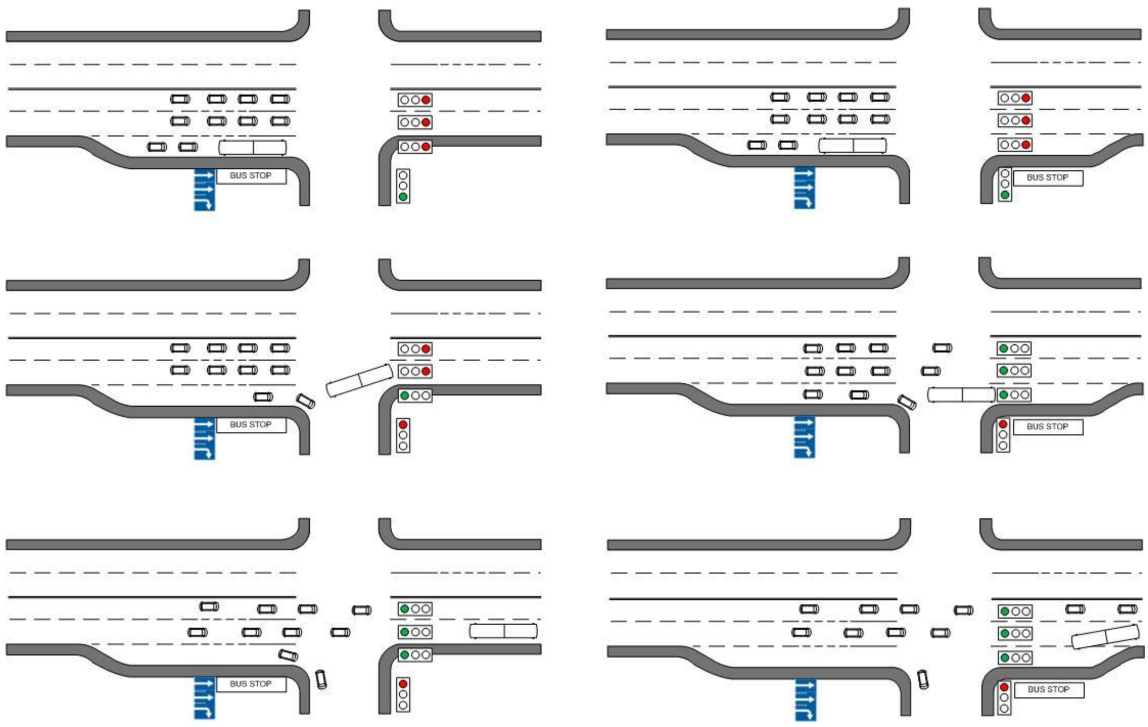

Figure 3. Usage of right turn lane as bus by-pass lane on intersections [18].

To the other measures for giving the priority to public transport relate parking restrictions on the curbside and in the middle of the roadway that will allow to allocate additional place for bus lanes allocation; turn restrictions on intersections that will decrease the amount of conflicts between turn traffic flows and buses that move straight in the case if separated bus lanes are located in the middle of the roadway.

4. Discussion

The peculiarity of the road network of Lviv city is the fact that the city has historically formed network that has a radial-ring planning scheme. On radial directions to the center go arterial streets. The disadvantage is that with the approach to the center the width on these streets reduces. Such a situation negatively reflects on traffic movement: in peak periods almost on all arterial streets traffic jams appear. On arterial streets, public transport routes exist which connect peripheral districts of the city with the central part. Other buses move on the routes that connect given radial directions.

Another negative moment is the fact that in the city public transport almost on all streets moves in mixed traffic. Individual cases of separated public transport movement from the rest traffic flow are known. For example, on Lychakivska st. and Kn. Olgy st., and also Chervonoi Kalyny av. a separated tramway exists. Also on sections of Svobody av. and Horodotska and Kopernyka st. separated bus lanes exist. The length of given lanes does not exceed 500 m. in every direction moreover after their end buses should flow in mixed traffic that creates additional delays in their movement.

Positive moment is the existence of traffic light systems on certain intersections of the city, where active priority in tram movement exists. But measures, counted before, are not sufficient for the effective functioning of public transport in the city.

With the aim of determination the strategy of city transport network development in Lviv city there was conducted questionnaire of citizens about the main directions of existing infrastructure development. It was carried out by the method of express-interview in different city districts. Sample size is 1100 respondents of four age categories: 20-35 years old; 35-45 years old; 45-60 years old and above 60 years old. Everyone could choose to three variants of proposed answers. Questionnaire results are given on Figure 4.

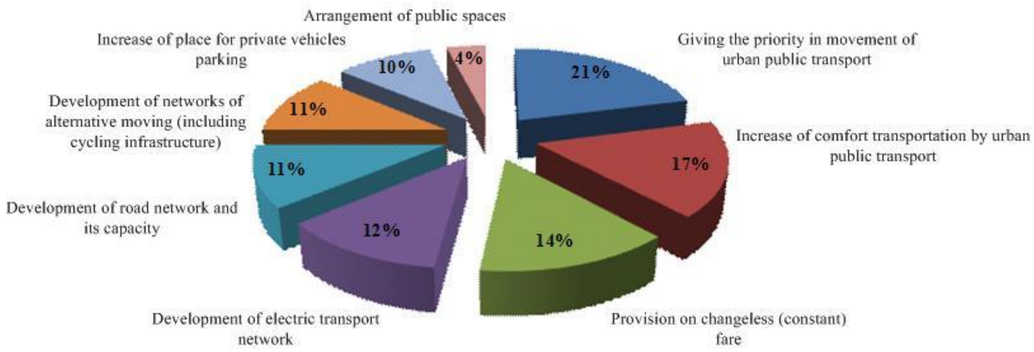

Figure 4. Priority of the main directions of city transport network development for citizens of Lviv city.

As it can be seen from the figure, great attention (38%) citizens of Lviv pay to the quality of transportation by the urban public transport, in particular giving it the priority in movement and increase of comfort transportation, although frequently the second is the derivative from the first as it includes speed of transportation. These questionnaires show that frequently fare cannot be in priority (for its temporary quantitative expression) if it will be backed up by the quality of service provision. Also topical is the task of development of infrastructure non-automobile moving, in particular electric transport, cycling, walking etc., which connects almost 27% of respondents.

5. Conclusions

Despite the high popularity of BRT systems, obstacles to their implementation still exist. One of such obstacles is complexity during designing the running ways in cities with dense construction area. But sources, analyzed in the article, point on the diversity of variants which can be used for giving the priority for bus movement. The most spread measures for giving the priority to public transport in cities with dense construction area is allocation the curbside bus lanes and also the usage of traffic light system with absolute priority for bus movement.

Results of conducted questionnaire show that 21% of city residents prefer giving the priority in the movement of urban public transport, and 11% – development of road network and its capacity in general. That is why, basing on the results of this questionnaire, and also given variants, the best solving the problem is a combination of organizational and engineering measures. Hence, in future it is necessary to carry out field research with gathering the data about traffic flows intensity on the streets where urban public transport routes exist, and also the volume of passenger flows. Received data will allow conducting further engineering solutions about giving priority to urban public transport.

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Dynamic analysis of gas flow through the ICE ring seal

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Abstract: (1) Purpose: The effect of axial movement of piston rings in the piston grooves is estimated by calculation and experimentally for the passage of gases in an internal combustion engine (ICE). (2) Methodology: When modeling the effect of axial movement of piston rings in the piston grooves for the passage of gases in the ICE, theoretical positions are used. It is based on the fundamental theory of heat engines, thermodynamics and hydraulics. Running was investigated using theoretical and theoretical research methods; (3) Results: The effect of axial movement of piston rings in the piston grooves on the passage of gases in the ICE is established. This creates prerequisites for a more accurate assessment of their sealing ability and the search for ways to further improve them. Calculated dependences are obtained for calculating the pass of gases depending on the relative position of the rings in the piston grooves. The dependences of gas escapes on the engine crankshaft rotation speed are obtained, which is especially important for idling modes, by which one can judge the dynamic stability of the ring seal and solve the problems of improving its operational properties; (4) Practical implications: This paper proposes the practical method for estimating the dynamic stability of an annular seal based on gas escape dependencies on the crankshaft rotation speed in ICE is proposed. In addition, this study contributes to the development of practical recommendations for the further improvement of engine ring seal designs.

Keywords: ICE ring seal, piston ring mobility, calculation of gas escape.

1. Introduction

The internal combustion engines (ICE) of trucks used in the mining industry are one of the critical units with expensive repairs. The ICE requires a preliminary diagnosis which assesses the technical condition of both the engine and the truck as a whole. The technical condition of the parts of the cylinder-piston group (CPG) can be determined by gas escape in the ICE.

The modern development of the high-speed ICE is the way to improve their technical, economic and environmental performance. This predetermines [1-5]:

a) The expansion of research and development projects on the further design and technological improvement of parts of the CPG of the ICE

b) The choice of optimal conditions for interfacing their contacting surfaces and

c) Improving the quality of used materials.

Piston rings (PR) are the most high-wear parts of the CPG, so the issues of improving their performance and reliability are of current importance when creating prospective engines used in the mining industry.

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The main factors that determine the normal running of the ICE are the condition of coupling of surfaces of the compression rings with the cylinder wall and their ends with the top and bottom planes of the piston grooves. This is connected with the sealing of the combustion chamber and prevention a considerable blow-by in the engine case.

Gas escapes through the gaps in the parts mating of the CPG break the oil film and increase wear which, in its turn, increases the gas escape. This furthers the seizing of the piston rings, the increasing of oil consumption and fuel, and smoking. The final result is jamming and the engine trouble.

A wide variety of factors influencing the operation of the PR complicates analysis and generalization of the experimental data and development of general principles of the theoretically substantiated choice of designs of the ICE ring seal. The solution of this issue should be based on the account of the totality of the main phenomena that determine the operability of CPG and PR parts.

Numerous papers cover experimental and theoretical study of the PR operation. In [6] it was found that the hydrodynamic friction increased with the initial wear of the PR in conditions of increasing minimum thickness of the oil film. This contributes to the fact that the PR can remain operational during the entire service life. Hydrodynamic friction for high rings can be reduced using a narrow parabolic profile which is impossible for narrow rings.

A laser fluorescence system was developed to visualize the thickness of the oil film between the PR and the cylinder wall of the running gasoline engine through a small optical window installed in the cylinder wall. The results show significant differences in the profiles of the thickness of the lubricant film for the ring seal if the lubricant deteriorates, which affects the ring friction and, ultimately, fuel economy [7].

The diagnostic methodology can effectively determine the control of the condition of the PR in accordance with the characteristics of combustion [8].

The calculation of the gas flow through the ICE ring seals with regard to the piston rings dynamics allows diagnosing the engine technical condition.

2D CFD model is used to study the effect of the ring seal design on the friction process, oil consumption and oil flow. Calculations of the piston rings dynamics are carried out on the assumption of forces balance [9].

Methods and devices to study mechanical friction losses are developed [10]. A simplified floating liner method is used and the test equipment is developed to fill the gap in between the full floating liner engine and the typical component bench test equipment.

The purpose of research [11] is to study the potential of the laser oil pockets new design to improve the piston rings lubrication. These pockets make it possible to achieve significant friction reduction by using appropriate geometric parameters.

At the moment there is a wide range of solution of the PR reliability and operating life problems. However, the dynamics of the parts of the CPG are not considered sufficiently. In particular, this is the PR movement in the piston grooves. This is connected with the engine running where all piston rings moving is difficult to measure; there are no theoretical dependencies that link the PR mobility in the piston grooves with gas escapes through the ring seal.

2. Materials and methods

In general, the problem of the gases flow through the volumes on lands and piston ring grooves is quite complicated. However, it can be simplified if the following experimental and theoretical justifications of assumption are introduced:

a) The gas flow process is taken to be quasi-stationary

b) The areas of the flow passage between the PR, the piston and the cylinder liner should be replaced by the equivalent area of the flow passage of the piston-ring lock and

c) Geometric relationships in the ring seal can only be changed due to axial unloading of the rings and their subsequent separation from the bearing area of the groove.

In this paper the problem is considered on the example of the ring seal consisting of three rings in various cases of their relative position in the grooves, which received experimental confirmation in the papers.

The principal features of the adopted model are that it takes into account the throttling effect of the upper fascia of the piston and the change in the areas of the flow sections and the volume of the annular spaces due to the movement of the rings in the grooves.

It is accepted that the separation of the rings from the support surfaces of the groove in the direction of the piston axis occurs at the moments when the sum of the forces from the gas pressure P_G, the inertia of the ring P_j and the friction P_f are zero, which means

$$\sum P = P_G + P_j + P_f = 0 \quad (1)$$

The theoretical studies were based on the differential equations of mass and energy balances, as well as the criterion equation of heat exchange for the gases flow in micro-gap channels. For the second and third piston grooves, the gases flow was accepted to be isothermal with a gas temperature equal to the arithmetic average of the temperatures of the piston grooves and the cylinder liner.

As a result of the dynamic calculation the total forces that act on the piston rings, as well as various cases of their positional relationship in the grooves and their corresponding possible gas flows in the ring seal were identified.

Blow-by *m* through the PR leakiness was calculated by the equation:

$$dm = \mu \cdot f \cdot \psi \cdot p \cdot \sqrt{\frac{1}{R \cdot T}} d\tau \quad (2)$$

here $\mu \cdot f$ – discharge coefficient and flow section between volumes on lands and the piston ring grooves [m^2]; ψ – speed function, which depends on the pressure ratio; p, T – pressure [Pa] and gas temperature in the grooves [K]; R – gas constant, R=287 [J/(kg·K)]; τ – time [s].

The following formulas to calculate the pressures and the blow-by in various cases of the positional relationship of the rings in the piston grooves were obtained.

2.1. Case 1 of the positional relationship of the rings in the grooves of the piston, when $\sum P_1 > 0$, $\sum P_2 > 0$ *and* $\sum P_3 > 0$

The calculation of the blow-by when the sum of the forces acting on the rings $\sum P$ is positive and the gases pressure decreases from the top PR to the bottom (Figure 1) is the following: $\sum P_1 > 0$, $\sum P_2 > 0$ and $\sum P_3 > 0$ with $p_1 > p_2 > p_3$.

Then

$$\frac{dp_1}{d\bar{\tau}} = a_1 \cdot p_{cyl} \times \left[\overline{\mu \cdot f_0} \cdot \psi \cdot \left(\frac{p_m}{p_{cyl}} \right) \cdot \frac{k_{cyl}}{\beta_1} \sqrt{T_{cyl}} - k_1 \cdot \psi \cdot \left(\frac{p_2}{p_1} \right) \cdot \frac{p_1}{p_{cyl}} \cdot \sqrt{T_1} - \frac{\alpha \cdot F_1 \cdot \Delta t_1 \sqrt{R}}{\overline{\mu \cdot f_1} \cdot \beta_1 \cdot c_{cyl} \cdot p_{cyl}} \right] \quad (3)$$

here V_1 – volume of ring groove I [m^3]; t_n, t_w – average temperature of the piston head [K]; t_f – the determining gas temperature [K]; p_m – gas pressure in the minimum section of the jet [Pa]; p_{cyl} – gas pressure in the cylinder [Pa]; p_H – gas pressure in the crankcase [Pa]; k_1 – the adiabatic coefficient of gas per ring I; k_{cyl} – the adiabatic coefficient of gas in the cylinder; T_{cyl} – gas temperature in the cylinder [K]; α – heat exchange coefficient from gases to surfaces of the cylinder and the piston [$\frac{W}{m^2 \cdot K}$]; F_1 – heat receiving surface area [m^2]; c_{V_1} – mass heat capacity of gases at constant volume in the ring groove I [$\frac{J}{kg \cdot K}$]; c_{cyl} – mass heat capacity of gases at constant volume in the cylinder [$\frac{J}{kg \cdot K}$]; $a_1 = \mu_1 \cdot f_1 \sqrt{R_T}/V_1$; $\overline{\mu \cdot f}_0 = \frac{\mu_0 \cdot f_0}{\mu_1 \cdot f_1}$; $\overline{\mu \cdot f}_1 = \frac{\mu_1 \cdot f_1}{\mu_2 \cdot f_2}$; $\beta_1 = C_{V_1}/C_{V_{cyl}}$; $\Delta t_1 = 2 \cdot t_f - t_w - t_n$ and $t_f = \frac{t_{cyl} + t_1}{2}$.

The equation for the second and third grooves (m = 2, 3, $p_4 = p_H$) is the following:

$$\frac{dp_m}{d\tau} = a_m \cdot p_{m-1} \times \left[\overline{\mu f_{m-1}} \cdot k_{m-1} \cdot \psi\left(\frac{p_m}{p_{m-1}}\right) \cdot \frac{T_m}{\sqrt{T_{m-1}}} - k_m \cdot \psi\left(\frac{p_{m-1}}{p_m}\right) \cdot \left(\frac{p_m}{p_{m-1}}\right) \sqrt{T_m} \right] \tag{4}$$

here k_m – the adiabatic coefficient in *m*-th groove; T_m – gas temperature in *m*-th groove [K].

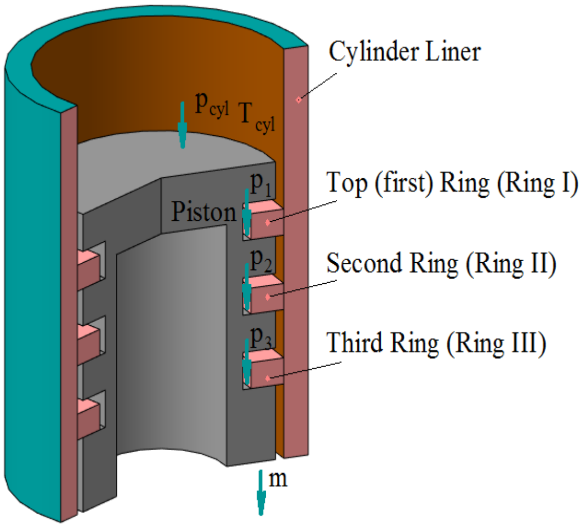

Figure 1. Case 1 of the positional relationship of the rings in the grooves of the piston, when $\sum P_1 > 0$, $\sum P_2 > 0$ and $\sum P_3 > 0$: m – mass gas escape; p_1, p_2, p_3 – gas pressure in annular piston cavities I, II and III.

Then Equation (2) is the following:

$$\frac{dm}{d\tau} = \mu_3 \cdot f_3 \cdot \psi \cdot \left(\frac{p_H}{p_3}\right) \cdot p_3 \sqrt{\frac{1}{R \cdot T_3}} \tag{5}$$

here $\mu_3 \cdot f_3$ – Discharge coefficient and flow section over PR III [m²]; p_3 and T_3 – pressure [Pa] and gas temperature in ring groove III [K].

Pressure in ring groove II has the following by Equation (6) if $p_{cyl} < p_1 < p_2$ and $p_2 > p_3$ (Fig. 2).

The Equation (6) is following:

$$\frac{dp_2}{d\tau} = -a_m \cdot k_2 \cdot p_2 \cdot \sqrt{T_2} \left[\overline{\mu f}_1 \cdot \psi\left(\frac{p_1}{p_2}\right) + \psi\left(\frac{p_3}{p}\right) \right] \tag{6}$$

here V_2 is a volume of ring groove II [m3]; $\frac{dp_3}{d\tau}$ is determined by the Eq. (4) with m = 3; V_3 – Volume of the ring groove III [m3]; $p_1 = p_{cyl}$; $a_2 = \frac{\mu_2 \cdot f_2 \cdot \sqrt{R}}{V_2}$; $\overline{\mu f_2} = \frac{\mu_2 f_2}{\mu_3 f_3}$; $a_3 = \frac{\mu_3 \cdot f_3 \cdot \sqrt{R}}{V_3}$; $\overline{\mu f_3} = \frac{\mu_3 f_3}{\mu_1 f_1}$ and $a_{23} = \frac{\mu_2 \cdot f_2 \cdot \sqrt{R}}{V_2 + V_3}$.

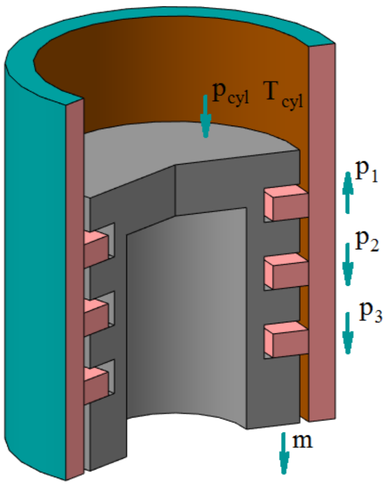

Figure 2. Case of the positional relationship of the rings in the grooves of the piston, when $p_{cyl} < p_1 < p_2$ and $p_2 > p_3$.

2.2. Case 2 of the positional relationship of the rings in the grooves of the piston, when $\sum P_1 > 0$, $\sum P_2 < 0$ *and* $\sum P_3 < 0$

The calculation of the blow-by if the sum of the forces acting on the ring I is positive and on the rings II and III is negative (Fig. 3,a) is the following: $\sum P_1 > 0$, $\sum P_2 < 0$, $\sum P_3 < 0$ with $p_1 > p_2 > p_3$.

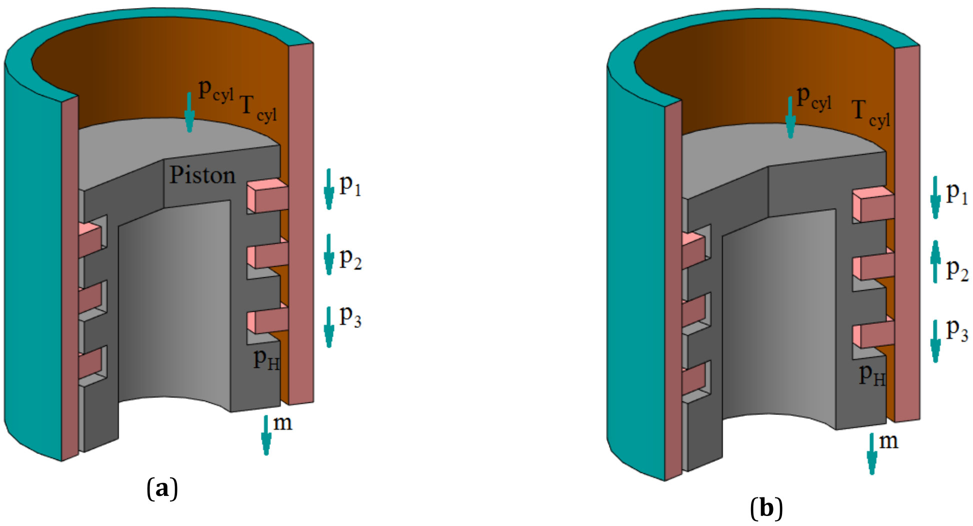

Figure 3. Case 2 of the positional relationship of the rings in the grooves of the piston, when: **(a)** $\sum P_1 > 0$, $\sum P_2 < 0$ and $\sum P_3 < 0$; **(b)** $p_1 < p_2 > p_3$.

Then $\frac{dp_1}{d\tau}$ is determined by the Equation (3); $\frac{dp_2}{d\tau}$ is determined by the Equation (4) with m = 2 and $p_3 = p_{cyl}$.

When $p_1 < p_2 > p_3$ (Fig. 3,b):

$$\frac{dp_2}{d\bar{\tau}} = -a_2 \cdot K_2 \cdot p_2 \cdot \left[\psi \cdot \left(\frac{p_1}{p_2} \right) + \frac{1}{\overline{\mu \cdot f_2}} \psi \cdot \left(\frac{p_H}{p_3} \right) \right] \sqrt{T_2} \quad (7)$$

here p_2 – gas pressure in the in the ring groove II [Pa]; $a_2 = \frac{\mu_2 \cdot f_2 \cdot \sqrt{R}}{V_2}$ and $\overline{\mu \cdot f}_2 = \frac{\mu_2 \cdot f_2}{\mu_3 \cdot f_3}$.

Then Eq. (2) is the following:

$$\frac{dm}{d\tau} = \mu_3 \cdot f_3 \cdot \psi \cdot \left(\frac{p_H}{p_2} \right) \cdot p_2 \sqrt{\frac{1}{R \cdot T_2}} \quad (8)$$

here T_2 is gas temperature in the ring groove II [K].

2.3. Case 3 of the positional relationship of the rings in the grooves of the piston, when $\sum P_1 > 0$ *,* $\sum P_2 < 0$ *and* $\sum P_3 > 0$

The calculation of the blow-by if the sum of the forces acting on the ring I and III is positive and on the ring II is negative (Fig. 4,a) is the following: $\sum P_1 > 0$, $\sum P_2 < 0$ and $\sum P_3 > 0$ with $p_1 > p_2 = p_3$.

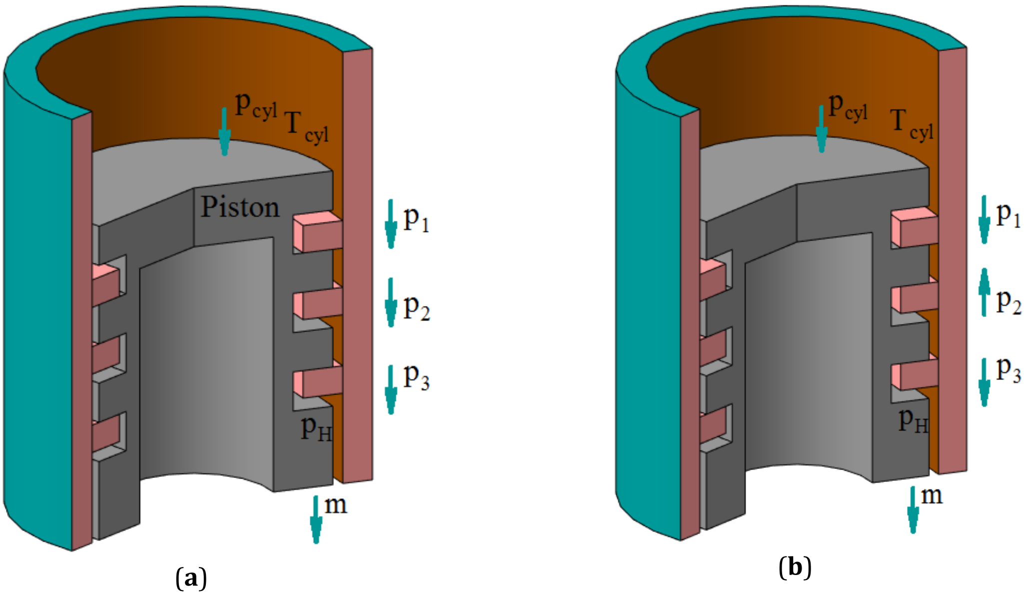

Figure 4. Case 3 of the positional relationship of the rings in the grooves of the piston, when: (**a**) $\sum P_1 > 0$, $\sum P_2 < 0$ and $\sum P_3 > 0$; (b) $p_2 = p_3 > p_1$.

Then $\frac{dp_1}{d\tau}$ is determined by the Eq. (3)

$$\frac{dp_2}{d\bar{\tau}} = \frac{dp_3}{d\bar{\tau}} = a_{23} \cdot K_2 \cdot p_1 \cdot \left[\frac{\psi \cdot \left(\frac{p_2}{p_1} \right) \cdot T_2}{\sqrt{T_1}} - \frac{1}{\mu \cdot f_2} \psi \cdot \left(\frac{p_H}{p_3} \right) \cdot \frac{p_2}{p_1} \cdot \frac{p_3}{p_1} \sqrt{T_2} \right] \quad (9)$$

Where $a_{23} = \frac{\mu_2 \cdot f_2 \cdot \sqrt{R}}{V_1 + V_3}$.

When $p_2 = p_3 > p_1$ and $p_1 = p_{cyl}$ (see Fig. 4,b):

$$\frac{dp_2}{d\tau} = \frac{dp_3}{d\tau} = -a_{23} \cdot k_2 \cdot p_2 \left[\psi \left(\frac{p_1}{p_2} \right) + \frac{1}{\mu f_2} \cdot \psi \left(\frac{p_H}{p_3} \right) \right] \sqrt{T_2} \quad (10)$$

Then Equation (2) is the following:

$$\frac{dm}{d\tau} = \mu_3 \cdot f_3 \cdot \psi \cdot \left(\frac{p_H}{p_3} \right) \cdot p_3 \sqrt{\frac{1}{R \cdot T_3}} \quad (11)$$

2.4. Case 4 of the positional relationship of the rings in the grooves of the piston, when $\sum P_1 < 0$, $\sum P_2 < 0$ and $\sum P_3 > 0$

The calculation of the blow-by if the sum of the forces acting on the ring I and II is negative and on the ring III is positive is the following (Figure 5): $\sum P_1 < 0$, $\sum P_2 < 0$ and $\sum P_3 > 0$ with $p_1 < p_2 > p_3$. Then Equation (11) is considered.

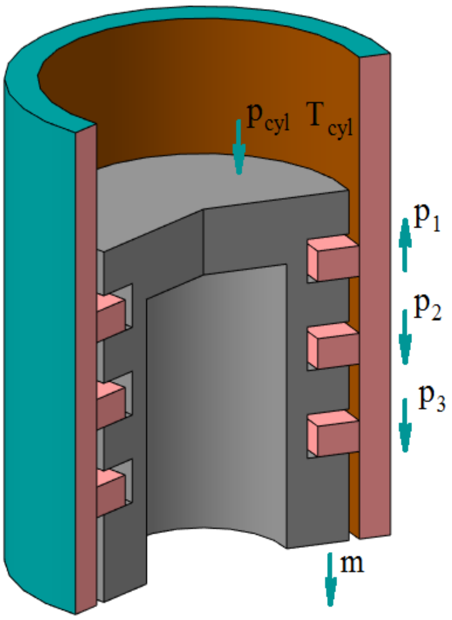

Figure 5. Case 4 of the positional relationship of the rings in the grooves of the piston, when $\sum P_1 < 0$, $\sum P_2 < 0$ and $\sum P_3 > 0$.

2.5. Case 5 of the positional relationship of the rings in the grooves of the piston, when $\sum P_1 < 0$, $\sum P_2 < 0$ *and* $\sum P_3 > 0$ *with* $p_1 < p_2 > p_3$ *and* $p_1 = p_{cyl}$

The calculation of the blow-by if $\sum P_1 < 0$, $\sum P_2 < 0$ and $\sum P_3 > 0$ with $p_1 < p_2 > p_3$ and $p_1 = p_{cyl}$ is the following Fig. 6.

Then $\frac{dp_2}{d\tau}$ is determined by the Equation (5) with $a_{23} = a_2$; $p_H = p_3$ and $p_3 = p_2$.

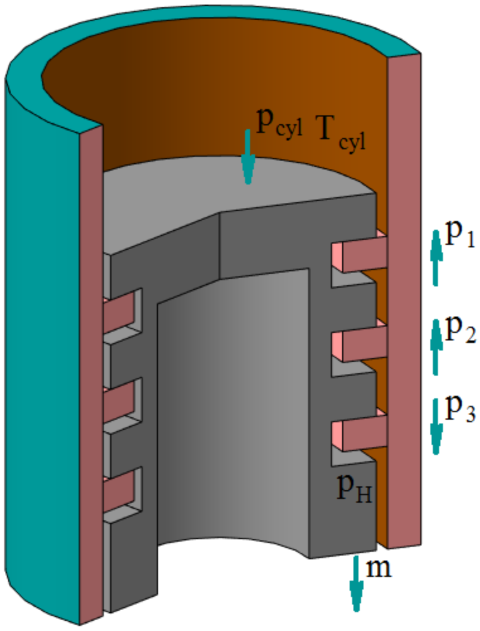

Figure 6. Case 5 of the positional relationship of the rings in the grooves of the piston, when $\sum P_1 < 0$, $\sum P_2 < 0$ and $\sum P_3 > 0$ with $p_1 < p_2 > p_3$ and $p_1 = p_{cyl}$.

2.6. Case 6 of the positional relationship of the rings in the grooves of the piston, when $\sum P_1 < 0$, $\sum P_2 > 0$ *and* $\sum P_3 > 0$ *with* $p_1 < p_2 > p_3$, $p_1 = p_{cyl}$ *and* $p_2 = p_1$

The calculation of the blow-by if $\sum P_1 < 0$, $\sum P_2 > 0$ and $\sum P_3 > 0$ with $p_1 < p_2 > p_3$, $p_1 = p_{cyl}$ and $p_2 = p_1$ is the following Figure 7.

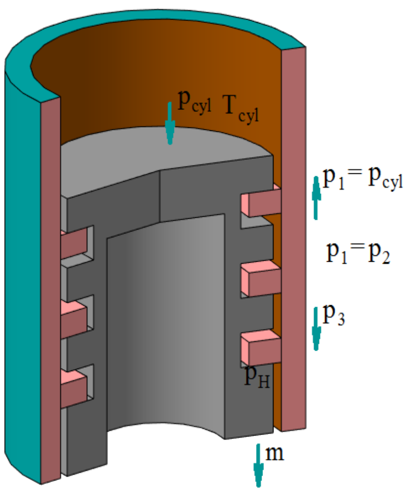

Figure 7. Case 6 of the positional relationship of the rings in the grooves of the piston, when $\sum P_1 < 0$, $\sum P_2 < 0$ and $\sum P_3 > 0$ with $p_1 < p_2 > p_3$, $p_1 = p_{cyl}$ and $p_2 = p_1$.

Then $\frac{dp_3}{d\tau}$ is determined by the Equation (4) with $m = 3$, $p_4 = p_H$.

For further analysis it is convenient to consider the relative magnitude of gas escapes:

$$\overline{m}(\varphi) = \frac{m}{m_{cyl}} \quad (12)$$

here m is current gas escape in the crank angle [kg]; m_{cyl} is total gas escape per cycle [kg].

3. Results

The dependencies $\overline{m}(\varphi)$ and m_{cyl} for the diesel with the main initial data are shown in Fig. 8 and 9:

- Engine power Ne = 155 kW;
- Engine speed n = 2600 min^{-1};
- value of flow section $\mu_2 \cdot f_2 = \mu_3 \cdot f_3$ = 0.3·10^{-6} m^2;
- volume on lands and the piston ring grooves: $V_2 = V_3$ = 1.73·10^{-6} m^3.

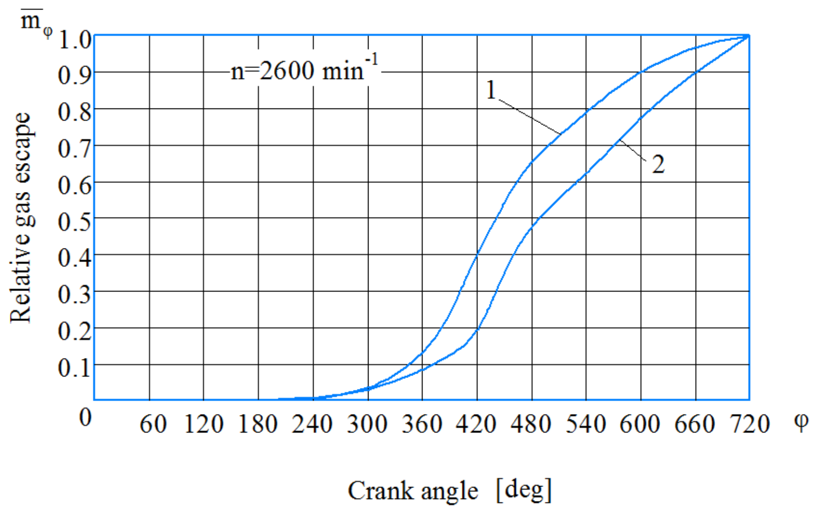

Figure 8. Changes of the relative gas escape $\overline{m}(\varphi)$ depending on the crank angle (n = 2600 min^{-1}) subject to: 1 – the movement of the rings in the grooves; 2 – the fixed rings.

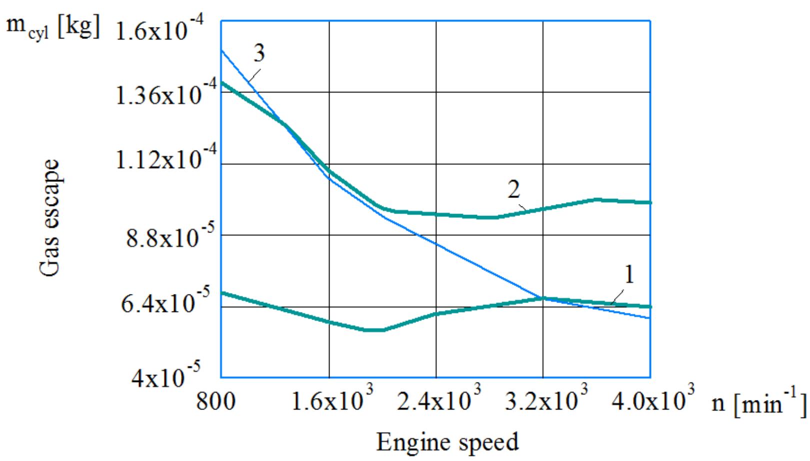

Figure 9. Changes of the gas escape m_{cyl} depending on the engine speed: 1 – idling conditions; 2 – load conditions; 3 – the fixed rings.

The initial and boundary conditions were set according to the results of indexing and thermometry of the diesel engine at the rated duty; discharge coefficient μ =0.85.

Movements of the rings in the grooves noticeably affect the gas escape into the crankcase, especially when the pressure in the cylinders is the biggest, that is, at 360-660° crank angle (see Figure 8). After 660° crank angle, the difference in gas escape values can be neglected.

4. Discussion

The analysis of dependences $m_{cyl} = f(n)$ confirms the significant influence of the dynamics of rings on the course of cyclic gas escape curves (see Fig. 9). The deterioration of the sealing properties of the piston rings with increasing the engine speed was noted earlier in other studies [12-13].

This fact especially manifests itself in the idling modes due to the reduced pressure in the combustion chamber.

Thus, according to the gas escape flow nature dependence on the engine speed it is possible to assess the compression ability of the diesel ring seal, the quality operation of the piston rings. This allows determining the technical condition of the CPG parts which is especially important for mining industry trucks..

5. Conclusions

1. The effect of the axial movement of the piston rings in the piston grooves on the blow-by in the ICE is established. This creates prerequisites for a more accurate assessment of their sealing ability and the search for the ways to further improve them.

2. The calculated dependences to calculate the blow-by depending on the positional relationship of the rings in the piston grooves are obtained.

3. The dependencies of the gas escapes on the engine speed allow judging upon the dynamic stability of the ring seal and solving the issues of evaluating the technical condition of the CPG parts and improving their operational properties, especially for idling modes.

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Some components of safety and comfort of a car

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Abstract: This paper addresses the need to minimize of vibration levels of unsprung weight of elements of vehicles suspension are considered. In the study design, some methods of parametric optimization with dynamic vibration absorbers (DVA) in elements of a nonlinear suspension with dynamic mechanical properties have been applied. To determine the low frequency components of vibration of laminated composite plates with the DVA system numerical estimates of the vibration of the equivalent plate of Timoshenko used. One structural version for ensuring the preservation of the residual space of the passenger cabin of the bus during the rollover according to norms 66 is considered. The energy-absorbing structure of the roof of the bus is made in the form of tubular space-frame made of composite materials.

Keywords: suspension, unsprung masses, damping, dynamic vibration absorber, bus rollover, passenger residual space, European regulation ECE R66.

1. Introduction

One of the important problems of designing modern vehicles, in particular wheeled vehicles, is the safety and comfort of the driver and passengers while maintaining the optimal technical and economic performance, such as functionality, efficiency, energy and material consumption, maintenance costs, repair costs, and so on. The primary task in this direction is the need to improve the analytical method for calculating the effect of dynamic loads in order to approximate theoretical results to experimental data and achieve rational and efficient design of safety and comfort elements.

An important issue for the development of modern vehicles is the reduction of vibration. DVA are widely used to reduce vibration and noise levels in vehicle cabs, rotating parts machines, unsprung weight of wheeled vehicles. So it is expedient to consider the suspension of a car with DVA. This devices should also be used in shock absorber safety devices by accident's. They distinguish from traditional energy absorbing elements and can serve as vibration and noise protection elements also.

The traditional suspension system of vehicle consists springs and dampers and be classified as passive suspension. It does not require external control, but only dissipates energy. This system has weak adaptability due to the fixed characteristics of springs and shock absorbers. A good designed

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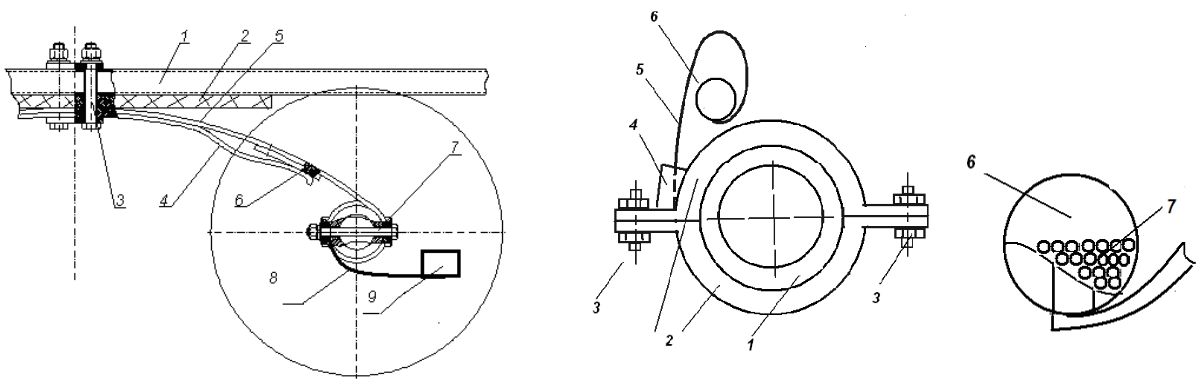
passive suspension can, to some extent, optimize the quality of ride comfort and stability, but cannot completely eliminate the consistency between characteristics of suspension [1].

An important characteristic of the suspension is its smooth ride, which is usually characterized by displacements of unsprung masses. This is due to ensuring the contact of the wheels with the road. This criterion differs from the more general criterion of controllability of the system on some programmatic moves [2]. Although the criterion for the movement of unsprung masses can be improved by the suspension, however, the most effective way is to join of DVA to the unsprung masses. This is especially true for the newest designs of cars with electric motors on the axle of the wheels. For such structures, the traditional reduction in the weight of unsprung masses can not be achieved to improve handling. DVA is widely used to reduce vibrations [3-8]. An example of the use of DVA in a suspension of boom-sprayer is given in [9].

2. Materials and methods

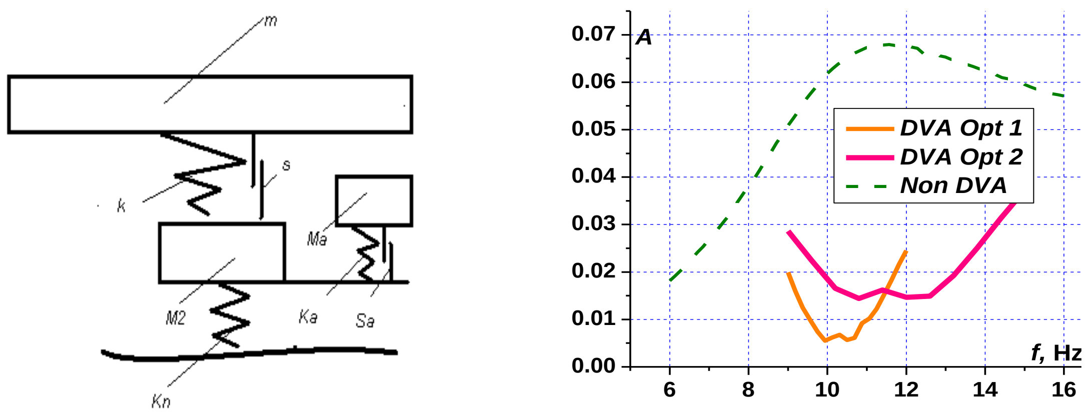
For vehicles many DVA have been developed. They differ in weight and dimensions, design features, ranges of regulation. One of the variants of non-linear suspension with DHA and container with vibration absorbing parts is in Figure 1 shown.



(a) (b)

Figure 1. Constructive variants of the suspension from the DVA: (a) - nonlinear suspension; (b) - suspension container with particles.

On the basis of the discrete-continual approach, a three-mass calculation scheme, taking into account the unsprung masses and the DVA attached to them, is obtained (Figure 2a) [10]. Optimization of parameters is carried out.



(a) (b)

Figure 2. (a) - calculation scheme of the suspension; (b) - the results of optimization in different frequency ranges: -amplitude of unpowered masses.

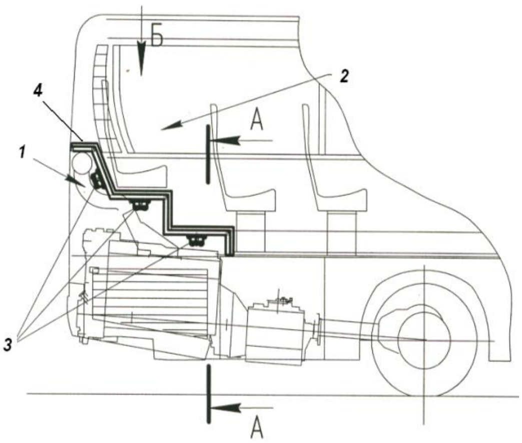
To obtain optimal projects in a plurality of constructive parameters, algorithms of genetic optimization were used in conjunction with condensed non-parametric circuits. The results of optimization are shown in Figure 2b for different frequency ranges.

3. Results

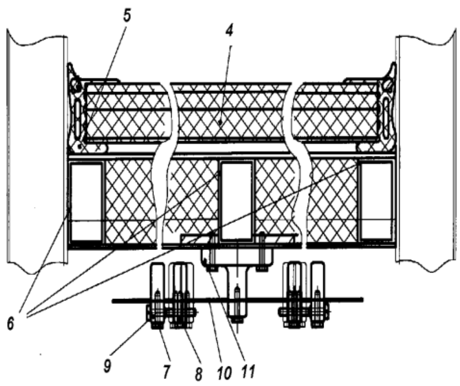
Noise-absorbing partition shown of a thin-walled element - the base of the partition and the attached DVA's which serve for noise protection against interference acting on the partition. Such a partition can be applied to the floor of the bus, in the elements of the body of the engine compartment of vehicles, and at a wall of the cabin, which are in conditions of high acoustic loads, as well as cabins of mining machinery, in schemes of sound insulation of premises, salon of airplanes, etc. However, thin-walled laminar noise-absorbing partitions that are used today are effective only in the higher frequency range and inefficient in the low-frequency range typical of many machines. Their noise-absorbing properties can be greatly improved in the low-frequency range with the help of DVA. At Figure 3 schematically shown the general view of the soundproof partition of the bus motor. The cross-section view shown the bus septum where: 1 - engine compartment, 2 - passenger compartment, 3 - DVA, 4 - internal part of the partition, 5 - elastic fastening of the partition , 6 - external part of the sound absorber of reinforcing elements, 7 - fixed mass DVA, 8 - moving mass DVA, 9 - adjusting screw, 10 - elastic plate member, 11 - DVA mounting node.

Between the engine 1 and the passenger compartment 2, a sound absorbing partition is installed to the outer part of which the DVA-11 unit with a stationary mass DVA 7 and a moving mass DVA 8 are mounted on the elastic plate member 10 with an adjusting screw 9 attached.

To study the soundproof properties of panels in the low-frequency range, the layered elements of partitions are drawn to the equivalent of them Timoshenko beams [11]. The algorithms of the reduction to the Timoshenko beam are considered in [12]. In works [13-24] the damping and sound protection properties of layered plates with additional elements are considered. Consider the three-layer beam. Its parameters: length L=0.6 m, thickness of the filler $H = 0.0254$ m, thickness of the facial layers h=0.003m; filler modules $C_{xx} = C_{zz} = 180$ MPa, $G = 35$ MPa, $C_{xz} = 40$ MPa, density ρ=240 kg/m^3); modules of rigid facial layers - C_{xx}=43 GPa; C_{xz}=6 GPa; G=0.6 GPa, ρ=2000 kg/m^3).



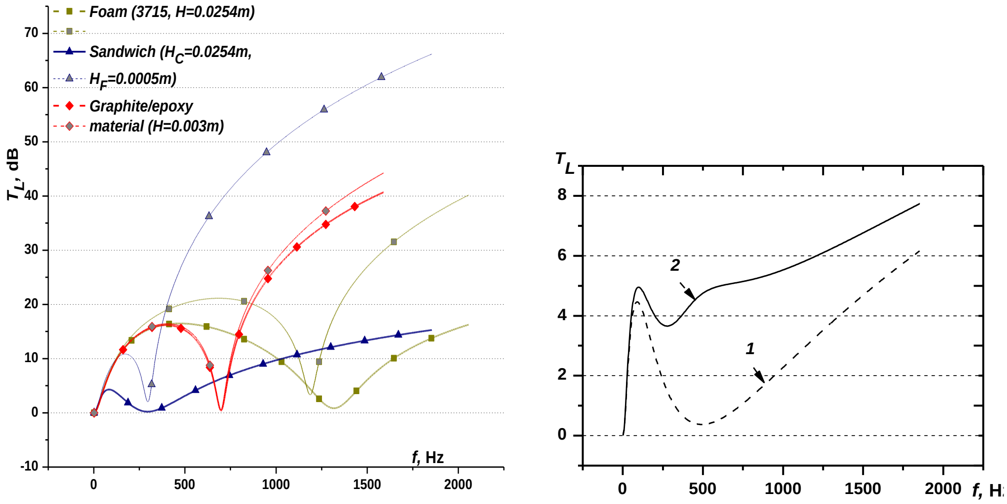
(a)



(b)

Figure 3. (a) - general appearance of the soundproofing of the bus; (b) - the cross-section of partition-wall.

Figure 4 shows the sound loss coefficient for various materials as a function of the dimensionless frequency f/fr. Figure 4a shows the coefficient of sound loss for different ratios of Young's modulus E to the coefficient of displacement G of the equivalent beam of Timoshenko, in Figure 4b - partition with DVA.



(a) (b)

Figure 4. (a) - coefficient of sound loss for different materials, (b) - sound losses for the partition with DVA.

4. Discussion

Noise-insulating material can also serve other purposes, namely to reduce the traumaticity of passengers in accidents. Layers of this material will improve the frames ability to absorb kinetic energy, while maintaining the residual space of passenger compartment. In order to ensure the structural integrity of the vehicle and its ability to absorb the impact of energy, it is important to examine the nature of the fracture to reduce peak loads and improve the power absorption of impact.

These factors can be reduced by using special energy-absorbing devices also. A rollover of a bus is one of the most dangerous accidents. The risk of fatal consequencei is greater than other cases. It is determined that at least the amount of accidents involving buses is smaller, but fatal consequences (31%) and serious injuries (21%) more than in other accidents. The UNECE Regulation 66 requires that the large vehicles superstructure strength need be sufficient to provide residual space during and after a rollover.

Superstructure contribute to the strength and energy absorbing capability of the bodywork, and preserve the residual space, which preserved in the passengers', crew and driver's compartment(s) better survival possibility for passengers, driver and crew in case of a rollover accident. Side superstructure is formed from cantrail and waistrail. Cantrail means the longitudinal structural part of the bodywork above the side windows including the curved transition to the roof structures. Waistrail means the longitudinal structural part of the bodywork below the side windows. In the rollover test the waistrail may be the second area to contact the ground after initial deformation of the vehicle cross-section. In the rollover test the cantrail hits the ground first. a structural part or element which does not have significant deformation and energy absorption during the rollover test means a "Rigid part".

The superstructure of the vehicle shall have the sufficient strength to ensure that the residual space during and after the rollover test on complete vehicle is unharmed. The residual space is continuous in the passenger, crew and driver compartment(s) between its rearmost and foremost plane and is defined by moving the defined vertical transverse plane through the length of the vehicle along straight lines through some points on both sides of the vehicle.

Passive safety European Regulation ECE R66 preferred real high cost roll-over test. The application for approval of a vehicle type with regard to the strength of its superstructure shall be submitted by the vehicle manufacturer and identify main data and parameters of the vehicle type, an overview of the main verification methods of bus rollover test precised analysis of virtual procedure of rollover test, detailed initial condition-system for rollover simulation and possible virtual method of reference energy. There "reference energy" is the potential energy of the vehicle type to be approved, measured in relation to the horizontal lower level of the ditch, at the starting, unstable position of the rollover process. In this paper a new type of energy absorbing devices is investigated.

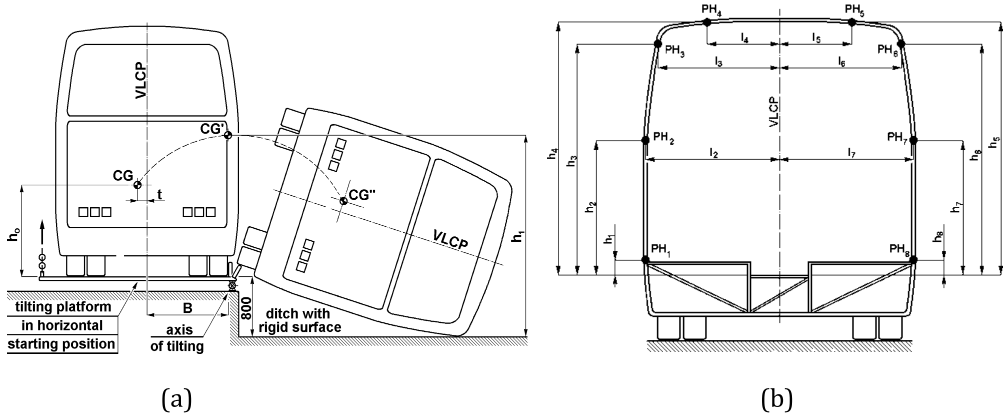


Figure 5. Rollover test (a) and geometrical parameters of plastic hinges on a bay (b) defined by UNECE Regulation 66.

Various designs of anti strike devices are known. They are widely used for wheeled cars. Their principle of work is plastic deformation of materials. During impact, energy absorption occurs due to crumple of construction.

During an accident at the moment of a collision of a car with an obstacle, the impact energy is absorbed by plastic deformation of the body parts. Such items are specifically provided in the design. To a certain level of loading they act as elements of body frame. When the load exceeds the threshold value, the energy-absorbing elements begin work as shock-resistant devices. Deskry "Plastic zone"(PZ) and "Plastic hinge"(PH). PZ means a special geometrically limited part of the superstructure in which, as the result of dynamic, impact forces:

- large scale plastic deformations are concentrated;
- essential distortion of the original shape (cross section, length, or other geometry) occurs;
- loss of stability occurs, as a result of local buckling;
- kinetic energy is absorbed due to deformation.

PH means a simple plastic zone formed on a rod-like element (single tube, window column, etc). However, most of devices work due to flattening various beams. This does not allow uniformly absorb the shock energy. They do not give them the opportunity to absorb the impact energy in the lateral reversal of the bus, which is often accompanied by injury of passengers.

In Figure 6 crash resistance bus roof is presented [19]. It contains of energy absorbing composite rod connected with horizontal beams of the roof, breaking rod and side racks of the bus. Energy absorption coupling installed in the places of attachment of bearing rods, hinged fixing of one half of the horizontal beam roof to the side rack. At Figure 6 the structure is depicted in a post-impacted state. The crash resistance roof of the bus contains energy-absorbing elements that are made in the form of a carrier spatial rod symmetric system, consisting of bearing rods 2, interconnected by a breaking rod 3 and connected to one absorbing composite rod 4 and energy absorbing couplings 5. The shock absorbing roof of the bus joins at plastic hinges on a bay.

The shock absorber roof of the bus works in such a way that the principle of its operation involves the presence of a mechanism for multi-point absorption of impact energy. During the rollover of the bus 1 during the impact load, for example, the left wall 1 (Figure 6), the membrane of the left side or right side rack 4 and the subsequent movement of the left or right bearing rod 2, causing the displacement of the composite rod 3, occurs in turn causes strain of the tensile strength of the composite rod 4 (detachment of one layer from the other) and the scroll of the absorbing clutch 5, crushing their internal construction, and emitting the entire structure of the roof when rotating against the hinge 6 upwards, which is substantially enhances the energy absorption efficiency, provides the minimum spatial deformation of the body of the vehicle (in the direction of the passenger compartment) and increases the level of safety in emergencies.

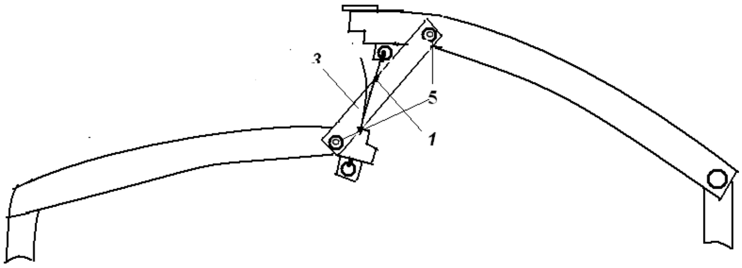


Figure 6. The shock absorber roof of the bus (after reaching the critical force value): 1 - energy absorbing composite rod; 2 - horizontal beams of the roof; 3 - breaking rod; 4 - side racks of the bus; 5 - shock absorbing coupling

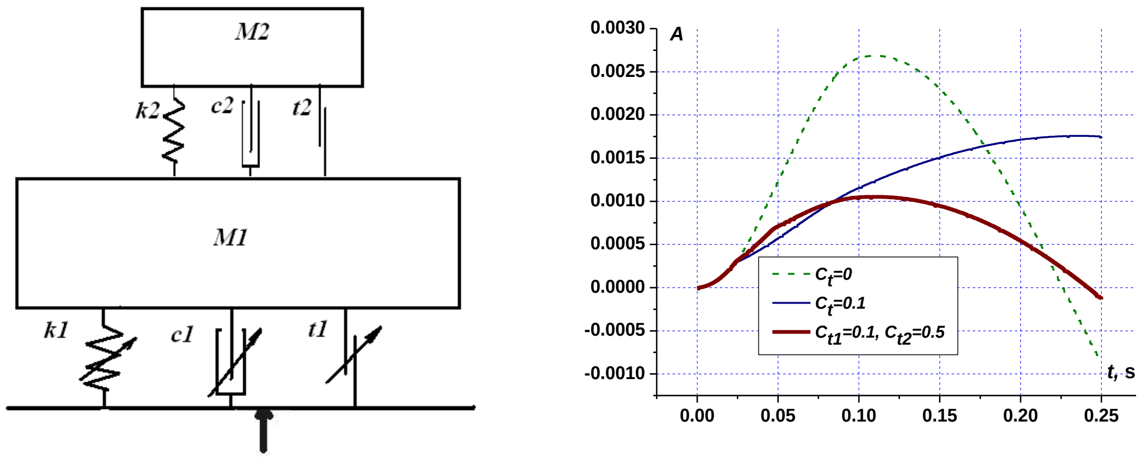
The minimum energy required to be absorbed by the body section (E_{min}) is the sum of the energy of the bays comprising the body section.The body section passes the loading test in case, when all the bays which form that body section are considered to have passed the quasi-static loading test and these results can be quoted in future requests for approval provided that the component bays are not expected to carry a greater mass in the subsequent superstructure. The body section fails the loading test if one of the bays go into the residual space.

The total energy (E_T) shall be distributed among the bays of the superstructure in the proportions of their masses. The total energy to be absorbed by the superstructure is:

$$E_T=0.75\,M\,g\,\Delta h$$

where: $M = M_k$ - unladen kerb mass of the vehicle if there are no occupant restraints; or, M_t, total effective vehicle mass when occupant restraints are fitted; g - gravitational constant; Δh - vertical movement of the vehicle centre of gravity during a rollover test.

A number of methods have been developed to investigate the mechanics of hinges demolition. Some models are simple, mostly single mass. To study the dynamics of the system: the basic design - the passengers will use a relatively simple two-axle model (Figure 7,a) with variable parameters. In Figure 7b shows optimization results with constant damping and controlled friction. Friction, and especially, controlled friction, reduces the acceleration of passengers, and grade of injuries.



(a) (b)

Figure 7. (a) – two mass model; (b) – optimization results with stable damping and controlling traction.

5. Conclusions

An important issue for the development of modern vehicles is the reduction of vibration. DVA are widely used to reduce vibration and noise levels in vehicle cabs, rotating parts machines, unsprung weight of wheeled vehicles. So it is expedient to consider the suspension of a car with DVA. This devices should also be used in safety devices by accident's. They distinguish from traditional energy absorbing elements and can serve as vibration and noise protection elements also.

The traditional suspension system of vehicle consists springs and dampers and be classified as passive suspension. It does not require external control, but only dissipates energy. This system has weak adaptability due to the fixed characteristics of springs and shock absorbers. A good designed passive suspension can, to some extent, optimize the quality of ride comfort and stability, but cannot completely eliminate the consistency between characteristics of suspension.

A series of vibration, noise and absorbing elements for vehicles are considered. In order to improve the smooth ride of the suspension, the use of DVA in unsprung masses is considered. Laminated partitions with DVA system are considered for noise reduction in car salons. Impact absorbing elements of the new type are considered in order to prevent injuries to passengers during rollover of buses. The resulting calculation schemes and optimal projects confirm the effectiveness of this kind of elements.

To obtain optimal projects in a plurality of constructive parameters, algorithms of genetic optimization were used in conjunction with condensed non-parametric circuits.

Noise-absorbing partition shown of a thin-walled element - the base of the partition and the attached DVA's which serve for noise protection against interference acting on the partition. Such a partition can be applied to the floor of the bus, in the elements of the body of the engine compartment of vehicles, and at a wall of the cabin, which are in conditions of high acoustic loads, as well as cabins of mining machinery, in schemes of sound insulation of premises, salon of airplanes.

Noise-insulating material can also serve other purposes, namely to reduce the traumaticity of passengers in accidents. Layers of this material will improve the frames ability to absorb kinetic energy, while maintaining the residual space of passenger compartment. In order to ensure the structural integrity of the vehicle and its ability to absorb the impact of energy, it is important to examine the nature of the fracture to reduce peak loads and improve the power absorption of impact.

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Research on transportation of metallurgical slag of tippers in the conditions of southeast of Ukraine

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Abstract: Research aim - to produce conclusions that will result in the increase of the productivity and reduction of specific expense of fuel of tippers, while taking into account the tippers operational characteristics at transportation of metallurgical slags and products of their processing.. As a result of research the analysis of tippers of BelAZ-7540 exploitation was conducted on a metallurgical enterprise in the climactic conditions of southeast of Ukraine,. In addition, factors contributing to the efficiency of the tippers use have been distinguished and examined. It was found that the efficiency of the use of tippers, namely the studied change of expense of fuel is contingent on the work of tippers. Thus, in the process of research, there was the educed periodicity of oscillation of expense of fuel of tippers. The application of the research findings is that appropriate procedures are recommended in terms of the rational use of fuel, in particular, in the process of determination, planning, setting of norms of the necessary amount of fuel, which is one of the most essential and actual tasks for modern metallurgical enterprises today.

Keywords: tippers, slag, transportation, transport process, metallurgical enterprise, open pit.

1. Introduction

Motor transport, in particular, industrial transport of enterprise - the constituent of a transport system of Ukraine is important. An industrial transport works in workshops, on open works, prevails in careers. He is presented, mainly, by the tippers of different carrying capacity. Dump trucks are used for transportation in opencast mines [1]. Him structural subdivisions and transport vehicles provide continuity and reliability of production. Worsening of operating indexes of work of tippers in a career results in systematic lag of volumes of booty to worsening of the productivity of work of quarry motor transport, rising in price of eventual products. Optimization of work of tippers in the routes of transportation of metallurgical slags and products of their processing in the conditions of quarry of metallurgical enterprise is important direction of scientific and technical progress on a transport. The for today operating events of increase of the productivity at transportation of metallurgical slags and products of their processing operating of tippers conditions cannot recreate in the conditions of quarry of metallurgical enterprise. Energy consumption rises as mines extract ore from deeper levels [2].

Fuel consumption of mining dump trucks accounts for about 30% of total energy use in surface mines [3]. The "empty idle time" truck was the main contributor to unnecessary fuel consumption [4].

Nowadays, there is a strong tendency to optimize—in wide sense—production efficiency, safety of operations, environmental impact etc. in mining industry. One can notice in different media that mining

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industry evolves to be green, intelligent, smart, invisible, safe and effective. Different actions have been taken to achieve it. Undoubtedly, transfer of technology to mining industry that covers monitoring system, IT solutions, computer aided management systems, automation/robotics, etc. significantly helps in modernization of mining industry [5].

Vehicle platooning has become important for the vehicle industry. Yet conclusive results with respect to the fuel reduction possibilities of platooning remain unclear. The focus in this study is the fuel reduction that heavy-duty vehicle platooning enables and the analysis with respect to the influence of a commercial adaptive cruise control on the fuel consumption [6].

Nowadays and in the near foreseeable future the quarry road transport will be the most common in the open-cut mining method. This is due to a range of advantages of open-pit dump trucks usage as compared with other types of quarry transport, i.e. autonomy, the possibility of using in any mining engineering and climatic conditions etc. [7].

Automobile quarry transport, namely heavy tippers, occupy an important place in a transport system of industry [8]. Automobile quarry transport has significant advantages over other types of transportation, therefore at this stage of open development of deposits it is used most often by domestic and foreign miners. The experience of the use of road transport has confirmed its high technical and economic performance in certain mining conditions. Due to the release of new high-performance large-capacity cars and improvement of their maintenance and repair system, the scope of this type of transportation has expanded significantly in recent years (in Ukraine it is approximately 60...70% of the total volume of transport). It is known that automobile quarry transport has high mobility; it does not depend on external power supplies, which allows it to be used in difficult conditions of mineral deposits, during the construction phase of a career, as well as in the development of deposits with limited reserves and a short lifetime. By car you can move rocks with different physical and mechanical properties; it can overcome the rather steep climb of the highways, which reduces the length of the routes and allows you to save on mining costs during the construction of outgoing trenches; simplify the process of transportation. A significant disadvantage of road transport is its dependence on climatic conditions and the state of highways, which inevitably leads to a decrease in traffic volumes during the periods of rains, snowfalls and ice. In addition, its use implies a short distance of transportation (3...4 km, and most appropriate for 1.2...1.5 km); in the process of work there is a high level of pollination and pollution of the atmosphere by harmful emissions (up to 200 tons per year) of exhaust gases due to the high intensity of traffic and limited size of the career; Also, there is a low level of staff productivity due to the need to maintain a state of drivers; at the same time, we note the relatively high energy consumption of cars and significant operating costs. Currently, in the quarries used heavy truck dumpers and trains BelAZ brand with a hydro mechanical and electromechanical transmission, load capacity from 27 to 220 tons. Road transport can be used quite effectively for the construction of quarries when developing fields with irregular contours, with a selective extraction of useful fossil fuels The rational distance of transportation of cargoes cannot exceed 3...4 km, therefore the transport will be appropriate in the quarries, which in terms of relatively limited size (up to 2.0...2.5 km). Divers of roads can be 80...100%, and the size of the largest radius of rotation on the roads can reach 40...50 m, the smallest 8...12 m. The depth of quarries where the road transport works usually does not exceed 200...250 m. The prospect of its use in deep quarries may be realistic due to combined transport schemes within the CPT, by improving the routes of vehicles in the quarry, developing automated control systems for dump trucks, along with excavation excavators [9].

2. Literature review

Unlike other modes of transport, industrial transport is rigidly associated with the technology of basic production. Technological transportations by dump trucks of metallurgical slags determine extremely stressful working conditions and high expenses of fuel resources, which make up a considerable share in the cost of road transport. In addition, the reliability of the transport system of the metallurgical enterprise as a whole depends on the efficiency of transport and the quality of fuel and its availability. At the same time, there is a problem of increasing productivity and maximally accurate valuation and forecasting of fuel consumption by dump trucks during transportation of metallurgical slag and products of their processing in the conditions of a metallurgical enterprise career. On the basis of estimated numbers of hours for both overnight idling by sleepers and long-duration idling by all size classes during their workdays, the total fuel use by idling trucks is estimated to be more than 2 billion gallons per year [10]. The rational use of fuel dump trucks in the routes of transportation of metallurgical slag and products of their processing in the conditions of a metallurgical enterprise career is an important direction of scientific and technological progress in transport. Current measures to increase productivity and reduce fuel consumption when transporting metallurgical slags and their products are not well-known and, of course, can not adequately reproduce the current conditions for the operation of dump trucks in the conditions of a metallurgical enterprise career. The metallurgical industry in the country's economy occupies an important place, being the basic industry.

Modern metallurgical combines are characterized by complex production technology, large volumes and assortment of products and, as a consequence, a significant need for iron and other types of raw materials. A characteristic feature of the promotion of material flows of such enterprises is that, throughout their trajectory, from the receipt of raw materials to the shipment of finished products, they necessarily include in their structure transport links [11,12].

Large metallurgical enterprises are characterized by complex production technology, large volumes of production reaching 5-6 million tons per year, and with their high transport capacity (up to 10-12 tons) - a significant need for material resources [13].

In modern conditions, an open way of developing minerals is characterized by further deepening of quarries and, consequently, more stringent requirements for the stability of the operation of the transport and technological complex [14].

At present, theoretical and scientific-practical ways and measures for increasing productivity and reducing fuel consumption of mining dump trucks are considered in many scientific works of domestic and foreign scientists.

The article [15] examines the dependence of dumper performance on technical performance indicators and the introduction of cargo monitoring and control systems as one of the ways to increase productivity in the mining industry. This paper investigates the factor parameters of the transport process of the BelAZ truck dump truck and develops ways to increase the productivity of dump trucks under specific conditions of operation.

In article [16] the peculiarities of transportation of mining mass by automobile quarry transport are analyzed. The technical and operational parameters of work of the rolling stock on the route that influence the transport process are determined. It was established that the technological process of transportation of mined weight has a high level of mechanization, which, in turn, requires the organization and planning of transportation in order to effectively use it.

The article [17] investigates the performance of dump trucks and increases their productivity in the conditions of the field of migmatites. According to the author, one of the important factors in improving the efficiency of the use of dump trucks is the status of quarry roads. The state of the quarry roads directly affects their performance. On the basis of graphical and analytical dependencies, we obtained indicators that allow us to determine the ways of increasing the productivity of dump trucks in the conditions of the Stryzhavsky deposit of migmatites.

This paper discusses the fuel economy question with respect to road geometry data and future speeds, a condition that can be determined for an autonomous haulage system with relative ease [18].

This paper a new raster-based GIS model that combines multi-criteria evaluation and least-cost path analysis was developed to determine the optimal haulage routes of dump trucks in large scale open-pit mines [19].

3. Research methods

The study of the transport process of transport of metallurgical slag by dump trucks was carried out on the basis of existing statistical information. The method of complex systematization of statistical information was used. Namely, the collection of primary statistical material through the registration of facts; construction and grouping of collected data during statistical observation of primary data by dividing them into certain groups or classes on one or more grounds; analysis of consolidated data based on generalized synthetic indicators in the form of absolute, relative or average values; on the basis of analytical indicators. The mentioned method was used in article [15, 29, 3, 24].

4. Research of parameters of a transport process of transportations of metallurgical slag

Automobile career transport has become widespread in the open development of mining industries around the world. The use of motor transport in mining affirms its high technical and economic performance when used in difficult conditions: deep or complex deposits of minerals, the development of deposits with limited resources (with a limited size in the plan of up to 2.5 km) or a short lifetime [20]. Dump trucks today are the main means of transport for the extraction of rock mass from quays in mining, delivery of rocks for the construction of tailings dams at iron ore mines and for the transport of slags in metallurgical enterprises [21]. The mining industry provides more than 80% of material and energy resources necessary for mankind [22].

Due to its advantages, road transport is widely used in various mining conditions practically on most enterprises of the mining industries of Ukraine, other countries of the former USSR, as well as all developed countries of the world. At the iron ore quarries of Ukraine, motor transport has become the most widespread: it carries about 60...70% of the entire mining mass. The volume of these transportation at large mining and processing enterprises of Ukraine and Russia makes 30...130 million tons each year. In particular, in Ukraine, iron ore quarries transport 50...125 million tons of cargo annually. The use of automobile quarry transport is a technological process for the transfer of mining mass from quarries by dump trucks, in combination with reloading points to reception facilities of concentrating factories or in dumps. As has been noted more than once, this type of transport is characterized by high maneuverability of rolling stock, and cars are able to overcome steep slopes to a slope of 80...100% at a fairly high speed, which results in a significant reduction in the length of transport communications, in addition to increasing the productivity of excavators on 15...25% in comparison with work in the scheme of rail transportation, thanks to reduction of downtime in anticipation of loading. Under these conditions, the process of transportation is simplified due to the less complexity and the possibility of reducing the area of dump trucks; and also it is possible to provide high speed management of rolling stock. In the meantime, when using road transport, it is necessary to take into account its negative characteristics, which include restrictions on the rational distance of transportation to 3 ... 4 km; the dependence of the operation of roads and rolling stock on climatic conditions; high level of dustiness and environmental pollution in conditions of high traffic intensity and limited size of a career; low labor productivity, due to the need for a large number of drivers; high energy intensity, considerable expenses for operation and repair of rolling stock and highways, and therefore, relatively high cost of transportation [9].

The rolling stock of vehicles is usually estimated according to the following technological parameters:

- Load-carrying capacity (t), that is, the maximum weight of the load that the tool maintains in terms of structural strength (dump trucks with a load capacity of 10 to 180 tons and more, but often 75...120 tons);
- geometric capacity of the body (m3), which ensures maximum use of lifting capacity;
- This parameter distinguishes machines for small and medium cargo (the bulk density of the breed is 1.0...1.2 t/m3), as well as heavy duty vehicles (1.75...2.0 t/m3);
- utilization rate of the container, which is the ratio of the vehicle's own weight to its load-carrying capacity(in modern dump trucks with hydro mechanical transmission it equals 0.7...0.77, and with electromechanical transmission - 0.71...0.85);
- Specific power (kW/t), that is, the ratio of engine power to the full weight of the vehicle, reflects the traction properties or the ability of an dumper to overcome resistance to movement in different road conditions (in modern cars is 5...6 kW/t);
- speed (V=25...35 km/h, maximum up to 60 km/h);
- normalized braking distance (lg=16 m, if V=30 km/h);
- fuel consumption (from 140 to 700 liters per 100 km of run);
- minimum radius of the curve (10...12 m). The concept of the effectiveness of road transport gives the following main characteristics of this type of transport: - volume of transportation, million tons/year;
- Annual volume of transportation in recalculation on one registered dump (in the quarries of Ukraine it is 1.5...3.0 million tkm);

- average annual mileage, which, depending on mining conditions, fluctuates within 20...60 thousand km;

- coefficient of using the fleet of cars, the value of which is determined by the level of organization of work and repair of dump trucks (is in the range 0.2...0.8) [9].

Road haulage is considered to be effective under the following conditions: during the development of quarries, in particular, in the development of fields with irregular contours of limited size in the plan (2.0...2.5 km), as well as during selective extraction of minerals. At the same time, the annual volume of transportation may exceed 80 million tons; the rational length of transportation is 3...4 km, the depth of the quarries is 200...300 m. The further development of motor vehicles is associated with the use of large-capacity cars, increasing their reliability and service life, improving roads and systems of technical exploitation [9].

Dump trucks are one of the main means of transportation of metallurgical slags and their processing products. To date, dump trucks have become widespread in the quarries of metallurgical enterprises. This is primarily due to its high technical and operational performance in difficult operating conditions. When transporting and producing hot-metal metal in which the BelAZ-7540 dump trucks are used, they determine extremely stressful operating modes with high resource costs. In the system of PJSC "Mariupol Metallurgical Combine them. Ilyich "the park of dump trucks BelAZ-7540 works on 18 different routes, differing among themselves conditions of a transport process.

For transportation of slag it is the most stressful conditions and often forced work determined by the instability of physical and chemical properties of the cargo, the distance of cargo, the distance of transportation from 5 to 17 km, the daily volume of transportation from 850 to 2500 tons, the intensity of traffic to 16 trips per day. A similar situation exists in many other metallurgical enterprises. In the conditions of metallurgical enterprises, the organization of work of dump trucks career dump is built in accordance with the interests of industrial material flow, coordinated interaction with the rhythm of shops and units, with work in difficult environment transport and logistics system [23]. The mining operations of loading and haulage have an energy source that is highly dependent on fossil fuels [24]. It is possible to substantially increase the productivity of mining equipment by improving the system of maintenance and repair, which will reduce the length of time of cars in the repair zone [25].

The efficiency of the use of quarry transport depends on various factors that determine the parameters of the machine, which can be attributed [25, 26]: climatic conditions (temperature and humidity of the ambient air, wind speed), productivity of the enterprise, distance of transportation, relief, the type and quality of the road surface, the type of lorry, the type of cargo and its characteristics, the condition of the repair base, the speed modes of the machine, the type and age of the machine [28]. The productivity of a quarry dumper primarily depends on the speed of their movement and load capacity [29].

To date, the question remains about the production of innovative models of dump trucks that will meet the conditions of transportation of rock mass in quarries.

In this work, climatic conditions and their impact on fuel consumption of dump trucks were investigated.

In Figure 1-3 shows the dynamic series of climatic conditions of dump truck operation in the conditions of the southeast of Ukraine.

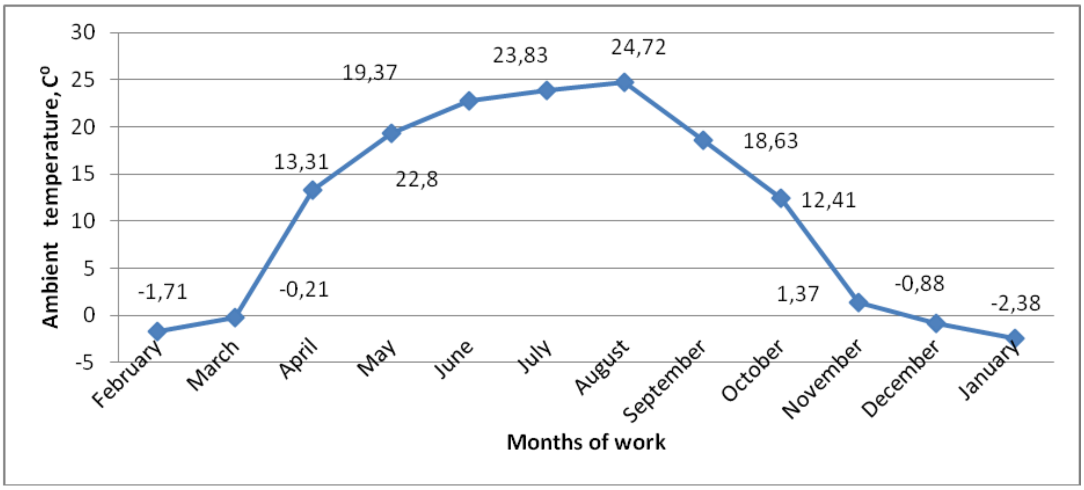

Figure 1. Dynamic row of monthly mean values of ambient temperature.

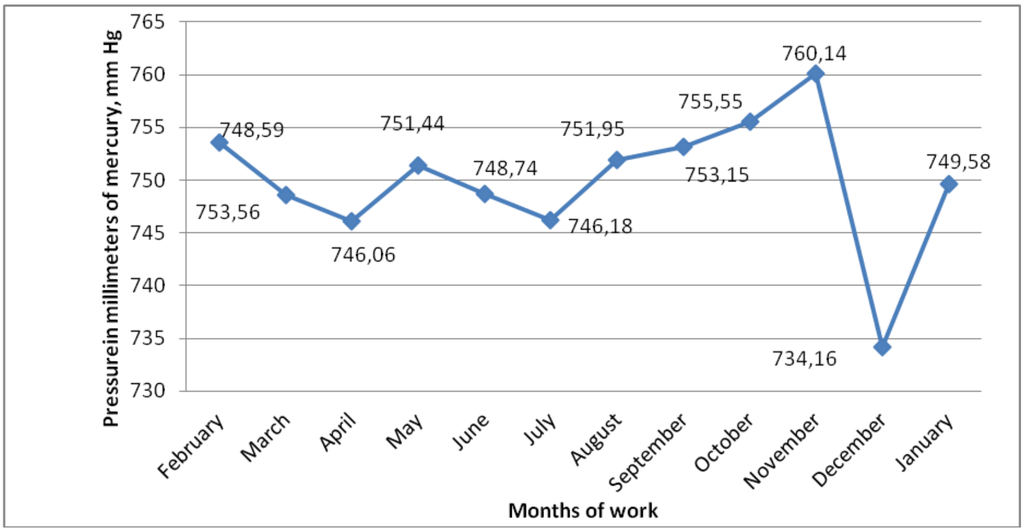

Figure 2. Dynamic row of monthly mean values of atmospheric air pressure.

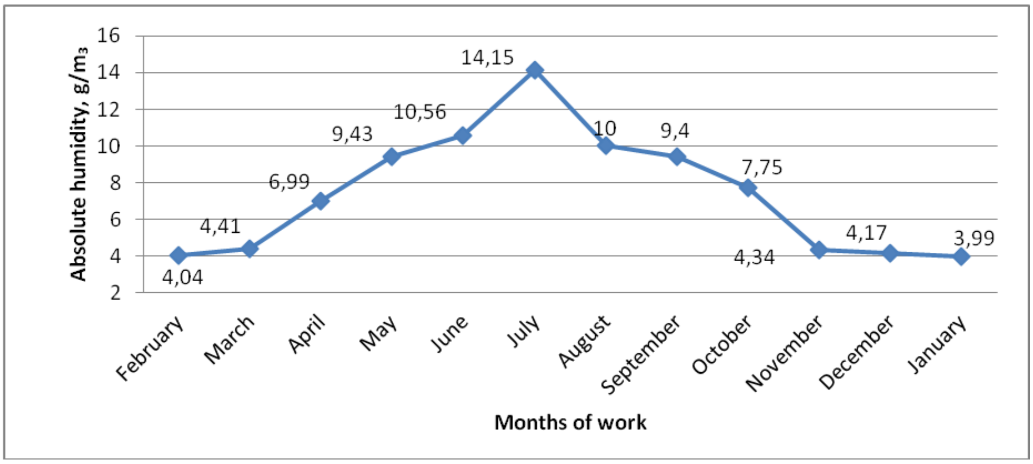

Figure 3. Dynamic row of monthly mean values of absolute humidity.

On Figure 4-9 dynamic rows over of climatic external of tippers environments are brought in the conditions of southeast of Ukraine.

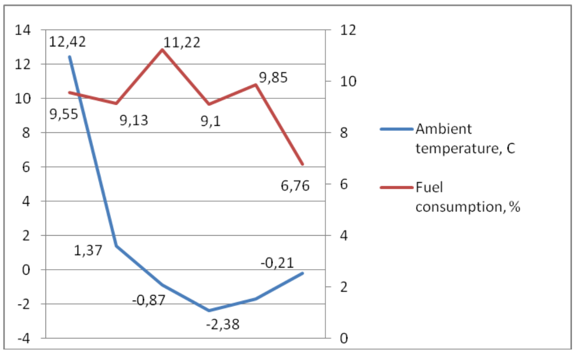

Figure 4. Dynamic row of average monthly values of ambient temperature and overrun of fuel in a cold period.

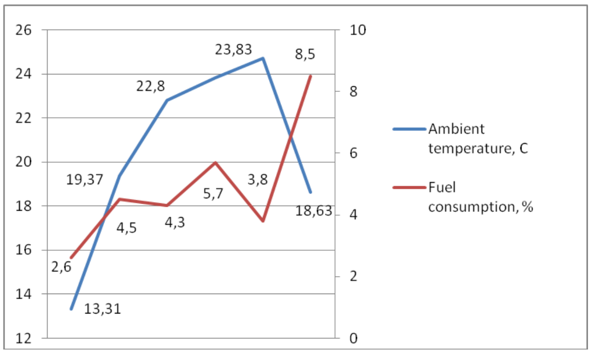

Figure 5. Dynamic row of average monthly values of ambient temperature and overrun of fuel in a warm period.

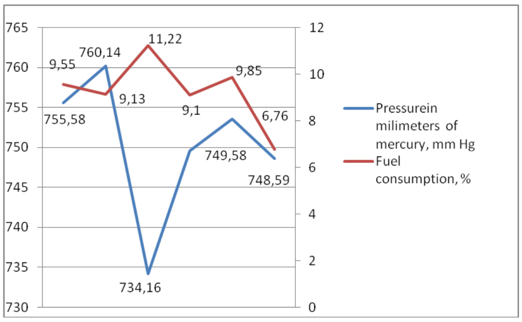

Figure 6. Dynamic row of average monthly values of atmospheric pressure and overrun of fuel in a cold period.

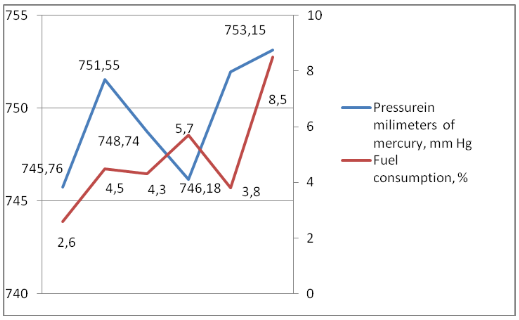

Figure 7. Dynamic row of average monthly values of atmospheric pressure and overrun of fuel in a warm period.

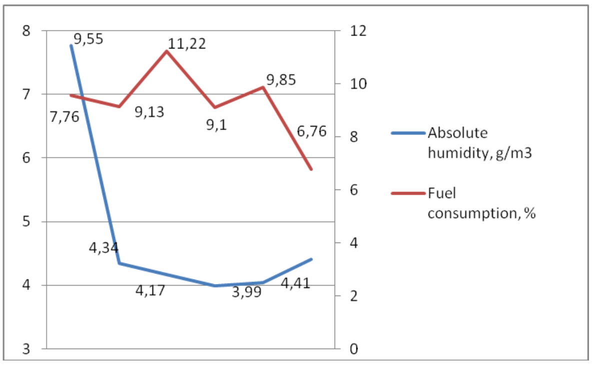

Figure 8. Dynamic row of average monthly values of absolute humidity and overrun of fuel in a cold period.

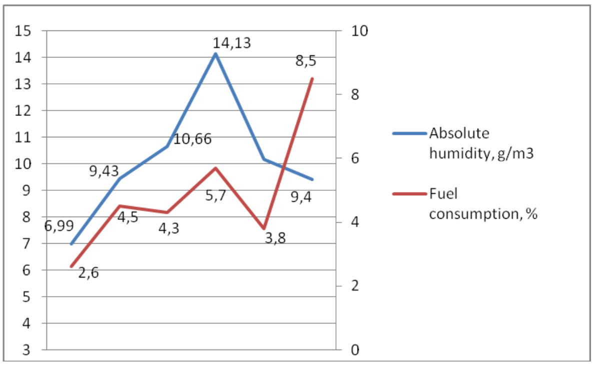

Figure 9. Dynamic row of average monthly values of absolute humidity and overrun of fuel in a warm period.

5. Discussion of the results

The study produced the following results. The territory of the southeast of Ukraine is characterized by the following climatic conditions (Figure 1-8). The average annual temperature is 11 degrees Celsius, and the warmth of the year is only 6 months: April May, June, July, August, and September, where the warmest month is August, and the remaining months are the cold season. The average annual atmospheric pressure is 749.9 mm Hg. The average annual atmospheric humidity is 7.44 g/m3. In cold period, excessive fuel consumption than in warm period. In cold period, the average monthly fuel consumption was - 9.27%. In warm period, the average monthly fuel consumption was - 4.9%.

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Methodological approach to estimating the efficiency of the stock complex facing of transport and logistic centers in Ukraine

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Abstract: The aim of this paper is to present a methodological approach to estimating technological process in the warehouse complex of the transport and logistics centers with respect to their efficiency. It was determined that one of the main directions of modern transport policy is the transition to transport logistics in the transport and logistics system, which allows us to provide comprehensive services to consumers of transport services, creating conditions for the development of combined transport, reducing the harmful influence on the environment. It is established that in order to carry out the successful implementation of the entire complex of works and reduce the cost of operations in the transport and logistics centers, as an important component of it, it is necessary to implement transport and technological processes, which must be based on progressive techniques and advanced methods. While constructing a mathematical model of an object, it was taken into account that the value of the general criterion of effectiveness depends on the values of the characteristics of the criteria of the effectiveness of the active elements of the system. The technological process of functioning of the warehouse complex of the transport and logistics centers, which is proposed in this paper, allows us to see the whole chain of operations from the moment of arrival of the vehicle with the load to the warehouse until the moment the consignment is shipped to the recipient. The approach to determine the efficient organization of the work of the warehouse complex of the transport and logistics center, according to the criterion, includes the total costs affected by: the intensity of the types cargo flows, the cost of one unit work and one hour work of one worker, the time of execution of the operation, and the amount of resources involved to perform each operation. The analytical models of determination of the estimation parameter are developed. In order to obtain the most reliable data on changes in the parameters of the warehouse process it has been determined the required number of observations be established . Based on the analysis of the order flow parameters of most transport and logistics centers of Ukraine, it has been found that the intensity of the input, internal and output flow of cargo is distributed according to the exponential law. This conclusion was confirmed by an appropriate level of confidence. The experiment, conducted in accordance with the principle of constructing a full-factor plan for the experiment, obtained the results of research on the proposed criterion for determining the efficient organization of the transport and logistics centers warehouse complex for three variants. Relying on the basic data

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regression models (linear and power) were constructed. An analysis of these models shows that the regression model in linear form with non-zero coefficients is the most adequate one, since the value of the indicator R^2 is the largest and it is equal to unity. On the received models the values of the criterion of efficiency are defined as total costs, for each variant. On the basis of the received changes in total costs for the organization of the warehouse complex, significant influence of the intensity of the incoming flow of goods has been identified, which in turn requires higher expenses of resources in the zone of acceptance of goods.

Keywords: transport and logistics system, transport and logistics center, warehouse complex, technological operations, mathematical model, vantage.

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1. Introduction

The current state of development of the logistics market of any country, including Ukraine, depends on the state of its economy. The volumes provided in the field of logistics services directly depend on the level of activity of their consumers, the dynamics of production, the domestic and foreign trade. In the example of the countries of the European Union (EU), the logistics sector, in its broadest sense, ranks the 3rd among the sectors of the economy. The underestimation of the role of logistics in Ukraine as a factor which affects to the efficiency and competitiveness of the economy worsens its position in international ratings. In 2018, in the World Bank's Logistics Performance Index (LPI) ranking, Ukraine has ranked the 66th in terms of the logistics efficiency index [1]. The logistical component of the Gross Domestic Product (GDP) in developed countries is on average 10-15% (in the EU and the United States of America it is 12-16%, in China - 26%, in Japan - 6%). As for Ukraine, most experts relate the level of its economy to the level of Third World countries, in which logistics costs can reach 40% of GDP. For Ukraine this indicator ranges from 30-35%. At the same time, 70% of logistical expenses are accounted for transport ($ 7 billion), 25% for storage ($ 2.5 billion) and about 5% for managing logistics flows ($ 0.5 billion) [2].

According to shown information, we can assume that one of the main directions of modern transport policy is the transition to transport logistics in the transport and logistic system (TLS), which allows us to provide comprehensive services to consumers of transport services, to creat conditions for the development of combined transport, to reduce the environmental influence on the environment [3]. The structure of the TLS of Ukraine should consist of a set of interconnected elements of interaction at the regional and local levels. As the main elements of the system, it is possible to separate transport infrastructure objects: regional distribution centers; terminal complexes; transport and logistics centers (TLSs) [4].

Taking into account the current trends in the development of logistics services, it can be argued that the main elements of commodity flow management were TLSs. In general, such centers play a coordinating and integrated role in the circulation and transportation of goods [5]. The introduction of the new modern technologies requires the creation of a network of infrastructure objects such as TLS, which perform functions of interaction between modes of transport and organization of material distribution in the economic region. They are the basic for material flow management, providing interaction between senders, consumers, carriers, and others [6].

As part of the formation of an effective system of TLS, it has been considered 3PL-operators of TLSs and shippers of Ukraine and an assessment of the quality of logistics services was performed. Thus, the current state of the market can be defined as following: 40% - logistics is in a state of stagnation; 37% - at the stage of formation and development; 21% - at the stage of formation; 2% - at the redistribution stage [7]. Consequently, customers and providers of logistics services seek to optimize costs, introduce new technologies, improve the quality of logistics services, and establish the effective communication between customers and suppliers of logistics services for increasing the level of loyalty of end-users [8]. The main obstacles to the development of the TLS market are seen by international companies in Ukraine in imperfect legislation - 79%; the factor of corruption - 69%; in the customs office - 66%; low quality of infrastructure - 66%; in the absence of professional staff- 28%; market monopolization - 17%. Ukrainian companies also highlighted the factors of imperfect legislation and corruption factors - 68% and 61%, respectively, 50% of incomplete infrastructure, 43% of respondents see difficulties in customs, 43% of respondents feel that they have 29% problems, and 18% say about monopolization. All these factors can greatly affect the development of TLS. Taking all everything into account the experts highlight the implementation of EU legal acts and regulations [3,9].

Properly organized technological process of work of the TLS should ensure: a clear and timely quantitative and qualitative acceptance of goods; efficient use of means of mechanization of loading and unloading and transport and warehouse work; consistent and rhythmic performance of warehouse operations [10], which contributes to the systematic loading of staff and the creation of favorable working conditions; rational warehousing of goods, which ensures maximum use of warehouse volumes and areas; preservation of goods; clear organization of centralized delivery of goods.

The main tasks of the functioning of the TLS include: improving the coherence of the various modes of transport in the organization of mixed and intermodal transportation [29]; proper organization of complex transport services for clients; expanding the types of services provided and improving their quality; attraction of additional volumes of transportation of transit cargoes; shortening the time of delivery of transit cargoes by reducing downtime at the points of transshipment of cargoes for other modes of transport and at border crossings; expansion of international cooperation; attracting new customers. The largest logistics operators in the volume of their own and the rented area, where logistics operations are carried out, are presented in the Table 1 [4].

Table 1. Powerful logistic operators providing warehousing services in Ukraine

Name of Company	Area, thousand square meters	Type of service
«ZAMMLER»	75	local
«Kuehne+Nagel»	67	international
«Raben»	53	international
«Ekol»	58	international
«FM Logistic»	55	international
«УВК»	50	local
«Logistic Plus»	27	local
« NP Logistics »	27	local

The analysis of recent researches and publications shows that the general problems of the creation and development of transport logistics and freight transportation in the TLS are represented by the following authors: Mirotin L.V. [9], Gladley J., Elovoy I.A. [11], Lifar V.V. [12], Bowersox Donald J. [13], Tankov K. M. [14], Naumov V.S. [15], Kricavsky Ye.V. [16].

Problems of the formation of a transport logistics network in Ukraine, taking into account the functioning of the warehouse complex of the TLS, have been devoted to their work by such scientists: Prokofieva T.A. [17], Popova N.V. [18], Bentzen K. [19], Aleshinsky E.S. [20], Veremeenko E.G. [21], Kampf R. [22], Stopka O. [23], Nagornyi Ye.V. [24].

Thus, it can be argued that the revival of the logistics market entails an increase in demand for warehouses and leads to an increase in consumer requirements for the quality of provision of services for the storage and processing of goods in warehouse complexes. [25]. The structure of most TLSs operating in Ukraine is allowed for a wide range of transport and logistics services. This is especially true for a sufficiently high-quality warehouse service. There are scientific developments of theoretical foundations on the introduction of modern technologies in the logistics and storage (terminal) systems of such scientists as Nagorny Ye.V., Shramenko N.Yu., Aleshinsky Y.S., Mirotin L. V. and other [15]. In work on improving the delivery of cargo TLS focuses on the development of the infrastructure component of the TLS without determining the optimal values of technological parameters of the operation of warehouses [26, 27, 28, 29]. The analysis has revealed the problem of forming an efficient organization of the TLS warehouse complex in the TLS of Ukraine.

2. Materials and Methods

In order to carry out the successful implementation of the entire complex of works and reduce the cost of operations in the TLS, as an important component of it, it is necessary to implement transport and technological processes, which must be based on progressive techniques and advanced methods.

To solve this problem, the author proposes the development of theoretical foundations for the formation of an efficient management of material flows management in order to reduce the cost of functioning of the TLS due to the introduction of an efficient organization of work.

In this paper, the technological process of the operation of the TLS warehouse complex is considered as a sequence of operations:

1) the arrival of cargo on the warehouse (preparation of technical means for receiving the cargo, documents, familiarization of the workers with the plan of unloading);
2) checking the integrity of the packaging of the goods in the vehicle (TC) (checking the attachment and the presence of appropriate seals and markings, revealing external damage);
3) unloading of cargo by loading and unloading mechanisms (LUM);
4) acceptance and loading of the cargo in the reception area (moving of the respective consignments in the allocated areas of the receiving zone and its placement);
5) acceptance of cargo by quantity and quality (opening of containers, counting by quantity and verification with documentation, withdrawal);
6) selection and transfer of cargo to the storage and acquisition zone;
7) preservation of the cargo in the warehouse;
8) the collection of batches of cargo and dispatch from the storage and reception zone (a batch of cargo is formed for the corresponding order: the quantity of cargo and type of packaging is determined; packaging is carried out in packing and sealing; documents are prepared);
9) the movement of the finished cargo unit to the departure zone;
10) checking of cargo by quantity, and also compliance with documents;
11) cargo load in the vehicle and the transfer of documents.

Determination of the effective organization of work conducted by the estimated parameter - the total cost, which form a set of values of the corresponding costs for each element of the scheme of the technological process:

$$C = \{C_1, C_2, ..., C_n\}, \tag{1}$$

where $C_1, C_2, ..., C_n$ - the corresponding expenses for each technological operation of the TLS warehouse complex, US $; i - the number of the corresponding operation, $(n = 11)$.

Costs of the second operation are the functions of the following elements:

$$C_n = \{I_p, S_p, S_R, t_{VO,} N_P\}, \tag{2}$$

where I_P – the intensity of the corresponding cargo flows, t/h.; S_P – cost per unit of work, US $/t.; S_R – cost per hour of work of one worker, US $/h.units; t_{VO} – the time of execution of the corresponding operation, h.; N_P – the number of resources involved to perform the operation, units.

Each of the presented elements of the corresponding flows is characterized by a list of components, the intensity of the flows of cargo has three components:

$$I_P = \{I_{VP}, I_{VV}, I_{VIP}\}, \tag{3}$$

where I_{VP} – the intensity of the input cargo flow, t/h.; I_{VV} – the intensity of the internal flow of cargo, t/h.; I_{VIP} – the intensity of the outflow of the cargo, t/h.

When constructing a mathematical model of an object, it has been taken into account that the value of the general criterion of effectiveness depends on the values of the characteristics of the criteria of the effectiveness of the active elements of the system. For each dependence in the model, the conditions for their application must be determined.

According to the technological process of the warehouse complex TLTS total costs are:

$$C = \sum_{i=1}^{11} C_i, \tag{4}$$

where C_1 - the cost of the arrival of the goods to the warehouse, US \$; C_2 - costs for checking the integrity of packing of goods in TK, US \$; C_3 - expenses for unloading of LUM cargo, US \$; C_4 - expenses for acceptance and packing of the cargo in the reception area, US \$; C_5 - costs for acceptance of cargo in quantity and quality, US \$; C_6 - costs for the selection and transfer of cargo to the storage and assembly area, US \$; C_7 - costs for the storage of cargo in the TLC warehouse, US \$; C_8 - packing and delivery costs from storage and reception area, US \$; C_9 - costs of moving the finished cargo unit to the sending zone, US \$; C_{10} - the cost of checking the cargo by quantity and compliance with the documents, US \$; C_{11} - costs of loading of cargo in TC and transfer of documents, US \$.

Using the norms and resources for carrying out operations, as well as their cost characteristics, we receive the following analytical expressions for costing the cost.

The cost of the arrival of cargo on the TLS is:

$$C_1 = \left(\frac{I_{VP} \cdot S_{PRV}}{N^O{}_{PR}} + N^O{}_{PR} \cdot S^O{}_{RPR} \right) \cdot t_{PR}, \tag{5}$$

where S_{PRV} – cost of preparation for the receipt of cargo (determination of the order of unloading and location of the cargo in the reception area, preparation of facilities for LUM, auxiliary equipment, etc.), US \$/t.; $S^O{}_{RPR}$ – cost of one hour of work of one worker involved in the preparation for acceptance of cargo, US \$/units; $N^O{}_{PR}$ – the number of workers involved in the operations for preparing for the receipt of goods, units; t_{PR} – the time of carrying out operations for preparation for acceptance of cargo, h.

Costs for checking the integrity of packaging in TC:

$$C_2 = \left(\frac{I_{VP} \cdot S_{PV}}{N^O{}_{PV}} + N^O{}_{PV} \cdot S^O{}_{RPV} \right) \cdot t_{PRV} + I_{VP} \cdot S_{PVb} \cdot k^{TZ}{}_b \cdot t_{PRVb}, \tag{6}$$

where S_{PV} – the cost of checking the integrity of the packing of the cargo, US \$/t.; $S^O{}_{PRV}$ – cost per hour of work of one worker involved in operations for checking the integrity of the packing of the cargo, US \$/units; $N^O{}_{PV}$ – the number of workers involved in the operations for checking the integrity of the package, units; t_{PRV} – time of operations for checking the integrity of the package, h.; S_{PVb} – cost of execution of work on registration of acts concerning damaged cargo, US \$/t.; $k^{TZ}{}_b$ – the level of cargo detected with damage, in relation to the total quantity, when checking the TAP; t_{PRVb} – time of execution of operations on drawing up of acts concerning damaged cargo, h.

The cost of unloading the LUM cargo:

$$C_3 = \left(\frac{I_{VP} \cdot S_{RV}}{n_{NRM} \cdot N^O{}_V} + N^O{}_V \cdot S^O{}_{RV} \right) \cdot t_{RV}, \tag{7}$$

where S_{RV} – cost of unloading cargo, US \$/t.; $S^O{}_{RV}$ – the cost of performing the work by the relevant workers when unloading the goods from TP, US \$/h.; $N^O{}_V$ – the number of workers involved in the work, units; n_{NRM} – number of LUM, units; t_{RV} – time of discharge of cargo with TC, h.

Costs of acceptance and packing of cargo in the reception area:

$$C_4 = \left(\frac{I_{VP} \cdot S_{PRU}}{N^O{}_{PRU}} + N^O{}_{PRU} \cdot S^O{}_{RPRU} \right) \cdot t_{PRU}, \tag{8}$$

where S_{PRU} – cost of acceptance and packing of cargo in the reception area, US \$/t.; $S^O{}_{RPRU}$ – the cost of one hour of work of one worker involved in the acceptance and stowage operations, US \$/units; $N^O{}_{PRU}$ – the number of workers involved in the operations for the acceptance and loading of cargo, units; t_{PRU} – time of acceptance and loading operations, h.

The cost of receiving the cargo by quantity and quality:

$$C_5 = \left(\frac{I_{VP} \cdot S_{PKY}}{N^O{}_{PKY}} + N^O{}_{PKY} \cdot S^O{}_{RKY} \right) \cdot t_{PRY} + I_{VP} \cdot S_{PKYb} \cdot K_b \cdot t_{PKYb}, \quad (9)$$

where S_{PKY} – cost of checking cargo by quantity and quality, US $/t.; $S^O{}_{RKY}$ – cost per hour of work of one worker involved in operations for checking quantity and quality of cargo, US $/units; $N^O{}_{PKY}$ – the number of workers involved in operations for checking the quantity and quality of goods, units; t_{PRY} – time of carrying out operations on checking quantity and quality of cargo, h.; S_{PKYb} – cost of execution of works on registration of acts to damaged cargo when checking quantity and quality of cargo, US $/t.; k_b – the level of cargo found to be damaged in relation to the total quantity when checking the quantity and quality of the cargo; t_{PKYb} – time of execution of operations on drawing up of acts concerning damaged cargo and detection of losses, h.

Costs of selection and movement of cargo to the storage and picking zone:

$$C_6 = \frac{I_{VP} \cdot a_{zb} \cdot S_{ZB} \cdot t_{ZB} + I_{VP} \cdot a_{zk} \cdot S_{ZK} \cdot t_{ZK}}{N^O{}_{ZBK}} + N^O{}_{ZBK} \cdot S^O{}_{ZBK} \cdot \frac{t_{ZB} + t_{ZK}}{2}, \quad (10)$$

where S_{ZB}, S_{ZK} – accordingly, the cost of picking up and moving the cargo to the storage and assembly area, US $/t; $S^O{}_{ZBK}$ – the cost of one hour of work of one worker involved in operations for the selection and transfer of cargo to the storage and assembly area, US $/units; a_{zb}, a_{zk} – respectively, the proportion of cargo sent to the storage and assembly area; $N^O{}_{ZBK}$ – the number of workers involved in operations for the selection and transfer of cargo to the storage and assembly area, units; t_{ZB}, t_{ZK} – respectively, the time of execution of operations for the selection and transfer of cargo to the storage and assembly area, h.

Costs for the storage of cargo in the TLS warehouse:

$$C_7 = I_{VP} \cdot S_Z \cdot a_{zk} \cdot t_Z, \quad (11)$$

where S_Z – the cost of storing the cargo in the storage zone, US $/t.; t_Z – time of storage in the storage area, *h*.

Costs of picking up the shipment from the storage and reception area:

$$C_8 = \frac{I_{VV} \cdot S_{KZB} \cdot t_{KZB} + I_{VP} \cdot a_{zk} \cdot S_{KZP} \cdot t_{KZP}}{N^O{}_{KZBP}} + N^O{}_{KZBP} \cdot S^O{}_{KZBP} \cdot \frac{t_{KZB} + t_{KZP}}{2}, \quad (12)$$

where S_{KZB}, S_{KZP} – accordingly, the cost of manning the shipment from the storage and reception zone, US $/t.; $S^O{}_{KZBP}$ – the cost of one hour of work of one worker involved in the operations for the assembly of consignments from the storage and receiving zone, US $/units; $N^O{}_{KZBP}$ – the number of workers involved in operations for the assembly of consignments from the storage and receiving zone, units; t_{KZB}, t_{KZK} – respectively, the time for completing cargo shipments from the storage and reception area, h.

Costs of moving the finished cargo unit to the departure zone:

$$C_9 = \left(\frac{I_{VIP} \cdot S_{PZV}}{N^O{}_{PZV}} + N^O{}_{PZV} \cdot S^O{}_{RPZV} \right) \cdot t_{PZV}, \quad (13)$$

where S_{PZV} – the cost of moving a finished cargo unit to the dispatch zone, US $/t.; $S^O{}_{RPZV}$ – the cost of one hour of work of one worker involved in the operations for moving the finished cargo unit to the sending zone, US $/units; $N^O{}_{PZV}$ – the number of workers involved in operations for the movement of the finished cargo unit into the departure zone, units; t_{PZV} – time of execution of operations on moving the finished cargo unit to the dispatching area, h.

Costs for checking cargo by quantity and compliance with documents:

$$C_{10} = \left(\frac{I_{VIP} \cdot S_{PP}}{N^O{}_{PP}} + N^O{}_{PP} \cdot S^O{}_{RPP} \right) \cdot t_{PP}, \quad (14)$$

where S_{PP} – the cost of checking the cargo by quantity and compliance with the documents, US $/t.; $S^{O}{}_{RPP}$ – cost of one hour of work of one worker involved in cargo checks by quantity and compliance with documents, US $/units; $N^{O}{}_{PP}$ – number of workers involved in cargo inspection operations by quantity and compliance with documents, units; t_{PP} – the time of execution of operations of checking of cargo by quantity and compliance with documents, h.

Costs of cargo loading in TC and transfer of documents:

$$C_{11} = \left(\frac{I_{VIP} \cdot S_{NV}}{n_{NRM} \cdot N^{O}{}_{PP}} + N^{O}{}_{N} \cdot S^{O}{}_{RN} \right) \cdot t_{RN}, \quad (15)$$

where S_{NV} – cost of loading load, US $; $S^{O}{}_{RN}$ – the cost of carrying out work by the corresponding workers at loading of the cargo on TC, US $/h.; $N^{O}{}_{N}$ – the number of workers involved in the work, units; t_{RN} – time of load loading on TC, h.

Total expenses are reflected in the form (4) and calculated by formulas (5) - (15), imagine how the target function:

$$C = f\left(I_{P}, S_{P}, S_{R}, t_{VO}, N_{P}\right) \to \min. \quad (16)$$

We establish a system of constraints for the warehouse complex for a specific target function on the basis of experimental and organizational data with the values of the relevant factors which have been identified during the analysis of statistical data of the functioning of the warehouse complexes of the TLC of Ukraine.

$$\begin{cases} 7.6 \le I_{VP} \le 36.05\ t/h; \\ 0.23 \le I_{VV} \le 2.53\ t/h; \\ 1.4 \le I_{VIP} \le 12.3\ t/h; \\ 0.36 \le S_{P} \le 17.86\ US\$/units; \\ 5.36 \le S_{R} \le 12.5\ US\$/h; \\ 0.25 \le t_{VO} \le 2.0\ h; \\ 1 \le N_{P} \le 4\ unit. \end{cases} \quad (17)$$

Planning an experiment on the study of cargo flows at the warehouse complexes of the TLC of Ukraine has been used to find the optimal conditions for the organization of work. While doing this, we were using the normalization of experimental data on flow of goods in a warehouse complex. This operation is necessary to obtain reliable data on studies of changes in costs while improving warehouse work.

3. Results

Experiment planning has been used for finding optimal conditions, construct interpolation formulas, choosing the meaningful factors, evaluating and refining the constants of theoretical models, and so on.

It has been used a complete factor experiment - a set of several measurements, which responds to the following conditions:

- the number of measurements is k^{n}; where k - the number of levels of variation of factors; n - number of factors;
- in the process of measuring the value of the factors combined in all possible options.

The advantages of a full factor experiment are the following :

the simplicity of the solution of the system of equations of estimation of parameters,

the statistical redundancy of the number of measurements, which reduces the impact of the errors of individual measurements on the estimation of parameters.

Levels of variation of factors I_{VP}, I_{VV}, I_{VIP} pare have been given in Table 2.

Table 2. Levels of variation of the intensity of the cargo in the warehouse complex with the basic option during the peak of flows

Parameter	Minimum value	Maximum value
Intensity of the input cargo flow, t/h.	7.60	36.05
Intensity of the internal cargo flow, t/h.	0.23	2.53
Intensity of the output cargo flow, t/h.	1.4	12.3

In order to obtain the most reliable data on changes in the values of the factors of the warehouse process, it has been determined the required number of observations:

$$n = \frac{\sigma^2 \cdot t_\beta^2}{\varepsilon^2 + t_\beta^2 \cdot \frac{\sigma^2}{N}}, \quad (18)$$

where n – sample size; t_β – probability indicator for a given confidence level; equal $\beta_\partial = 0,95, t_\beta = 1,96$ – mean-square deviation of the results of observations; ε – calculation error; N – total number of observations, $N = 40$ units.

Calculation of indicators $\varepsilon, P_\partial, \sigma$ and μ has been carried out according to the following formulas:

$$\varepsilon = \mu \cdot (1 - P_Д), \quad (19)$$

where μ – mathematical expectation; $P_Д$ – confidence level at $P_Д = 0.95, t_\beta = 1.96$.

Mean-square deviation of observational results:

$$\sigma = \sqrt{\frac{1}{n} \cdot \sum_{i=1}^{n} (x_i - \mu)^2}, \quad (20)$$

where x_i – mean value for i-th observation; μ – mathematical expectation.

$$\mu = \frac{1}{n} \cdot \sum_{i=1}^{n} x_i, \quad (21)$$

The results of calculations are given in Table 3.

Table 3. Results of calculations of sample size

Indexes	Intensity of the input flow of cargo, IVP, t / h	Intensity of the internal flow of cargo, IVV, t / h	Intensity of the initial flow of cargo, IViP, t / h.
Mathematical expectation, μ	22.06	1.58	6.69
Mean square deviation,σ	7.17	0.55	2.21
Calculation error, ε	1.1	0.08	0.33
Sample size, N	32	33	33

The criterion χ^2 or the "Pearson square" is used to verify the significance of the relationship between the two variables - this is the simplest criterion that allows you to compare frequency distributions, regardless of whether they are normalized or not. Frequency refers to the amount of occurrence of an event. Using the program Statistica.exe, calculations were made to identify the laws of distribution of input parameters: I_{VP}, I_{VV}, I_{ViP}.

Calculated numerical values of Pearson's criterion were compared with tabular ones.

$$x_{calcul.}^2 \le x_{tabl.}^2, \quad (22)$$

where $x_{calcul.}$ – Pearson Criterion Calculated; $x_{tabl.}$ – criterion Pearson table.

Then, it is assumed that under these conditions a hypothesis regarding the model of the distribution of covariates is adopted and it does not deny observation and can be used in subsequent calculations. Proceeding from this, we accept the normal law of distribution of covariates of their intensities for the input factors of cargo flows (Fig. 1-3).

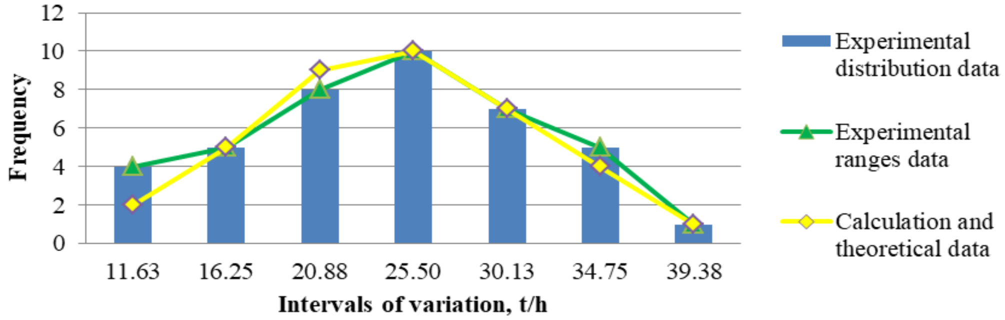

Figure 1. Distribution of the values of the intensity of the input cargo flow according to the normal distribution law: the degree of freedom is 4; the significance level is 0,05; critical value of the Pearson criterion is 9,49; estimated value of the Pearson criterion is 2,36.

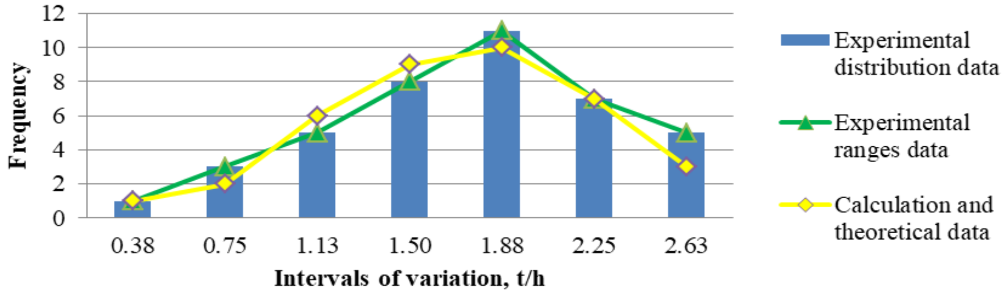

Figure 2. Histogram of the distribution of the values of the intensity of the internal cargo flow according to the exponential distribution law: the degree of freedom is 4; the significance level is 0,05; critical value of the Pearson criterion is 9,48; estimated value of the Pearson criterion is 2,21.

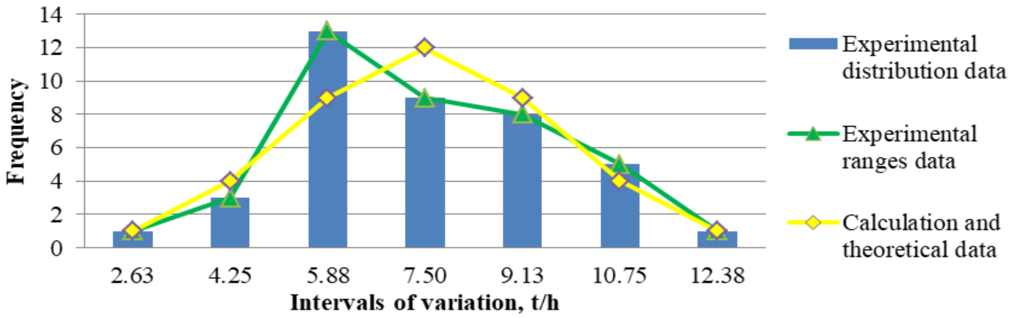

Figure 3. Histogram of the distribution of the values of the intensity of the outflow of the cargo according to the exponential distribution law: the degree of freedom is 4; the significance level is 0,05; critical value of the Pearson criterion is 9,49; estimated value of the Pearson criterion is 3,14.

For the experiment the intervals of the variation of the corresponding input factors were substantiated as follows: on the basis of the previous studies, it has been established that the intensity of the input flow of the cargo varies from 7.6 to 36.05 t / h; the intensity of the internal cargo flow varies from 0.23 to 2.53 t / h; the intensity of the outflow of the cargo varies from 1.4 to 12.3 t / h. and it is distributed according to the normal law of the distribution of the covariates (Fig.1-3), which is confirmed by the corresponding values of the confidence level and the Pearson criterion.

Using the MS Excel program and the HIOBR function, we define a table value x^2, which is 9.49. Since the calculated value for the first indicator (Fig.1) x^2 is 2.36, the condition $x^2_{calc\leq} x^2_{table}$ is satisfied, that is 2.36 <9.49. While conducting experimental studies on road transport, the confidence level should be at least 95%. As a result it has been confirmed the distribution hypothesis In calculations for the second indicator (Fig.2) the table value x^2 was 9.48, that is, 2.21<9.48, and, consequently, the condition is fulfilled. The confidence level should be at least 95%. As a result it has been confirmed the distribution hypothesis In calculations, the value for the third indicator (Fig.3) x^2 was 3.13, that is, 3.13 <9.48, and, consequently, the condition is fulfilled. The confidence level should be at least 95%. As a result it has been confirmed the distribution hypothesis.

Based on the received and processed experimental data (Figures 1-3), we shall form a database to detect changes in the criterion of efficiency of the organization of the warehouse complex. For the formation of cargo flows, we shall operate with the minimum and maximum values in the peak period (Figure 4).

Table 4. The value of the input parameters of the experiment in the base version during the period of peak traffic in the warehouse complex

Series of experiments	Levels of variation		
	Intensity of the input flow of cargo, t/h	Intensity of the internal flow of cargo, t/h	Intensity of the outflow of cargo, t/h
1	11.63	0.23	1.40
2	11.63	0.23	12.3
3	11.63	2.53	12.3
4	11.63	2.53	1.40
5	39.38	0.23	12.3
6	39.38	0.23	1.40
7	39.38	2.53	1.40
8	39.38	2.53	12.3

According to the experiment carried out using the mathematical models of total costs (formulas (5-15)) and the principle of constructing a full-factor plan of the experiment, the results of the research were obtained to determine the efficient organization of the work of the TLC warehouse complex for three variants (table5): the basic (initial), and the second and third an option to improve the organization of warehouse work. As a result it has been used the proposed efficiency criterion. The second option is to increase the number of workers by one in each section to execute the corresponding work in the warehouse. The third option is to increase the loading and unloading mechanisms involved in the warehouse work up to two in each section to execute the relevant work in the warehouse complex. All other resource options are left in the base version.

Table 5. Results of calculations of total costs when organizing the work of the warehouse complex of the TLS under various options

Series of experiments	Total expenses, US $		
	The first option is basic	The second option: with an increase in the number of workers	The third option: when increasing the number of loading and unloading mechanism
1	53.87	77.89	62.38
2	100.86	96.41	90.84
3	103.81	97.39	92.31
4	59.92	78.88	63.85
5	391.73	293.49	406.65
6	347.84	274.98	378.19
7	350.79	275.96	379.66
8	394.67	294.47	408.12

On the basic data it has been constructed the obtained regression models (linear and power) An analysis of these models shows that the regression model in linear form with non-zero coefficients is the most adequate, since the value of the indicator R^2 is the largest and is equal to unity. On the received models the values of the criterion of efficiency are defined - total costs, for each variant Table 6.

Table 6. Results of calculation of the criterion of efficiency for different variants of organization of the warehouse complex

Series of experiments	Total expenses, US $		
	The first option	The second option	Third option
1	57.01	77.89	62.38
2	100.90	96.41	90.84
3	103.84	97.39	92.31
4	59.96	78.88	63.85
5	392.41	293.46	406.64
6	348.53	274.95	378.19
7	351.47	275.93	379.66
8	395.36	294.45	408.12

On the basis of the received changes in total costs for the organization of the warehouse complex, significant influence of the intensity of the incoming flow of goods has been identified, which in turn requires higher expenses of resources in the zone of acceptance of goods. Minimizing time costs and reducing non-production downtime allow to increase the efficiency of the entire warehouse complex of TLSs.

4. Discussion

When conducting an assessment of the effectiveness of the proposed solutions, the values of total costs for the three option were compared by determining the economic effect:

$$E_k = C_{\cos t} - C_k \tag{18}$$

where $C_{\cos t}, C_k$ – respectively, total expenses for one and other variants, US $ ($k = \overline{1,3}$).

The results of calculating the economic effect for all possible comparative combinations are given in Table 6.

Table 6. Results of determining the economic effect with different variants of comparisons

Series of experiments	Value of economic effect, US $		
	When comparing the second and first options	When comparing the third and first variants	When comparing the second and third options
1	20.88	5.37	15.51
2	-4.49	-10.06	5.57
3	-6.45	-11.53	5.08
4	18.92	3.89	15.02
5	-98.95	14.23	-113.18
6	-73.58	29.66	-103.24
7	-75.54	28.19	-103.73
8	-100.91	12.76	-113.67

The results of the determination of the economic effect have shown that the second option (an increase in the number of workers) will have an effect (22.88 US $) when compared with the first only with the minimum intensity values of the corresponding flows of cargo. The third option (increasing the number of LUM) compared with the first one is effective only with an increase in the intensity of the initial flow of cargo to the maximum level, the effect - 11.53 US $. And when comparing the second and third variants, the effect decreases for the third with an increase in the intensity of the input stream - the maximum effect is 113.67 US $.

5. Conclusions

The technological process of functioning of the warehouse complex of the TLS, proposed in this paper, allows to see the whole chain of operations from the moment of arrival of the vehicle with the load to the warehouse until the moment the consignment is shipped to the recipient. The necessary types of resources involved in these processes are also taken into account. In order to determine the efficient organization of the warehouse complex, it has been proposed the criteria such as total costs affected by the following parameters: the intensity of the varieties of cargo flows: the cost per unit of work and one hour of work of one worker, the time of execution of the corresponding operation, the number of resources involved to perform each operation.

Based on the analysis of the order flow parameters of most TLSs of Ukraine, it has been found that the intensity of the input, internal and output flow of cargo are distributed according to the exponential law. This was confirmed by an appropriate level of confidence. According to the conducted studies and the proposed criteria, it has been determined the effectiveness of organizing the work of the TLS warehouse complex for the three options.

The results of the research can be used for improving the work of the warehouses not only of the TLS, but also other enterprises in Ukraine and in other countries.

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Improving of transitway operating properties

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Abstract: Modern public transport systems are increasingly seen as an important means of promoting the safe mobility of the population, especially in urban areas suffering from growing traffic jams. The Transitway or the new bus system "Bus Rapid Transport" (BRT) is the result of the development of a bus public transport network. In comparison with the subway, this project has obvious advantages: lower cost of network creation, lower cost of rolling stock, mobility, etc. These advantages are manifested, first of all, with the maximum use of passenger capacity of transitways, that is, with the application of three-axles transitways and with their motion on the maximum possible speeds. The purpose of this paper is to present the findings of the transitway motion stability research, which was based on the analysis of solutions of motion differential equations. These equations were compiled with respect to the variables of the longitudinal and transverse velocities of the center of the bus mass and the angular velocities of the bus and of two couplings. As a result of the research, the critical velocity of the three-axles transitway has been determined and factors influencing its numerical value have been analyzed. It has been shown that during the operation of the transitway it is necessary to maintain such pressure in the tires so that, for the selected load on the wheels of the axes of the auto-train, the coefficient of resistance to the lateral separation of the wheels of the steered wheels of the bus and the trailer is smaller than the wheels of uncontrolled axes. The practical value of the research is that this finding will be used for increasing the critical speed v_{cr} of the auto-train.

Keywords: transitway, auto-train, bus, trailer, speed, stability

1. Introduction

Safe public transport systems are increasingly seen as an important means of safe promoting the population mobility, especially in urban areas suffering from growing traffic jams. In many high-income cities, the policy of reducing the use of private transport is particularly emphasized through investments in the development of public transport networks. Investments in safe public transport are also seen as a mechanism that stimulates the growth of physical activity and, therefore, contributes to the health of the population.

The transitway or the new bus system "Bus Rapid Transport" (BRT) is the result of the development of a bus public transport network. In comparison with the subway, this project has obvious advantages: lower cost of network creation, lower cost of rolling stock, mobility, etc. [1].

The BRT system has a number of undeniable advantages [2,3]

- high passenger capacity and efficient payment systems provide low-cost travel;
- high speed of movement allows the transitway to carry a large share of passenger traffic, which contributes to reducing the number of cars on the city roads and, accordingly, reducing emissions of exhaust gases;

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- an expanded information system informs passengers about bus timetables.

Convenience, safety and improved organization of the traffic are not only items which can give passengers a system of high-speed bus transport. In this system, passenger high-speed buses drive on specially created lanes. They are separated from the carriageway and are equipped with closed passenger stations with platforms on the same level and underground passages [4].

The rolling stock used in the BRT system has two types: the first one is a classic two-axles transitway with an engine operating on both diesel and gas fuels; the second is a three-axles transitway of a new generation with a hybrid electric gas engine. These two variants are inherent in articulated buses, 18 and 24 meters long [5].

Testing hybrid public transport in Gothenburg has showed that the fuel consumption of the Volvo bus is less than 11 liters per 100km. This is much less than an equivalent diesel bus consumes. Hybrids (3 buses were involved in the project) set off on public transit routes, periodically charging the battery at stops. Charging was done by connecting to the charging tire.

Consequently, the main advantages of BRT systems are the relatively small construction cost, the speed of the line construction, the small cost of buses, the ability to flexibly change passenger traffic due to traffic intensity, the possibility of partially using the BRT line for another special transport. It can use separate lanes, or move on existing roads. Bus can drive on a high speed in the city on separate lanes. Bus may have different routes on the same line, unlike the subway. It reduces the use of private vehicles, improves the transport situation and gives the chance to completely abandon small buses in cities [2, 6]. These advantages are manifested, first of all, on the maximum use of passenger capacity of transitways, that is, with the application of tree-axles transitways.

The peculiarity of the functional systems design providing stability and controllability of auto-trains and transitways (further vehicle) is the parallel processes of their design, optimization and modeling of the vehicle dynamics, in general under the multicriteria of sometimes contradictory tasks [7].

The characteristics of stability and handling, as is known, are determined by a combination of operational, mass-geometric and structural parameters of the vehicles modules. In general, it is desirable to combine these parameters in terms of stability and handling even for the same vehicle in the range of operating loads and speeds varying. As a consequence, it is difficult to obtain the exact constructive parameters and quantitative indicators on the criteria of stability and controllability of traffic at the early stages of the vehicle construction [8].

While considering the motion stability of the tree-axles vehicles it has been considered for two control schemes – open and closed. With open control scheme, it has been assessed the vehicle potential stability is assessed, with closed – stability of the driving system - vehicle [8].

The theoretical basis of the analysis is made on the mathematical models of rectilinear and controlled motions of the car and the auto-train designed for automobiles and two-axles auto-trains [9]. On their basis, it has been obtained the differential equations of perturbed traffic of vehicles, the equation of the limits of stability of rectilinear motion of cars and the differential equations of trajectories of characteristic points of parts of auto-trains are obtained, the solutions of which allow to determine the motion critical speed, with the help of which it is possible to predict the behavior of both controlled and uncontrolled vehicles.

2. Materials and Methods

In works [8-11], which are considered the issues of maneuverability and durability of three-axles auto-trains, it has been adopted the modular construction of an auto-train was adopted. Under this condition, the auto-train was presented in the form of three modules - a car-tractor and two trailer couplings. In turn, the car-tractor was presented as a single module - a skeleton with front-mounted steering wheels, and in the form of two kinematically independent elements - a skeleton with two (one) rear axes and a steering wheel module. The trailer couplings were also represented in the form of either a single module - a skeleton with non-rotating wheels (axes) or from two kinematically independent elements - a platform and a carriage when each bearing system of a semi-trailer or trailer is based on a carriage, and there is a hinge link between them, and driven by wheels or axes of a semi-trailer and a dual-axes trailer to control them. Thus, the differences in the designs of three-axles auto-trains in most cases are determined by the differences in the design of trailer couplings, since the design of car-tractors remains unchanged.

Motion differential equations for determining the indicators of maneuverability and stability of the auto-trains are either using the method of intersections, or using general theorems of mechanics: about the change of the main vector and the momentum. With the use of the intersection method, the differential motion equations of the car-tractor and trailer couplings can be unified, however, with the increase in the number of auto-train axles, the use of this method becomes problematic due to the need to determine the reactions at the unification points of the auto-train axles. This disadvantage is deprived of the method using general theorems of mechanics, which can be applied to any lay-out scheme of an auto-train, including for a transitway.

Making the motion differential equations for the transitways relative to the variables of the longitudinal v, the transverse u and the angular velocity of the car-tractor ω and the angles of axles assembly of the auto-train φ1 and φ2 will be performed on the following data:

- the auto-train is moving along a flat horizontal surface;
- the unspotted mass is considered to be uncorrected;
- the controlling influence on the parameters of the auto-train is carried out through the steering wheels of the car-tractor;
- do not take into account the presence of gaps in drawbar couplings;
- the distance between the axles of the auto-train does not change because of the small angle of assembly;
- when driving a auto-train on the roads of a real microprofile, the angle of twisting of the frame and its rigidity on torsion are not taken into account;
- the constituent elements of the auto-trains are absolutely solid bodies:
- the passengers in the BRT are located so that the centers of mass axles, as well as the tension-coupling devices connecting them, are located in the vertical plane of axle symmetry;
- the trajectory of the tractor center center is taken as the main trajectory;
- the interaction of the wheels with the bearing surface is expressed through the reaction of the road cloth in the longitudinal and transverse plane, which is a function of the rolling resistance coefficient and the angle of displacement, namely [8]

$$X_i = G_i \times f,$$

$$Y_i = \frac{k_i \delta_i}{\sqrt{1+k_i\,(\varphi^2 G_i^2)^{-1}\,\delta_i^2}},$$

where G_i - vertical load on the wheel;

f - coefficient of rolling resistance;

δ_i, Y_i - angles of discharge and lateral reactions;

k_i - coefficient of resistance to lateral withdrawal;

φ - coefficient of adhesion between the tire and the supporting surface in the transverse direction (we consider φ the constant value for the given road conditions).

In addition, the car-tractor will be presented in the form of a single module - a skeleton with front-controlled wheels, the average turning angle of which θ_1. The two rear axes of the tractor are irreversible and located behind the center of the tractor's masses. Both trailers consist of one module - a skeleton with non-rotating wheels (axes).

The work [12] describes a system of equations describing the plane-parallel motion of a three-axles trailer auto-train, which can be applied to the transitway, Fig. 1, in the form of:

$$m(\dot{u} + v\omega) = Y_2 \cos\theta_1 + Y_{21} + YA - YB\cos\gamma_1 + XB\sin\gamma_1;$$

$$I\dot{\omega} = aYA - b(Y_2\cos\theta_1 + X_2\sin\theta_1) - bbY_{21} + c(YB\cos\gamma_1) + M_1 + M_2;$$

$$I_1\dot{\omega}_1 = -YA\lambda\cos\theta + XA\lambda\sin\theta - M_1 = 0; \qquad (1)$$

$$I_2\dot{\omega}_2 = d_1 YB - b_1 Y_3 - b_{11} Y_{31} + c_1 YC - M_3;$$

$$I_3\dot{\omega}_3 = d_2 YC - b_{21} Y_{41} - b_{22}(Y_{42}\cos\theta_{32} + X_{42}\sin\theta_{32}) + M_2 - M_3;$$

In the written equations, the following notations are taken:

V – longitudinal component of the speed of the bus mass center;

λ (*lambda*) – take-off of the steered wheel of the bus;

m, J – mass and central moment of inertia of the bus;

v, u – longitudinal and transverse projection of the velocity vector of the mass center on the axis associated with the tractor;

ω (*omega*) – angular velocity of the bus relative to the vertical axis;

m_1, J_1 – mass and central moment of inertia of the driving wheel module of the bus;

v_1, u_1 – longitudinal and transverse projections of the velocity vector of the masses center of the control wheel module of the bus;

ω_1 – angular velocity of the control wheel module of the bus;

m_2, J_2 – weight and central moment of inertia of the wheel trailer module control (second axle);

v_2, u_2 – longitudinal and transverse projections of the velocity vector of the mass center of the second axle;

ω_2 – angular velocity of the second axle;

m_3, J_3 – weight and central moment of inertia of the control wheel of the second trailer (third axle);

v_3, u_3 – longitudinal and transverse projections of the velocity vector of the center;

m_3, J_3 – weight and central moment of inertia of the control wheel of the second trailer (third axle);

ω_3 – angular velocity of the third axle;

m_4, J_4 – mass and central moment of inertia of the second trailer (fourth axle);

v_4, u_4 – longitudinal and transverse projections of the velocity vector of the mass center of the fourth axle;

V – acceleration in the longitudinal direction;

$X_1, X_{2i}, X_{3i}, X_{4i}$ – longitudinal forces on the auto-train axes;

M_1, M_2, M_3 – moments of resistance to turning sections of the auto-train;

a, d_2, d_3 – distance from the center of the bus mass, the first and second trailers, to the front axis respectively;

b_{12} – distance from the center of mass to the middle axis of transitway;

b_{13}, b_{22}, b_{42} – distance from the center of the bus mass, the first and second trailers, to the rear axis respectively;

c – distance from the rear axis of the bus to the point of coupling with the first trailer;

l_2, l_3 – distance from the center of the mass of the first and second trailers to the corresponding points of the coupling.

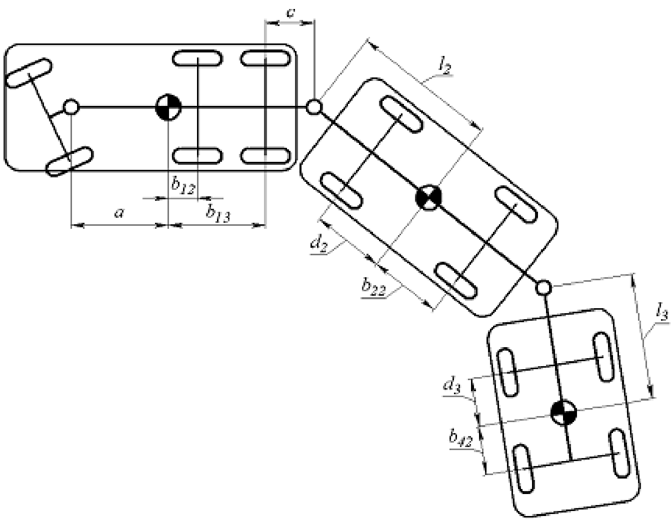


Figure 1. Scheme of the BRT tireless turn

After determining the reactions at the coupling points of the bus with the first trailer and the first trailer with the second, the integration of the original system of equations is carried out using the software Maple. At the same time, each of the modes was modeled by one or another law of rotation of the car-tractor steering wheel. For computer simulation of the most typical auto-train rotation on 90 °, which was moving ahead of it straightforwardly, the law of controlling the driving wheels of the car-tractor is given in the form [12]:

$$\theta = \begin{cases} 0 & at \ \ 0 \le t \le t_0 \\ \beta t & at \ \ t_0 < t \le t_1 \\ \beta t & at \ \ t_1 \le t \le t_2 \\ -\beta t & at \ \ t_2 < t \le t_3 \\ 0 & at \ \ t > t_2 \end{cases}, \quad (2)$$

where [0; t_0] i [t_3; t_k] – time of the auto-train movement on a straight line in accordance with the entry into turn and after the turn off;

[t_0; t_1] – time of entry into turn, controlled wheels of the car-tractor are evenly returned with speed β = 0,05 c^{-1};

[t_1; t_2] – interval of time of the auto-train movement by circle (may be absent);

[t_2; t_3] – time interval of the exit of the auto-train from a turn (the steering wheels of the car-tractor are evenly returned to the neutral position).

To study the behavior of the auto-train in such a turn the speeds of 5 m / s at the angle of rotation of the controlled wheels of the tractor from θ = 3,0 ... 35 deg. are taken.

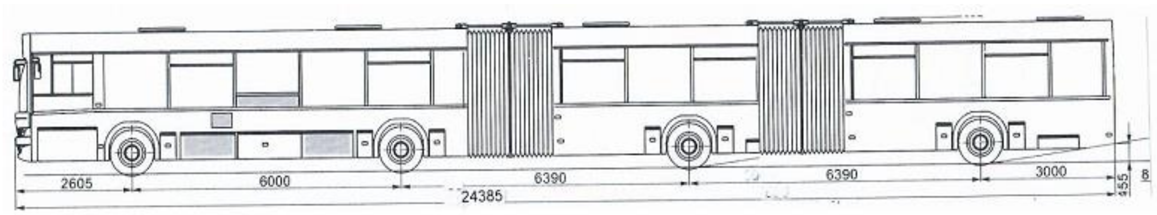


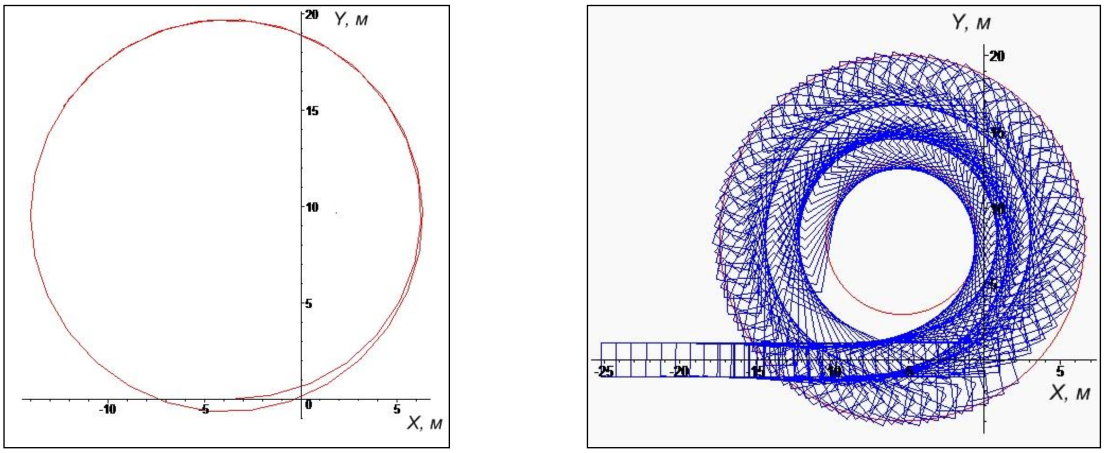
Figure 2. The BRT compass scheme

v =5, λ (lambda) =–0,023, a=3,68; b=2,32; c=8,71; d1 =4,17; d2 =4,17;m=18000; J=38500; bus; m1=400 J1=18,5 m2=9500; J2 =31200; m3=400; J3 =11,2; m4=9500; J4 =31200; kf =0; k1=160000; k2=32000; k3=180000; k4=180000; kk1=2600, kk2=1800; h1=30, h3=30; φ11=0,8; φ22=0,8; φ33=0,8; φ44=0,8; θ0 =0; θ=θ0 +kθ×n; kθ=0.05; n=1,2...10; θ3 =0,2×θ; V =0.

3. Results

The overall lane of traffic is determined by the traffic flow of the transitway. At the same time, it was taken the angles of the controlled wheels rotation of the bus, as well as the speed of the auto-trains and trajectories of the mass center of the bus, fig. 3a, on which later the overall dimension of the transitway was constructed, fig. 3b. As it follows from fig. 3b, three-axles BTR with selected parameters for a controlled second-trailer meets the requirements of Regulation 36 on maneuverability.

The obtained system of equations also allows us to investigate the behavior of a three-axles transitway in both stationary and non-stationary movements [13, 14, 15]. In order to determine the stability parameters of the transitway in the general motion case it is necessary to integrate the system of equations (1). This integration was accomplished with the help of the Mathcad 2014 software. As the main estimator of the stability of the transitway a critical speed was chosen.

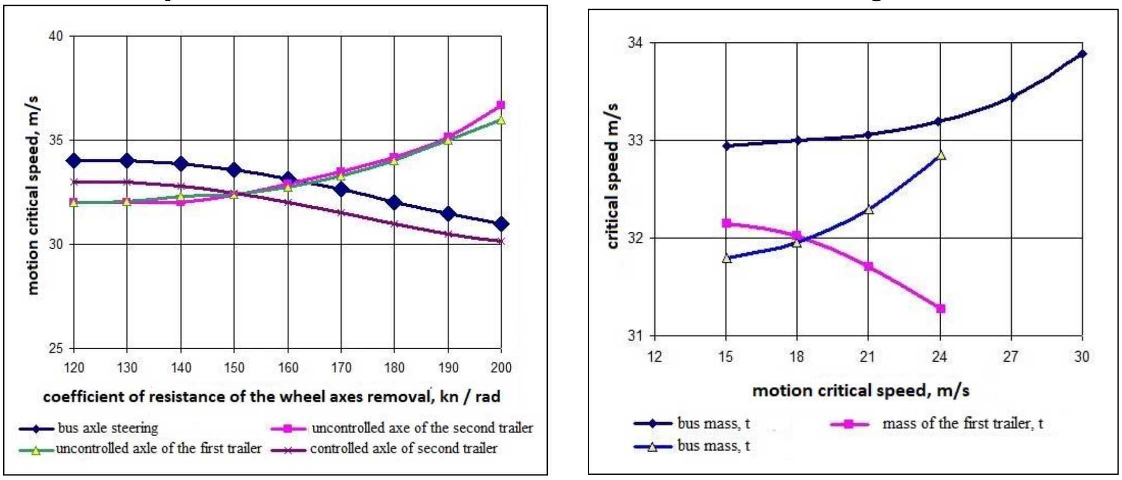


(a) (b)

Figure 3. Trajectories of the mass center of the bus (**a**) and transitway (**b**) at the speed of 5 m / s

Fig. 4 shows the results of calculations of the BRT critical speed depending on the listed parameters.

The analysis of the above dependencies shows that the increase of the BRT critical speed is positively affected by the decrease of the resistance coefficient of wheels of the driving axes of the bus and the second trailer (for example, by reducing the air pressure in the wheel tires of these axes). Similarly, the increase in the critical speed leads to an increase in the coefficient of resistance of wheels removal of trailer uncontrolled axes, reducing the distance between the mass center of the bus and the coupling point with the first trailer, increasing the mass of the bus and the first trailer, fig. 4a. However, an increase in the resistance coefficient of wheels of the controlled driving axes leads to a decrease in the BRT critical speed, as well as an increase in the mass of the second trailer, fig. 4b.



(a) (b)

Figure 4. Dependence of the BRT critical speed on the resistance of the removal wheels of the BRT axes (**a**) and the masses of the axles (**b**)

4. Discussion

Critical speed is one of the main indicators of the BRT stability. The recommendations for its increasing due to the rational choice of mass and layout parameters, in particular increasing the bus mass and the first trailer, reducing the distance between the bus and the first trailer, as well as between the first and second trailers, reducing the resistance ratios of the removal controlled axes wheel and increasing - uncontrolled BRT axes. In view of the fact that the transitway critical speed is lower than the maximum speed for its energy properties, the velocity of the appearance of vibrational instability, which is corresponded to the appearance of the first positive root in the solution of the characteristic equation, was determined further. According to the results of calculations, it has been found that for optimally chosen BRT parameters the critical velocity was 33.5 m / s, while the velocity of oscillatory instability was 30.8 m / s. However, this conclusion needs to be checked also in tensile modes of movement, in particular in such regimes as "twist", "jerk of a steering wheel", movement "snake", S-shaped twist, etc. Each of the following modes can only be considered after integrating the original system of equations. In addition, it is desirable in the future to consider the BRT spatial model, which will enable to take into account the change in load on its axis in dynamics, and accordingly, the change in the parameters of the wheel removal, which may affect the change in critical speed and the rate of appearance of oscillatory instability, which is decisive for the examining transitway.

5. Conclusions

The paper deals with the indicators of maneuverability and stability of the three-axles transitway through the solution of the original system of equations. The overall traffic lane, which characterizes the BRT maneuverability, is determined by the circular traffic of the transitway with the selected parameters for the controlled second trailer. It has been established that it meets requirements of Rule 36 regarding maneuverability.

As a result of the research, it has been determined the critical velocity of the three-axles transitway was determined and factors influencing its numerical value have been analyzed. It is shown that during the BRT operating it is necessary to maintain such pressure in the range of the allowable for this tire type, so that for the selected load on the wheels of auto-train axes, the coefficient of resistance of the lateral separation of the wheels removal of the bus steered wheels and the trailer is smaller than one of wheels of uncontrolled axes. It will be used for increasing the auto-train critical speed v_{kr}.

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Dynamic scheduling of highway cargo transportation

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Abstract: Purpose: The purpose of this paper is to present the methodology of improving the process of schedule compiling, and its implementation in the face of increasing requirements for their quality. Methodology: The main data of scheduling is the set of orders forecasted. It allows us to reach the minimum delays of goods delivery. Prediction is given with time windows, which is a required tolerance due to uncertainty. However, many external factors are random, and they can break these tolerances. We used combined meta-heuristic methods of iterated local search with variables clustering for solving it. It has been applied a priory signs of optimality of schedules. Results: Thus, we have provided grounds to classify received orders by compatibility, geographic location, arrangement and urgency. The article gives definitions, and proves the crucial importance of compatibility, as well as proposes the set of indicators of full, or partial, compatibility, and incompatibility of cargo transportation tasks. It has been proved that the most important property of orders is their organizational compatibility. The optimization criterion of total duration of all scheduled vehicles has been applied. Total delays and idle mileage of trucks, or their idle time also considered as the quality indicators. The algorithm of operational correction of the pre-scheduled decomposition with respect to external disturbance has been developed. So, the study has investigated the impact of planning horizon on scheduling efficiency. The theoretical contribution: Assessing of orders compatibility gives us the ability to integrate single orders into complex transport tasks within the time horizon of planning. This allowed one to achieve a guaranteed optimal schedule. Based on operational information request, one can re-qualify the whole demand and make changes in the already developed schedule without changing its quality. Practical implications: The algorithm leads to an approximated optimal solution of total duration of cargo transportation and its delays.

Keywords: cargo delivery, dynamic scheduling, time windows, multiple vehicle routes, orders batching.

1. Introduction

Long distance delivery of large groups of goods has become a very important resource in modern transport systems. This is due to the growth of cargo turnover, significant competition trucking companies, limited modes of operation of trucks, and their crews. On the other hand, the usage of intelligent transportation systems requires careful approach to intelligence analysis, decision making, and monitoring their implementation. The management of intercity highways road transportation has certain features, which increase the problem of fleet performance.

This is, firstly, a considerable distance from the points of departure to the acceptance of goods, in which the duration of the whole process depends on the time of departure, and arrival of the trucks to the place of delivery of the goods. Secondly, it is an idle mileage of trucks, which considerably raises the

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cost of transportation, so carriers can not afford it. And thirdly, it is a wide geographical distribution of cargo stations, and acquisitions of cargo flows, through which the development and compliance of the schedule have significant limitations. In this regard, designing methodology, and monitoring of their work scheduling requires special attention.

While designing schedules, one is using the orders prediction and reaches the minimum delays in the transport process based on this. As a rule, they are executed with time windows that are a certain reservation for uncertainty.

However, many external factors are random, which may violate these tolerances if there is an unfavourable coincidence of circumstances. First of all, these are unpredictable orders, arising on the planning horizon, and also cancellation of known orders that have already been included in the previously designing schedule. It is also impossible to reliably predict a change of cargo delivery operations duration, traffic congestion, and the reduction of the throughput capacity of highways, fails of vehicles, and their leaving of the routes too. Taking into account, or ignoring these factors, and making changes to the previous timetable can reduce the efficiency of transportation. The purpose of these studies was to improve the method of routes and timetables of vehicles constructing on the intercity network, taking into account the complication of circumstances, and requirements for the performance of transportation.

Scientists have been focusing on vehicles routing for over 50 years [1]. Solved by them problems became further gradually more complicated in order to get closer to the real conditions of transportation of passengers and goods. There was growing interest of dynamic routing problems in recent years, as well as the development of on-line schedules for transportation operators [2]. This is due to an increase in the amount of available data, at the same time, the improvement of the means of transmission and processing of information, which has become a driving factor of process management. The main intention of the researchers is to provide reliable and accurate solutions of routing, which have changes over time. The usage of information and telecommunication technologies has transformed the methodology of scheduling into a bottleneck, taking into account random factors. Thus, in particular, it has been shown that the use of a large number of sensors, parallelization of the process, and the introduction of cloud technologies in transport management significantly increases information flow of that is processed by outdated methods [15]. Therefore, the arrival of intelligent technologies in the transport is constrained by current methodology.

Overviews of various routing problems were done in publications [1, 2, 9, 10]. Vehicle routing problems (VRP) belong to combinatorial analysis, and they are divided by the probability and availability of information flow for static, dynamic, and stochastic. Static VRP has been sufficiently processed in previous works, but it solving loses relevance, according to that trucks dispatchers switch to use operative control methods [3]. In addition, many types of static VRP can not be solved by methods, which give sufficiently accurate and effective solution. Having solved the static VPR and scheduling in practice, carriers still have to apply the reserving of fleet capacity, and when faced with unforeseen circumstances, they suffer considerable economic losses.

Events occur during the transport planning process in modern production situations, or when the plan is in progress. The questions of whether to consider, or ignore them, and how to take into account new developments, affect the quality of the adopted plan, which further complicates the task of routing and leads to greater uncertainty. That is why, a class of dynamic routing problems has arosen, which is also so called on-line plan with real-time tasks, the content of which is to correct the previous designed operational plan in relation to changing circumstances. Such tasks were formulated and their initial review was made in the work of Psaraftis in 1988 for the first time [7]. In the works of Larsen and Madsen [10], Jaillet and Wagner, Schorpp and Pillac there were offered a variety of algorithms for solving dynamic routing and scheduling. However, they all applied methods which previously been used with varying success to static problems. There were the nearest neighbour method, the method of the taboo on a separate set of decisions [5] and meta-heuristic, other heuristic methods, which are discussed in detail at the work [9]. As the flow of information grows, dynamic routing techniques, taking into account the time factor, namely the time tolerances, the so-called time windows, proposed by Larsen and Wagner, become less effective. It was indicated by Larsen, that the growth of orders volume to fulfil, and unplanned increase in when the process is already in progress, fundamentally affects new solutions [10]. The size of the planning horizon in this case no longer plays such a key role, as for small orders and small fleets of vehicles. That is why, the researcher proposed to apply orders sorting, taking into account the urgency of their execution and time expenditures for this purpose. In his works, as well as, Karsten Lund and Rygaard [11], it was proposed to evaluate the routing and scheduling task in terms of rate of dynamism. This is an estimation of the flow of unscheduled events comparative to the planned ones. It can be successfully used to select the appropriate solution algorithm.

Stochastic VPR concern, mainly, random factors that lead to unexpected changes in the duration of travelling, idle time, and other delays. Essentially complete review of modern developments in the methodology of this direction was made in their research by Ritzinger U., Puchinger J., and Hartl R. F. [9]. The presence of random temporal factors does not change the planned route, or not update after implementation, in most cases, as stochastic routing optimization is often called a priori.

The category of dynamic and stochastic tasks of dynamic routing has led to an increase of scientific interests recent years. Thanks to the latest advances in information and communication technology, this new class of problems allows to more accurately process real data flows. The advantage is that besides the effective processing of dynamic events, stochastic knowledge of detected events is considered. Flatberg [16] reviewed the problems of this mixed type, but he focused on dynamic ones in particular, while Ritzinger and Puchinger [9] gave a review of Dynamic Vehicle Routing Problem (DVRP), but with an exclusive emphasis of the various hybrid methods applied to this direction.

There are several approaches to the classification of combinatorial optimization of DVPR. The main features are accuracy, type of space of solutions, structure of the computational scheme, etc. [1, 7]. As to accuracy, algorithms could be divided into precise ones which give a global solution, approximate, and heuristic. Approximate algorithms can be divided into actually approximating ones, which do not find only a solution with certain accuracy, but even allow one to get it certain estimates, and heuristic algorithms, which are based on probable reasons, although they do not give any estimates to the solution found [3]. Meta-heuristic are very promising methods among the modern approximate optimization methods, which give a solution of the problems of discrete optimization such as multi-route travelling salesmen. Meta-heuristics are hybrid methods of problems solving, built with combining known procedures, in which one acts as the leading role and the other (or several others) is subordinated. Certain known heuristics or other algorithms are usually performed as both, leading and subordinate procedures. We can select such a kind of algorithms as simple ones, hybrid algorithms, meta-heuristics, hybrid meta-heuristics, and hyper-heuristics by the complexity of the structure of the optimization of discrete structures.

The DVPR and a strategy for their solving based on the paradigm of Ant Colony systems considered in the paper of Montemanni R., Gambardella L., Rizzoli A., and Donati A. [8]. The method was evaluated by few tests, which were identified from a set of widely available problems. The results of the calculations confirm the effectiveness of the proposed strategy. However, such sets are not always available.

The methodology of genetic algorithm (GA) of DVRP model solving is presented in a large number of papers, in particular Hanshar F., Ombuki-Berman B. [12]. The effectiveness of the proposed algorithm is estimated using a set of indicators found in the literature. The author proposed a GA methodology that performs better functions of minimizing travel costs in comparison with the taboo search approach, implemented in the above-mentioned works. However, the use of GA requires a large amount of training data and their use is restrained by the need for training cycles.

A review of well-known publications demonstrates the advantage of adaptive methods for DVRP compared to non-adaptive approaches. If the data stream is pre-processed, then such a decision-making approach yields an average improvement of 0-5%, while RA-based methods receive up to 10% improvement. However, the approaches to online solutions are beneficial [9].

Taking into account the performed review, we can argue that adapting incoming data and its clustering is the best direction of dynamic optimization of vehicle fleet routes algorithm improving and it can provide a higher quality solution to the DVPR.

2. Materials and Methods

Normally dynamic routing is based on the fact that the forecast of orders for cargo transportation on the given transport network is done for some period T_{pr}. Then one makes a scheduling of their implementation that is a set of the moments of vehicle arrival at the stations of loading and unloading, taking into account the random location of the trucks on the network, after that. It is known the parameters of orders. If there are more vehicles than available for a travels in the planned period, then the timetable should include the next loading station after the previous delivery of the goods. The route of each vehicle is planned continuously, taking into account the efficiency of the entire fleet capacity. The following criteria of optimal scheduling are used, as the minimum of total guaranteed transportation lasting of all cargoes (most often for perishables goods), the minimal of transportation expenses, and the maximum of total incomes. But the criteria of the minimum of travel distance and the minimum of idle time are often used for long-distance large consignment transportation instead. The main transport network of road freight transport has such properties, that a departure point of some cargoes may be a destination point for others. This happens at random moments of time. Therefore, trucks are idly waiting for a long time, very often, for possible orders, while avoiding a futile mileage. The last two indicators for a single process are not contradictory. If the number and size of scheduled transportation on the planning horizon are stable, then such a problem is considered as static. One solves it by the mentioned methods of mathematical programming, heuristic, or meta-heuristic methods. Orders, which are scheduled to be executed, are characterized by having a station of departure, and delivery of goods. The duration of each of them is a random variable that is estimated by mathematical expectations $\overline{t_i}$ and a known deviation. Each order has also the permissible time delay of their execution called as a time windows. Time window lower border $t_{b.i}$ is the earliest time point, before which it can not be executed and upper border $t_{e.i}$ is the latest moment, after which this order must be executed. The size of the time window is, preferably, wider, than the maximum deviation of the time of execution of the order itself. The solutions of the static problem found were previously met by the dispatching services of the carrier for accuracy and reliability. The maximum number of planed scheduled orders does not exceed 100-120 in practice, which makes it possible to design an approximation of the optimal scheduling, and estimate its deviation.

Consequently, the previous optimal schedule is a set of moments $t_1, t_2, \dots t_n$, for N_a vehicles, the amount $N_{a.1}$ of which is involved in the transport process. Other vehicles are reserved. Minimum project execution time is T_1, $T_{pr}>T_1$. There are unforeseen circumstances, among which the following events are possible, when the project is executed at some point of time from the zero reference $0<t<T_{pr}$:

a) new orders are received with time windows that intersect with the planning horizon;

b) previous planned order is cancelled;

c) estimated transportation time t_{ij} has increased / decreased, where i, j, respectively, are the point of departure and receipt of the cargo;

d) a vehicle failed and descended from the route.

The presence of such events changes the static routing problem into a dynamic one. Such events are of a random nature and, according to research, are subject to the Poisson law [10]. The reaction to such events by carriers may be one that is accepted or rejected by one of the possible solutions:

a) to refuse an acceptance of new orders;

b) to ignore cancelled orders;

c) to change the sequence of orders;

d) to change the number of vehicles on the routes, including the reserve.

In this article, we tried to solve two topical issues. Firstly, it will be the changes of the previous order affect the quality that it has achieved before? Secondly, how the process of constructing / correction of optimal timetable and routes is influenced by the availability of information about the properties of scheduled and new orders.

The formulation of the problem is as following. The scheduled time T_{pr} is set, which can be changed depending on the desired forecasting range. There is also a known set of orders for carrier company, $P=\{1,2,\dots,p\}$, which have to be executed with minimal delay in one or more truckloads that are originally located on the transport network in a random way. The content of each order is to deliver a unitary group of goods $Q_{i.j}$ from some point g_i to another g_j, $i,j=1 \dots n$, $n<p$. It was accepted that there is a path between any two station on a given transport network (the network is strongly connected), so the distance between them is known, but for convenience, it is evaluated indirectly by the travelling time $t_{i.j}$ at a known steady average operating speed. Since the problem relates to trunk transport (intercity, international), then the main criterion for a carrier here is, preferably, the maximum useful mileage during a given period. Otherwise, this is the minimum time of idle mileage.

Since a time, $\bar{t}_i \le T$, then during each planning period, each truck can execute several orders. To start the first one the vehicle must be submitted to the point, where the order is formed no later, than the policy moment of the time $t_{e.i}$. Consequently, it is necessary to take into account the duration of initial mileage, as well as the travelling time between *i* and *j* stations – $t_{i.j}$. To perform each subsequent order the vehicle must be submitted for loading to the adjacent transport facility, where there is a corresponding request, or download at the same place where the previous unloading took place.

The feature of this problem is that there are no finite restrictions for all orders of set *P* for the period T_{pr}. This problem is associated with a time ordering of operations and their assignment to the available vehicles. That is why, it can be associated also with known classification features, as tasks of cyclic unitary schedules compiling for streaming project operations by several operators [3]. When planning the transportation execution, it is necessary to develop, on the one hand, the shortest route for each vehicle that will be involved in the process, and on the other hand, the best schedule for orders executing for a combination of trucks with minimal unproductive downtime in the presence of time constraints, i.e. without delays. Such a problem should also be attributed to optimization, considering the structure and properties of a typical transport process of medium and large transport systems [5].

Developed problem relates to NP complex one in strong sense by the complexity of optimal solution, that is, there is a non-deterministic algorithm for finding a successful exact, or approximate solution for polynomial time. The method of mixed graph ordering is used for its development [17].

According to it the whole set of known orders represents the oriented mixed graph *A(G,U,V)*, where *G* is the set of vertices $\{g_1 \ldots g_p\}$ where $g_2 \ldots g_{p-1}$ symbolizes the moments of their execution starting. The vertex g_1 is fictitious, representing the formal moment of the beginning of the whole project. The vertex g_p is fictitious too symbolizing the end of a scheduled cycle of duration T_{pr}. *U* is the set of arcs each of them represents communication time $a_{i.j}$ between the moments of the start of the execution of the i-th and j-th orders by the same vehicle. Arc of graph *A* are weighted. If there is an order, it is reflected in the graph *A* with the arc of the weight $a_{i.j} > 0$. The requirement must be fulfilled:

$$-a_{j.i} \le t_{o.j} - t_{o.i} \le a_{i.j} \tag{1}$$

where $t_{o.j}$, $t_{o.i}$ – the moments of the *i*-th and *j*-th orders execution start, respectively.

Arcs $a_{1.i}$ are earliest moments of the possible start of each order. Arc $a_{i.R}$ is the time communication, or "pure" duration of the execution of the *i*-th order, matches the event as if, a vehicle does not spend a time for zero mileage, before it begins the loading in the *i*-th station. Obviously:

$$a_{i.P} \le a_{i.j} \tag{2}$$

Condition (2) must be fulfilled for any *i* and *j*. The arc with a negative weight, $-a_{i.j}$ represents the time limit for the execution of the order. For example, $-a_{p.1}$ is the allowed time to execute all known orders (as a rule, it coincides with the T_{pr} period). Arcs $-a_{p.i}$ reflect deadlines of the most late-end of *i* orders. All other non-existent or insignificant connections of the graph are represented by arcs with $-\infty$ weight.

There is also given a set of edges in the model of the disjunctive (mixed) graph *A*, each of which [*i*, *j*] corresponds to the pair of weights $a_{i.j}$, $a_{j.i}$. If there is an edge between vertices *i* and *j*, this means, then, their temporal independence, and the corresponding operations of *i*-th and *j*-th orders will be executed simultaneously or with partial overlap.

K vehicles may be involved in the carriage process. They should work synchronously, each executing several orders in sequence. This means that one needs to select *k* chains in the graph *A*, which start at the vertex g_1, pass through some vertices of the graph, which are related to existing orders, and finish at the vertex g_p. We are looking for the minimum useless run in this variant of the problem, with minimal delays of the process. Therefore, the desired chains must pass through those vertices for which $q_{x.y}>0$. If the chain reaches the vertex y, and then there is no path in the graph A with an integral or nonzero weight, then the chain goes to the vertex g_p. The transport cycle for these vehicles will be considered as complete, despite the fact that there is a spare time to fulfil other, not yet executed orders. The problem in this formulation is similar to the typical task of several salesmen routing. The algorithm for solving this problem for a relatively small number of orders is based on the method of branches and boundaries and its development is described in previous studies [18]. If we consider a certain mixed graph, the sense of the problem is to replace or remove all its edges and arcs, which cause the presence of contours of positive weight (Fig. 1).

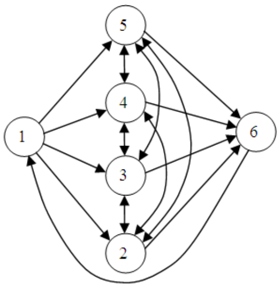

Figure 1. Test model for scheduling the execution of orders for the carriage of goods: $a_{i.j}$ – weight of the corresponding arcs

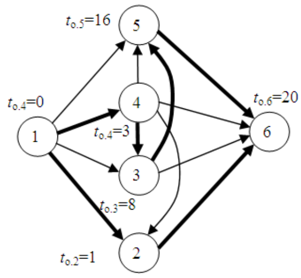

Figure 2. Results of the ordering of the mixed initial graph in the presence of deadlines for orders completion, the number of cars m=2

If all orders are independent, then the edges exist between each pair of vertices. Therefore, the complexity of the combinatorial search algorithm is measured by the number of search options from 2^{2n-1}, where n is the number of vertices of the initial graph. The duration of the algorithm at 100 vertices exceeds the permissible expectations and the search for a complete overload is complicated. Therefore, a heuristic based on the expression is used, and serves to select a conflict edge from the whole set of given:

$$h_{ij} = t_{e.j}\left(G,U\right) + \vartheta_j\left(G,U\right) + a_{i.j} - \vartheta\left(G,U\right), \tag{3}$$

where $\vartheta_j\left(G,U\right)$ – the maximum weight of the path in the graph $A\left(G,U\right)$, starting at the vertex g_j; $\vartheta\left(G,U\right)$ – the total longest path in the graph $A\left(G,U\right)$.

The searching of the most conflicting edge of all conflicting of set $V\left(\alpha_i\right)$ is based on the value $\min\left(h_{i.j}, h_{j,i}\right)$ calculation. The edges with this value found is the largest, is the most conflicting one. The ordering of the mixed graph leads to the construction of the oriented one (Fig. 2), in which there are no contours of positive weight, and which uniquely represents the optimal after speed schedules and routes, for two cars in this sample. The values $t_{0.i}$ marked at the vertices of the oriented graph are the moments of time, when the execution of the i-th operation should be started. However, when the number of orders increases as a result of incoming of additional operational information, then the presented model will contain only the edges that associate the new vertices with the available ones. Therefore, the optimal solution will be local and the quality of the new schedule may be worse. Therefore, to improve the algorithm we applied a grouping of orders, which is executed on the basis of the proposed classification.

Several features have been applied for the classification some of them are more significant for ordering the time graphic model. We will distinguish one-time, periodic, and permanent orders by frequency. This classification sign refers to the relationships of orders objects, one of which is the sender, and another is the consumer of goods. One-off order occurs once upon all planning periods. Periodicity orders are characterized by the fact that between the moments of their reception there is an idle time, which is, in general, a random variable. Permanent orders are characterized by the fact that they always exist at the point of departure of goods, regardless of the time of arrival of the vehicle for loading.

The order Z_1 and Z_2 will be divided into fully compatible, partially compatible, and incompatible. We will call such orders i, j a quite compatible, if whose execution in the sequence $i \rightarrow j$ with one vehicle is characterized by a complete absence of useless mileage and idle pending loading (Fig. 3). Partly compatible are such kind of orders, the execution of which leads to a futile run and / or idle in anticipation of the next boot (Fig. 4). Incompatibility of orders means that it is impossible to execute them in one flow with one vehicle. Incompatibility of orders Z_1 and Z_2 excludes their execution in one thread in one track due to the presence of overlapping time windows. Models of fully compatible and partly compatible transportation orders are shown in Fig. 3, 4.

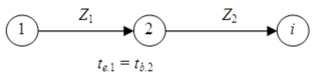

Figure 3. Model of fully compatible orders

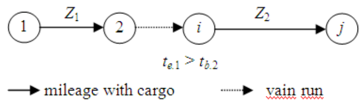

Figure 4. Model of partially compatible orders

The compatibility or partial compatibility ratio is not reversed. Moreover, if the indicated *com* relations are completely compatible, *inc* are incompatible, *pc* are partially compatible, then the following logical expressions can be written, which follow the notation for orders *a, b, d*.

1. If *a com b,* then *b inc a.*
2. If *a com b,* and *b com d,* then *a pc d.*
3. If *a com b,* and *a com d* then *b pc d.*
4. If *a pc b,* and *a inc d*, then *d pc b.*

These are basic logical dependences, on the basis of which, using logic algebra, one can write other logical expressions that combine orders into logistic chains.

If there are several orders that can be included in a single stream in the aggregate, then the entire set can be estimated by quantitative indicators such as:

- order of compatibility ratio, which we define as:

$$K_{com} = \frac{n_{com}}{n_{\Sigma}}, \tag{4}$$

where n_{com} is the number of compatible orders (events) in the array ordered, n_{Σ} – the total number of events.

According to the definition of compatibility, the maximum value of K_{com} = 0,5. That is, if a maximum of half of orders is a compatible, then second half of this relationship is not mirrored;

- the coefficient of partial compatibility is determined from the expression:

$$K_{p.com} = \frac{n_{\Sigma} - n_{\max.flows}}{n_{\Sigma}}, \tag{5}$$

where $n_{\max.flows}$ – the maximum number of flows (with ruptures), which can be designed in the initial graph. The numerical value of the partial compatibility factor may lie within the range of 0..1;

- the coefficient of incompatibility of orders (events) is determined from the expression:

$$K_{inc} = \frac{n_{inc}}{n_{\Sigma}}, \tag{6}$$

where n_{inc} is the number of incompatible events in the entire set of them. This coefficient can reach a maximum of 1.0, since orders can be located on the network, and demanded so, that none of them can be executed by the same vehicle.

Using the compatibility signs, one can divide the orders into such groups, which will be executed in the same flow at the stage of the initial scheduling. Returning to the previous example of a static problem, we can mark in the initial graph arcs and their ratio of the full compatibility between the vertices, or the absence of an arc or edge as the complete incompatibility (Fig. 4).

If one compares the given in Fig. 5 model with initial one on Fig. 1, the full compatibility of orders 4-3 and 3-5 can be seen, as well as the incompatibility of orders 2-3 and 3-2. Such a batching greatly simplified the optimization of the design of the decomposition, and led to the same result that in Fig. 2. If the number of orders increases, then we can assume that the quality of the constructed schedule will be better, than applying the above heuristic algorithm without classification and grouping of objects.

If unplanned orders are received during the planned horizon, then, taking into account their time parameters, they can also be classified. In order to get the optimal solution for the order of performing unplanned tasks, it is necessary to rebuild the disordered mixed graph, taking into account that there will already be no edges connecting the vertices, which at the moment of receipt of new orders are already excluded from the current schedule, because the events they represent has gone. The complexity of arranging a new graph will not be higher than the previous one, since new vertices have established compatibility links, and some vertices are already excluded from the review. Let us consider an example of the model above with four orders and two cars. Previously, it was well-ordered and looked like Fig. 2. At time $t_{o.7}$=9 hours from the beginning of the plan of transportation implementation, two trucks began to move around the network. One of them at the time $t_{o.4}$=3 hours has completed the order 4 and has been sent to the next item for the order 3, which, according to the schedule, was completed at the time $t_{o.3}$=8 hours.

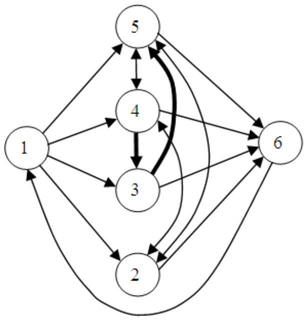

Figure 5. A model of schedule design with the terms of full orders compatibility (continuous solid arrows) marked on them

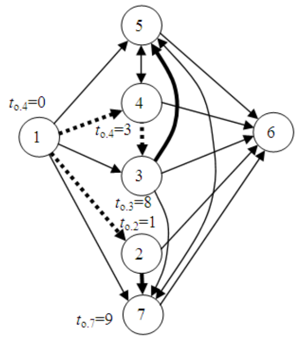

Figure 6. Model for adjusting the schedule after reception of unplanned order 7; the number of vehicles is m=2

Another vehicle has already completed order 2 and, according to the previous timetable, should complete whole transportation plan. The new order 7 is fully compatible with order 2 after its parameters evaluated before. Therefore, the next re-optimization results change the schedule, according to which second track has to execute a new order 7 after the execution of order 2. In this case, the total duration of the project does not increase, but the performance of both vehicles increases.

3. Results

The proposed algorithm was applied to a large array of sample data. It has been considered the order for the carriage of goods between cities on the transport network was considered, which presents L'viv region of Ukraine, which is approximately 150×150 km. The average travel time between the cities is about 6,5 ± 3,5 hours. The fleet of vehicles is initially located in the regional centre. Its number is 40 trucks. The same is the maximum initial number of orders. In other words, there is the possibility to distribute existing orders between the available fleet, so that each vehicle will be occupied with one order execution. The transportation of goods is carried out by the pendulum kind of routes, however if the point of consumption and the point of departure of the goods coincide, then the possible version of the circular route with the breakdown of the traffic flow exists. The maximum planning horizon was 195 hours of continuous time that is approximately 8 days. Each order is characterized by the average duration of its execution as well as time windows. Thus, in the set of orders, the relationship between the couple of events was established.

The ratio of their full compatibility is $K_{com}=0,1$, partial compatibility is $K_{p.com}$ = 0,5, ratio of incompatibility is $K_{inc} = 0,2$. All orders are periodic and they are located on the specified geographical area, so that from all 44 cities of the region 10 are involved in the project, and approximately 20% from the total 31.5 thousand km length of regional roads can be used for the execution of all orders. During the planning period, new orders are received by the carrier, which can be described by the Poisson process with the intensity $\lambda=0.09$ orders per hour. The new requirements for carriage are such that they do not change the previously accepted compatibility metrics. It was assumed that the volume of transportation corresponds to the cargo capacity of each of the available vehicles of the fleet.

The initial optimization of known orders was carried out with a variable horizon of 20...195 hours. The dependence of the duration of forecasting from the number of planned orders is reflected in Fig. 7. These data were obtained from the transport and logistics company on the basis of the application information. The number of random orders received in the allocated planning period is shown in Fig. 8.

The properties of orders and location of vehicles at the initial moment remained stable, when designing schedules and routes with different horizons of planning. This was related to their time windows, medium duration, and others. Tables 1-3 show the optimization results in two methods:

applying the proposed classification of orders and grouping them, and using the heuristic algorithm " branch-and-bound" [17]. In the first case, the initial model is subject to limitations, but they are such of kind that make the best decisions.

As it can be seen from the results and their comparison, the proposed algorithm shows a higher level of quality scheduling and routing. This is especially noticeable in terms of unproductive idle vehicles, due to the fact that the execution of the order is discordant. It may occur when the vehicle has already executed a pre-order, and the next can not be started, or when all current orders are already executed, or distributed, and there are no new accepted orders. Three tables show clear that the idle time is especially relevant at large planning horizon.

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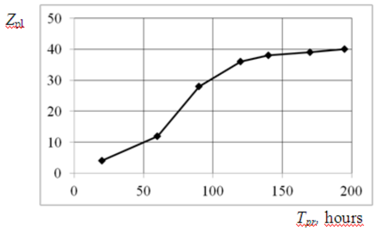

Figure 7. Dependence of the number of planned orders from the duration of the planning horizon

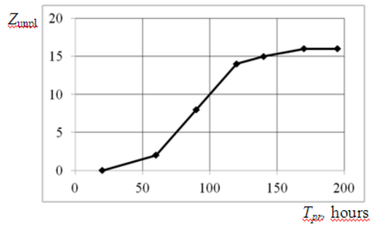

Figure 8. Dependence of the number of unplanned orders from the duration of the planning horizon

Table 1. Indicators of quality of designed dynamic schedules at the initial planned quantity of orders 40

Indicator, unit of measurement	Methodology		Level of new algorithm %
	branch-and- bound, without orders classifying	branch-and- bound with the previous classification of orders	
Planning horizons. hours	195	195	0.0
The number of actually executed orders	33	36	+9.1
Number of actual unscheduled orders	14	16	+14.3
The number of actually involved vehicles	38	36	−5.3
Minimum guaranteed project duration. hours	22.2	19.5	−12.2
Mileage duration of all vehicles with cargo. hours	312	346	+10.9
Duration of useless mileage of vehicles. hours	112	94	−16.1
Duration of idle time of all vehicles. hours	84	47	−44.0

Table 2. Indicators of quality of designed dynamic schedules at the initial planned quantity of orders 36

Indicator, unit of measurement	Methodology		Level of new algorithm %
	branch-and- bound, without orders classifying	branch-and- bound with the previous classification of orders	
Planning horizons, hours	120	120	–
The number of actually executed orders	27	32	+18.5%
Number of actual unscheduled orders	12	14	+16.7%
The number of actually involved vehicles	30	26	−13.3%
Minimum guaranteed project duration, hours	22.2	19.5	−12.2%
Mileage duration of all vehicles with cargo, hours	265	246	−7.2%
Duration of useless mileage of vehicles, hours	87	84	−3.4%
Duration of idle time of all vehicles, hours	24	17	−29.2%

The application of the classification algorithm gives up to 44% reduction in the downtime of all vehicles with an actual number of 36 scheduled and 16 unscheduled orders, which were accepted. The number of actually executed scheduled orders is 32, and unplanned – 14 with a smaller scheduled horizon of 120 hours. Although the volume of execution of orders decreased slightly, but in this case, the idle time was shortened not so much, only for 29,2%. This is due to the fact mainly, that the duration of the project has not totally changed; therefore the algorithm has led to a thickening of the schedule with a slight decrease in the actual work performed.

Reducing the planned horizon does not significantly affect the quality of the schedule. After all, the relation between the planning period T_{pr} and the guaranteed duration of the project is 1: 8.8 and 1: 5.4, that is, the projected time exceeds the design by at least 5.5 times. If we analyze the data in Table 3, then it becomes obvious that the optimization algorithm with the previous classification is ineffective. But routing and scheduling is a static process, in fact, since there are no unplanned orders.

Table 3. Indicators of quality of designed dynamic schedules at the initial planned quantity of orders 4

Indicator, unit of measurement	Methodology		Level of new algorithm %
	branch-and-bound, without orders classifying	branch-and-bound with the previous classification of orders	
Planning horizons, hours	20	20	–
The number of actually executed orders	4	4	0
Number of actual unscheduled orders	0	0	0
The number of actually involved vehicles	2	2	0
Minimum guaranteed project duration, hours	19.6	19.4	–1.0%
Mileage duration of all vehicles with cargo, hours	30.2	30.2	0
Duration of useless mileage of vehicles, hours	5.2	4.4	–15.4%
Duration of idle time of all vehicles, hours	1.4	1.2	–14.3%

4. Discussion

The influence of the number of vehicles engaged in the process of transportation on the length of execution of a fixed number of orders is also investigated (Fig. 9). There are 40 scheduled and 12 non-scheduled orders. If the number of vehicles increase from 14 to a maximum of 40 units, then the length of the process will be reduced, but nonlinear. The research establishes the condition, that all 52 orders must be fulfilled. As one can see at Fig. 9, the increase in the number of cars over 31 does not lead to shorter project duration, because all operations will be distributed among existing trucks, and their performance will be reduced.

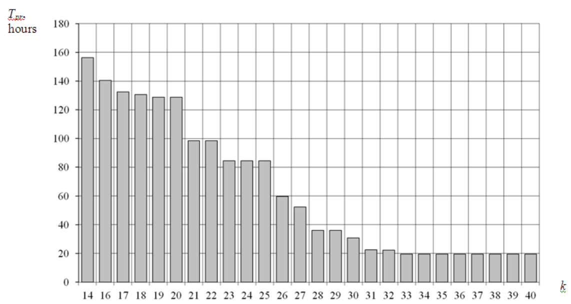

Figure 9. Dependence of the minimum durability of the project with the size of 40 planned + 16 unscheduled orders from the number of involved vehicles

5. Conclusions

The analysis of known routing and scheduling techniques showed that they become ineffective in terms of quality of results with increasing number of orders, especially unscheduled. The application of the previous classification is a way that improves the result. The corresponding algorithm, which is based on the ordering of mixed graphs, uses purpose-oriented restrictions in the form of oriented relationships between orders of one class. Classification of orders, in fact, has to be provided on the basis of time compatibility, taking into account time windows.

While applying the developed methodology for dynamic routing and scheduling, it has been found that it provides a significant improvement in the quality of the schedule by idle. But such an effect is achieved with a large planning horizon and large volumes of orders.

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Formation of transport-logistic clusters in Ukraine

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Abstract: Transport play an important role in the development of the economy. For efficient functioning of the transport system there should be not only high technical conditions of rolling stock, but also a developed transport infrastructure. The geographic position of Ukraine makes it a promising transit state. The purpose if this paper is to present the results of the research on the Ukrainian transport-logistic infrastructure. Since transport is one of the main components of economic development, it is relevant to study this sector of the economy and identify prospective directions for improvement, namely the formation of Transport-Logistics Clusters (TLC) in Ukraine. As a result of the research, it has been found that in Ukraine there are priority terrestrial modes of transport in comparison with other types. The value of the research is that having analyzed the experience of other countries in the establishment of TLC, the authors have identified the benefits of different cluster strategies for the formation of TLCs in Ukraine.

Keywords: clustering, transport-logistic cluster, cluster, transport network.

1. Introduction

One of the main tasks of the present time for Ukraine is to increase the competitiveness of the national economy. Transport has a great influence on all spheres of the economy, as it provides the promotion of material flows in macro-logistics chains. The development of the transport-logistic system is one of the important components of the Ukrainian economy. Considering the experience of economically developed countries, it can be argued that in order to increase the level of technological potential of the country, it is necessary to introduce innovative methods into its general economic system.

One of the modern innovative technologies for the development of the transport-logistic system is the formation of a transport-logistic complex in Ukraine. This requires effective operation of the transport infrastructure, the attraction of an efficient rolling stock for the transport process, as well as investments to ensure the quality work and competitiveness of the transport industry in the European and domestic markets of transport services. The modern direction of improving the efficiency of transport sector enterprises is the creation of transport-logistic clusters.

Many foreign and domestic scientists consider issues relating to the functioning of cluster units and the peculiarities of the formation and development of transport-logistic clusters, among them: Porter M. [1], Solvell O. [2], Williams M. [2], Kergel H. [3], Hatsch S. [3], Delgado M. [4], Stern S. [4], Wennberg K. [5], Lindqvist G. [5], Ketels Ch. [6], Kovbatyuk M.V. [7], Doroshchuk V.O. [8], Chupaylenko O.A. [9, 10], Grytsenko S.I. [11], Karpenko O.O. [12]. Goblyk V.V. [13], Ivanov S.V. [14], Popova N.V. [15], Volkovska G.G. [16], Yanovskyi P.O. [16] and many other.

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In scientific works of these authors the theoretical and methodological aspects of cluster formation, the preconditions for their creation and influence on the competitiveness of the region, within which formed cluster structures, were studied.

The founder of the cluster approach, M. Porter has defined the cluster as a concentration in the geographic region of interconnected and interrelated enterprises and institutions within a particular region [1].

Researchers O. Solwell and M. Williams in their work have considered the evolutionary and constructive factors which influence the mechanisms of cluster creation and determine its development and competitiveness [2].

In the work of the scientist K. Ketels [6] it has been put forward a hypothesis regarding the most effective policy of cluster support. It is a policy of cluster activation aimed at overcoming the negative factors that hinder the evolution of clusters, improving the business environment, infrastructure development, etc., which creating the conditions that allow the cluster to develop on its own.

Author Kovbatyuk M.V. in his scientific work has determined that the cluster represents itself a networked production and commercial structure that has the ability to concentrate and bring together related manufacturers, often even competing, for the purpose of co-operation for the production of competitive products [7]. This is confirmed by the development of a network of clusters in Europe and their integration into global, primary and secondary TLCs.

Doroshchuk V.O. is engaged in research of the concept of clusters. He has given a generalized definition of the concept of "cluster", having determined that the cluster is a territorial and voluntary association of business structures, scientific institutions, institutions of market infrastructure and institutions of the authorities for the purpose to increase the competitiveness of its own products and promote the economic development of the region and enhance the competitive advantages of each other through the effect of synergy [8]. They are created from a small (10-15 companies) and a large number of enterprises and structures (6-7 thousand companies) in various forms of associations and organizations. The cluster is considered as the geographical concentration of companies operating in a separate business, and the conglomeration of large and small firms, some of which may be the property of foreigners. They appear in traditional industries and in the areas of high technology, in the production and commercial segment or in the service sector, as well as in social spheres.

Author Chupaylenko O.A. in its researches has defined the transport-logistic cluster as a set of regional motor transport enterprises, representatives of enterprises of other types of transport, logistics companies, licensed warehouses, local authorities and research institutes in the form of associative unit with adequate financial contributions of participants, operating infrastructure, modern communications that enhance the interaction and benefits compared to other competitors, which allows to increase investment attractiveness and sustainable development of regional areas. They are divided into three categories: port, border and territorial (regional) [9].

Author Grytsenko S.I. in his monograph has described the concept of a transport-logistic cluster, which involves the unification of certain regional, functional and economically connected logistics units: international transport corridors, transport nodes of main infrastructure, transport and distribution logistics centers, main, regional and local routes of connection into a single system of transportation process, able to provide high-quality logistic service to internal or external consumers in minimizing general logistics expenses [11].

Having examined the work of clusters, author Karpenko O.O. has determined that the creation of clusters will contribute to the growth of productivity and innovative activity of enterprises that are the parts of the cluster, as well as to increase the intensity of development of small and medium enterprises, to increase the attraction of investments, will help accelerate socio-economic development of regions, where the cluster will placement, which will allow to increase the number of jobs, salaries, revenues to budgets of all levels, increase the stability and the competitiveness of the regional economy [12].

Among the strategic priorities of the European Commission is the development of cluster concepts, since cluster policy has been recognized as one of the foundations for building Europe's competitiveness and its dynamic development through the introduction of innovations. The purpose of the European Commission for clusters is to maximize the contribution of clusters to the development of the European economy, the growth of entrepreneurship and the enhancement of regional economic competitiveness [17].

3. Materials and Methods

An essential condition for obtaining new knowledge on the basis of discovered scientific facts during the conduct of scientific research is the use of well-founded scientific research methods. Obtaining the desired result directly depends on the original theoretical position, from the principle approach to the problem statement and the definition of the path of research.

In order to reveal the theoretical foundations, peculiarities and characteristics of the processes of formation of transport-logistic clusters in Ukraine, a statistical analysis of the activity of international transport-logistic clusters and indicators of activity of the transport industry of Ukraine and modes of transport included in its transport system was used, and the general scientific methods of research were used: method of empirical research (monitoring, comparison), method of theoretical research (formalization), general methods of research (analysis, synthesis, analogy).

4. Results

The leading countries of the world with high indicators of development of the national economy have achieved their competitiveness through the introduction of innovative technologies.

The world experience of recent decades confirms that cluster initiatives are rapidly expanding in developed countries. Due to the fact that a number of states have a federal structure, in some of them the cluster policy began to be implemented at the regional level earlier than at the federal level. According to the European cluster observatory in Europe there are more than 2 thousand regional clusters, and the potential for the development of cluster entities for the future is estimated at 9 thousand units [18].

In the EU countries, demand for transport-logistics services is growing every year. One of the most promising technologies at present time is the formation of Transport-Logistic Clusters (TLCs). There are more than 86 logistic clusters in the territory of Europe, of which about 25 are the main ones that can be considered as global clusters of European significance (through them pass the main cargo flows), as well as about 60 secondary clusters. The qualitative functioning of the TLC will contribute to the high level of service of transport and logistics consumers. In this case, it is necessary to take into account the needs and wishes of consumers, to establish a strong relationship between all enterprises involved in the process of cargo transportation, which will promote competitiveness and customer satisfaction with logistics services.

EU countries adhere to the principles of the operation of TLCs, which allow the provision of quality logistics services, the main of which are:

- the offer of the most complete list of transport and related services on the basis of contractual relations with each participant of the logistics chain (the formation of a data bank of logistic chains);
- organization of complex transport services on the basis of a single contract for integrated services and a single order for all services, the formation of tasks for participants of the logistics chain based on the order of the user of transport services, centralized control of the order fulfillment;
- standardization and unification of transport and other documents used by participants in logistics chains and which are necessary for carrying out transportation, in order to ensure the possibility of creating a single information space;
- development of a unified marketing strategy and tactics of logistics chain participants in the market of transport services, joint conducting market researches and marketing activities that ensure the promotion of all participants in the logistics chain in the market of transport services and formation of demand for integrated transport services;
- the distribution of structural units of the cluster on a geographic basis in order to maximize the coverage of the market of transport services, the implementation of operational management of the work of logistics chains in the places of formation and intersection of freight traffic;
- organization of cooperation with Ukrainian and international organizations involved in transport logistics;
- development of organizational principles of work on the basis of world standards and international treaties, agreements, conventions;

- integration with international logistics centers and provision of information exchange;
- standardization of information interaction of logistic chains of participants of the international transport-logistic cluster [13].

Joining the cluster it gives a number of benefits to the enterprises and institutions that it includes, the main of which are: a clearer orientation to the market of transport services and the possibility of adjusting it to the needs of consumers; the opportunity for the cluster participants to more effectively defend their interests at the level of local authorities, participate in large investment projects and join the joint promising program of their development. The transport-logistic cluster should include transport, transport-logistics enterprises, as well as enterprises that serve the service, institutions of legislative and executive power of different levels. Carrying out high-quality transport activity depends on cooperation of business, science and authorities. Therefore, the formation of a transport-logistic cluster is influenced by certain sectors, such as the manufacturing sector, the administrative sector, the transport-logistic sector, the service sector, the financial sector, the innovation sector (specialized universities, research institutes that develop new innovative methods for implementation in the transport process, consulting centers), state-legal sector [19].

The geographic and geopolitical position of Ukraine is positioning it as a country with a high transit rate. According to forecasts, 5 of the 11 branches of Hyperloop high-speed ground transport can pass through the territory of Ukraine, of which three pass through Kyiv: the first will connect China, Europe and Canada; the second one - Asia, the Middle East, Europe and North Africa; the third - Spain and China [14]. The main part of clusters is expected to be formed at the intersection of main cargo streams and in places of passage of transport corridors, which allows to reach the objects of warehouse infrastructure. Therefore, the formation of TLC will provide the need for both external and internal logistics services.

Today, the world practice of forming and functioning TLC considers several models that have their own peculiarities in work. There are three varieties of clusters: scientific clusters, transferring their technologies to industry; clusters that combine research and production; clusters that arise on the basis of innovative firms operating in a competitive environment.

The Italian cluster model consists of a set of small firms (small and medium enterprises), which are united in various associations to enhance their competitiveness. In this model, the state plays a significant role, providing its support. Significant role in the development of Italian clusters has "collective institutes" - national conferences, industrial parks, financial and marketing consortia, technological institutes [15, 16].

The peculiarity of the American model of the cluster is the joint activity of state structures, industrial enterprises and academic organizations. Such a model of cluster development is aimed at increasing global competitiveness on the basis of scientific and technological advances and innovations.

In the German model of clustering, the preference is given to the development of the economy on the basis of high technology - this is precisely in this direction the consolidation of the efforts of industrial and scientific centers.

The British model of clustering involves reviewing the priorities of industrial policy, which results is the formation of a so-called promising technological program on the basis of a mixed sector-cluster approach [15]. An example of the operation of the British TLC model can be the see cluster, which was established in 2003. Its aim was to increase investment in the industry and increase its efficiency at the local, regional, national and international levels.

An important component of the TLC is transport and its infrastructure. For a better understanding of the opportunities and prospects of an indicative selection of a TLC model for Ukraine, we need to consider trends in transport and transport infrastructure development in our country, using statistical data [20].

The analysis of freight volumes (Figure 1) has showed that there has been a tendency for their increase during the last four years, even though the volume of transportation in 2018 decreased by 4.9% compared to 2017. However, compared to 2015, volumes of transportation grew by 8.7%.

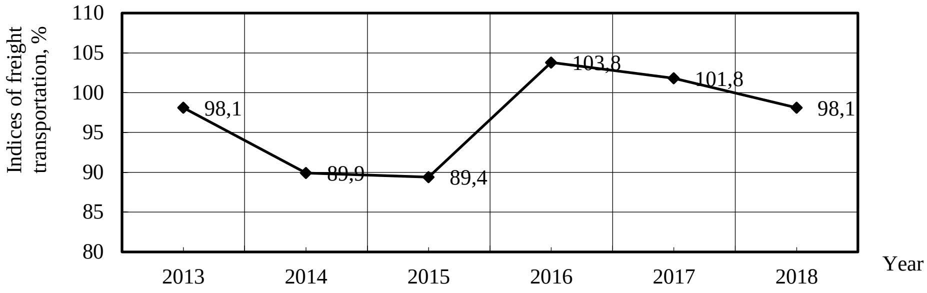

Figure 1. Indices of freight transportation (percentage to the previous year) for the period 2013-2018

Transportation of goods by land transport in the period of 2013-2017 was a priority (Table 1).

Table 1. Volumes of freight transportation by types of transport, (million tons)

Type of transport	Year					
	2013	2014	2015	2016	2017	2018
Rail	441,8	387,0	350,0	344,1	339,5	322,3
Road	183,5	178,4	147,3	166,9	175,6	187,2
Pipeline	125,9	99,7	97,2	106,7	114,8	109,4
Water	6,3	6,0	6,4	6,7	5,9	5,6
Air	0,1	0,1	0,1	0,07	0,1	0,1

In the last five years there has been a tendency to increase volumes of transportation of freights by rolling stock of road transport (Table 2). Thus, in 2018 more than 29% of the total volume of freight transportation was carried out by road transport. Compared to 2013, the specific gravity of road transport increased by more than 5%. In 2018, the specific gravity of freight transportation by rail was 51.6% of the total volume and decreased by almost 7% compared to 2013.

Table 2. Specific gravity of types of transport in freight transportation, (%)

Type of transport	Year					
	2013	2014	2015	2016	2017	2018
Rail	58,32	57,66	58,24	55,10	53,39	51,60
Road	24,22	26,58	24,51	26,73	27,61	29,97
Pipeline	16,62	14,85	16,17	17,09	18,05	17,52
Water	0,83	0,89	1,06	1,07	0,93	0,89
Air	0,01	0,01	0,02	0,01	0,02	0,02

The contribution of various types of transport to freight turnover for the period 2013-2018 is shown in Table 3.

Table 3. Freight turnover by type of transport and percentage of growth / decrease to the previous year, (million ton-kilometers / %)

Year	Type of transport									
	Rail		Road		Pipeline		Water		Air	
	million tkm	%	million tkm	%	million tkm	%	million tkm	%	million tkm	%
2013	224017,8	94,2	40487,2	103,2	109651,8	98,2	4615,2	86,7	273,0	75,2
2014	209634,3	95,5	37764,2	94,9	82050,9	118,5	5462,3	73,6	240,0	88,3
2015	194321,6	92,5	34431,1	91,2	80944,1	100,1	5434,1	98,9	210,9	88,2
2016	187215,6	96,0	37654,9	109,1	94378,9	117,0	3998,6	73,6	225,9	107,0
2017	191914,1	102,3	41178,8	108,4	105434,4	111,7	4257,1	106,3	272,7	120,5
2018	186334,1	97,1	42569,5	102,7	99239,9	94,1	3363,0	78,7	339,7	123,4

Analysis of the dynamics of freight flows for the period 2015-2018 showed a tendency to reduce the carrying out of transport work by all types of transport, except for road (Figure 2).

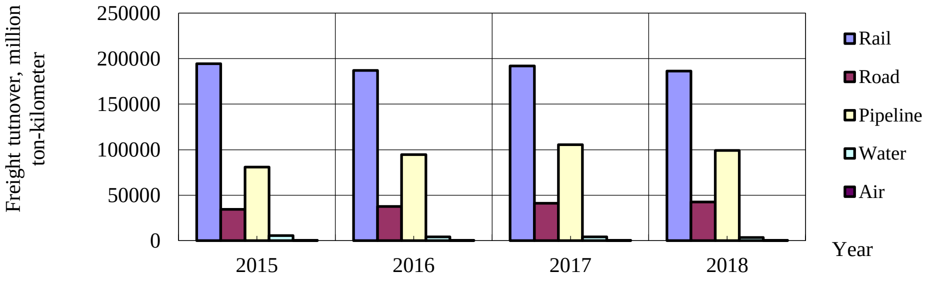

Figure 2. Dynamics of freight turnover by types of transport for the period 2015-2018 years

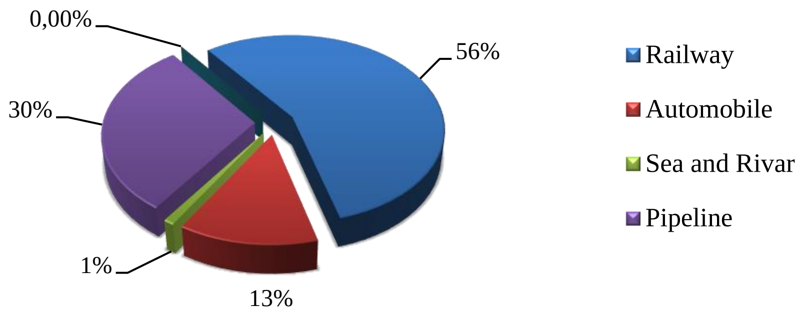

Figure 3. Structure of freight turnover by types of transport for 2018 (in percent)

At the same time, in the first place, as in the analogous period of 2017, rail transport remains. According to the results of the analysis of the data in 2018, freight turnover by rail decreased by 3% compared to the previous year. For the last three years, freight turnover by road transport has a steady upward trend. In 2018, it increased by more than 3% compared with 2017.

There is a tendency to fluctuate data on the average distance of freight transportation by different types of transport (Table 4). According to the data of the table in recent years there is an increase in the average distance of transportation of 1 ton of freight by all types of transport, except water.

Table 4. The average distance of transportation of 1 ton of freight by different

types of transport, (km)

Type of transport	Year					
	2013	**2014**	**2015**	**2016**	**2017**	**2018**
Rail	507,0	541,7	555,2	544,1	565,3	578,1
Road	220,3	211,7	233,7	225,6	234,5	227,4
Pipeline	870,9	823,0	832,7	884,5	918,4	907,1
Water	732,6	910,4	849,1	596,8	721,5	601,6
Air	2730,0	2400,0	2109,0	3227,1	2727,0	3397,0

An analysis of the transport sector in the provision of services (Table 5) shows that the volumes of transport services provided in 2018 amounted to almost 5% of the total volume of services sold by enterprises of various types of economic activity. The largest specific gravity has the services of transport, warehousing and enterprises that provide transport services and belonging to the transport infrastructure.

Table 5. Volumes of realized transport services in 2018 for categories of consumers, (million UAH / %)

Service	Volume of services that has been implemented, million UAH	Distribution of services implemented by different categories of consumers (% to total volume)		
		for the population	for businesses	for other categories of consumers
Services provided by enterprises in the sphere of services in different types of activities	7387326,3	22,3	65,9	11,8
Services provided by transport companies	208148,3	14,4	66,4	19,2
Services provided by warehousing and enterprises that provide transport services	135942,4	1,9	92,7	5,4

Ukraine is an active participant in the international transport services market. It has significant potential to increase offers to external parterres and expand their capacity to deliver. Analysis of the dynamics of the transport services structure provided in the "export" and "import" modes (Figure 4) shows that there is a tendency for exports to prevail over imports. But the current tendency to gradually increase the volume of transport services in the mode of "import" shows the growing demand for domestic transport services in the international market.

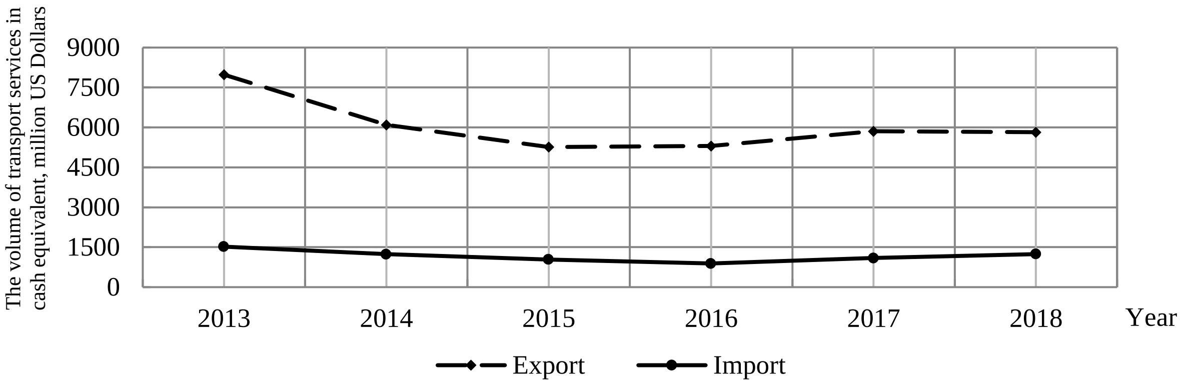

Figure 4. Volumes of transport services in the customs export and import modes for the period 2013-2018 years

Analysis of the volume of provision of transport services in different customs modes by various types of transport (Figure 5, Figure 6), allows us to conclude that in the export mode, the highest rates have a pipeline transport, but in the mode of import the most popular are air and rail transport. It should be noted that for the last three years, the volume of provision of transport services in different customs modes by all types of transport has a steady tendency to increase.

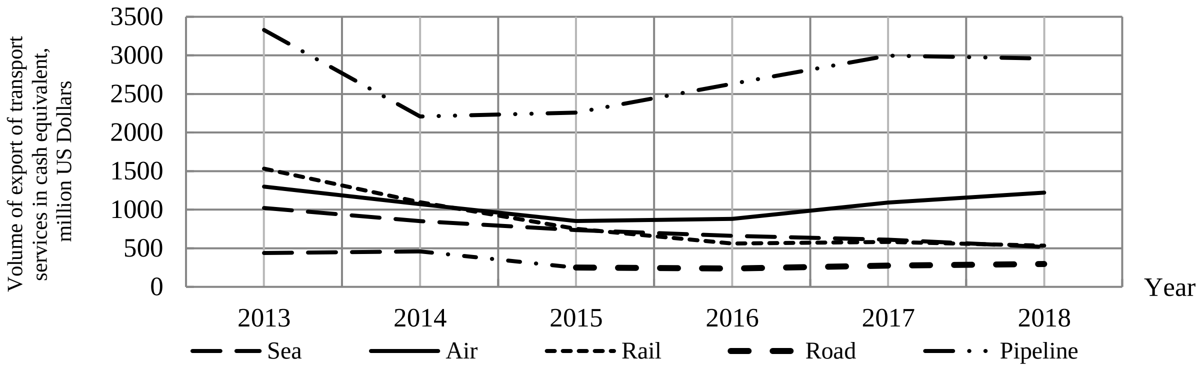

Figure 5. Volumes of transport services in the mode of "export" by different types of transport for the period 2013-2018

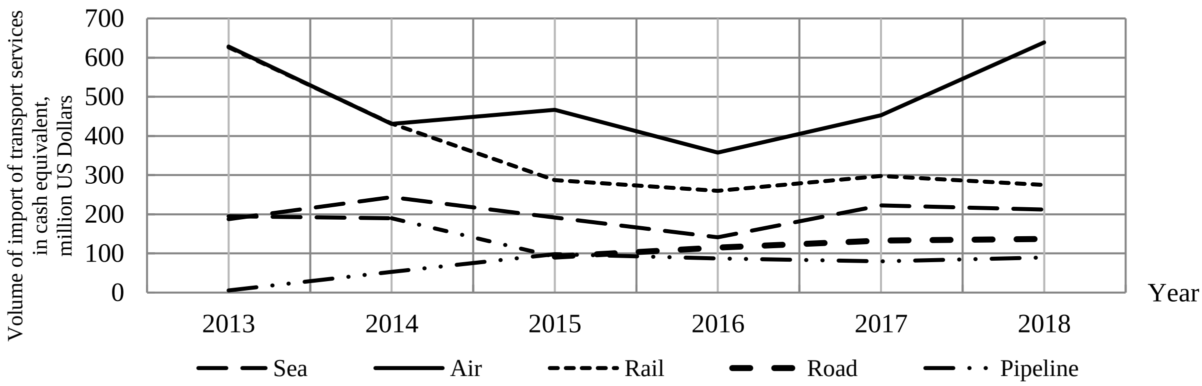

Figure 6. Volumes of transport services in the mode of "import" by different types of transport for the period 2013-2018

Research and analysis of the indicators of the transport industry has shown that they have ambiguous dynamics. The factors influencing the volatility of volumes of freight transportation may include such as the reduction of industrial production due to the external markets, the reduction of domestic demand due to the decrease in purchasing power of the population.

5. Discussion

Ukraine's orientation towards European integration and market transformations, a positive trend towards increased a cargo flows to the European Union requires solutions to issues related to ensuring competitiveness of the transport industry enterprises of the country, scientific substantiation of the possibilities of Ukraine's integration into the European transport system and development of its transport sector by creating effective transport-logistic clusters taking into account the experience of developed countries of the world. Formation of transport-logistics clusters will increase the competitiveness of the transport industry both at the national and regional levels, which will facilitate the process of integration of Ukraine's transport network into European and world transport and trade networks [19]. Introduction of clustering in the processes of management of the transport industry activity contributes to the formation of a new strategy of cooperation between enterprises that are part of the transport- logistics cluster, to increase the efficiency of their operation and promotes the development of the transport sector of the country. Clustering provides the opportunity to increase the competitiveness of the economy of regions and the state as a whole. Due to clustering, opportunities for combining enterprises, organizations and institutions in both separate regions and countries can be considered in order to increase the efficiency of their activities, to facilitate the formation of new enterprises taking into account their favorable geographical location and the creation of new jobs.

The state, regional and local structures of Ukraine have begun the introduction of clustering in the processes of formation, management and optimization of competitive units in various sectors of social production. The development of clustering in Europe should positively affect the formation of TLCs in Ukraine. Formation of a cluster unit leads to increased competitiveness, the formation of a new strategy for cooperation between enterprises, organizations and institutions of various levels. Cluster associations can perform various functions - industrial, technological, innovative and others. A fundamentally new direction is the use of cluster capabilities in providing information and educational activities, conducting on the basis of clusters of educational and scientific work, creation of advisory and training centers on the development of the transport industry. Taking into account the passage through Ukraine of four out of ten pan-European transport corridors (No. 3; No. 5; No. 7; No. 9) and four transcontinental transport corridors (Europe-Asia, TRACEKA, Baltyka-Black Sea, Black Sea transport ring), and also extremely advantageous transit status of Ukraine, it is possible to talk about the creation of a network of main and major transport-logistic clusters on the territory of Ukraine as an integral part of the pan-European network of TLCs [10].

The transport network of Ukraine has a powerful potential for the efficient operation of transport-logistics clusters. Currently, there are about 50 clusters operating in Ukraine, among which the following can be distinguished: Carpathian region (transport-logistic cluster); Odessa region (cluster "Odessa"); Kherson region (transport-logistic cluster "Southern Gates of Ukraine"). The most promising cluster centers can be considered such large cities as Kiev, Kharkiv, Zaporizhzhia, Odessa, as they are the leading centers of railways and highways of their region.

According to its specificity and territoriality, two categories can be distinguished among clusters: it is the port (Izmail, Bilhorod-Dnistrovsky, Illichivsk, Odessa, Southern, Mykolaiv, Kherson, Mariupol, Zaporizhzhia, Dnipro, and others) and internal ones, which can be divided into border (Kovel, Chop, Kharkiv, Chernihiv and others) and regional (Kyiv, Zhytomyr, Vinnytsia, Poltava, Sumy, Dnipro, Kirovograd, Lviv and others).

One of the important cluster is the Odessa cluster due to its ability to integrate into the trans-European transport network TEN-T and provide transit of goods between the major economic centers of the world: the Asia-Pacific region and the European Union.

Its main components are:

– multimodal transport corridors of Ukraine;
– deep-water port in Hadjibei estuary;
– cargo terminal of Odessa airport;
– International Center for High Technology B-ZONE;
– a comprehensive line of electric transport of Odessa agglomeration;
– Green Island in the center of Odessa.

Such a powerful potential of this cluster could allow it to become the largest port-industrial complex of Eurasia [21].

6. Conclusions

The foreign experience of using a cluster approach to the formation of transport-logistic clusters has shown that at present there are no universal approaches in solving this issue. Each country develops its own models and approaches to creating clusters and managing their development, taking into account the availability of natural, technological, financial, labor and intellectual resources.

An analysis of the models of TLC functioning in the leading countries of the world, an analysis of the state and trends of the transport industry in Ukraine over the last years, allows us to conclude that the Italian model is the closest to the implementation in Ukraine. In the Italian model of the cluster the focus of its operation is given to small competing firms that unite to enhance competitiveness. In such a cluster model, the state exercises its influence at the level of local self-government.

The formation of transport-logistics clusters is an innovative and promising direction for improving the efficiency of the transport industry in Ukraine. The basis for forming a transport-logistic cluster should be the transport, logistics and other enterprises that serve the service function, as well as the legislative and executive institutions of different levels. Merge into a cluster has a number of benefits for enterprises, organizations and institutions that it includes, the main of which are: a clearer focus on the market of transport services and the ability to respond promptly to its needs. Therefore, the development of theoretical foundations for the formation of TLCs is a topical issue and it needs further research.

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Influence of a system "vehicle – driver – road – environment" on the energy efficiency of the vehicles with electric drive

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Abstract: The purpose of this paper is to present the results of an investigation as to the interconnection between main exterior factors which can influence the power consumption during the vehicle movement in the conditions of real operation. According to the results of theoretic researches, there was determined an influence of every factor on the power consumption during vehicle movement in the modes typical for Lutsk city. There was established a contribution of the factors into the total power consumption on micro and macro levels. As a result of the study it was evaluated that an influence of a driver on a power consumption is situated within 50…80 %, an influence of an air resistance is up to 10 %, an influence of a longitudinal profile and a road resistance varies within 20…35 %. According to the results of experiments, there were determined the bus driving modes in urban conditions, and according to their results, there was built an average graph of bus movement in Lutsk city. There was made a mathematic modelling of electric vehicle movement, along with that there was taken into account the most probable range of change of the exterior factors, namely vehicle acceleration, road resistance, air resistance. It was proved that while speed is growing, the influence of road resistance and of air resistance is growing up and has a parabolic character, along with that the contribution of a driver is decreasing. The contribution of the study consists in that, There were proposed the coefficients of taking into consideration the influence of exterior factors on the power consumption by the vehicle and there was built a mathematic model for their determination. These coefficients of taking into consideration the influence of exterior factors on the power consumption give a possibility to evaluate the critical influences and to make an operative decision about the minimization of power consumption as for some specific vehicles, and for an enterprise. Further researches will focus on the plotting of telemetric means of informing, in a mode of real time, of the drivers of the vehicles, of the controllers of an enterprise about the exterior influences, that will give a possibility to make the appropriative decisions instantly. Besides, the given results can be used in order to determine the level of qualification of a driver, the state of road pavement, will give a possibility to find some more rational layout of bus stops, traffic lights, to optimize the routes of vehicles movement.

Keywords: exterior factors, power consumption, energy efficiency, influence factors, driving cycle.

1. Introduction

Nowadays the vehicles with electric drive are developed very intensively all over the world. Almost every manufacture deals with the electric cars production. The constructions of the vehicles with electric drive are improving, the motion reserve is growing up, and along with that during the real

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operation one can see some problems, the main of which are: a power consumption, and relatively a motion reserve are rather less than those declared by a manufacturer, a premature death of the storage batteries and energy storages. Mentioned problems are caused by the mutual influences of a system «vehicle – driver – road – environment». As a result of all that, there appears a task to examine a system «vehicle – driver – road – environment», to find the interconnections and to offer some measures to improve the energy efficiency of the vehicles with electric drive.

A number of factors influences the operation qualities of a vehicle, including power consumption: vehicle construction, exterior conditions (climate, state of road pavement), conditions of a vehicle movement (road traffic, operating mode of traffic lights, motion mode of traffic stream), driving style and driver's qualification. All these factors are inseparably interrelated, though the change of one won't always lead to the change of another one. The interconnections inside the system «vehicle – driver – road – environment» are shown at Fig 1.

At picture 1 the factors which can not be changed during the process of movement are painted yellow. The influences related with the driver, depend exclusively on his qualification and knowledge to use the economically efficient motion modes. Along with that, the vehicles manufacturers, during their designing, put in their construction some energy indices, including motion reserve and power consumption. One of the main indices which influence the power consumption and respectively the motion reserve, is the vehicles motion mode. Usually to calculate the traction and speed characteristics and power indices of a vehicle, the standardized driving cycle is taken. For the vehicles of category M1, the standards EN 1986-1:2000, EN 1986-2:2001, UN ECE № 101 are valid, meanwhile for buses such driving cycles are absent at all.

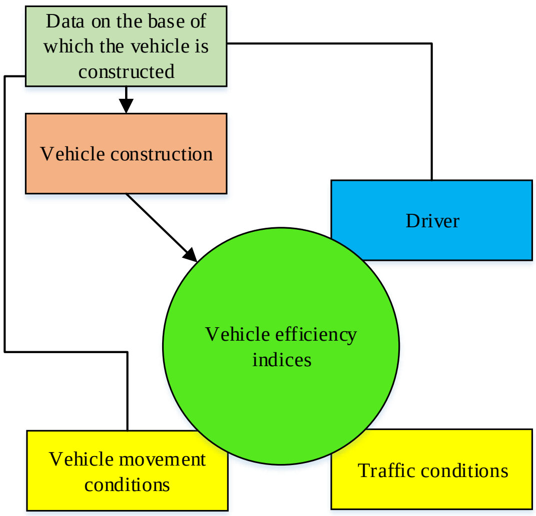


Figure 1. Interconnection of the factors of a system «vehicle – driver – road –environment»

But in real conditions of exploitation, the motion modes differ a lot from the standardized ones, and that leads to the disfiguration of the data concerning power consumption and energy efficiency of the vehicles, that's why it is necessary to make researches of the vehicles motion modes in real conditions and to offer the method of influence determination of given factors on the vehicle power consumption.

2. Literature review

Review and analysis of literature sources say about the actuality and importance of the research of a system «vehicle – driver – road – environment». Using of recuperative braking influences a lot the indices of energy efficiency of an electric car [1]. In their work the authors have made the preliminary researches of the interconnection between different electric vehicles and their power consumption in real motion conditions, a lot of attention is also paid to the efficiency of recuperative braking. The researches and modelling of roads net, traffic streams and choice of route by the drivers take a great interest [2].

In the research work [3] there were made the considerable researches about the evaluation of power consumption and CO2 emissions, and there was made an analysis of criteria of vehicles evaluation by the drivers taking into account their behaviour during the movement. A problem of making the real driving cycle for vehicles is examined in the research work [4], it is necessary to mention that in given research results there are also studied the movement parameters, taking into account real modes used by the drivers. The problems of efficiency of using the hybrid vehicles, from the point of view of fuel economy, in Bangkok city, are considered in the work [5]. In this work there was determined an influence of aggressive driving style on the fuel consumption by hybrid vehicles and there were offered the possibilities of fuel economy. Also the researchers from India [6] deal with the problem of creation a real driving cycle, taking into account the multi-parameters model. Practic methodology of making a typical driving cycle, which reflects the real conditions of movement, is worked out for testing the emissions and evaluation of a vehicle and is given in the work [7]. In order to determine a real driving cycle in the work [8] there was used Markov's theory and matrices of probabilities of passing of system states. Using Markov's theory and Monte-Karlo's method is layed in the base of modelling the real driving cycle, shown in the work [9]. Method of clasterization for making a driving cycle is used in the work [10]. Using of world geographic systems during the making of driving cycles is applied during the researches of movement conditions in Liubliany city [11]. The synergy of standardized and real driving cycles are applied in the work [12] that laid to an appearing of a new method of receiving of equivalent driving cycle of movement. A method of segmental division of driving cycles on the base of a bus station and a method of making a cycle of bus driving on a base of full journey is offered in a work [13].

A system of electrical energy control on a base of identification of a driving cycle, and depending on loading, is examined in the researches [14], the offered online strategy of control helps to improve the fuel economy of a vehicle.

In the researches [15] there is examined an influence of different styles of driving on a fuel consumption by an ordinary and hybrid vehicles. As a result of made researches, it was determined that fuel consumption can vary up to 34 %, depending on a scenario and style of driving.

A considerable influence on an efficiency of electric vehicle work is caused by an environment, thus, in a work [16] there is investigated an influence of environmental temperature on an efficiency of electric vehicles work in the USA. In a work [17] there was made a research of influence of extreme temperatures on accumulators charging and productivity of electric vehicles work.

The researchers from Brussels university [18] have made a great work about the investigation of influence of exterior factors. During the research, the authors took for a base five factors, each of them can have an influence on power consumption. Influence of exterior factors is examined on macro and micro levels. Using the main physic values, expressed in the equation of dynamic of the vehicle, there were built three models of prediction of EV energy consumption by the way of applying a statistic method of multiple linear regression to the data of real movement and power consumption for EV. Multi-level model for the evaluation of power consumption by an electric vehicle taking into account the influence on environmental temperature, individual inhomogeneity of drivers' behaviour is offered by the authors in [19]. The evaluation of fuel consumption by the electric cars according to the standardized driving cycle NEDC with the aim to study different movement modes at different ambient temperatures are shown in the work [20]. In the article [21] there were made the researches of influence of behaviour and personal driving style, transportation conditions and project of infrastructure in real world on the energy efficiency EVS. The researches were made with Nissan LEAF in the frames of typical driving cycle on a roads net of Beijing with the purpose to better understand the changes of energy efficiency among the drivers in different urban conditions. Instant model of vehicle movement [22], determined on the base of vehicle speed, acceleration level and gas pedal control, is used in suburban modes of movement, has shown rather exact results for total power consumption of a vehicle.

The authors of the work [23], to estimate the energy consumed by an electric vehicle, have built a model of multi-variant linear regression (MLR), taking into consideration an influence on power consumption, the next four factors are analized: distance, speed, initial SOC and ambient temperature. Identification and quantitative estimation of relations between exterior factors such as topology of roads, traffic, driving style, environment and cinematic parameters of a vehicle and its power consumption are the aim of a work [24]. Article [25] represents a system for prediction of the necessary energy for chosen journeys of electric vehicles, which can be used for different assistants. Given system applies the statistic characteristics, obtained from the speed profiles, as though they take into account different factors of influence on individual driving style and overwhelming movement conditions. Model of statistic prediction uses these functions to predict the deviation from an average energy consumption by an electric vehicle. In the work [26] there was proposed a route conducting of engine of an electric vehicle, which also takes into consideration the driver's characteristics and road conditions using data bases. The coexistence of people and the world of machines depends not only on technical possibilities, costs of technology implementation, legal regulations, but also on social acceptance and people's ability to coexist with technologies [32].

The results of influence of an environment on a power consumption of a vehicle are given in [27]. Along with that, there was used a four-factors model which varies depending on the change of operation conditions of a vehicle. The estimation of sensitivity of necessary engine capacity of an electric vehicle and the degree of influence on environmental factors and a general battery power and energy consumption was made in the researches [28].

In such a way, according to the results of analysis of modern researches concerning the problem of determination of influence of exterior factors on a power consumption of a vehicle, there was found a great actuality of given problem. A huge problem is made of movement modes which differ a lot in different cities and countries from the standardized driving cycles, that makes researchers to make investigations of real movement modes of a vehicle in specific inhabited settlements. Besides, the research of power consumption requires an integrated approach to a system „vehicle – driver – road – environment" taking into account the specific operation conditions of the vehicles. Also it is necessary to remark, that it is reasonable to make a complex research of exterior factors, which would vary on all possible levels, as it is shown in [27, 28], that is to make a multi-criteria model, which will give a possibility, in future, to exactly evaluate the power consumption of the vehicles in real operation conditions and, as a result, to take measures to minimize its charges.

Great part of researches of electric vehicles is dedicated to the estimation of CO2 emissions and their ecological influence on the environment [3-5]. Taking into consideration the fact that the standardized driving cycles substantially influence the power consumption of the vehicles, the researches of the motion modes in real operation conditions and the development of real driving cycles are also important [6-9]. The environment affects a lot the efficiency of electric vehicle operation, namely the climatic conditions [10] and [11]. The researches were made by the scientists from different countries and show the necessity of taking the standardized driving cycle to the real motion conditions. A number of researches were made in this field [12-15].

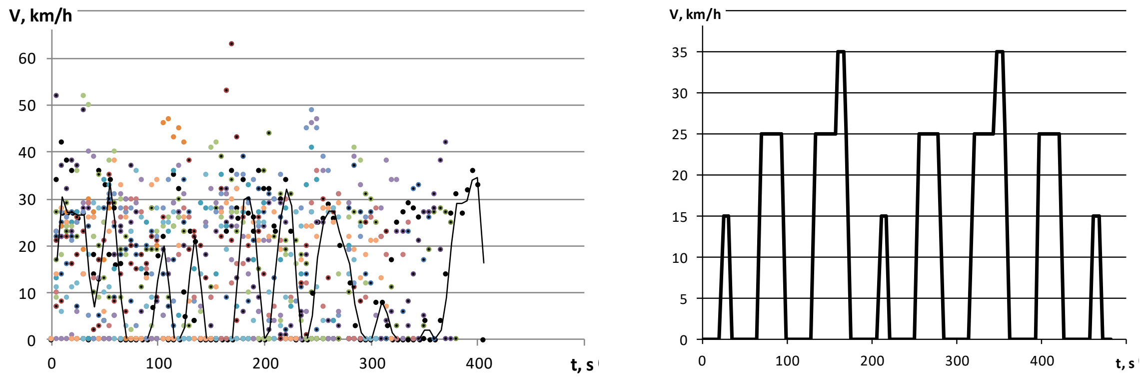
3. Research methods

To solve the given problem, there were received some data concerning the motion mode of the vehicles in Lutsk city by mean of an experiment. Taking into consideration a complication of receiving the real bus movement modes, in order to receive the experimental data, there were used the data of systems of monitoring of public transport movement MAC, which is introduced and operates in Lutsk. Periodicity of data renovation was equal to 5 second [5,8,10,18]. After that, using the methods of statistic results processing and the methods of mathematic modelling, there was made a calculation of the vehicles motion modes. According to the experimental data concerning the buses motion modes, the driving cycle for Lutsk city was determined. On the base of received driving cycle, using the statements of vehicle theory, there was made an investigation of influence of exterior factors on a power consumption. During the mathematic modelling the exterior factors varied in the most probable ranges, thus the acceleration and deceleration changed within 0…2 m/s2, wind speed – 0…8 m/s, road slope – 0…8°, vehicle speed – 0…20 m/s. To determine the mathematic dependences of change of influence coefficients, there was used an approximation of received data. To determine the necessary capacities that are spent to overcome the forces of resistance of the car, a mathematical model of the balance of power was used, similarly as in [28]. To determine the mathematical dependencies of the change in the coefficients of influence, approximation of the obtained data was used, as in [29]. This combination of applied research methods makes it possible to construct a three-factor model of variation of the factors of influence of external factors. This model can easily be adapted to any specific operating conditions or any vehicles.

4. Research results

The researches of flow of traffic modes were made on the city bus routes of Lutsk city, using multimedia automated complex МАК. Complex МАК, using the system of GPS-monitoring, allows to follow the characteristics of the city buses traffic on-line. The choice of city public transport which goes along the determined routes, is caused by a number of reasons, the main of which are: availability of strict route and traffic schedule, rise of communities' interest to the usage of electric buses as public transport, substantial affect of the traffic modes on the indices of energy efficiency and power consumption for this mean of transport.

According to the results of made experiments there was built a curve of urban driving cycle for Lutsk city (Fig. 2) [16, 17]. The given results were averaged using the linear filtration by a group of points which are situated on the same time period, in such a way there was received an average graphic model of a driving cycle for city buses.



(**a**) (**b**)

Figure 2. City driving cycle of a bus: (**a**) experimental data; (**b**) averaged curve

The made researches will contribute to the next developing of a question of creation of a standardized driving cycle for electric buses.

In general case the power consumption by a vehicle with electric drive is a ratio of a performed work A, J and general efficiency η_Σ:

$$E = \frac{A}{\eta_\Sigma} \quad (1)$$

General power consumption E_Σ is determined by the instant power consumption, for every second of driving cycle E_Σ:

$$E_\Sigma = \sum_{i=1}^{t} E_{mi} = \sum_{i=1}^{t} \frac{A_{mi}}{\eta_\Sigma} \quad (2)$$

On the other hand, work A, which was performed during the movement of a vehicle, is calculated by the dependence:

$$A = \int_0^t \left(P_k \cdot V\right) dt = \int_0^t \left((P_j + P_f + P_w \pm P_h) \cdot V\right) dt \quad (3)$$

where P_k, H – tractive force on the wheels; P_j, H – force of inertia of a vehicle; P_f, H – rolling resistance force; P_w, H – air resistance force; P_h, H – elevation resistance force; V, м/с – speed of a vehicle; t, c – time.

In given quotation the forces P_j, P_f, P_w, P_h characterize an influence of exterior factors on the power consumption of a vehicle. Especially the force of inertia of a vehicle P_j depends on the acceleration, which in its turn depends on the driving style, road circumstances and road infrastructure, also characterizes the process of braking of a vehicle. The rolling resistance force P_f characterizes the state of road pavement. The air resistance force P_w – weather conditions. The elevation resistance force P_h - longitudinal road profile. The speed is determined by the road circumstances, the state of road pavement, the driver, the availability and the branching of road infrastructure. So, using the force balance of a vehicle, one can determine an influence of exterior factors on the power consumption of a vehicle.

For theoretic researches there was chosen an electric bus Bogdan A70100, manufactured by Daughter enterprise «Automobile assembling factory № 1» of public joint-stock company «Automobile Company «Bogdan Motors», whose characteristics are given in Table 1.

Table 1. Characteristics of electric bus A 70100

Title of an index	Units of measurement	Value
Bus model	-	A 70100
Full mass	kg	18000
Overall height	mm	3500
Overall width	mm	2550
Transmission ration of main gear	-	9,2
Radius of wheel rolling	m	0,49
Engine power	kW	235
Maximum speed	km/h	70

On the Fig. 3-5 there is shown an influence of different factors on the power consumption of a bus. During the calculating there were taken the next ranges of indices change: acceleration – 0.1…2.00 m/s²; wind speed – 0…8 m/s; slope – 0…6°. The choice of given ranges was made taking into consideration the real conditions of buses operation in cities. Calculating was made up to the speed 20 m/s.

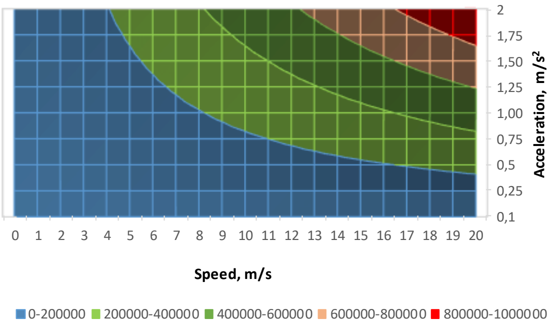


Figure 3. Dependence of power on acceleration at the speed change

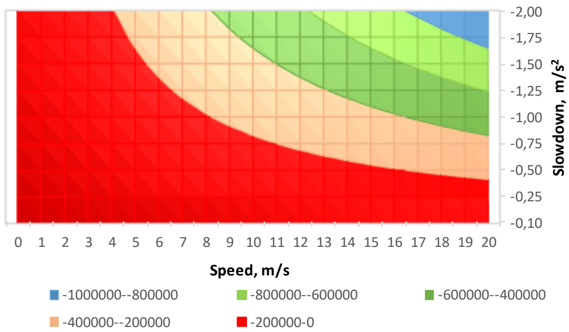


Figure 4. Dependence of power on deceleration at the speed change

In order to simplify the calculation of force of rolling resistance and force of elevation resistance, it is reasonable to consider together, $P_h + P_f = P_\psi$, because both these forces depend on the angle of road slope α.

Fig. 4 shows the dependence of influence of deceleration change on the bus power consumption. In this case it is taken into consideration that a vehicle is equipped with a system of recuperative braking, that is why due to the returned energy, its total consumption will decrease.

Fig. 5 shows a graph of influence of cross-wind speed on the bus power consumption. In a case of fair wind – total power consumption will decrease.

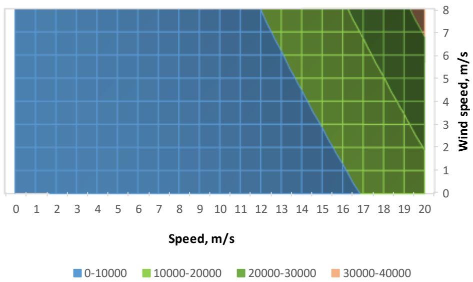


Figure 5. Power necessary to overcome an air resistance at speed change

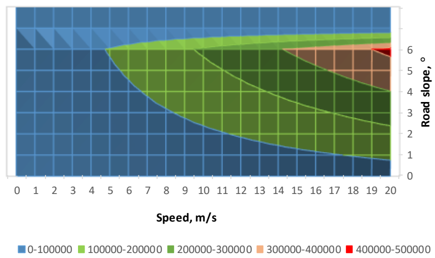


Figure 6. Power necessary to overcome an road resistance at speed change

In order to determine an influence of factors on the vehicle power consumption, all the factors, respectively to the quotation of power balance, are put to the power necessary for bus movement, than a quotation will look like:

$$\frac{N_j}{N_k}+\frac{N_\psi}{N_k}+\frac{N_w}{N_k}=\frac{E_j}{E_k}+\frac{E_\psi}{E_k}+\frac{E_w}{E_k}=1, \quad (4)$$

where N_k, E_k – respectively power and energy spent for vehicle movement, kW; N_j, E_j – respectively power and energy spent for vehicle acceleration, kW; N_w, E_w – respectively power and energy spent for overcoming an air resistance, kW; N_ψ, E_ψ – respectively power and energy spent for overcoming a road resistance, kW.

It was achieved from a dependence (4):

$$k_1+k_2+k_3=1, \quad (5)$$

where $k_1=\frac{N_j}{N_k}=\frac{E_j}{E_k}$ – coefficient, which takes into account an influence of acceleration on power consumption (describes an influence of a driver); $k_2=\frac{N_\psi}{N_k}=\frac{E_\psi}{E_k}$ – coefficient, which takes into account an influence of road on power consumption; $k_3=\frac{N_w}{N_k}=\frac{E_w}{E_k}$ – coefficient, which takes into account an influence of air resistance on power consumption (describes an influence of exterior factors).

Research of a contribution of every factor to the power consumption is rather difficult process, because it is necessary to make an investigation of a car multiple-factor dynamic model where all the factors change in time by chance. That is

$$E=\left\{E_j;E_w;E_\psi\right\}, \quad (7)$$

where $E_j=\left\{E_{j1},E_{j2},E_{j3},...E_{jn}\right\}$ – set of energy change, spent for vehicle acceleration; $E_w=\left\{E_{w1},E_{w2},E_{w3},...E_{wn}\right\}$ – set of energy change, spent for air resistance overcoming;

$E_{\Sigma fh}=\left\{E_{\psi 1},E_{\psi 2},E_{\psi 3},...E_{\psi n}\right\}$ – set of energy change, spent for road resistance overcoming.

If one goes to the influence coefficients, the dependence will look like:

$$E=\left\{k_1;k_2;k_3\right\}, \quad (8)$$

Along with that, the change of influence coefficients takes place continuously, dynamically in time and as it is shown at Fig. 3 – 6, depends on speed, that is why it is reasonable to make modelling of mutual influence of a system «vehicle – driver – road – environment» taking into account speed of a vehicle. A mathematic model of interconnection of influence coefficients can be shown in matric view:

$$E_c = \begin{matrix} k_{11} & k_{12} & k_{13} \\ k_{21} & k_{22} & k_{23} \\ \dots & \dots & \dots \\ k_{(n-1)1} & k_{(n-1)2} & k_{(n-1)3} \\ k_{n1} & k_{n2} & k_{n3} \end{matrix}, \quad (9)$$

where E_c – energy spent for movement during some time or cycle; n – range of speed change during some time or cycle.

In a dependence (9) an amount of all rows of matrix is equal to 1.

As it is almost impossible to make experimental researches with variation of all factors on all levels, there was made a mathematic modeling and determination of coefficients k_1, k_2, k_3. The coefficients were determined respectively to the dependences (4) and (5). The modeling was made by a method of accidental numbers, generating a change of vehicle acceleration, of wind speed, of road slope. The characteristics of road pavement corresponded to a dry bituminous concrete covering.

As it is known, if a number of experiments $m \to \infty$ accidental values take the characteristics of constant. That is why there were determined 5000 of values of influence coefficients for speeds 1, 5, 10, 15 and 20 m/s. According to received values there was built a dependence of influence coefficients from vehicle speed (Fig. 7), in addition to that a matrix of influence coefficients looks like:

$$E_c = \begin{matrix} 0,642 & 0,0028 & 0,3552 \\ 0,648 & 0,0058 & 0,3462 \\ 0,637 & 0,0110 & 0,3520 \\ 0,638 & 0,0170 & 0,3450 \\ 0,629 & 0,0259 & 0,3451 \end{matrix}, \quad (10)$$

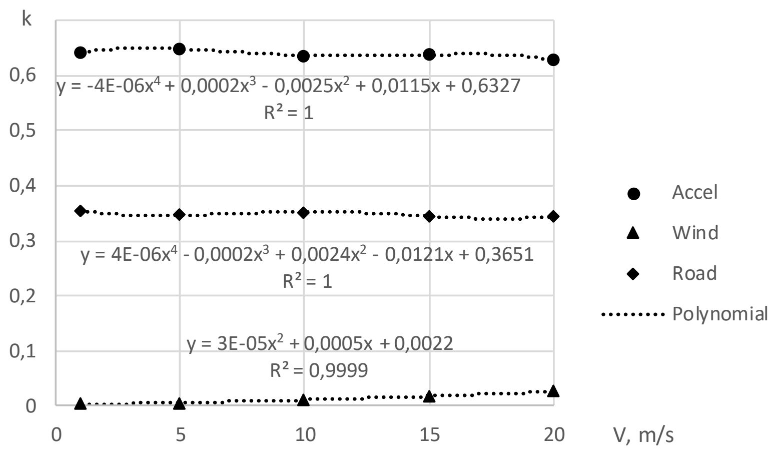


Figure 7. Change of influence coefficients from vehicle speed

Along with that, a dependence (10) does not allow to estimate an influence of factors which lead to diminution of power consumption. That is why it is offered to calculate a contribution of factors according to some values of power consumption. It is offered to take a power consumption of a vehicle in normal conditions as a base. In addition to that, taking into consideration the requirements of UN ECE during road tests, it is recommended to take the next values: an acceleration is equal to 0,75 m/s², a wind speed is equal to 0, a road slope is equal to 0, a value of power consumption E received during the calculation, will become a standard value. Than a calculation of influence of exterior factors on an actual power consumption E_c of a vehicle will reduce to a calculation of system of quotations:

$$\begin{cases} k_{11}\cdot E_c + k_{12}\cdot E_c + k_{13}\cdot E_c = E \\ k_{21}\cdot E_c + k_{22}\cdot E_c + k_{23}\cdot E_c = E \\ \dots\ \dots\ \dots\ \dots\ \dots\ \dots\ \dots\ \dots \\ k_{(n-1)1}\cdot E_c + k_{(n-1)2}\cdot E_c + k_{(n-1)3}\cdot E_c = E \\ k_{n1}\cdot E_c + k_{n2}\cdot E_c + k_{n3}\cdot E_c = E \\ k_{i1} = 4\cdot 10^{-6}V^4 + 2\cdot 10^{-4}V^3 + 25\cdot 10^{-4}V^2 + 1{,}15\cdot 10^{-2}V + 63{,}27\cdot 10^{-2} \\ k_{i2} = 4\cdot 10^{-6}V^4 + 2\cdot 10^{-4}V^3 + 24\cdot 10^{-4}V^2 + 1{,}21\cdot 10^{-2}V + 36{,}51\cdot 10^{-2} \\ k_{i3} = 3\cdot 10^{-5}V^2 + 5\cdot 10^{-4}V + 22\cdot 10^{-4} \end{cases}, \quad (11)$$

Given system of quotations (11) does not completely reflect the real traffic modes. According to the statements of automobile theory, the values of speeding-up during an acceleration of a vehicle stand for:

$$\begin{cases} j = 0\dots 1{,}0\ npu\ V = 0\dots 5\ m/s \\ j = 0\dots 0{,}7\ npu\ V = 5\dots 10\ m/s \\ j = 0\dots 0{,}5\ npu\ V > 10\ m/s \end{cases}, \quad (12)$$

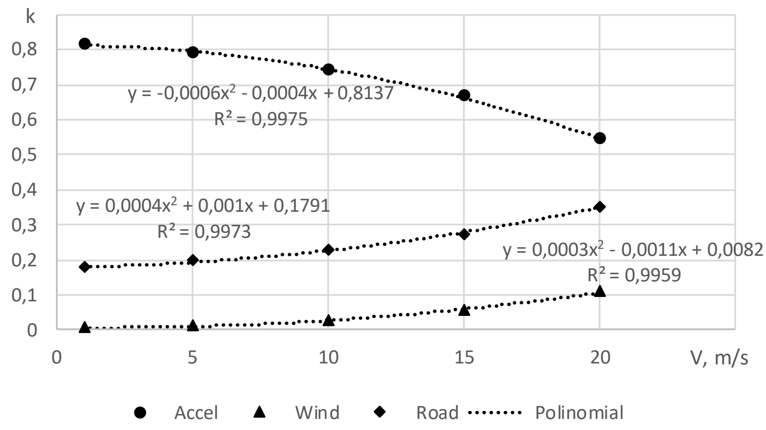


Figure 8. Change of influence coefficients from the speed of a vehicle with inserted restrictions

Than, taking into account the data of a graph shown at picture 8 and restrictions (12), a system of quotations (11) will look like:

$$\begin{cases} k_{11}\cdot E_c + k_{12}\cdot E_c + k_{13}\cdot E_c = E \\ k_{21}\cdot E_c + k_{22}\cdot E_c + k_{23}\cdot E_c = E \\ \dots\ \dots\ \dots\ \dots\ \dots\ \dots\ \dots\ \dots \\ k_{(n-1)1}\cdot E_c + k_{(n-1)2}\cdot E_c + k_{(n-1)3}\cdot E_c = E \\ k_{n1}\cdot E_c + k_{n2}\cdot E_c + k_{n3}\cdot E_c = E \\ k_{i1} = -6\cdot 10^{-4}V^2 - 4\cdot 10^{-4}V + 81{,}37\cdot 10^{-2}, \\ k_{i2} = 3\cdot 10^{-4}V^2 + 11\cdot 10^{-4}V + 82\cdot 10^{-4} \\ k_{i3} = 4\cdot 10^{-4}V^2 + 10^{-3}V + 17{,}91\cdot 10^{-2} \\ j = 0\dots 1{,}0\ m/s^2\ npu\ V = 0\dots 5\ m/s \\ j = 0\dots 0{,}7\ m/s^2\ npu\ V = 5\dots 10\ m/s \\ j = 0\dots 0{,}5\ m/s^2\ npu\ V > 10\ m/s \end{cases} \quad (13)$$

In order to solve a problem of determination of external influence levels on a power consumption of a vehicle on some road or a part of road, it is necessary to determine coefficients k_1, k_2, k_3 in a system of quotations (14):

$$\begin{cases} k_1 = -6\cdot 10^{-4}V^2 - 4\cdot 10^{-4}V + 81{,}37\cdot 10^{-2} \\ k_2 = 3\cdot 10^{-4}V^2 + 11\cdot 10^{-4}V + 82\cdot 10^{-4} \\ k_3 = 4\cdot 10^{-4}V^2 + 10^{-3}V + 17{,}91\cdot 10^{-2} \end{cases}, \quad (14)$$

In such a way, there were established two ways of determination of influence of exterior factors on a power consumption of a vehicle on micro and macro levels. It is offered to establish an influence of exterior factors on micro level, that is on every simple part of cycle of vehicle movement, using the dependence (13). Using the dependence (14) it is offered to determine an influence of exterior factors by the results of passing some part of a road, that is on macro level. In this case it is reasonable to take into consideration an average technical speed of a vehicle while calculating. It is worth to mention that the research of influence of exterior factors on micro level, that is a growing of number of detailing points, essentially increases the exactness of calculation, but along with that it rather complicates the process of calculation and needs a usage of probabilistic methods, that will be made for certain in future researches.

5. Discussion of the results

According to the results of analysis of taken researches, there was determined an influence of exterior factors, namely a driving style, an air resistance and a road profile on a power consumption of a bus equipped with electric drive. It was shown that an influence of bus driver decreases along with bus speed increasing, and an influence of road pavement and air resistance grows up.

By a defined city bus driving cycle shown at picture 1a, there was determined a total power consumption at ideal conditions (Fig. 9), and at a condition of increasing of bus acceleration for 30 % (Fig. 10), that is an imitation of aggressive traffic conditions.

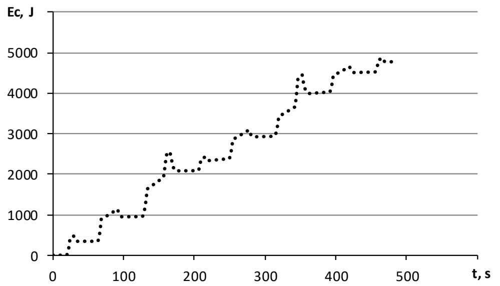


Figure 9. Power consumption during the bus movement by a driving cycle at normal conditions

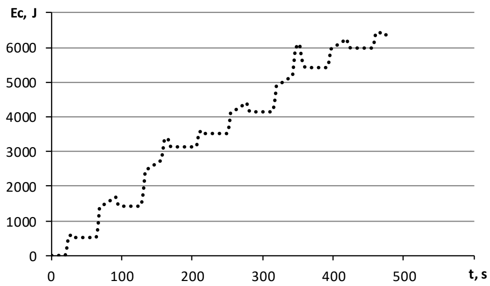


Figure 10. Power consumption during the bus movement by a driving cycle at increase of acceleration for 30 %

Power consumption, with taking into account an operation of energy recuperation system, in first case stands for 4761.5 kJ, in second case – 6376.9 kJ. The results of calculating the coefficients of influence are given in table 2.

Table 2. Results of calculating the coefficients of influence k_1, k_2, k_3

	k_1	k_2	k_3	Quantity of spent energy, kJ	Average technical speed of movement, m/s
Normal conditions	0.787367	0.019997	0.192636	4761.5	4.7
Aggressive type of movement (at acceleration increasing for 30 %)	0.779975	0.023325	0.19670	6376.9	5.5

As it is evident from Table 2, at the aggressive movement mode, the coefficients of driver's influence is a little decreasing, and influence of environment and of road resistance are respectively growing up, what is caused by higher speeds. Along with that power consumption increased for 34%. Such disconformity is caused by a factor that the calculation of influence coefficients was made for driving cycle shown at Fig. 2(**b**), and in order to get more exact evaluation of influence of exterior factors, it is worth to make their calculation for elementary parts of driving cycle.

6. Conclusions

The aim of present researches was to explore an influence of exterior factors on the power consumptions of the vehicles which go along set city routes. Used method foresaw the data collection about real traffic modes of buses in Lutsk city, a treatment of their results and a determination of driving cycle, an exploring of contribution of exterior factors in power consumption.

Received results of theoretic researches give a possibility to divide an influence of main factors on power consumption of a vehicle and to determine their contribution on macro level. It was found that an influence of a driver on power consumption is within 50…80 %, an influence of air resistance is up to 10 %, an influence of longitudinal profile and road resistance changes within 20…35%.

Received results can be used rather widely: a determination of driver qualification level, of state of road pavement, will give a possibility to find more reasonable placement of bus stops, cross-lights etc.

Offered researches results can not be directly used for other traffic conditions, regions, using another vehicles without additional researches. Along with that the present object research assures the previous results aimed at the decreasing of influence of exterior factors on power consumption of the vehicles.

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System of urban unmanned passenger vehicle transport

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Abstract: This article describes the system of unmanned urban passenger transport based on mobile autonomous robotic vehicles. The article describes an algorithm for drawing up a non-conflicting plan of passenger transportation on demand. The relevance of this system is conditioned changing social and economic conditions in the large cities, as well as modern features of scientific and technical progress. This paper presents a study aimed at improving the quality and efficiency of passenger transport in the "loaded" urban transport environment. It describes a mathematical model of computer control unmanned transport system. As a result of the study an algorithm for organization passenger transportations using unmanned vehicles has been proposed. The proposed model is adaptive to changes of road conditions and is intended to enhance the mobility and flexibility of passenger transport in the context of high traffic flows. The value of the study is that it brings economic and environmental benefits, since the method of transporting passengers by unmanned vehicles provides a high throughput of urban transport systems with a high level of passenger comfort.

Keywords: intelligent transport system, information transport, unmanned passenger vehicle, mobile transport system, system of unmanned transport.

1. Introduction

Personal road transport is not able to provide a high transport capacity because according to information [1] in each car moves on average 1.2-1.5 human. Hence, to avoid traffic conflicts, it is need unload oversaturated road ways through the expansion of public land transport with high performance that will be comparable to subway.

In the practice of transportation for describing of the needs urban passengers and for regular analyze the conditions of passenger transportation a category is named "passenger traffic" [2,3] is used, that is characterized by "intensity" (average number of passengers that are transported per unit of time). Data about the intensity of passenger traffic are used for choice the type of transport with necessary capacity and determine the number of vehicles are required for transportation.

The vehicles of different capacity can be used on each route. The choice and justification of the required vehicle capacity for quality passenger service is a complex managerial task, especially in the conditions of incomplete and often not reliable information. The capacity of the vehicle is determined according to the distribution of the intensity of passenger traffic and the pattern of its unevenness in time along the route and directions. Often the information is probabilistic.

Thus, the current state of passenger traffic has the following disadvantages:

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- the absence of objective information in real time about the intensity of passenger traffic on the route that prevents the adoption of optimal decisions and leads to economic losses;

- the presence of the human factor in making responsible decisions on the choice of the quantity and volume of the vehicles that must be sent to this route and at this time of day

- the small nomenclature of vehicles of different capacity to more accurately cover the changing passenger traffic. Unfortunately, this drawback in modern technical support of urban passenger transport vehicles is impossible to overcome, since the industry is not able to manufacture many types of buses of different capacity.

2. Literature review

The last decade is characterized by active development in the field of autonomous and unmanned vehicles. Many scientific work, studies, publications and books are dedicated wide coverage of aspects road unmanned vehicle automation, including management, social consequences, legal issues and technological innovations from the perspective of many public and private actors. In those works the current situation and prospects for the development of unmanned vehicles, traffic planning, traffic safety with the participation of unmanned vehicles are analyzed. (Meyer & Beiker, Road vehicle automation, 2014) [4], (Choromanski, Grabarek, Kowara, & Kaminski, "Personal Rapid Transit-Computer Simulation Results and General Design Principles", 2013) [5], (Chen & Li, Advances in intelligent vehicles, 2014) [6], (Bucsky, "Autonomous vehicles and freight traffic: towards better efficiency of road, rail or urban logistics?", 2018) [7], (Wagner, "Traffic Control and Traffic Management in a Transportation System with Autonomous Vehicles", 2016) [8], (Friedrich, "The Effect of Autonomous Vehicles on Traffic", 2016) [9]. The coexistence of people and the world of machines depends not only on technical possibilities, costs of technology implementation, legal regulations, but also on social acceptance and people's ability to coexist with technologies [29].

The largest modern projects in the field of unmanned vehicles VIAC (2007-10), SPITS (2008-11), HAVEit (2008-11), Cybercars-2, GCDC (2009-11), e-Safety (2002-13), DARPA and Google Driverless Car develop optimal control transition interfaces from automatic to manual mode. «There are several human factor concerns with highly autonomous or semiautonomous driving, such as transition of control, loss of skill, and dealing with automated system errors. Four CityMobil experiments studied the eLane concept for dual-mode cars, and the results of one are described» (Toffetti, Wilschut, & Martens, " CityMobil: Human Factor Issues Regarding Highly-automated Vehicles on an eLane", 2009, p. 1) [10]. Today there are five levels of autonomy for cars: lack of autonomy, when the driver has full control over the cars without any warnings or assistance; the presence of assistance systems, when the driver still has full control, but there are systems of support by signals or sound, for example, during the maneuver of the lane change; semi-automated cars, when partial control in certain situations or conditions can be delegated to the system, for example, adaptive cruise control, parking assistance; highly automated cars, when the assistance system assumes the main control tasks, but if necessary, the control can still be transferred to the driver; fully automated cars when the car is completely autonomous, even in difficult situations.

Work on Advanced Driver Assistance Systems (ADAS) is carried out in areas such as: lane change assistance systems; pedestrian safety systems; collision avoidance and warning systems; adaptive headlight control systems; parking assistance systems; night vision systems, cruise control systems; internal monitoring systems that allow the driver to detect the sleeping state and warn of a dangerous situation (Wees & Brookhuis , "Product liability for ADAS; legal and human factors perspectives ", 2005) [11], (Kasjanik & Shuts, "Mobile assistant driver in choosing a driving strategy", 2012) [12].

The next step includes the creation of cooperative adaptive cruise control systems based on V2V interaction, traffic signs recognition systems and traffic lights systems that use information from digital maps. The development of ADAS will influence on vehicle safety requirements and over time, the use of such systems will become mandatory, making the machines more autonomous. In recent years, varieties of technologies have emerged in Intelligent Transport Systems (ITS) that can change drastically our understanding of transport. In particular, large changes may occur in the near future in the organization of urban passenger traffic.

The unmanned electric shuttles with flexible control based on network technologies will play a crucial role in the megalopolises of the future, while ensuring safe, comfortable, efficient and environmentally friendly transportation. This is another important step towards the full implementation of the concept of unmanned urban public transport. Advanced software solutions and cloud services will play an important role as an integrated automotive unmanned platform. Driving is safer and more efficient. These paradigms are based on artificial intelligence algorithms that provide communication between the vehicle and the infrastructure. (Thomas & Kovoor, "A Genetic Algorithm Approach to Autonomous Smart Vehicle Parking system", 2018) [13], (Kurniawan, Sulistiyo, & Wulandari, "Genetic Algorithm for Capacitated Vehicle Routing Problem with considering traffic density", 2015)[14], (Potuzak, "Time Requirements of Optimization of a Genetic Algorithm for Road Traffic Network Division Using a Distributed Genetic Algorithm", 2014) [15], (Mulloorakam & Nidhiry, "Combined Objective Optimization for Vehicle Routing Using Genetic Algorithm", 2019) [16], (Wang, Ning, & Schutter, "Optimal Trajectory Planning and Train Scheduling for Urban Rail Transit Systems | Yihui Wang", 2016) [17].

The urban public transport will include the possibilities and features of personal transport (Anderson, Contributions to the Development of Personal Rapid Transit, 2016) [18]. Personal Rapid Transit (PRT) is a transport system that meets the following seven criteria set by The Advanced Transit Association (ATRA): fully automatic vehicles (without drivers); vehicles are only on special paths (guideway), which are intended for the exclusive use of such vehicles; small vehicles are available for exclusive use by one passenger or a small group that travels together in their choice - without random travel companions. Transport services are available 24 hours a day; small special paths may be above ground, at ground level or underground; vehicles can use all special paths and stations in a single PRT network; direct communication from the point of departure to the point of destination, without the need to transfer or stop at intermediate stations; transportation services are available on demand, not on fixed schedule (Personal rapid transit. (2019, March 02). Retrieved April 27, 2019, from https://en.wikipedia.org/wiki/Personal_rapid_transit) [19], (Baumgartner & Chu, "Personal Rapid Transit User Interface", 2013) [20], Mcdonald, S. S. (2013). Personal Rapid Transit and Its Development. Transportation Technologies for Sustainability, 831-850) [21].

In this work below a transport system is proposed that located between personal and public transport in terms of consumer qualities. The system is very close to personal automatic transport, but differs from it by high carrying capacity as opposed to PRT. This is a new way of conveyor-cassette urban passenger transport.

3. Conveyor & cassette method of urban passenger traffic

The evolution of information technology allows to revise the structure and concept of management of modern urban transport. In particular, the entire diversity of urban passenger vehicles can be reduced to one transport unit of nominal capacity that is named "infobus". Infobus is an unmanned electric vehicle with a small capacity (up to thirty passengers). Depending on the intensity of the passenger traffic on the route (measured by sensors in automatic mode) the control computer (coordinating server) sends such a number of infobuses to the route so that their total volume was equal to or slightly higher than the passenger traffic. In this case the infobuses are collected in cassettes (it determines the term “cassette type of transport”) which can consist of various quantity of units of infobuses (one, two,...) depends on the passenger traffic at the current time. This approach gives possible quickly and inexpensively to assemble a vehicle of any capacity that is required on the route now, since there are no mechanical connections in the cassette. All connections in the cassette of infobuses is virtual as in the road trains [22]. The minimum safe distance between the infobuses in cassette of infobuses is controlled electronically. The cassette method of organizing the transport of passengers is a major step forward, which is comparable with applying of the transportation of goods by container method in the past century. When the passenger pass through the turnstile and payees the fare, he indicates the destination stop to which he should fare. Also in this way he initializes his appearance in the transportation system for receiving transporting using infobus train without stop or with minimum number of stopping points.

Such a transport system is adaptive to passenger traffic, because it changes oneself operational and timely and successful adapts to the current conditions. In this reason, the system is the most cost-effective and most satisfactory, because vehicles will not run half-empty or overly crowded.

It is necessary that the road network is, as much as possible, neutral to the traffic of the info buses. Unfortunately it is impossible make fully achieve zero impact on road users, as in the subway. However, this influence can be reduced by allocating a special lane, as is done for public transport such as a bus or trolleybus in many large European cities.

The disadvantage of this allocation of road lanes for infobuses is the reduction in the number of lanes for other road users and reduction in the carrying capacity of the highway. In addition, the intensity of the use of dedicated band is low sometimes. Hence the requirement for the width of the information bus is: it should be minimal, for example, it should be 1-1.5 meters. This choice is due by following factor: if the width of the main lane is 3-3.5 meters, than it is enough to divide this lane into two and as a result, we will get two lanes (direct and reverse) for the infobuses.

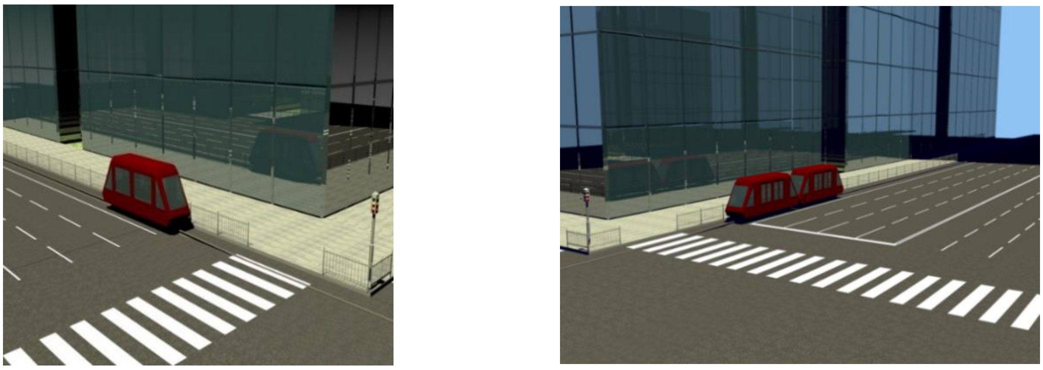

Figure 1. Auto train from one and two information buses at the intersection

The road lane for the information buses directly adjoins the sidewalk and is separated from it by a fence and from the main road to the left by a solid line (Fig. 1). In some cases, lightweight fencing may be used in the form of plastic cones are mounted on a solid line. The intensity of the use of road infrastructure, and in particular of road lanes, by infobuses is high. That means, the intensity of the use of road infrastructure by infobuses is higher than it is in the case of the classic road lane, since the transportation of an equal number of passengers by a narrower vehicle requires a greater number of vehicles, therefore, the road lane for them will be constantly involved.

Another important point in the definition of this transport system is such its property as conveyor. That means, as in any conveyor, the movement of infobuses in such system goes along a narrow dedicated lane without overtaking. In another words any previous infobus will be always the previous, and the next one will be the subsequent always and the sequence numbering of the infobuses remains constant. The movement of infobuses is carried out from Drive 1 to Drive 2, located at the end points of the route (Fig. 2).

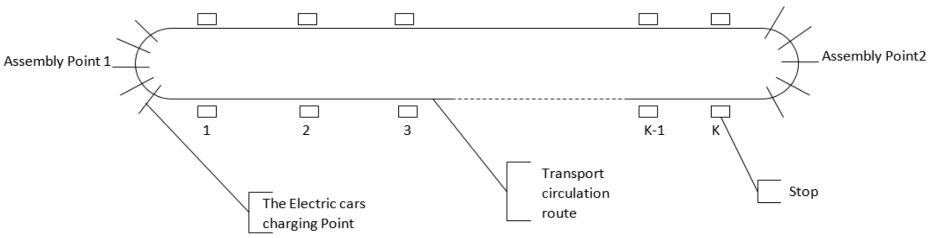

Figure 2. Infobus traffic pattern

4. System operation description

System of urban unmanned passenger vehicle transport consist of [23,24,25]:

- a dedicated narrow section of the roadway that adjacent to the sidewalk and fenced off on both sides, both from the carriageway and the pedestrian part;

- stopping points for boarding and disembarking passengers, equipped with turnstiles;

- fleet of unmanned vehicles (infobus), fixed small capacity (up to 30 passengers), connected with the coordinating server, whose teams are trained by the vehicle

The functioning of the system is as follows:

- the client (passenger) at the stopping point at the time of payment through the turnstile indicates the stop to which this passenger wishes to go;

- information from the terminals goes to the coordinating server, which forms a special matrix is named matrix of correspondences M_z, $Z=1,2,...$, and contains information about points of departure and destination of passenger

- the plan of passenger transportation begins to form after some time when information about some number of passengers has be accumulated in the matrix of correspondences M_z, $Z=1,2,...$. According this information infobuses will sent to transport passengers to the destination stations;

- the intervals of movement between stops and the time of parking at stops for this system are known.

The transportation plan - is a procedure of assignment number for each infobus that will be sanded to rout line and sequential sending of numbered infobuses from Assembly Points to the route line (Fig. 2) with indicating the final destination station and, perhaps, several intermediate stopping points for each numbered infobus individually.

Each arriving infobus on departure station has information on own display about destination points also this information is shown on monitor of departure station. Passengers, which have as the final destination the proposed set of stops, take places in this infobus. The other passengers wait for their infobus.

Thus, each infobus, which has gone from the Assembly Point on the route, has an individual sequence number and a list of stations at which it needs to make a stop for unloading and loading passengers. The current matrix of correspondences M_z, $Z=1,2,...$. - is a base for the development of the transportation plan.

Each element m_{ij} of the matrix of correspondences M_z, $Z = 1,2, ...$ determines the number of passengers which want travel from stop i to stop j $(i, j = 1, ..., k)$. Here k is the number of stops of one direction of the route (Fig. 2). All elements on the main diagonal of the matrix M_z and under the main diagonal are equal to zero, because that the passenger cannot get off at the stopping point, where he has sat down, and cannot drive back [9,26,27]:

$$M_z = \begin{pmatrix} 0 & m_{12} & m_{13} & \dots & \dots & m_{1j} & \dots & m_{1k} \\ 0 & 0 & m_{23} & \dots & \dots & m_{2j} & \dots & m_{2k} \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ 0 & \dots & 0 & m_{ii+1} & \dots & m_{ij} & \dots & m_{ik} \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ 0 & \dots & \dots & \dots & \dots & \dots & 0 & m_{k-1k} \\ 0 & \dots & \dots & \dots & \dots & \dots & \dots & 0 \end{pmatrix}$$

When a delivery plan is developing for the current matrix of correspondences M_z, $Z = 1,2, ...$, it is necessary to ensure conflict-free traffic on the route. A delivery plan is composed for the matrix M_z, $Z = 1,2, ...$, that has each element is less than the volume of the infobus V:

$$m_{ij} < V, i = \overline{1, k-1}, \ j = \overline{1, k}. \quad (1)$$

The process of functioning of the transport system is cyclical and consists of repeated procedures:

- accumulation of information in the current matrix of correspondences M_z about the passengers arriving at the stopping points

- determination of the moment sufficient filling the current matrix of correspondences M_z, $Z = 1,2 ...$

- development of a delivery plan for current matrix and the implementation of this plan.

It is assumed that the delivery schedule for the current matrix of correspondences M_z, $Z = 1.2 ...$ begins at the time t_{0z} and ends at the time t_{kz}, that is, the duration of the delivery is $T_z = t_{kz} - t_{0z}$. Moreover, the delivery time T_z, $Z = 1,2, ...$ is not fixed, but depends on the data structure in the matrix M_z.

It is also assumed, that the delivery plan remains unchanged until own end regardless of the fact of arrive new passengers on stopping points during the period T_z of its execution. Their delivery should also be provided by the current plan of delivery. In order to ensure this, the elasticity coefficient $a \in (0.8,1)$ is introduced. Then condition (1) of the requirement for the elements of the current matrix M_z is written as follows:

$$m_{ij} = a \cdot V, a \in (0.8,1), i = \overline{1,k-1}, \overline{j = 1,k}. \quad (2)$$

The start of development of the delivery plan is comming in the moment, when one of the elements of the M_z matrix begins to satisfy condition (2) and, therefore, all elements of the M_z matrix are less than the infobus capacity V. Moreover, must be a supply that allows transporting passengers, who has come to the station in the moment of arrive of infobus there and was not counted when the matrix M_z has formed.

A delivery plan is drawn up for each row separately. First, a plan is drawn up for the first row of the M_z matrix, then for the second, and so on. The implementation of the delivery plan is carried out in the same sequence, in other words, transportation of passengers begins from the first stop, then from the second, etc. The number of passengers at the first stop is the sum of the elements of the first row of the matrix:

$$m_1 = \sum_{j=1}^{k} m_{1j} = \sum_{j=2}^{k} m_{1j}.$$

For line i, the number of passengers at the stop i is calculated by the formula:

$$m_i = \sum_{j=i+1}^{k} m_{ij}, i = \overline{1,k-1}.$$

Then the lower range of the required number of infobuses for the export of passengers from the first stop can be estimated as the nearest integer greater than the quotient from division $\frac{m_{1j}}{V}$:

$$n_{1LR} = \left\lceil \frac{m_{1j}}{V} \right\rceil.$$

The required number of infobuses equal to the value of the lower range means that some infobuses are loaded with passengers from several neighboring destination stations. In this case, the passenger gets to the destination with a little bit number of intermediate stops (on average no more than two).

The upper range of the required number of infobuses to export all passengers from the first stop is equal to:

$$n_{1UR} = k - 1.$$

Such a case occurs on condition, that for each pair of near elements $(m_{1j}, m_{1j+1}), j = \overline{2,k-1}$ of the first row of the matrix of correspondence M_z, the condition $m_{1j} + m_{1j+1} > V, j = \overline{2,k-1}$ is satisfied, in other words passengers that go to two neighborhood stops do not fit in one bus. In other words, each infobus is loaded with passengers, which follow to the same destination station, and each passenger arrives non-stop at his destination.

For any row i of the correspondence matrix M_z, it is possible to immediately specify the lower and upper ranges of the required number of all infobuses are needed for export all passengers from the stop i:

$$n_{iLR} = \left\lceil \frac{m_i}{V} \right\rceil = \left\lceil \frac{\sum_{j=i+1}^{k} m_{ij}}{V} \right\rceil, n_{iUR} = k - i, i = \overline{1,k-1}.$$

The lower and upper ranges allow estimating the required number of infobuses to transport all passengers of the correspondence matrix M_z for a route from k stops:

$$N_{LR} = \sum_{i=1}^{k-1} n_{iLR}, N_{UR} = \sum_{i=1}^{k-1} n_{iUR}.$$

The lower and upper ranges of the required number of infobuses, which are used for export all passengers according to the matrix of correspondence M_z, give only estimated values of the parameters of transportation. But it does not answer of the question: « How it is possible to transport passengers in such a way, that the infobuses will not delay each other , when driving, and at the same moment the minimum number of infobuses were used in delivery plan of the matrix M_z, $Z = 1.2$ ...?». The answer to this question is given by the algorithm for constructing a plan for carrying passengers on the route.

Authors should discuss the results and how they can be interpreted in perspective of previous studies and of the working hypotheses. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted.

5. Algorithm of constructing a delivery plan of passengers on the route

The delivery plan must be developed for each row i of the matrix M_z in this algorithm, i.e. for passengers starting their way from stop *i* to the next stops. For further reasoning the moment of the beginning the execution of the delivery for row *i* will be indicated as t_{i0}, and through t_{ik} - the moment of the ending of the execution the delivery for the string *i*.

For the ensuring the conflict-free traffic of infobuses during delivery passengers from the stopping *i* to further stoppings infobuses will be sent first to the most distant destination stoppings, then to stoppings that are located nearer. Each infobus receives its own sequence number varying from 1 to n_i . Here n_i is the number of infobuses are required for delivery all passengers from stopping *i* to all another stoppings on route, in another words to stoppings *i + 1, i + 2,..., k*.

In more detail, this can be represented as follows: during the transporting of passengers from the first stopping (during processing the first row of the matrix of correspondences M_z) the first infobus receives number 1. This infobus will follow to the last stopping and possibly to some neighboring stoppings provided the total number of passengers that have these stoppings as destination will not exceed the volume of the *V* infobus.

Each infobus with a sequence number $\dot{n}_i \in \{1, 2, \ldots, n_i\}$ has its own set of stoppings are available to it. For further reasoning, this set of stoppings will be called as a potential set of stoppings and indicated as $J_{\dot{n}_i P}$. This set includes all the stopping points that are located behind the starting point of departure with the exception of those stoppings, to which the previous infobuses, carrying from the same stopping, have already delivered passengers. However, the infobus will deliver passengers not to all points of the potential set of stoppings, but only to some of them. These delivery points form the set will named for further discussions as real set of stoppings of the infobus, and will be denoted as $J_{\dot{n}_i}$. It should be noted to, the real set of infobus stoppings is a subset of potential set of infobus stoppings $J_{\dot{n}_i} \subset J_{\dot{n}_i P}$.

For example, if infobus 1 goes from the first stopping only to the last two stoppings: *k* and *k-1* (Pic. 2), then the potential set of stoppings J_{1P} of the infobus 1 will consist of all points of the route, starting from the second stopping, i.e. $J_{1P} = \{2, 3, \ldots, k\}$, and the real set of stoppings J_1 of the infobus 1 is limited to two points $J_1 = \{k-1, k\}, J_1 \subset J_{1P}$. If the infobus 2 following infobus 1 will came from the first stopping to the stoppings *k-2, k-3* and *k-4*, then the potential set of its stoppings is defined as $J_{2P} = \{2, 3, \ldots, k\} \setminus J_1 = \{2, 3, \ldots, k-2\}$ and the real set of infobus 2 will consist of $J_2 = \{k-4, k-3, k-2\}, J_2 \subset J_{2P}$. Thus, the potential set of stoppings of any infobus that make delivery from a stopping *i* is the difference of the set of all stoppings on the route, starting from stopping *i+1*, and of the set that is aggregate of stops to which the previous infobuses made a delivery.

The real set of stoppings of infobus 1 is determined from the conditions:

$$\begin{cases} m_{1k} + m_{1k-1} \le V \\ m_{1k} + m_{1k-1} + m_{1k-2} > V \end{cases} \Leftrightarrow \begin{cases} \sum_{j=k-1}^{k} m_{1j} \le V \\ \sum_{j=k-2}^{k} m_{1j} > V \end{cases}. \quad (3)$$

That is, the number of passengers traveling from stop 1 to the two last stoppings is less than or equal to the infobus capacity *V*, but the number of passengers traveling to the three last stops is greater than infobus capacity *V*.

According mathematical definition [28]: "The supremum (abbreviated sup; plural suprema) of a subset *S* of a partially ordered set *T* is the least element in *T* that is greater than or equal to all elements of *S*, if such an element exists." The supremum of the number set *S* is denoted as *sup S*. For further considerations, the stopping with the greatest sequence number from the potential set of infobus stoppings $\dot{n}_i, \dot{n}_i \in \{1, 2, \ldots, n_i\}$ will be denoted as $\sup J_{\dot{n}_i P}$. The composition of the real set of infobus stoppings depends on its capacity and the number of passengers, but the stop with sequence number $\sup J_{\dot{n}_i P}$ will always be in the real set of infobus $\dot{n}_i$ stoppings: $\sup J_{\dot{n}_i P} \in J_{\dot{n}_i}$.

To determine the real set of stoppings $J_{\dot{n}_i}$ of infobus $\dot{n}_i, \dot{n}_i \in \{1, 2, \ldots, n_i\}$, the algorithm uses a value $\Delta_{\dot{n}_i}$, that represents the number of stoppings are included in the real set stoppings of infobus $\dot{n}_i, \dot{n}_i \in \{1, 2, \ldots, n_i\}$, without the stopping $\sup J_{\dot{n}_i P}$, i.e. $\Delta_{\dot{n}_i} = |J_{\dot{n}_i}| - 1$. So, for infobus 1 from the example $\Delta_1 = |2| - 1 = 1$, and for infobus 2 $\Delta_2 = |3| - 1 = 2$.

For infobus 1, the conditions for determine a potential set of infobus stoppings J_{1P}, also value Δ_1, and the real set of infobus stoppings J_1 can be defined as:

$$\begin{cases} J_{1P} = \{2, 3, \ldots, k\} \\ \sum\limits_{j=\sup J_{1P} - \Delta_1}^{\sup J_{1P}} m_{1j} \le V, \quad \sum\limits_{j=\sup J_{1P} - \Delta_1 - 1}^{\sup J_{1P}} m_{1j} > V. \\ J_1 = \{ j \mid \sup J_{1P} - \Delta_1 \le j \le \sup J_{1P} \} \end{cases} \tag{4}$$

or

$$\begin{cases} J_{1P} = \{2, 3, \ldots, k\} \\ \sum\limits_{j=K-1}^{K} m_{1j} \le V, \quad \sum\limits_{j=K-1-1}^{K} m_{1j} > V \\ J_1 = \{ j \mid K - 1 \le j \le K \} \end{cases} \tag{5}$$

That is means, the real set of infobus 1 stoppings is all stoppings, starting from the last point of the route (stopping *k*), and in the direction of decreasing stoppings sequence numbers until the total quantity of passengers, that travel to these stops, is less than or equal to the infobus capacity. From condition (5), it follows that $J_1 = \{k-1, k\}$.

The real set of stoppings J_2 for infobus 2 can be defined similarly. Infobus 2 can proceed to all other stoppings of the route that are not included in the real set of infobus 1 stoppings. Consequently, there are a potential set of infobus 2 stoppings is $J_{2P} = \{2, 3, \ldots, k\} \setminus J_1 = \{2, 3, \ldots, k-2\}$. Hence, $\sup J_{2P} = k - 2$. At the same time the require condition for formation of the real set of destination points for infobus 2 is: the number of passengers that travel using infobus 2 cannot exceed the capacity of the infobus 2. This requirement is described by the following system:

$$\begin{cases} m_{1k-2} + m_{1k-3} + m_{k-4} \le V \\ m_{1k-2} + m_{1k-3} + m_{k-4} + m_{k-5} > V \end{cases} \Leftrightarrow \begin{cases} \sum\limits_{j=k-4}^{k-2} m_{1j} \le V \\ \sum\limits_{j=k-5}^{k-2} m_{1j} > V \end{cases}.$$

For infobus 2, the conditions for determine a potential set of infobus stoppings J_{2P}, also value Δ_2, and the real set of infobus stoppings J_2 can be defined as:

$$\begin{cases} J_{2P} = \{2,3,...,k\} \setminus J_1 \\ \sum_{j=\sup J_{2P}-\Delta_2}^{\sup J_{2P}} m_{1j} \le V, \quad \sum_{j=\sup J_{2P}-\Delta_2-1}^{\sup J_{2P}} m_{1j} > V. \\ J_2 = \{ j | \sup J_{2P} - \Delta_1 \le j \le \sup J_{2P} \} \end{cases} \tag{6}$$

or

$$\begin{cases} J_{2P} = \{2,3,...,k\} \setminus \{k-1,k\} = \{2,...,k-2\} \\ \sum_{j=(k-2)-2}^{k-2} m_{1j} \le V, \quad \sum_{j=(k-2)-3}^{k-2} m_{1j} > V \\ J_2 = \{ j | k-4 \le j \le k-2 \} \end{cases}. \tag{7}$$

From condition (7) it follows that $J_1 = \{k-4, k-3, k-2\}$. The essence of the formation sets of stoppings for infobuses 1 and 2 is shown in the following example. It suppose, the capacity of the infobus is V=25. There is a matrix M_z at a certain moment, whose elements $m_{1k-5}, m_{1k-4}, m_{1k-3}, m_{1k-2}, m_{1k-1}, m_{1k}$ have following values 5,9,8,7,9,11:

$$M_Z = \begin{pmatrix} 0 & m_{12} & ... & ... & 5 & 9 & 8 & 7 & 9 & 11 \\ 0 & 0 & ... & ... & ... & ... & ... & ... & ... & m_{2k} \\ 0 & 0 & 0 & ... & ... & ... & ... & ... & ... & ... \\ 0 & 0 & ... & ... & ... & ... & ... & ... & ... & m_{ik} \\ 0 & 0 & ... & ... & ... & .... & ... & ... & ... & ... \\ 0 & 0 & ... & ... & ... & ... & ... & ... & 0 & m_{k-1k} \\ 0 & 0 & ... & ... & ... & ... & ... & ... & 0 & 0 \end{pmatrix}.$$

For the infobus 1, that transports passengers from the first stoppings, the potential set of stoppings is $J_{1P} = \{2,\ldots,k\}$. Therefore $\sup J_{1P} = k$. According to conditions (4), (5):

$$\begin{cases} \sum_{j=\sup J_{1P}-\Delta_1}^{\sup J_{1P}} m_{1j} = \sum_{j=k-1}^{k} m_{1j} = 9+11 = 20 \le 25 \\ \sum_{j=\sup J_{1P}-\Delta_1-1}^{\sup J_{1P}} m_{1j} = \sum_{j=k-1-1}^{k} m_{1j} = 7+9+11 = 27 > 25 \end{cases} \Rightarrow J_1 = \{k-1,k\}, \Delta_1 = 1.$$

For the infobus 2 the potential set of stopping will be $J_{2P} = \{2,3,...,k\} \setminus J_1 = \{2,3,...,k-2\}$ and $\sup J_{2P} = k-2$. According to conditions (6), (7):

$$\begin{cases} \sum_{j=\sup J_{2P}-\Delta_2}^{\sup J_{2P}} m_{1j} = \sum_{j=(k-2)-2}^{k-2} m_{1j} = 8+9+7 = 24 \le 25 \\ \sum_{j=\sup J_{2P}-\Delta_2-1}^{\sup J_{2P}} m_{1j} = \sum_{j=(k-2)-2-1}^{k-2} m_{1j} = 5+9+8+7 = 29 > 25 \end{cases} \Rightarrow \begin{cases} J_2 = \{k-4, k-3, k-2\} \\ \Delta_2 = 3 \end{cases}.$$

In general case, for any infobus $\dot{n}_i, \dot{n}_i \in \{1,2,...,n_i\}$, the potential set of stoppings $J_{\dot{n}_i P}$, the value $\Delta_{\dot{n}_i}$ and the real set of stoppings $J_{\dot{n}_i}$ are determined from the following conditions:

$$\begin{cases} J_{\dot{n}_i P} = \{2,...,k\} \setminus \bigcup J_{\dot{n}_i-1}, J_0 = \varnothing, \dot{n}_i \in \{1,2,...,n_i\}, \\ \Delta_{\dot{n}_i} = \{0,1,2,...\}, \sum_{j=\sup J_{\dot{n}_i P}-\Delta_{\dot{n}_i}}^{\sup J_{\dot{n}_i P}} m_{1j} \le V, \quad \sum_{j=\sup J_{\dot{n}_i P}-\Delta_{\dot{n}_i}-1}^{\sup J_{\dot{n}_i P}} m_{1j} > V, \\ J_{\dot{n}_i} = \{ j | j \in N_0, \sup J_{\dot{n}_i P} - \Delta_{\dot{n}_i} \le j \le \sup J_{\dot{n}_i P} \}. \end{cases} \tag{8}$$

Thus, according to system (8) a lot of real sets of infobuses stoppings $\bigcup J_{\dot{n}_i}, \dot{n}_i \in \{1,2,\ldots,n_i\}$ for the row *i* of the correspondence matrix *M*z, *Z = 1, 2,…* is formed. This a lot of stopping sets is a delivery plan for the row *i* of the correspondence matrix *M*z. Indeed, the index $\dot{n}_i, \dot{n}_i \in \{1,2,\ldots,n_i\}$ of the real set of stoppings $J_{\dot{n}_i}$ indicates the sequence number of the infobus, and the contents of the set $J_{\dot{n}_i}$ indicates the numbers of the stoppings at which this infobus will make delivery. A lot of $\bigcup_{i=1}^{k-1}\bigcup J_{\dot{n}_i}, \dot{n}_i \in \{1,2,\ldots,n_i\}$ corresponds to the delivery plan for the entire current matrix of correspondence *M*z, *Z = 1,2, ….* The order of passenger delivery from the stopping i is performed by increasing the sequential numbers of infobuses that are sanded on the route, i.e. 1,2, ..., n_i.

In this part conclusions from the research and their implications should be presented, for instance: from the practical point of view; from the scientific point of view, in the context of the literature review.

In this part of the paper the analysis of the research results should be carried out. This section is not mandatory, but can be added to the manuscript if the discussion is unusually long or complex.

6. Conclusions

A new type of urban public transport is proposed in this article. This type of transport is capable to function in a saturation street and road traffic without interference from other vehicles also to deliver a large number of passengers that is comparable to the metro power. The transport system is closed. That means the system functions independently from human participation. The information processes (information gathering, information processing, making decision) follow continuously in such system and form its basis. The single vehicle unit in this system is an unmanned electric car is named infobus.

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Alternative fuels in internal combustion engines

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Abstract: Automobile industry is one of the most developed industries in Ukraine and in the world today. The ever-increasing demand for transportation leads to an increase in demand for fuel, which in turn increases its deficit and value. Therefore, the high cost of traditional hydrocarbon fuels and the constant reduction of their world reserves compels scientists to find renewable biofuels. The objective of this paper is to present results of a study aimed at investigating the possibility of using alternative fuels derived from the alcohol industry waste, in pure form and as additives to hydrocarbon fuels. According to the results, the main technical and operational properties of alternative fuels received on the basis of A-92 petrol and fusel oils, experimental values of density, viscosity, distillation temperature on the ENGLER machine, temperature of formation steam congestion, their optimal percentages in the mix for different types were obtained in internal combustion engines. The findings of the research also indicate that an addition of fusel oils to A-92 gasoline leads to improvement of the viscosity-temperature characteristics of formed mixtures and increase in the temperature of formation steam cork, which ultimately reduces the consumption of fuels by 10-12% and also contributes to solving the problem of recycling fusel oils.

Keywords: gasoline, addition, fusel oil, improvement, density, temperature, viscosity, economy, recycling

1. Introduction

Automobile industry is one of the most developed industries in Ukraine and in the world today. The ever-increasing demand for transportation leads to an increase in demand for fuel, which in turn increases its deficit.

Characteristics of most fuels currently in use no longer satisfy the ever-increasing requirements of their fire safety and the content of harmful impurities in the exhaust gases. The growth of the environmental requirements of Euro-5,6 for fuels leads to an increase in oil refining costs, and, ultimately, to an increase in fuel prices.

Consequently, the high cost of traditional hydrocarbon fuels and the constant reduction of their world reserves compels scientists to find renewable biofuels.

In Brazil and elsewhere in the world, alcohols are used as an alternative fuel in their pure form, and in mixtures with gasoline in certain ratios today.

2. Literature review

Ethanol or E85 (15 % gasoline) is commercially used on the fuel market, for example, Brazil and Sweden. It is also used as fuel in a mixture of up to 10 % of gasoline in the EU and the US [1].

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In [2] it is proposed to apply higher alcohols as an anti-knock gasoline additive, which will increase its environmental safety. Since lead and other heavy metals used earlier are very harmful to the environment [3].

In Brazil and other countries at present are widely used as an alternative fuel alcohols both in pure form and in mixtures with gasoline in particular proportions.

In [4], it is proposed usage higher alcohols as an anti-knock gasoline additive because the lead used earlier is very harmful to humans and the environment [5].

Usage of methanol as an additive to gasoline is made in China, a mixture containing methanol from M5 to M30 used in standard gasoline engines, and from M85 to the M100 methanol used in special machines [6].

Although usage of methanol is very dangerous for humans because of its high toxicity, it reduces the risk of fire by 95 % and the negative impact on the environment from leakage and is derived from biological regenerative raw materials, and therefore methanol is a promising substitute gasoline [7].

The authors [8] investigated the economic impact of using bioethanol as motor fuel. According to research results, for used bioethanol and gasoline prices, it has been established that with an increase in the percentage of bioethanol content in equivalent fuel to 80 % there is an increase in the economic efficiency of using bioethanol due to the use of low-octane gasoline in fuel. Reduction in the cost of equivalent fuels ranges from 5.8 % to 30 %.

Results of the research in [9] show that usage methanol in the power supply system of automobiles, it is possible to improve the environmental performance compared to gasoline, reducing CO_2 and NO_x emissions by 20 % and 90 %, respectively.

Usage of methanol and ethanol in engines with spark ignition was investigated in [10]. Methanol and ethanol are compatible with existing fuels and are easily stored in a vehicle. This study shows that thermal fuel efficiency is somewhat improved on gasoline. NO_x emissions are significantly reduced for fuels with higher water content. The study of methanol as a fuel was also carried out in [11]. The physical and chemical properties of ethanol and gasoline related to the DIC are considered.

Methanol in comparison with gasoline has a high heat of evaporation, which is a significant advantage over gasoline.

Similar results were obtained in [12], as a result of the research, good environmental performance of the engine and the EGR valve was ensured, as well as not a significant increase in fuel consumption, although, as noted, for example, in the work.

Of the other processes [13] are also influenced by fuel consumption namely the work of the automobile's friction couples.

In this work, the authors [14] investigated usage mixture of gasoline and methanol. Measured spent gases of the car on the content of hydrocarbons, methanol and aldehydes, as well as the trend of carbon emissions. According to the results, the emissions of aldehyde on methanol were approximately one order higher than those resulting from usage of commercial fuels and the hydrocarbon composition of the spent gases was similar to commercial fuels.

Therefore, the production of fuel alcohol can significantly reduce the demand for commercial fuels, and the use of it in the form of mixtures with gasoline does not require changes in the design of the power supply [15].

An important competitor of hydrocarbon fuels for engines and alcohols is hydrogen in which combustion products do not contain toxic products of incomplete combustion of hydrocarbon fuels and alcohols (CO, C_nH_m, NO) [16].

Usage of hydrogen based fuels was investigated in [17].

The advantages of hydrogen as fuel are improving fuel economy and environmental performance, the ability to adapt fuel for all types of engines and power plants.

However, for usage of hydrogen as a fuel for road transport, it is necessary to solve the problem of its mass and cheap production, as well as to create reliable means of storage of hydrogen fuel on board the car [18].

Fighting against harmful emissions of engines is mainly solved by the neutralization of spent gases in the vehicle's exhaust system by oxidizing waste gases by supplying them with additional air in the thermal, absorption of toxic components by liquid in liquid neutralizers, the use of catalytic converters and soot filters in diesel engines, the transfer of diesel engines to alternative fuels [19].

The high level of purification of spent gases and the use of alternative fuels in road transport will greatly increase the environmental safety of the car for the environment.

Therefore, the main purpose of the work is to explore the possibility of using the waste alcohol industry as an alternative fuel.

To achieve this goal were formulated following tasks:

- investigation of technical and operational indicators of gasoline, depending on the percentage of volumetric content of fusel oils;
- the experimental installation of optimum content of fusel oils in the alternative fuel produced;
- investigation of environmental and technical and economic parameters of the internal combustion engine in the process of using alternative fuels.

3. Materials and Methods

Main technical and operational indicators of blends of commercial fuels with fusel oils are density, kinematic viscosity, temperature of distillation, etc. were investigated experimentally.

During the course of experimental research and processing of the results, methods of least squares and mathematical statistics were used.

Methods of research were developed taking into account the basic physical and chemical properties of fusel oils. All experiments in this work were carried out on fusel oils obtained from the Ivano-Frankivsk regional state association of alcoholic and alcoholic beverages "Knyaginin" that meet the standard [20] and were checked in the chemical laboratory of the said enterprise.

Process of mixing fusel oils with commercial gasoline A-92 was carried out in a closed vessel using an electric stirrer for 5 minutes. During this time there was a complete dissolution of fusel oils in gasoline A-92.

The main studies of the environmental performance of the engine were performed on the developed installation for study of operational and environmental performance of the engine on alternative fuel Fig. 1. Load for the engine (8) is generated by the electric generator (4) and maintained by the regulation of current on the rotor of the electric motor using a rheostat (2).

To study the effects of additives of fusel oils on commercial gasoline A-92 on the toxicity of spent gases in the scheme of the experimental installation used an engine that is not equipped with a catalytic converter.

Toxicity of the spent gases was investigated using the automotive gas analyzer AvtoTest 02.03P.

Research of technical and operational indicators is carried out for fuel mixtures, created by mixing fusel oils with gasoline in proportions recommended in [21].

Mixing was carried out at a temperature of components of 20 ^{o}C and atmospheric pressure of 740 mm. ht Art.

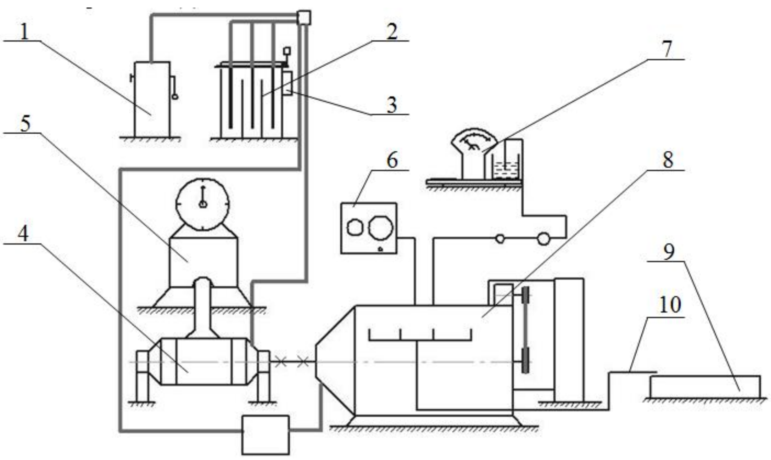

Figure 1. Installation for the study of operational and environmental performance of the engine on alternative fuels: *1* - power cabinet; *2* - rheostat; *3* - regulator of depth of immersion of electrodes; *4* - electric generator; 5 - weight to determine the load of the model VKM-32; *6* - panel of control-measuring devices; *7* - weight to determine mass fuel consumption; *8* - carburetor engine ZIL-130; *9* - exhaust trac; *10* - pipeline.

Viscosity and density of gasoline A-92 significantly affect the supply of fuel through the nozzle. The higher viscosity of the fuel, the less its rate of flow through the injector nozzle and density increasing with increase of mass flow. The density of gasoline also affect the composition of the fuel mixture and quality of training in the combustion chamber of internal combustion engine, as well as high density leads to poor mixing of fuel produced drops large diameter that does not do it completely burned in the camera (mechanical incomplete combustion), as a result - increase in specific fuel consumption.

The results of experiments to determine the density and viscosity of the mixture of gasoline and FO shown in Fig. 2.

Shown in Fig. 2 curve of density and viscosity are described in the following approximation dependences of correlation coefficients of 0,954 and 0,963 respectively:

$$\rho_f = a + b \cdot V_{FO}, \tag{1}$$

$$\upsilon_f = a_1 + b_1 V_{FO}, \tag{2}$$

where a, b, a_1, b_1, - experimental coefficients listed in the table 1 and determined by the least squares method.

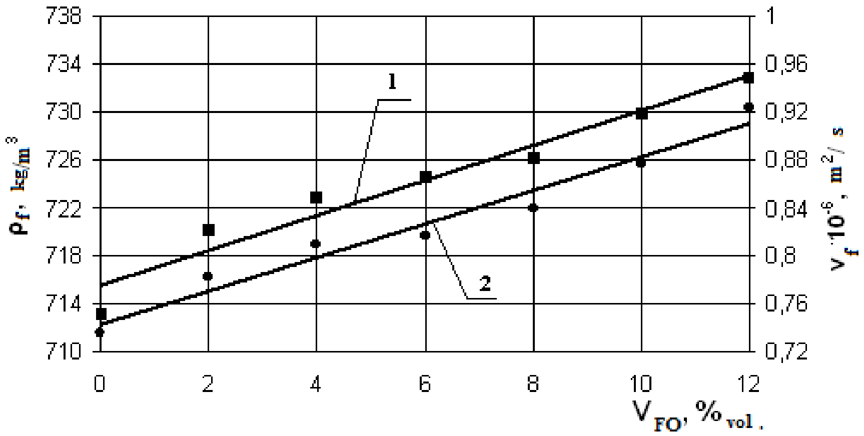

Figure 2. Effect of volume content of fusel oils V_{FO} on kinematic viscosity ν_f and density ρ_f fuel mixtures: *1* - density fuel; *2* - kinematic viscosity fuel.

Table 1. Experimental coefficients in equations (1) and (2)

Values of the coefficients			
ρ_F, **kg/m³**		ν_F, **m²/s**	
a	***b***	a_1	b_1
715.55	1.14554	$0.7426 \cdot 10^{-6}$	$1.4 \cdot 10^{-8}$

Small value of the coefficients at V_{FO} in equation (2) show that the kinematic viscosity derived fuel mixtures are not significantly different from the viscosity of pure gasoline. So fusel oil additive to gasoline of up to 12 % vol. not adversely affect the flow of the mixture through the filter system power.

Fig. 3 shows a graphical dependence of the temperature in the engine compartment, where the formation of vapor lock in the system power output from the percentage in gasoline fusel oils.

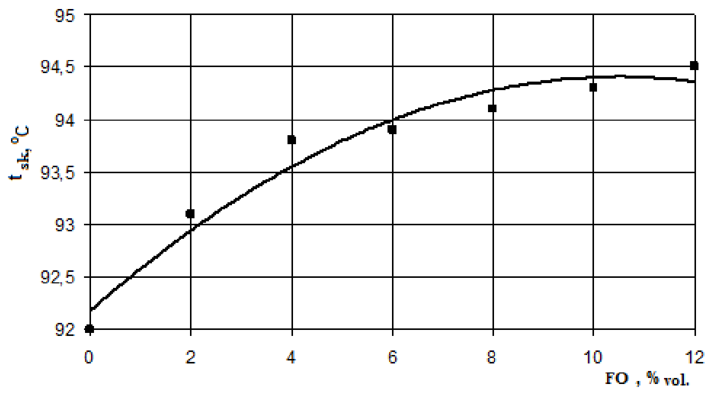

Figure 3. Change of temperature formation of vapor lock t_{sk} in the system power engine depending on the percentage of gasoline fusel oil.

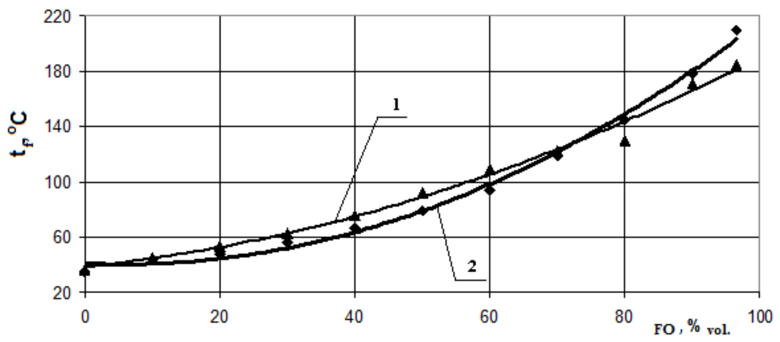

Figure 4. Effect of fusel oil content (% vol.) at temperature t_f distillation of petrol: *1* - A-92; *2* - mixture of petrol A-92 and 12 % vol. FO.

Important indicator for gasoline according to DSTU is a fractional composition that affects the engine performance in all operating modes, depending on which factors such as the ease of starting engine, speed of warming up, usage the wear of the cylinder-piston group, lacquer and formation of the nail on the engine parts, composition and volume of combustion products.

Fractional composition of the mixtures was investigated on a standard device (the device of the ENGLER) according to GOST.

Results of researches the temperature of distillation ogasoline and mixtures of gasoline with fusel oils 2, 4, 6, 8, 10, 12 % by volume filed under table 2.

Table 2. Fractional composition of the mixtures

Volume of waste gasoline, %	**Boiling point of the mixture of gasoline and FO, °C**						
	Gasoline A-92	**1 % vol. FO**	**2 % vol. FO**	**4 % vol. FO**	**5 % vol. FO**	**10 % vol. FO**	**15 % vol. FO**
Start distillation	35	35	35	36	36	36	37
10	44	45	44	43	43	43	45
50	79	80	81	81	81.5	84	92
90	178	178	175	178	179	178	171
End of distillation	210	209	209	208	208	204	185

The temperature of the beginning of boiling (t.b.) of gasoline affects not only the pressure of saturated vapors, but also on its physical stability. To ensure normal fuel storage conditions, this temperature according to the State Standard should be 30°C or more. An additive to fusel oil gasoline slightly increases this temperature (see Table 2), which improves fuel storage conditions.

Temperature of 10% ebullition ($t_{10\%}$) characterizes the ease of starting an ICE and the intensity of wear during start-up. It should be in accordance with DSTU for gasoline not more than 75 °C, as evident from the experiments, the temperature of mixture corresponds to these limits.

Temperature of 50% boiling ($t_{50\%}$) affects the ICE heating, its dynamism, the intensity of acceleration of the car to a certain speed after the sharp opening of the throttle valve. It should not exceed 120 ºC for gasoline. This condition will also be ensured as the temperature of the $t_{50\%}$ boiling mixture corresponds to these limits.

Important operational indicator for fuels is their propensity to burn the carbon in the combustion chamber. It is known that the construction of the engine and fuel composition have a significant influence on the formation of carbon in the combustion chamber. It is established that the formation of carbon significantly affects the high content of high-boiling olefinic and aromatic hydrocarbons in fuel, and therefore their content in fuel is limited to 25 and 55% vol.

Since fusel oils contain higher alcohols, when using them as additives to commercial fuels, a slight increase in the ability to form a carbon in the combustion chamber may be insignificant.

In Fig. 5 the experimental dependence of changing in the volume of the residual in the flask, together with the losses of fuel and fuel mixtures in distillation, is constructed, depending on the percentage volumetric content of fusel oils in it.

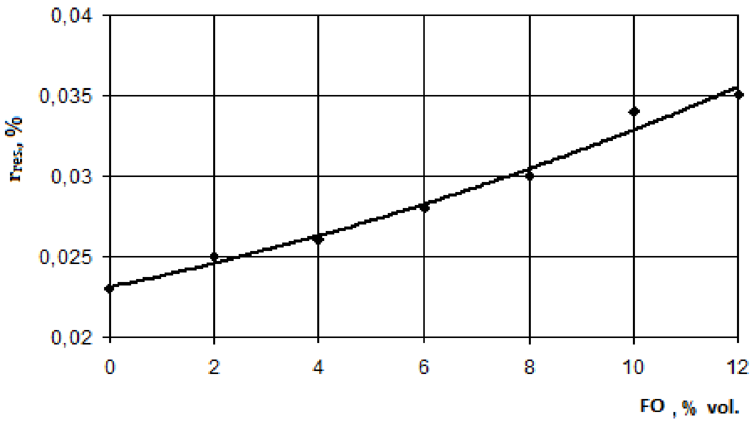

Figure 5. Dependence of the relative volume of the residual $r_{res.}$, % of the content of fusel oils in gasoline A-92.

Relative amount of residue in the flask r_i calculated from the relationship:

$$r_i = \frac{V_{rem.}}{V_{gen.}}, \qquad (3)$$

where V_{gen} - the total amount of fuel taken for distillation, ml.;

$V_{rem.}$- amount of fuel remaining in the flask after distillation, ml.

As shown in Fig. 5 dependence adding fusel oils in fuel leads to a slight increase in the residue flask and loss of fuel during distillation, but they do not exceed 4 % of that regulated standards for gasoline and, therefore, the addition of fusel oils to gasoline up to 12 % by volume is acceptable. On the content of CO, NO i C_nH_m in the spent gases of gasoline ICE impact angle of inflammation, and therefore, in order to exclude the impact of this angle during the experiment, it did not change.

Experiment results are given in Tables 3-6.

Experimental dependence of the content of CO, C_nH_m, NO in the spent gases of the experimental engine on the volumetric content of fusel oil in fuel mixtures VCM, while working in idle mode, is shown in Fig. 6 and 7.

From Fig. 6 and 7 it follows that as a result of an increase in the content of fusel oil in fuel up to 10 %, an increase in fuel consumption is observed due to an increase in the density of fuel mixtures (Fig. 2) and a slight increase in the concentration of hydrocarbons and nitrogen oxides in the spent gases of the engine.

Table 3. Results of determining the content of CO in the spent gases of the engine

The content of fusel oils, % vol.	Contents CO, % vol.			
	1	2	3	Average value
0	1.51	1.52	1.5	1.51
5	1.45	1.45	1.43	1.44
8	1.42	1.41	1.4	1.41
10	1.37	1.35	1.35	1.36

Table 4. Results of determining the content of C_nH_m in the spent gases of the engine

The content of fusel oils, % vol.	Contents C_nH_m, million $^{-1}$			
	1	2	3	Average value
0	1400	1400	1450	1416
5	1450	1450	1450	1450
8	1450	1500	1500	1483
10	1500	1500	1550	1550

Table 5. Results of determining the content NO in the spent gases of the engine

The content of fusel oils, % vol.	Contents NO, million $^{-1}$			
	1	2	3	Average value
0	210	200	210	210
5	240	240	230	236
8	260	250	260	257
10	270	280	280	276

Table 6. Results of determination of mass fuel consumption of the engine

The content of fusel oils, % vol.	Mass fuel consumption G, g/min			
	1	2	3	Average value
0	80	81	81	80.7
5	82	83	82	82.3
8	85	84	84	84.3
10	86	86	87	86.3

However, it should be noted that with increasing content of fusel oils in fuel, there is a decrease in the concentration of carbon monoxide (Fig. 6).

Experimental dependencies (Fig. 6) are approximated by the following equations:

$$CO = a_2 - b_2 \cdot V_{FO} - b_3 \cdot V^2_{FO}, \tag{4}$$

$$G = a_3 + b_4 \cdot V_{FO} + b_5 V^2_{FO} \tag{5}$$

where CO - concentration of carbon monoxide in the spent gases of the engine during its operation on fuel mixtures of gasoline with fusel oils, % vol.;

G - consumption of a fuel mixture of gasoline with fusel oils, g /min.

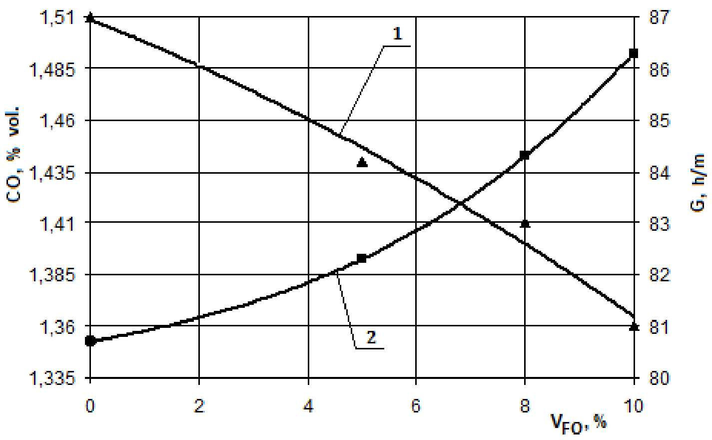

Figure 6. Dependence of the content of CO in the waste gases of the experimental engine and fuel consumption G from volumetric V_{FO} content to fuels of fusel oils: the correlation coefficients for the curves $\rho_1 = 0.98$ and $\rho_2 = 0.99$; *1* - the content of CO in the spent gases of the engine; *2* - minute fuel consumption G; idle mode.

In Table 7 shows the experimental coefficients for equations (4) and (5).

Table 7. Experimental coefficients for equations (4) and (5)

Value of coefficients					
CO, % vol.			G, g /min		
a_2	b_2	b_3	a_3	b_4	b_5
1.51	0.0105	0.0004	80.708	0.0635	0.0492

$$O = a_4 - b_6 \cdot V_{FO} + b_7 \cdot V^2_{FO} \quad (6)$$

$$C_nH_m = a_5 + b_8 \cdot V_{FO} + b_9 \cdot V^2_{FO} \quad (7)$$

where C_nH_m - the concentration of hydrocarbons in the waste gases of the engine ZIL-130 during its work on fuel mixtures of gasoline with fusel oils, million^{-1};

NO - concentration of nitrogen oxides in the spent gases of the ZIL-130 engine during its operation on fuel mixtures of gasoline with fusel oils, million^{-1}.

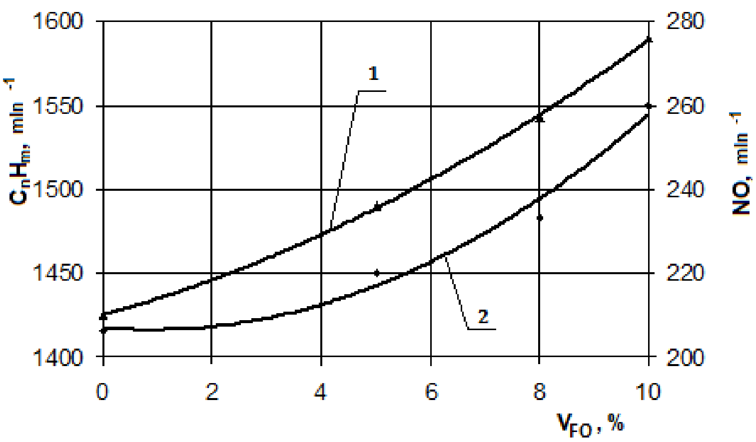

Figure 7. Dependence C_nH_m and NO content in the spent gases from the engine research V_{FO} volume content in the fuel fusel oil: the correlation coefficients for the curves $\rho_1 = 0.97$ and $\rho_2 = 0.99$; *1* - NO content in the spent gases of the engine; *2* - C_nH_m content in the spent gases of the engine; idle mode.

The experimental coefficients for equations (6) and (7) are given in Table 8

Table 8. Experimental coefficients for Eq. (6) and (7)

Value of coefficients					
NO, mln-1			CnHm, mln-1		
a4	b6	b7	a5	b8	b9
1417.4	2.614	1.5322	210.1	3.6053	0.2947

4. Results and discussion

Adding FO other brands of gasoline available only in small quantities because gasoline A-95 and A-98 have high octane, so the negative impact on their physical and technical indicators will not.

According to research conducted by the authors additive to gasoline A-92 in an amount up to 10 % fusel oil improves a number of performance indicators:

- increases octane fuel mixture, which will allow for the use of fuel mixtures of low octane gasoline;
- reduced vapor pressure, which reduces the likelihood of vapor lock in the system of power and loss ICE gasoline in storage, transportation and refueling vehicles;
- increasing the density of the fuel mixture from 710 to 727 kg/m^3, which reduces fuel loss through compaction, improves mixing in the cylinders of internal combustion engines.

Density value different grades of motor gasoline according to the standards ranges from 710 to 785 kg/m^3. Determined in experiments density fuel mixtures in the range from 713 to 734 and does not exceed the specified range, and a slight increase in the density of fuel mixture will affect the level of fuel in the float chamber compared to gasoline.

As can be seen from Fig. 6 and 7 addition to commercial gasoline A-92 fusel oils in the amount from 2 to 10% vol. leads to a decrease of the CO content in the spent gases of the ICE by 9.3%, an increase in fuel consumption by 6.5%, a 10.2% reduction in hydrocarbons and 16.9% increase in nitrogen oxides.

The growth of C_nH_m and NO in the spent gases of the engine will not create practical problems in the use of developed alternative fuels due to the presence of these compounds in the modern vehicle by efficient converters.

5. Conclusions

The experiments carried out are continuation of research on the possibility of using fusel oil - waste from the alcohol industry, as a component of commodity fuels and allowing to expand the base of alternative fuels.

As a result of research the technical and operational properties of the created alternative fuels, the correlation between the density values, the kinematic viscosity and the balance in the flask from the percentage content in the fuel of fusel oils was established.

Obtained results are described by approximation equations with rather high coefficients of correlation of 0.954 and 0.963, which confirms the adequacy of the obtained results.

Obtained and investigated alternative motor fuel is suitable for use in accelerated ICE with external mixture formation, which require the use of gasoline only with an ON≥95.

Usage fusel oils in conjunction with gasoline improves the environmental performance in terms of the content of CO in the waste gas of the internal combustion engine.

According to the results of the study, the addition of fusel oils to A-92 gasoline leads to improvement of the viscosity and temperature characteristics of formed mixtures, namely, viscosity, density, distillation temperature on the device of Engler and the temperature of formation of steam cork, and therefore as a result of their addition to gasoline allows to reduce by 10-12% the need for the latter and at the same time solve the problem of ecologically safe utilization of fossil oils without additional costs of energy resources, and the use of these additives does not require changes in power system design engines, making fusel oils promising alternative fuel.

Regarding environmental performance, the detected growth of C_nH_m and NO in the spent gases of the engine will not create practical problems of usage developed alternative fuels due to the presence of effective compounds of these compounds on the car.

Consequently, the addition to fossil oils A-92 gasoline makes it possible to improve their basic performance and solve the problem of waste recycling of the alcohol industry.

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Characteristics and thermomechanical modes of aluminum alloys hot deformation

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Abstract: The widespread use of aluminum alloys is determined by their technical, physical and mechanical properties. The purpose of this paper is to present the characteristics of thermomechanical models of aluminum alloys hot deformation and to explain how they impact the properties of the these alloys. The application of the workpiece rolling process under the conditions of isothermal deformation makes it possible to maximize the effect of ductility. The deformation of hot workpieces is done by the tool heated to the same temperature (or close to them). Such a scheme of hot deformation will reduce the effort by increasing the ductility of the treated metal which occurs due to the full course of stabilizing processes. Uniform deformation of the workpiece provides a good and comprehensive reconstruction of the structure, in the absence of complicated deformation zones and local overheating. And, as a result, it reduces the dispersion of properties in the workpiece volume. It was established that workpieces rolling in conditions of isothermal deformation are reduced the of metal pressure on a roll in 1.8 times or even more.

Keywords: aluminum alloys, hot deformation, ductility.

1. Introduction

Aluminum alloys are widely used in automobile engineering, shipbuilding, aircraft engineering. The most widespread use of aluminum alloys has been found in aviation (60-70%) and is currently one of the main structural materials in the aviation engineering. In the future wider use of aluminum and its alloys in automobile engineering is not excluded. Today, most cars of the Japanese brands such as Mazda, Mitsubishi use aluminum alloys in their designs. This is due to the sufficient strength of the alloys, good welding, which provides the ability to receive high-strength welded structures. The high corrosion resistance allows to reduce costs of surface treatment. Lightness reduces the specific energy consumption on a car's drive. The use of aluminum parts in modern cars allows to reduce the total weight of the car by 25-30%, which reduces the fuel consumption accordingly. The use of aluminum alloys in automotive industry facilitates technological operations of production of details as some aluminum alloys are easily deformed, others have good casting properties. This provides the manufacture of complex sections parts, which on indicators of stiffness do not concede steel. The ductility properties of aluminum provide a reduction in the level of vibration of the body in the process of motion of the car by uneven roads.

To aluminum alloys used in automotive engineering impose a certain complex of requirements: they must have high static strength properties (strength limit, yield strength, cut resistance),

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satisfactory ductility and thermomechanical characteristics which must be taken into account when developing technological processes of their hot deformation.

Technological properties of allows provide mass production of semi-finished products from aluminum alloys at metallurgical plants and comparatively easy parts treatment.

The structure and properties of products made of aluminum alloys are mainly determined by the method of their production, which is divided into two main groups: deformable – treatment by pressure (production of sheets, plates, profiles, forgings, stampings, pipes, etc.); foundry – production of shaped castings.

2. Literature review

The deformation behavior of a 2024 aluminum alloy sheet at elevated temperatures was studied by uniaxial hot tensile tests over the nominal initial strain rate range of 0.001-0.1 s(-1) and temperature range of 375-450 degrees C, in order to analyze the deformation behavior with higher accuracy, a Digital Image Correlation (DIC) system was applied to determine the strain distribution during hot tensile tests [1].

High cycle fatigue properties of 2124 aluminum alloy plates with different thickness were investigated by determining fatigue S–N curves, fatigue crack growth rates and fracture toughness of 2124-T851 aluminum alloy plates with the thickness of 30mm, 40mm and 55mm, respectively [2].

Hot torsion tests were carried out on an AA6005 modified with CaO-added Mg to study its hot deformation behavior. The flow curves indicated that the failure strain of the modified alloy was greater than that of the conventional alloy at low temperature and all strain rates employed in this study [3].

To characterize the hot deformation behavior of commonly used aluminum alloy, a homogeneous Al-Mg-Si-Mn-Cr alloy was analyzed by thermal simulation test at deformation temperature range of 653-803K and strain rate range of 0.01-10s(-1) [4,10].

A modified powder hot extrusion including gas atomization, pre-compaction and hot extrusion was used to fabricate an ultrahigh strength Al-Zn-Mg-Cu-Zr-Sc (7055) alloy, the results reveal that a homogeneous microstructure containing fine grains and tiny second phases is formed after extrusion [5].

The effect of increasing pre-stretching to higher levels, than are currently used in industrial practice, has been investigated on the strength, microstructure, and precipitation kinetics seen during artificial ageing an Al-Cu-Li alloy AA2195 - focussing on the behaviour of the main [6].

The inhomogeneous deformation which appears in hot rough rolling of aluminum alloy plate, reduces rolling output and negatively affects the rolling process, to study the formation mechanism of the inhomogeneous deformation, a finite element model for the five-pass hot rough rolling process of aluminum alloy plate is built [7].

In this paper different thermo-mechanical treatments were performed on the commercial aluminum alloy 2024-T3, in order to improve deformation characteristics, these treatments include the solution heat treatments of precipitates that have been performed at the temperature of 500 degrees C for 4, 6 and 8 hours followed by a quenching in water, hot and cold rolling, recrystallization [8].

Hot deformation in 6063 aluminum alloys was investigated by hot compression testing over the temperature range of 573-723 K with strain rates of 0.01-10 s(-1) using a Gleeble 3500 thermal-mechanical simulator [9].

The dynamic recrystallization behavior of 7085 aluminum alloy during hot compression at various temperatures (573-723 K) and strain rates (0.01-10 s(-1)) was studied by Electron Back Scattered Diffraction (EBSD), Electro-Probe Microanalyzer (EPMA) and Transmission Electron Microscopy (TEM) [10].

3. Research methods

Research methods. Now there are not enough works on a research of possible of workpiece rolling in isothermal deformation and close to this process one. Therefore, carrying out researches on influence of workpiece heating temperatures and rolling stamps, deformation degree on the process parameters of workpiece rolling in the conditions of isothermal and deformation close to it is a relevant task. The solution of this problem can lead to improvement of ductility and decrease in efforts of deformation, improvement of quality of semi-finished products.

The theoretical researches of the process of a current of metal in transitional and constant zones when workpiece rolling in a deformation source at volume deformation which is done taking into account the development of deformation in time, application of an imaginary coordinate grid, finite differences and variable parameter of elasticity.

The methods of coordinate grid, strain gauging, optical and electron microscopy, X-ray microanalysis, mathematical statistics are used in experimental research.

The hot deformation behavior of the homogenized Al-3.2Mg-0.4Er aluminum alloy was investigated at 573-723 K under strain rates of 0.001-1 s(-1), on the basis of compression experimental results, an accurate phenomenological constitutive equation that coupled the effects of strain rate, deformation temperature and strain was modeled [11].

Previous studies have demonstrated that the static softening kinetics of 7150 aluminum alloy showed typical sigmoidal behavior at 400 degrees C and softening plateaus at 300 degrees C, in present work, the static softening mechanisms, the microstructural evolution during post-deformation holding was studied by optical microscopy, scanning electron microscope, electron back-scattered diffraction and transmission electron microscopy [12].

4. Discussion

The features of the structure depend on the technology of semi-finished products, which includes: the duration of heating and the temperature of deformation; circuits, degrees, rates and duration of deformation. For example, the technology of sheet production is very different from the technology of production of stamping or profiles. Deformed semi-finished products (sheets, profiles, stamping, etc.), obtained from one alloy can vary significantly in mechanical and other properties after identical final heat treatment.

Typically, the properties of aluminum alloys are considered depending on the chemical composition and the mode of final heat treatment. Due to that, these factors determine the important structural parameters on which properties depend the concentration of the main alloying components in the solid solution, as well as the structure and size of the phases are separated from solid solution during heat treatment (annealing or aging) such approach to assessment of properties of alloys is optimal.

Aluminum alloys in the aviation industry are one of the main structural materials and are used mainly in a deformed state, which provides increased characteristics and reliability in operation.

Aluminum deformable alloys, with the possibility of pressures treatment in the heated state are conditionally divided into alloys of high, medium and reduced technological ductility [13].

In the paper [14] it is given aluminum alloys which are widely used for hot deformation (Table 1).

Table 1. Nomenclature of aluminum alloys for the production of forgings and stamping

Alloy Grade	Alloys System
Thermally not strengthened alloys	
AMg2, AMg3 AMg5, AMg6	Al-Mg
Thermally strengthened alloys	
D1 D20, D21 B93, B95, B96c AB AK6, AK6-1, AK8 AK4, AK4-1	Al-Cu-Mg Al-Cu Al-Zn-Mg-Cu Al-Mg-Si Al-Cu-Mg-Si Al-Cu-Mg-Si-Ni-Fe

Alloys that have high technological ductility are: AMC; AMg1; AMg2; AMg3; AD31; AD33; AD35; AB; AK6; 01205; ADO; АД1.

Middle technological ductility has alloys: D1; D1ч; D19ch; BAD1; BD17; D20; D21; 1201; AMg4; AMg5: AMg5p; AMg6: B92; B92c; B93pch; B95; B95pch; B96ch; 01963; 1913; 1230; 1915; M40; Ak4; Ak4-1; Ak4-1ch; Ak8; D16ch.

Reduced technological ductility is characteristic of powder materials such as: SAP1(1019); SAP2(1029); SAP3(1039); SAS1-400(1319).

The proposed classification of aluminum alloys for strength and ductility is given by the authors in the paper [15] (Table 2).

Table 2. Classification according to the strength of aluminum and alloys on its basis

Group	Strength and Ductility	Alloys	Mechanical Properties	
			$\sigma_в$ kg / mm²	δ, %
I	Soft, ductility	AD, AB, AMC, Mg1, AMg2, D31, AD33	Less 30	5-22
II	Medium strength and ductility	D1, AK2, AK4, AK4-1, AK6, AK6-1, BD17, AMg6	30-45	10-15
III	High strength with reduced technological properties	AK8, B98, B95, B96, BAD23	More 45	5

Significant influence on the ductility, mechanical properties and structure of the finished forging parets and stamps is provided by deformation modes such as temperature, rates and degree of deformation. Thermomechanical deformation modes should provide sufficient ductility, similar structure and high mechanical properties.

In the papers [13,16].the technical conditions and thermomechanical modes of deformation of aluminum alloys are given to ensure of these requirements (Table 3).

Table 3. Thermomechanical modes of forging and stamping of aluminum alloys

Alloy Grade	Temperature interval of deformation, ºC	Admissible degree of deformation %		Used forge equipment
		Casting workpiece	Pressed workpiece	
AMn, AMg1, AMg2,AB, AD31, AD33, AD35, AK6, AD0, AD1, 01205	470-300 470-300	70 70	90 90	Hydraulic press Hammer or mechanical press
D1, D1ch, BD17, 1230, AK8	470-370 450-350	60 -	70 60	Hydraulic press Hammer or mechanical press
D20, D21, 1201, AK4, AK4-1, AK4-1ч	470-350 430-320	60 -	70 60	Hydraulic press Hammer or mechanical press
AMg3,AMg4, AMg5, AMg5p, AMg6, B92,	430-320	60	60	Hydraulic press
M40, B92c, 1915, 1913	430-300	-	50	Hammer or mechanical press
B95, B95pch, B96C, B96Cpch, B96C3	430-350 430-320	60 -	60 50	Hydraulic press Hammer or mechanical press
D19ch, BAD1 (1191), D16ch	470-350 430-350	60 -	60 50	Hydraulic press Hammer or mechanical press

From the practical point of view, in the paper [13] it is recommended: "At the deformation of workpieces in the direction perpendicular to an axis (on forming), the value of tolerable deformation which are given in Table 3, have to be reduced for aluminum alloys by 15 - 25%". In order to avoid the formation of a coarse-grained structure, in the course of the ongoing processes of recrystallization, forging and stamping of aluminum alloys, we recommend carry them out with a deformation not less than 15 - 20% in one heating.

In the paper [16] it is noted that "Alloys of reduced strength (σ_B less than 30 kg / mm2), Table 2, as well as the medium strength alloy Aк6 have high ductility, which practically does not depend on the strain rates. Alloys of medium strength (σ_B= 30 – 45 kg / mm2) and high strength (σ_B> 45 kg / mm2) have good ductility», but with the increase in the rates of application of the deformation force from static (up to 0.3 m / s) to dynamic (up to 8.0 m / s), the ductility of these alloys is reduced by 15-20%, which should be taken into account when treatment them on mechanical presses and hammers.

In the paper [5], it was noted that aluminum alloys are less technologically advanced for hot deformation than steel. As relative lengthening δ, the index of ductility, at the forging temperatures in aluminum alloys is lower. Also, the physical and mechanical and thermomechanical properties of their hot deformation are different.

For carrying out experiments, production of stamped forgings from aluminum alloys of the lowered technological plasticity from powder materials SAP1, SAP2, SAP3, SaS1 - 400, will not be considered.

We consider alloys of high technological ductility - AMC, AMg1, AMg2, AMg3, AK6 and alloys of the average technological plasticity - AMg4, AMg5, AMg6, AK4, AK4 - 1, AK8.

The concept of "coefficient of technological ductility" is introduced in order to determine the technology of a particular alloy, which is defined from the following expression:

$$K = (\sigma^{\kappa}_v - \sigma^{n}_v)/(t^{\circ}_n - t^{\circ}_{\kappa}) = \Delta\sigma_B/\Delta t^{\circ} \quad (1)$$

Where σ^{κ}_v, σ^{n}_v - temporal resistance at the temperature of the beginning and end of the deformation, t°_n і t°_{κ} - the temperatures of the beginning and end of the deformation.

Taking into account that the relative lengthening of **δ**, as the index of ductility, at forging temperatures in aluminum alloys is lower than in steel., We can conclude that aluminum alloys are less technologically advanced for hot deformation as their coefficient C is higher than other equal conditions. This is confirmed by the analysis of data presented in Table 4, 5.

Table 4. Thermomechanical characteristics of aluminum alloys and steel

Material	σ_v, MPa			δ, %			ε_{max}, %		
	Temperature °C								
	400	450	500	400	450	500	400	450	500
	Aluminum alloys								
B93	78.5	39.2	29.4	54.0	63.0	74.0	62.0	55.0	40.0
AK4-1	49.0	39.2	19.6	50.0	60.0	44.0	60.0	60.0	50.0
AK8	39.2	31.4	24.5	40.0	35.0	30.0	72.0	72.0	72.0
	Temperature °C								
	1000	1100	1200	1000	1100	1200	1000	1100	1200
	Steel								
20	49.0	39.2	29.4	63.0	59.0	64.0	91.0	92.0	93.0
45	49.0	39.2	29.4	53.0	63.0	64.0	90.0	91.0	92.0
30HGSA	29.4	19.6	9.8	30.0	56.0	60.0	-	-	-

Besides, when developing technological process of production of stamped forgings of aluminum alloys, it is necessary to consider features of hot deformation of the aluminum alloys which are given in the paper [17] and include:

1. Lower ability of defect-free filling of deep cavities of the die by subsidence, than extrusion. This is explained by the deformation scheme during subsidence, in which a significant tensile stress appears, and the deformation scheme during extrusion reduces them to a minimum.

Table 5. The value of the coefficient of technological ductility for a number of aluminum alloys and steel

Alloys	Deformation temperature ° C		Temporal resistance, σ_v, MPa, at deformation temperature, C		Coefficient of technological ductility, C.	Scope angle α
	beginning	end	beginning	end		
AMg6	430	320	58.9	88.3	0.027	1°30′
AD31	470	350	24.5	58.9	0.029	1°40′
АК4	470	350	24.5	58.9	0.029	1°40′
AMg	470	350	39.2	78.5	0.033	1°00′
B95	400	320	58.9	88.3	0.037	2°10′
АК6	470	350	29.4	78.5	0.041	2°20′
B93	430	350	49.0	9.8	0.062	3°30′
BD17	450	380	58.9	9.8	0.057	3°20′
Sт.20	1250	800	19.6	78.5	0.019	1°10′
20H	1200	800	9.8	49.0	0.010	0°40′
30HGSA	1140	830	24.5	68.7	0.014	0°45′
H18n9t	1150	900	29.4	78.5	0.020	1°10′
U7a	1100	850	29.4	83.5	0.022	1°15′
R18	1150	920	24.5	9.8	0.032	1°50′

2. Rather narrow temperature interval of hot deformation which are for various alloys from 80 to 170°C (Table 3).

3. The top limit of deformation temperature interval of the thermo-strengthening alloys is close to upper the permissible temperature limit of heating temperature of alloys at their hardening, therefore strict control of temperature and time of heating of the workpieces is necessary to avoid formation of coarse-grained structure or metal overburning, especially during the heating and deformation of workpieces from low-plastic alloys [18].

4. The high thermal conductivity of aluminum alloys leads to fast decrease in the temperature of the workpieces in a die and the frequent occurrence of "cold" cracks in thin intersections (especially in the line of split stamps) during deformation.

5. The low plasticity of some alloys at deformation temperatures limits the tolerable degree of deformation which leads in some cases to formation of surface cracks and internal delamination in stamped forgings.

6. The small coefficient of drawing and the large expansion coefficient (in comparison with steel) make almost impossible these operations on the stamping equipment when carrying out open stretching.

7. The increased tendency to:

- welding of contact metal layers of the workpiece to the surface of the die engraving at high degrees of deformation, due to low-quality lubrication and chemical activity of aluminum alloys;
- the formation of clamps when filling deep and sufficiently wide cavities and edges due to the relatively large coefficient of friction of the metal on the contact of die figure surfaces. As a result of which the bent of the internal volumes of metal takes place with its deposited layers, which are in contact with the die surface;
- the appearance of folds and clamps at the deformation of pre-bent workpieces in the bending position, as well as during the operation of the open stretching;
- appeared defects of "crack" under edges on stamped forgings, especially at high deformation rates (5-7m/s);

- appearing of zones with coarse-grained structure on intersections of a stamped forging part after the strengthening operation of heat treatment. The cause of which is unevenness of deformation when stamping. To reduce of these zones formation, requires application of technological passages for metal volumes of initial workpiece redistribution.

At metal deformation by the cold or warmed-up up to the low temperature tool, possibilities of observance of the optimum thermomechanical mode are limited because of workpiece cooling during its carrying and further deformation. At the same time deformation resistance increases that causes the needs of use of more powerful equipment and decrease in ductility of metal. Owing to heterogeneity of the temperature field the unevenness of strength properties on all volume of a deformable body is observed, the wear of the tool is increased. Therefore, when determining the temperature interval of deformation, it is predict the inevitable heat loss by the workpiece during transport passages and in the process of deformation.

The degree of cooling of the workpiece depends on their size and the number of passages during the treatment. That is why an additional heating of the workpieces is introduced with a large number of passages, which increases the cycle of the technological process, reduces the quality of the parts and semi-finished products. To exclude the listed factors, it is often used heating to temperatures that is higher than the nominal treatment temperature during deformation of workpieces under normal conditions. It raises the energy consumption, raises the heating time of the workpieces, and also worsens the structure of the metal, reduces its ductility and strength properties, increases the thickness of the scale, degraded or defective layer on the surface of the workpiece. For example, with an increase in the temperature of the heating of titanium alloys from 960 to 1200°C, the average grain size increases from 0.06 to 0.8mm, and the thickness of the alfied layer also grows rapidly: 0.005mm at 850°C and 5 minutes; 0,025mm at 950°C; 0,05mm at 1000°C and 0,11mm at 1200°C.

Cooling of the workpiece in contact with the cold tool reduces the plasticity, greatly increases the deformation effort, especially in the manufacture of parts characterized by a large ratio of surface area to volume. Increasing the effort entails the use of more powerful equipment, the quality of forging is reduced because of the elastic deformation of the "equipment - tool" system. When deformed by a cold or slightly heated instrument in the preform, an inhomogeneous temperature field is formed, zones of difficult deformation arise and deformation localization cells appear. Particularly strong is the heterogeneity of the temperature field, when processing titanium alloys, which thermal conductivity is 5-6 times lower than that of steel.

It is especially important to prevent loss of temperature of the workpiece during hot deformation of metals with a narrow temperature interval of deformation.

The effectiveness of hot volumetric deformation can be increased by maintaining the heat of the stamped workpiece, using heat-shielding coatings (asbestos cladding, asbestos hinges of the suspension type, protective coatings on the basis of glass, graphite, etc.) that reduce the loss of heat when transferred from the stove to deforming equipment and in the process of deformation, increasing the temperature of the heating of stamps. When transporting the workpiece from the furnace, in order to maintain the heating temperature, various designs, heat-shielding metal sheaths are also used.

From the traditional methods of hot deformation in the treatment of metals by pressure, the isothermal is characterized by the fact that the shaping of the heated preform is carried out in the tool heated to the deformation temperature, and the temperature of the heated workpiece and deforming tool is maintained constant, close to the upper limit of the melting temperature, throughout the process.

Deformation of metal under isometric and deformation approaches is characterized by an increase in plasticity compared with plasticity when treated in a cold instrument. This is due to the lower rate of deformation, the lower limit of which is limited only by the productivity of the process. As a result, the time "fixing defects", which arises when metal deformation increases, decreases the temperature voltage in the volume of the workpiece, the deformation becomes more even.

Efforts and the work of deformation decrease in the conditions of isometric deformation, also the amount of released heat reduce too as a result of deformation, which is distributed in the volume of the workpiece rather evenly due to homogeneous deformation. This is especially important in the deformation of metals and alloys, the structure of which strongly depends on temperature changes. The uniform deformation of the workpiece in the absence of zones of the complicated deformation and local overheating due to the thermal effect, as a rule, provides a good and comprehensive treatment of the structure, high strength and plastic characteristics of the metal and reduces dispersion of properties in the volume of the workpiece.

Excluding of the workpiece cooling, it is possible to reduce the deformation temperature in comparison with the usual conditions and to process at a temperature close to the upper limit of the temperature interval for this alloy. For example, reduction of temperature of deformation by 50-200°C for titanium alloys facilitates carrying out deformation and provides to get of high-quality parts, reduces depth of an alfire layer.

Creation of conditions of isothermal deformation allows to carry out stampings in the optimum thermomechanical mode, to use superplastic phenomenon and to give the chance to make stamped forgings of a complex configuration (flanges, brackets, fittings, levers, swings, etc.), with minimum assumptions to mechanical treatment, minimal float, stamping scope 30'... 1°30', to provide a coefficient of metal use 0,8...0,85, Fig. 1. a, b, c.

(**a**) (**b**) (**c**)

Figure 1. Typical forging parts made by isothermal stamping

5. Conclusions

The accuracy of parts obtained under isometric deformation increases significantly due to:

- reduction of elastic deformations of the equipment system, since the resistance to deformation of the metal and the processing effort is reduced;

- reduction of deformation temperature fluctuations, which increases the stability of the geometric dimensions of the machined parts;

- reduction of residual stress that reduces deformation during the cooling and heat treatment and improves quality;

- reduction of the thickness of the defective layer and improvement of the quality of the part surface (semi-finished product) as a result of lesser action of the heated metal with the environment when the temperature deformation is reduced and the use of effective protective and lubricating coatings.

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Modeling of assessment of reliability transport systems

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Abstract: This article presents results of a study based on the analysis of the development of the theory of reliability whose indicators are formulated indicators of transport systems reliability and contributed to building a system of factors determining their reliability. It is established that the formation of the theory of reliability of transport systems today is not completed. Based on the specifics of the systems, new reliability indicators were proposed and substantiated such as emergency downtime and reliability of emergency downtime. On the basis of the performed studies, it was found that the specifics of the transport process require the introduction of emergency downtime close to the recovery time and the reliability of emergency downtime. It is necessary to introduce two close parameters such as the average recovery time and the average emergency idle time. They are associated with the need to distinguish between the idle time of a technological system, or a separate element when a failure occurs, and the idle time that is needed. For the technological links of the transport system, the main purpose of which is to ensure efficient operation transport process, the probability of emergency downtime can serve as a criterion for assessing their reliability.

Keywords: reliability, emergency downtime, probability of emergency downtime.

1. Introduction

The problem of reliability of transport systems is one of the main ensuring and improving the efficiency of their functioning. The reliability parameter of the transport system is one of the main indicators of the quality and efficiency of its operation, it manifests itself in time and reflects changes occurring in the system during the whole period of its operation. To date, the situation with the assessment and ensuring of the reliability of transport by road significantly impedes the achievement of the transport system indicators of transport strategy indicated in the Transport Strategy. The quality indicator in transport offered by scientists today is reliability taking into account mainly only the reliability of technical means, while reliability of performed services is practically not considered. There is also no standardization of reliability in road transport and in reports of motor transport enterprises

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there are no criteria characterizing reliability and efficiency of their work. The formation of the theory of reliability of transport systems is not completed to date. Therefore, the bulk of organizational and technological decisions to reduce the number of failures is based on the knowledge of the methodology for solving traffic safety problems, technical maintenance of vehicles, situational management of motor transport, the theory of reliability of technical systems, risk management, supply chain management and other scientific fields. The coexistence of people and the world of machines depends not only on technical possibilities, costs of technology implementation, legal regulations, but also on social acceptance and people's ability to coexist with technologies [18, 19].

The problem of reliability in transport has significant features and is not limited to the reliability of technical means. It also determined the conditions and laws of all elements of the transport process [15]. The main problems of the theory of reliability are to establish patterns of occurrence of failures and their recovery; determining the quantitative characteristics, methods of calculation of reliability. The most studied in this it is considered theory of reliability technical systems. Principles of reliability of technical objects are adapted to the conditions of reliability of supply chains [5], [17]. Reliability transport systems and road transport process has methodological connection with the reliability of technical systems since to improve the quality of delivery of cargo and passengers as well as in technique applied reservation. There are structural [11] and functional reservation [10], [12]. In reliability theory, in particular, processes occurrence of failures, recovery of production systems elements are described by methods of probability theory [16].

Pronnikov A.S., Druzhynin G.V. consider the reliability of the system based on determining the function of readiness system that consists of n subsystems. In this case the function of readiness system describes the probability of finding the system in working condition at any time [13], [7].

The problem of reliability is complex both in terms of its characteristics and measurements, and its cause-effect displays. Thus the reliability of vehicles is based on the classic approach to reliability that investigates the reliability of all systems and mechanisms that in recent works called "mechanical reliability" [8], and the reliability of the technical maintenance and repair and reliability in the process of commercial exploitation also take into account organizational and economic factors. In reliability theory, considerable attention is given to the impact of damages from insufficient of reliability machines as an economic expression of technogenic risk [14]. Aulin V.V., Golub D.V engaged in issues of legal regulation to provide reliability of functioning transport systems in Ukraine [1], also they have investigated methods for assessing and analyzing the reliability of automobile transport systems [2], [3], [4].

Classical methods of quantitative assessment of indicators of reliability of complex systems [9] applied to systems for which the notion of failure is clearly identified, that system is in one of two states: in a state working or in a state of recovery.

The proposed in the article recommendations are based on the definitions of probability reliability indicators of transport systems.

2. Materials and Methods

The main tasks of reliability theory are the establishment of patterns of occurrence of failures and their recovery, determination of quantitative characteristics, development of methods of evaluation and calculation of reliability. There are two approaches to solving these problems. The first approach is to study statistical the patterns of failure of the same type of technical means in certain operating conditions and is the basis for the establishment of distribution laws of the investigated parameters and obtaining of their numerical characteristics operational reliability.

Found in this way specifications which are used for calculating the reliability of technological systems consist of the types of technical means for which they are identified.

The second approach is aimed at studying the physical nature and mechanism of failures. It serves as a basis for the development of measures to improve the reliability of existing and planned technological systems. This approach is more efficient in terms of identifying physical essence reasons which caused the deviations options below acceptable limits, which means rejection. This path is used where, despite specificity of operation is still possible to obtain the necessary input data, such as the study of the reliability of transport systems.

To obtain analytical expressions of reliability of a transport system, we assume that it operates according to the following scheme: subsystems and elements, which were rejected, begin to recover; there are no restrictions on the number of restorations; failure of one of the elements or subsystems will result in the refusal of the transport system as a whole.

To evaluate the reliability of the elements of transport systems used probabilistic parameters of reliability.

The reliability of the functioning of transport systems and processes of road transport is a complex feature that includes the ability of the system to fulfill the requirements for the number and condition of the cargo carried, the safety of passengers and their luggage, compliance with the schedule of the transport process, as well as support and restoration of a given level of transport service.

One of the parameters of reliability is the probability of failure operation work. Failures in the transport system may be caused by some emergency situations in the functioning of its elements. Multi-transport system can occur in three forms: while eliminating the consequences of the situation in the transport process, when combined parties of their functions, the redevelopment of activity of the participants of the transport process. Any emergency situation caused by the refusal arising in the performance of transportation usually leads to changes in the technology of work its members. Reliability of transport system depends on several factors (Fig. 1).

Some emergency situations in road transport are common, such as a traffic accident or technical malfunction of the vehicle on line [11].

The algorithm of actions and approximate duration of treatment elimination of consequences of the typical situations is standard and is known in advance. Work by the transport process in the mode of elimination of the accident is a reserve (auxiliary) function and work as usual is the main function. Multifunctionality is reflected in the form of performances and methods of solving problems for managing reservation reliability of the transport process and its components.

In this case, based on the fact that at any time t state of the element or subsystem is described by the random vector

$$x(t) = \left[x_1(t), x_2(t)), \ldots x_n(t)\right] \tag{1}$$

which can take two values always at the one-dimensional variable: $x(t) = 1$, if the system or component is in working condition, and $x(t) = 0$ in case of failure. The components of the vector $x(t)$ can be the values of various parameters of the system.

Random vector $x(t)$ is characterized by a probability distribution $F(x_1, ..., x_2, x_n, t)$ i.e. the probability that the $x_1(t) \le x_1, ..., x_n(t) \le x_n$.

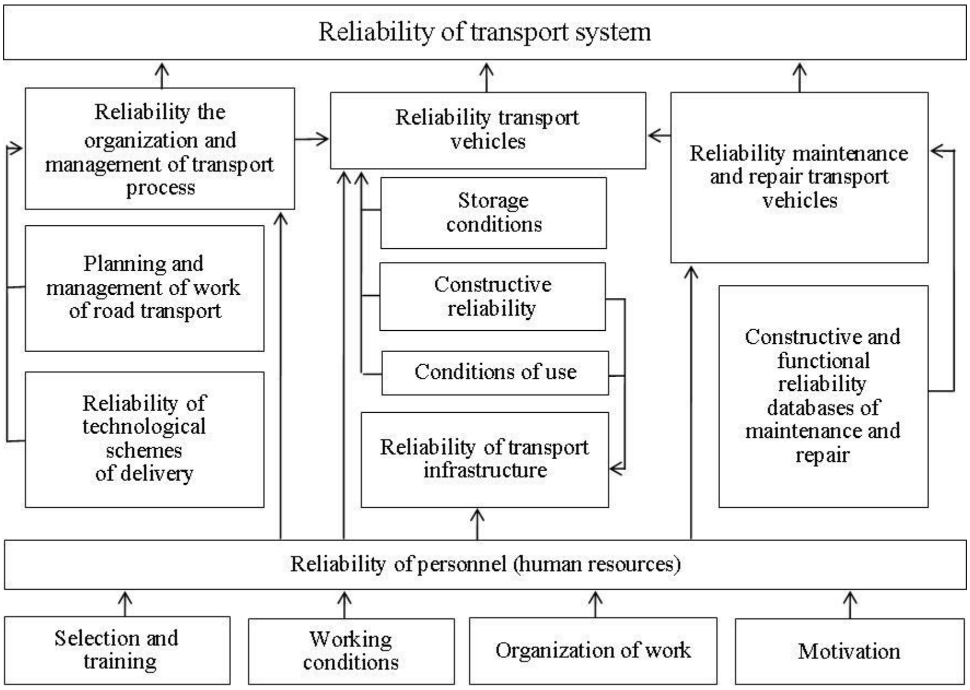

Figure 1. Factors that determine the reliability of transport system.

Each of the limit values that characterize the state of the system meets the mathematical expectation of the objective function *G(t)* at the interval of time $a \le x \le b$.

Reliability of elements that make up the technological system, characterized probabilistic indicators (Table 1), the most important of which are the uptime and recovery time. These options are probabilistic in nature and describe the relevant laws of distribution.

Table 1. Indicators of reliability.

Recoverable elements		
№	**The name of indicator**	**Mathematical expression**
1	Average uptime	$T_u = \int_0^\infty P(t)dt$
2	Average recovery time	$T_{ar} = \int_0^\infty \tau \, d\nu(\tau) = \int_0^\infty G(\tau) d\tau$
3	Reliabilities	$P(t) = Bep(T \ge t)$
4	Failure rates	$\lambda(t) = \frac{f(t)}{P(t)} = \frac{d \ln P(t)}{dt}$
5	Reliabilities for the time (0, τ)	$\nu(t) = Bep(T_B \langle \tau)$
6	The probability of no recovery time (0, τ)	$G(\tau) = 1 - \nu(t) = Bep(T_B \ge \tau)$
7	The density of probability of recovery the time τ	$\nu(t) = V \langle \tau)$
8	The intensity of recovery the time τ, τ_i – the duration of recovery of i-th failure, *n*- the number of failures	$\mu(\tau) = \frac{\nu(\tau)}{1 - V(\tau)}, \quad \mu = \frac{n}{\tau_i}$

Transport systems relating to renewable systems that are characterized by intervals periodically alternating correct operation and restore during the failure. Because of this indicators of reliability is selected in such a way that they can be would be to assess the reliability of individual elements, and generally renewable systems consisting of different types of elements.

Indicator of reliability which taking into account the uptime T_u and downtime τ_d is readiness coefficient:

$$K_R = \frac{T_u}{T_u + \tau_d}, \tag{2}$$

and the coefficient of failure:

$$K_f = 1 - K_R = \frac{\tau_d}{T_u + \tau_d}. \tag{3}$$

In Fig. 2 presented the dependence of the readiness coefficient and the coefficient of failure of uptime and downtime consumer.

In view of the data Table 1 we get

$$K_R = \frac{\int_0^\infty t \cdot f(t)dt}{\int_0^\infty t \cdot f(t)dt + \int_0^\infty \tau \cdot dV(\tau)}, \tag{4}$$

$$K_f = \frac{\int_0^\infty \tau \cdot dV(\tau)}{\int_0^\infty t \cdot f(t)dt + \int_0^\infty \tau \cdot dV(\tau)} \tag{5}$$

i.e. two parameters are characterized by distribution law uptime and recovery time and reflect the probability of finding components or systems in working order or in a state of failure, respectively.

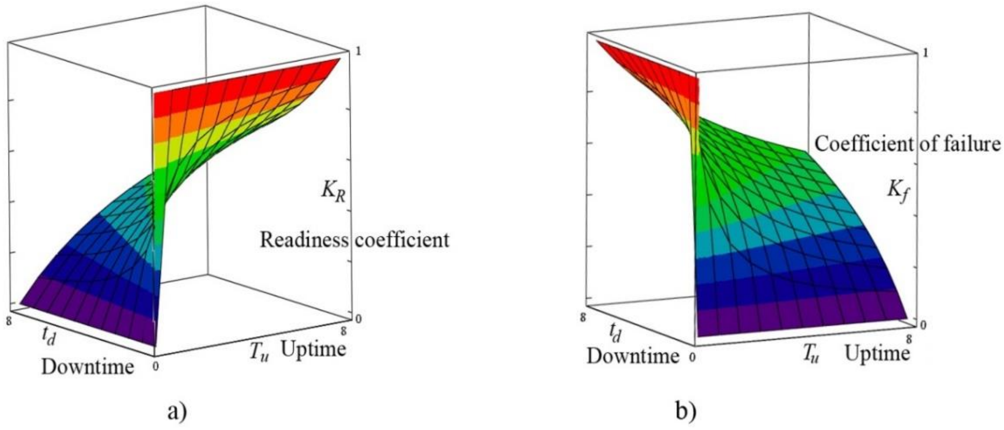

Figure 2. Dependence of the readiness coefficient and the coefficient of failure of uptime and downtime: a) dependence of the readiness coefficient of uptime and downtime; b) dependence of the coefficient of failure of uptime and downtime.

The relative time of consumer's downtime by reason of failure of the system over a period of work.

$$\overline{P}(e) = \frac{t_D}{T_{co}} = \frac{t_D}{t_D + T_{UP}}, \tag{6}$$

where: t_D is downtime of consumer for over a period of work; T_{UP} is uptime for a certain period.

Indicator $\overline{P}(e)$ of (6) is the probability of stimulated (emergency) downtime and form with a probability of a working state of complete group of events:

$$\overline{P}(e) + P(t) = 1 \tag{7}$$

These terms define more precisely the probabilistic nature of the indicators of reliability. They take into account the frequency of occurrence of failure and downtime and represented more comfortable by using.

Any considered technological scheme can be represented as a system composed of a number of elements. If the i-th element of the system has been in operation for the time T_E then this value consists of alternating time intervals, correct operation t_{co} and recovery time T_r. However, the recovery failure T_r does not fully reflect the time of consumer in forced waiting for service. This specificity characteristic for the transport process requires the introduction of another indicator that comes close to recovery time, namely, time of emergency downtime t_{ed}. Significantly it affects the type of the distribution of the random variable on the accuracy of results in calculations for reliability.

For example, the exponential distribution law uptime element or some technological system indicates that the flow of failures can be adopted the simplest.

Be noted the basic properties of the simplest flow failures:

a) failure rate is constant (λ = const) and average uptime:

$$T_u = \frac{1}{\lambda} A \tag{8}$$

b) density of probability of time intervals between the neighboring failures:

$$f(t) = \lambda \cdot exp(-\lambda t) \;, \quad f(t) = \lambda \cdot exp(-\lambda t) \tag{9}$$

c) probability of getting n events in the time interval $[t, t + \Delta t]$ gets according to Poisson:

$$P_n = \frac{1}{n!}(\lambda t)^n exp(-\lambda t) \tag{10}$$

where λt is the average number of failures in an interval of duration t;

d) the probability of absence of failures in the interval duration τ, which starts at a random time determined by the equation:

$$P_0 = exp(-\lambda t). \tag{11}$$

3. Results

The simplest flow failures and recoveries in transport technological systems can be quite completely described by three numerical indicators of reliability, which are important to get to practical use. These characteristics are the average intensity of failures λ_{av}, average recovery time T_{ar} and the average emergency downtime t_{av}. The introduction of two close parameters: the average recovery time T_{ar} and the average emergency downtime t_{av} is associated with the necessity of the separation time finding in state of downtime technological system or a separate element with the appearance of failure and downtime of consumer.

Probability of emergency downtime defined by the formula:

$$\overline{P}(e) = \frac{t_{ME}}{t_{ME} + T_{co}}, \tag{12}$$

where t_{ME} is the mathematical expectation of time of forced (emergency) downtime, $t_{ME} \approx t_{aed}$; T_{co} is the time of correct operation during the observation time; $T_{co} + t_{ME} = T_o$. is the observation time;

Or

$$\overline{P}(e) = \frac{n \cdot t_d}{N \cdot T_o} = \lambda \cdot t_d = \frac{t_d}{T_u}, \tag{13}$$

where n is the number of failures of elements of the system during the observation time T_o.; N is the number of elements of the system which are under the observation.

From (13) implies that the probability of emergency downtime represents size of relative of time of emergency downtime and therefore can be used to determine the economic damage caused by interruptions in the functioning of technological systems.

The probability of emergency downtime linked to probability of faultless work with the following ratio. With exponential distribution law uptime

$$P(t) = exp(-\lambda t) = exp\left(\frac{t}{T_u}\right) \tag{14}$$

whence

$$\lambda = -\frac{\ln P(t)}{t}, \quad \overline{P}(e) = \lambda t_d \tag{15}$$

If the probability of faultless work P(t) is given, then $\overline{P}(e) = \lambda_{av} t_{ed}$.

4. Discussion

Thus, specificity which is typical for transport process requires the introduction time of emergency downtime t_{ed}, which is close to the time of recovery. This indicator can be attributed to one of the main numerical reliability features that characterize a simplest flow failures and recovery in transport technological systems. The introduction of two close parameters: the average recovery time T_{ar} and the average emergency downtime t_{aed} is associated with the necessity of the separation time finding in state of downtime technological system or a separate element with the appearance of failure and downtime of consumer.

For technological parts of the transport system, the main purpose of which consists in maintenance conditions for effective functioning of the transport process, the probability of emergency downtime can serve as a criterion for evaluating their reliability.

5. Conclusions

An important indicator to assess the reliability of renewable transport systems is the probability of an emergency downtime, which reflects both the frequency of failure and the idle time.

From the practical point of view, the above models allow us to determine the general probability of a forced idle or other reliability measure for virtually any scheme of the transport process, and on this basis to assess its reliability either in absolute value of the indicator, or with the help of economic expression of reliability in the form, for example, mathematical expectation of damage.

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Optimization of machinery operation modes from the point of view of their dynamics

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Abstract: This paper presents an analysis and synthesis of optimization methods of machinery dynamic modes. Theoretical studies have shown that in order to find optimum, one must define a differential equation describing the motion of the system, which would ensure the most advantageous dynamic regime determined by the stationary value of the corresponding functional. The definition of this equation must be carried out while machinery construction is taking place, as its physical parameters and layout form the basis of these differential equations. Such approach requires the introduction of certain principles significantly affecting the development of optimization methods justified in this paper. To solve the problem of optimal machinery modes, it is more suitable to perform a separation of complex motion by its dynamic properties Suppose that the complex motion can be devided into the motion of the machinery unit as a whole, to the static displacements of its elements as solid bodies, to the increasing and damping components of motion and to the vibrational component. The findings of the study indicate that the most advantageous machinery dynamic mode is determined by the conditions of the technological process, which would ensure its highest productivity, the lowest energy consumption and other optimal technical and economic indicators. This regime corresponds to the motion of the unit as a whole, that is, to the variation in the quasi-cyclic coordinates. The vector of external forces applied to the machinery is reduced to the initial conditions of its motion; homogeneous differential equations are considered further. The fundamental system of their solutions depends on the initial conditions of motion generated by external systems.

Keywords: machinery dynamics, operation system damping, technological process.

1. Introduction

The analysis techniques methods to study the motion of machines are critical in machine design process as such analyses should be performed on design concepts to optimize the motion of a machine arrangement. A focus is placed on the application of kinematic theories to real-world machinery. The main task is bridge the gap between a theoretical study of kinematics and the application to practical mechanisms [1-5]. Science and technology problems of machinery dynamics have been becoming increasingly important every year. Especially a lot of them arise while creating and operating heavy machinery that have significant linear dimensions, masses and moments of inertia of movable links that are under the influence of transient loading. Dynamic process simulation differs from purely steady-state simulation in that the former requires the mechanical construction of process items be taken into account; the amount of mechanical detail being dependent upon the particular application.

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The reason for this is that dynamic mass, energy and momentum balances have to be continuously updated [6-8]. In such conditions, even small accelerations of the movable links lead to the appearance of considerable inertia forces causing large dynamic loads on the elements of machinery and designs. The study of dynamic processes in machinery and the creation of methods for calculating machinery taking into account current dynamic loads and links elasticity acquire special importance with the increasing speed of modern machinery, which ensures their high productivity [9-11].

Machinery dynamics includes the complex tasks of modern machine building and, despite the rather wide coverage in the specialized literature [12-16], requires further comprehensive study both for explaining dynamic processes taking place in machinery, establishing their regularities, and for developing reliable calculation methods. The wide development of computer technology makes it much easier to solve these problems and makes many of them accessible to engineering practice. At the same time, much attention should be paid not only to the design of machinery, but also to their dynamic adaptation to the operating conditions by optimizing their operating modes according to dynamic criteria.

2. Materials and Methods

Suppose that machinery constructive elements be formalized by square matrices: inertial $K = \|k_{ij}\|_1^m$, stiffness of elastic elements $C = \|c_{ij}\|_1^m$ and attenuation coefficients $B = \|b_{ij}\|_1^m$. If the state of the machinery at a point of time t is determined by the column vector of the generalized coordinates q the column vector of the generalized velocities $\dot{q}$, then its energy properties will be expressed by quadratic forms of the form:

$$E = \frac{1}{2}\dot{q}^T K\dot{q}, \quad \Pi = \frac{1}{2}q^T Cq, \quad \Phi = \frac{1}{2}\dot{q}^T B\dot{q}, \tag{1}$$

here T - a sign of transpose.

Suppose that Lagrangian corresponding to the forms (1) has the form:

$$L = L(q_1, \ldots, q_m; \dot{q}_1, \ldots, \dot{q}_m), \tag{2}$$

and let the determinant

$$\left|\frac{\partial^2 L}{\partial\dot{q}_s \partial q_i}\right| \neq 0, \quad (s = 1, \ldots, m; i = 1, \ldots, m). \tag{3}$$

Then the differential equations of machinery motion can be written in the form:

$$\ddot{q}_s = \varphi_s(t, q_i, \dot{q}_i), \quad (s = 1, \ldots, m; i = 1, \ldots, m). \tag{4}$$

If $q_1 = x_1, \dot{q}_1 = x_2, \ldots, q_m = x_{2m-1}, \dot{q}_m = x_{2m}$, then the system (4) will have a normal form of the form:

$$\dot{x}_i = f_i(x_1, \ldots x_n; t), \quad (n = 2m; i = 1, \ldots, n). \tag{5}$$

As coefficients, the system of equations (5) includes combinations of matrix elements K, C, B through forms (1), Lagrangian L and system (4). We represent these combinations in the form of a column vector $p \in P$, where P – parameter space with dimension k, bounded by a certain region. Let's give equations (5) a vector form:

$$\dot{x} = f(x, t, p), \tag{6}$$

here t belongs to some open interval $a < t < b$, which ends are real numbers; f – vector function completely defined in the region of $D(n+1)$ - dimensional space.

It has been supposed that requirements of the motion quality are formalized in the form of k functionals, depending on the machinery power mode and its structural elements in the form:

$$I_i = \int_{t_0}^{t_1} U_i[f(x, t, p)]dt, \quad (i = 1, \ldots, k; k < n). \tag{7}$$

Functionals (7) can express in the mathematical form the conditions for the highest productivity of machinery, the smallest modules of the elastic forces of its links, the decay of transient processes in the shortest time, and many other important technological and dynamic conditions. So, if a machinery operating cycle is presented in the form of a cyclogram with a cycle time T, then $I = T$, and its maximum performance is achieved at $T \to \min$. If the functional (7) is written with respect to the largest maximum modulus of elastic forces developed during the transient process

$$I = \max_{1 \le i \le n} \max_{0 \le t \le T} |x_i|, \tag{8}$$

then, its smallest value

$$\min I = \min_{c} \max_{1 \le i \le n} \max_{0 \le t \le T} |x_i| \tag{9}$$

also corresponds to the optimal dynamic mode.

Usually a machinery operating process is determined by the decay time of the transitient component of elastic oscillations t_{tr}. Then $I = t_{tr}$, the achievement of $\min t_{tr}$ optimizes the operating process by the decay time. Functionals (7) can also be written with respect to the consumption of fuel or energy. In this case, energy modes of the machinery units are optimized.

Thus, the problem of optimal dynamic modes lies in the fact that it is necessary to define such a differential equation (6), which realization would ensure the most favorable dynamic regime, determined by stationary value of functionals (7).

The differential equation (6) corresponding to the optimal mode must be defined in the process of machinery design, because its physical parameters and layout form the basis of these differential equations.

3. Results

The mathematical and practical complexity of problem solving requires the introduction of some new principles that significantly affect the development of methods for optimizing processes.

3.1. The principle of generalized input

Let's define the following Euclidean norms for the equations of motion (5):

$$\|x\| = \sum_{i=1}^{n} |x_i|; \tag{10}$$

$$\| f(x)\| = \sum_{i=1}^{n} | f_i(x_1, \ldots, x_n)|. \tag{11}$$

It has been supposed that on $f_i(x_1, \ldots, x_n)$, $(i = 1, \ldots, n)$ are imposed conditions under which

$$\frac{\| f(x)\|}{\|x\|} \to 0 \quad \text{at} \quad \|x\| \to 0. \tag{12}$$

Then, on a certain interval of argument variation belonging to the entire numerical axis, we can pass to a linear differential equation of the form:

$$\dot{x} = Ax + F(t). \tag{13}$$

In this equation $A = \|a_{ij}\|_1^n$ – a constant matrix of its coefficients, $F(t)$ – is a vector function of the external forces applied to machinery links.

The matrix A with its elements usually characterizes machinery, including the operation system. It is natural that different elements of the matrix correspond to a different quality of motion and that external forces influence this quality. In order to improve the machinery motion in a certain sense, the matrix A can be changed, or the vector function $F(t)$, or both.

It has been supposed that the design parameters of the machinery are changed so that they can be analytically represented in the form of the matrix $B_k = \left\| b_{ij} \right\|_1^n$. Let us write the equation of the unit motion in the form:

$$\dot{x} = B_k x . \tag{14}$$

We subordinate equations (13) и (14) to the same initial conditions, given in the form of a column x_0. We require that the solutions of these equations coincide everywhere on the interval $0 < t < \infty$. On this basis, we assume that the left-hand sides of equations (13) and (14) are equal to each other. Then:

$$(B_k - A)x = F(t) . \tag{15}$$

Let us show that when the equation (15) is satisfied, the solutions of equations (13) and (14) will be identical. Let us write the solution of the equation (13) in the form:

$$x = e^{At} x_0 + \int_0^t e^{A(t-\tau)} F(\tau) d\tau . \tag{16}$$

Substituting the value x from the equation (16), we reduce the equation (15) to the integral:

$$F(t) = (B_k - A)e^{At} x_0 + (B_k - A)\int_0^t e^{A(t-\tau)} F(\tau) d\tau . \tag{17}$$

As the kernel of the equation (17) is a function of the form

$$K(t,\tau) = (B_k - A)e^{A(t-\tau)} , \tag{18}$$

then its resolvent is written as

$$R(t,\tau) = \sum_{m=1}^{\infty} (B_k - A) \frac{(t-\tau)^{m-1}}{(m-1)!} = (B_k - A)e^{B_k (t-\tau)} . \tag{19}$$

If the matrices A and B_k commute, then the solution of the equation (16) will have the form:

$$F(t) = (B_k - A)e^{At} x_0 + \int_0^t (B_k - A)^2 e^{B_k (t-\tau)} e^{A\tau} x_0 d\tau . \tag{20}$$

After completing the quadrature, we get:

$$F(t) = (B_k - A)e^{B_k t} x_0 . \tag{21}$$

Comparing the results of (21) with the equality (15), we note that the initial coordinate x must simultaneously be the solution of equation (14), that is, equal to $e^{B_k t} x_0$.

Thus, the parameter variation of a machinery unit in a dynamic sense is equivalent to the variation of external forces acting on it. As the column vector $F(t)$ in the equation (13) is the system input, then the matrix equation (15), stating that the input is dynamically equivalent to its parameters variation, expresses the principle of generalized input. This principle, first of all, shows that the optimization of the power mode can be achieved through the rational choice of machinery design parameters.

3.2. The principle of motion separation by their dynamic properties

In classical mechanics, complex motion is devided into simple ones, as a rule, according to their geometric (kinematic) properties. To solve the problem of optimal machinery modes, separation of complex motion by its dynamic properties is more suitable. Suppose that the complex motion can be devided into the motion of the machinery unit as a whole, to the static displacements of its elements as solid bodies, to the increasing and damping components of motion and to the vibrational component.

The displacement of the object as a whole relatively to its center of inertia can be calculated with the help of equations (4) if they contain quasi-cyclic coordinates, understood as A.I. Lurie [17]. Let the generalized forces for quasi-cyclic coordinates have the form:

$$Q_{r+s} = Q_{r+s}(q_1, \ldots, q_r), \quad s = (1, \ldots, m-r), \tag{22}$$

but a quasi-cyclic pulse

$$p_{r+s} = \frac{\partial T}{\partial \dot{q}_{r+s}}, \quad s = (1, \ldots, m-r). \tag{23}$$

Then

$$\dot{P}_{r+s} = Q_{r+s}(q_1, \ldots, q_m), \quad s = (1, \ldots, m-r). \tag{24}$$

This system is solvable with respect to quasi-cyclic generalized velocities and its integration will determine the motion of the object as a whole.

Let the vector-column of external forces in equation (13) $F(t) \in W^{(r)}H^{(\alpha)}(M; a, b)$, that is, let them belong to some class of functions having $[a,b]$ derivatives of r, satisfying inequality

$$\left|F^{(r)}(t) - F^{(r)}(t')\right| \le M\left|(t - t')\right|^{\alpha}, \quad (t, t') \subset [a, b], \tag{25}$$

here $0 < \alpha \le 1$. In other words, $F(t)$ can be a polynomial, for example, of degree r:

$$F(t) = \sum_{i=0}^{r} F^{(i)}(0)\frac{t^i}{i!}. \tag{26}$$

Differentiating equation (26) $r + 1 = n$ times and setting $z = x^{(n)}$, we obtain:

$$\dot{z} = Az. \tag{27}$$

Defining the initial conditions $x(0) = x_0$ and $z(0) = z_0$, we have:

$$z_0 = x_0^{(n)}. \tag{28}$$

The solution of the equation (27) with the initial conditions (28) can be written in the form:

$$z = e^{At}z_0, \tag{29}$$

or

$$x^{(n)} = e^{At}x_0^{(n)}. \tag{30}$$

Integrating the equation (30) n times, we find:

$$x(t) = e^{At}\left[x_0 + \sum_{i=0}^{n-1} A^{-i-1}F^{(i)}(0)\right] - \sum_{i=0}^{n-1}\sum_{j=i}^{n-1} A^{-i-1-j}F^{(j)}(0)\frac{t^i}{i!}. \tag{31}$$

The first item on the right-hand side of this equation is the solution of the homogeneous equation (27) with the initial conditions (28):

$$z_0 = x_0 + \sum_{i=0}^{n-1} A^{-i-1}F^{(i)}(0). \tag{32}$$

The second item is a particular solution of the equation (13) if its right-hand member is the function $F(t)$. In fact, the general solution of the equation (13) has the form:

$$x = e^{At}x_0 + \int_0^t e^{A(t-\tau)}F(\tau)d\tau . \tag{33}$$

If $F^{(n)}(t) = 0$, then, integrating by parts, we get:

$$\int_0^t e^{A(t-\tau)}F(\tau)d\tau = e^{At}\sum_{i=0}^{n-1} F^{(i)}(0) - \sum_{i=0}^{n-1} A^{-i-1}F^{(i)}(t) . \tag{34}$$

Taking (26) into account, we have:

$$\sum_{i=0}^{n-1} A^{-i-1}F^{(i)}(t) = \sum_{i=0}^{n-1}\sum_{j=i}^{n-1} A^{-i-1-j}F^{(j)}(0)\frac{t^i}{i!} . \tag{35}$$

Putting in the equation (13) $\dot{x} = 0$, we define the so-called "quiescent" state, that is, the change in the coordinates of the system under the influence of the static action of the forces:

$$x = -A^{-1}F(t) . \tag{36}$$

If the law of external forces variation is given in the form

$$F(t) = const , \tag{37}$$

then (36) is a pure solution of the equation (13). Such a solution determines system deformability, understood in the most general sense, for example, as the elastic displacements of its elements. If external influences are variable in time, then the deformability of the object occurs at a certain rate.

Differentiating the equation (13) with respect to t , supposing that $x = 0$ and taking (35) into account, we obtain:

$$x = -A^{-1}F(t) - A^{-2}\dot{F}(t) . \tag{38}$$

Continuing deformability definition in the same order, i.e, equating to the zero all dominant derivatives, we find that the static displacements of the system are expressed by a particular solution (36).

Thus, if the external forces of the machinery unit belong to some fairly wide class of time functions, then the inhomogeneous differential equation (13) can be regarded as homogeneous with the initial conditions (32). By this there are distinguished the static displacements (35) and the dynamic component of the motion, determined by the solution (30) in the form:

$$x(t) = e^{At}\left[x_0 + \sum_{i=0}^{n-1} A^{-i-1}F^{(i)}(0) \right]. \tag{39}$$

The further separation of complex motion and its optimization, depending on the design parameters of the machinery unit, require the creation of a new form of a fundamental system for solving differential equations.

3.3. Fundamental system for solving differential equations in parameter space

As the external force vector, written in the differential equation (13), can be brought dynamically to the initial conditions (32) and to the static component of the motion (26), then we will consider the homogeneous equation (13). Suppose that there is a matrix of the form:

$$A = \begin{pmatrix} 0 & 1 & 0 & \cdots & 0 \\ 0 & 0 & 1 & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & \cdots & 1 \\ -p_n & -p_{n-1} & -p_{n-2} & \cdots & -p_1 \end{pmatrix}. \tag{40}$$

Then the homogeneous differential equation (13) can be written as follows:

$$x^{(n)} + p_1 x^{(n-1)} + p_2 x^{(n-2)} + \ldots + p_n x = 0 . \tag{41}$$

If we replace the variable by setting

$$x = y e^{-\frac{p_1}{n} t} , \tag{42}$$

then the equation (41) takes the form:

$$y^{(n)} + b_2 y^{(n-2)} + b_3 y^{(n-3)} + \ldots + b_n y = 0 . \tag{43}$$

Then replacing t with the value $\tau = t\sqrt{b_2}$ we will have:

$$y^{(n)}(\tau) + y^{(n-2)}(\tau) + g_1 y^{(n-3)}(\tau) + \ldots + g_{n-2} y(\tau) = 0 , \tag{44}$$

here

$$g_j = \frac{b_{j+2}}{b_2\left(\sqrt{b_2}\right)^j} , \quad (j = 1, \ldots, n-2) . \tag{45}$$

We put in the equation (44)

$$y^{(n)}(\tau) = U(\tau) . \tag{46}$$

We reduce it to an integral equation of the form:

$$U(\tau) + \int_0^{\tau} K(\tau, y) U(\eta) d\eta = y^{(n-1)}(0) K(\tau) - y^{(n-2)}(0) K'(\tau) - \ldots - y^{(n-k)}(0) K^{(k-1)}(\tau) - \ldots - y(0) K^{(n-1)}(\tau) , \tag{47}$$

which core is

$$K(\tau, \eta) = \sum_{n=0}^{n-1} \frac{(\tau - \eta)^n}{n!} . \tag{48}$$

In the monograph [18] it was proved that the resolvent of the equation (47) has the form:

$$R(\tau,\eta) = \sum_{m=1}^{\infty} (-1)^m \sum_{i=0}^{m} \sum_{k=0}^{m-1} \ldots \sum_{p=0}^{m-i-\ldots-l} \binom{m}{i} \binom{m-i}{k} \ldots \binom{m-i-\ldots-l}{p} g_1^p g_2^l \ldots g_{n-2}^i \frac{\tau - \eta^{2m+p+2l+\ldots+(n-2)i-1}}{[2m + p + 2l + \ldots + (n-2)i - 1]!} . \tag{49}$$

As in the resolvent (49) there are coefficients g_j $(j = 1, \ldots, n-2)$, related to the parameters p_i $(i = 1, \ldots, n)$, then the solution of the equation (46) and, hence, of the equation (36) is written in terms of object parameters - this solution forms a fundamental system in the parameter space, which form is presented in the monograph [19].

3.4. Separation of motion in parameter space

In the work [18] it is proved that the core (48) and the resolvent (49) are divided into two items:

$$K(\tau, \eta) = K^*(\tau, \eta) + L(\tau, \eta) , \tag{50}$$

$$R(\tau, \eta) = R^*(\tau, \eta) + Q(\tau, \eta) , \tag{51}$$

here

$$K^*(\tau,\eta)=\frac{(\tau-\eta)}{1}+g_2\frac{(\tau-\eta)^3}{3!}+\ldots+g_{n-2}\frac{(\tau-\eta)^{n-1}}{(n-1)!},$$
$$R^*(\tau,\eta)=\sum_{m=1}^{\infty}(-1)^m\sum_{i=0}^{m}\sum_{k=0}^{m-1}\ldots\sum_{l=0}^{m-i-\ldots-p}\binom{m}{i}\binom{m-i}{k}\ldots\binom{m-i-\ldots-p}{l}\times$$
$$\times g_2^l g_4^p\ldots g_{n-2}^i\frac{(\tau-\eta)^{2m+2l+4p+\ldots+(n-2)i-1}}{[2m+2l+4p+\ldots+(n-2)i-1]!} \quad (52)$$

If we substitute core and resolvent values into the integral equation (47), then its solution with respect to $y(\tau)$ will also consist of two parts:

$$y(\tau)=y_1(\tau)+y_2(\tau), \quad (53)$$

and the function $y_1(\tau)$ is formed by solving a differential equation of the form:

$$y_1^{(n)}+y_1^{(n-2)}+g_2y_1^{(n-4)}+\ldots+g_{n-2}y_1=0. \quad (54)$$

With a proper choice of the coefficients $g_2, g_4, \ldots, g_{n-2}$ the solution of the equation (54) will be an undamped, bounded by module almost periodic function of time. However, the original equation (43) has a time-increasing solution, as can be seen from its Hurwitz matrix

$$\begin{pmatrix} 0 & 1 & 0 & \cdots & 0 \\ g_1 & 1 & 0 & \cdots & 0 \\ g_3 & g_2 & g_1 & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & \cdots & g_{n-2} \end{pmatrix}. \quad (55)$$

As the minors of this matrix are $\Delta_1=0$, $\Delta_2=-g_1<0$, $\Delta_3=-g_1^2<0$,… at positive g_j $(j=1,\ldots,n-2)$, then the solution of the equation (43) increases with time. But the solution of the equation (43) is the sum of two functions (53), in which $y_1(\tau)$ at certain conditions it does not increase by the module. Consequently, the function increasing in time is $y_2(\tau)$. Passing to the argument t and taking into account the substitution (42), we write:

$$x=[y_1(t)+y_2(t)]e^{-\frac{p_1}{n}t}. \quad (56)$$

Thus, the complex motion of machinery unit elements is divided according to the formula (56), into an increasing component of $y_2(t)$ and on a purely oscillatory component – $y_1(t)$.

3.5. Process, optimal by attenuation

If we take as the beginning of the transient process $t=0$, then by its duration we mean the time from the moment when the oscillations start to the moment of equilibrium onset. The duration of the damped oscillatory process depends essentially on the design parameters of the object. Consider a three-mass system with attenuation k_{12} and k_{23}, proportional to the speed of oscillations. The differential equation of the oscillatory process has the form:

$$x^{(4)}+p_1\dddot{x}+p_2\ddot{x}+p_3\dot{x}+p_4x=0, \quad (57)$$

here

$$p_1=k_{12}\frac{m_1+m_2}{m_1m_2}+k_{23}\frac{m_2+m_3}{m_2m_3}, \quad (58)$$

$$p_2=c_{12}\frac{m_1+m_2}{m_1m_2}+c_{23}\frac{m_2+m_3}{m_2m_3}+k_{12}k_{23}\frac{m_1+m_2+m_3}{m_1m_2m_3}, \quad (59)$$

$$p_3 = (k_{12}c_{23} + k_{23}c_{12})\frac{m_1 + m_2 + m_3}{m_1 m_2 m_3}, \quad (60)$$

$$p_4 = c_{12}c_{23}\frac{m_1 + m_2 + m_3}{m_1 m_2 m_3}. \quad (61)$$

In this equation discrete masses are denoted by m_i $(i = \overline{1,3})$ and the stiffnesses of the elastic links by c_{12} and c_{23}.

The attenuation of the process is determined by the coefficients p_1 and p_3. These coefficients, and hence the duration of the process, depend not only on k_{12} and k_{23}, but also on all parameters of the system, that is, on the machinery design. Therefore, even with sufficiently large attenuation coefficients, not optimal selection of machinery design parameters reduces their efficiency, and vice versa - with small attenuation coefficients, but with a suitable ratio of discrete masses and rigidities, it is possible to realize rapidly damped in time process. If we pass to the phase space, then the optimal process by attenuation is determined as follows.

The system makes free attenuating oscillations; its initial state is given by the vector $x(0)$, determining the position of the point in the $2n$-dimensional phase space. It is necessary to use the system parameters so that the transition of the phase point to the origin of coordinates proceeds in the shortest time interval.

To solve the problem, we turn to the equation (56). First of all, the function increasing in time should be suppressed $y_2(t)$. Such an operation is considered in detail in the monograph [20]. However, it is often possible to solve the problem correctly in a purely intuitive way. The condition $y_2(t) = 0$ takes place if the equation (44) becomes the equation (62). To do this, all odd coefficients g_i $(i = 1,3,5,\ldots)$ must be turned into zero. These coefficients are associated with system parameters by conditions (42) and (45). Then the solution of the differential equation of the transient, written in the form (56), will be the following:

$$x = y_1(t)e^{-\frac{p_1}{n}t}. \quad (62)$$

The second step in the process optimization is the choice

$$\max_{p_1 \in P} p_1. \quad (63)$$

Then it is necessary that the function $y_1(t)$ is bounded by module. In the general case the function $y_1(t)$ is the solution of the differential equation of small oscillations of conservative systems.

3.6. Optimization of the vibrational item

Let us consider a more general form of the equation (54). Having substituted the variable y with the variable x, we get:

$$x^{(2n)} + a_0 x^{(2n-2)} + a_1 x^{(2n-4)} + \ldots + a_{n-1}x = 0. \quad (64)$$

A similar equation is used in the machinery dynamics with elastic links without taking energy dissipation into account. Substituting the argument

$$\tau = \frac{t}{\sqrt{a_0}}, \quad (65)$$

the differential equation (64) is reduced to the form

$$x^{2n} + x^{(2n-2)} + c_1 x^{(2n-4)} + \ldots + c_{n-2}x = 0, \quad (66)$$

here

$$c_i = \frac{a_i}{\left(\sqrt{a_0}\right)^i}, \quad (i = 1, \ldots, n-2). \tag{67}$$

As the coefficients $c_i \quad (i = 1, \ldots, n-2)$ are connected by means of the formula (67) with the system parameters, then, defining them in the form of inequalities

$$\begin{aligned} & c_1 < \frac{n-1}{2!n}, \\ & c_2 < \frac{(n-1)(n-2)}{3!n^2}, \\ & \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots, \\ & c_k < \frac{(n-1)(n-2)\ldots(n-k)}{(k+1)!n^k}, \\ & \ldots\ldots\ldots\ldots\ldots\ldots\ldots, \\ & c_{n-1} < \frac{1}{n^n} \end{aligned} \tag{68}$$

here $2n$ – the order of the differential equation, it is possible to guarantee the boundedness by module of the oscillatory item of the solution [15].

However, the optimization of this process must be continued until the maximum deviation is minimized or until the maximum elastic forces of the system are minimized. The fundamental system for solving the equation (66) in the parameter space $c_i \quad (i = 1, \ldots, n-2)$ is presented in the monograph [18] in the form of functions $x_0, x_1, \ldots, x_{n-1}$, expressing the system reaction to the defined initial values of the function and its derivatives up to $(n-1)$ - inclusively. Thus

$$x = \sum_{k=0}^{n-1} x_k. \tag{69}$$

Let the fundamental solution system form n-dimensional linear normed space X, i. e. $x_k \in X$ $(k = 0, \ldots, n-1)$ with the norm

$$\|x\| = \sum_{k=0}^{n-1} |x_k|. \tag{70}$$

As the module of functions is variable in time, the norm (70) also varies. Suppose that there is an absolute maximum of the norm, that is,

$$\max_k \max_{x \in X} \|x\| = \max_k \max_{x \in X} \sum_{k=0}^{n-1} |x_k|. \tag{71}$$

Assuming also that

$$\sup_{x \in X} |x_k| = \max_k \max_{x \in X} |x_k|, \tag{72}$$

and

$$\sum_{k=0}^{n-1} \max_k \max_{x \in X} |x_k| \geq \max_k \max_{x \in X} \sum_{k=0}^{n-1} |x_k|, \tag{73}$$

we will minimize the value of the form:

$$\|\bar{x}\| \geq \|x\|, \tag{74}$$

here

$$\|\bar{x}\| = \sum_{k=0}^{n-1} \max_k \max_{x \in X} |x_k| \quad . \tag{75}$$

The value (75) corresponds to the norm (70) under the most unfavorable conditions of motion in accordance with the so-called principle of unfavorable collinearity.

If x_k $(k = 0, \dots, n-1)$ – are the elastic forces of machinery links while transient is taking place, then the definition

$$\min_{c_i} \|\bar{x}\| = \min_{c_i} \sum_{k=0}^{n-1} \max_k \max_{x \in X} |x_k| \tag{76}$$

means the optimal problem solution, which ensures the lowest amplification factor.

Parameters (68) by which the system is optimized are proper fractions. The fractional denominator grows considerably with the increase in the index i, which makes it practically feasible to optimize them using PC. It should be noted that almost always it is possible to determine such a region of the form:

$$c_i \in C_p, \quad (i = 1, \dots, n-2), \tag{77}$$

which satisfies the condition (76).

4. Discussion

The solution of the problem of optimal modes in the machinery dynamics consists in the following:

1. The most advantageous machinery dynamic mode is determined by the conditions of the technological process, which would ensure its highest productivity, the lowest energy consumption and other optimal technical and economic indicators. This regime corresponds to the motion of the unit as a whole, that is, to the variation in the quasi-cyclic coordinates.

2. The vector of external forces applied to the machinery is reduced to the initial conditions of its motion according to the formula (32); homogeneous differential equations are considered further. The fundamental system of their solutions (69) depends on the initial conditions of motion generated by external systems. If the initial conditions are represented in the form of a row matrix of the form

$$x_0^T = (x(0), \dot{x}(0), \dots, x^{(n-1)}(0)), \tag{78}$$

and the fundamental system of solutions, corresponding to the ordinary initial conditions, in the form of a matrix-column

$$\tilde{x} = \begin{pmatrix} x_{(0)} \\ x_{(1)} \\ \dots \\ x_{(n-1)} \end{pmatrix}, \tag{79}$$

then

$$x = x_0^T \tilde{x} . \tag{80}$$

3. In real machinery, there are always reasons generating internal friction, and, consequently, energy dissipation. By turning parameters (45) with odd indexes into zero, one can intensify the process attenuation and thereby eliminate the possible accumulation of perturbations, for example, in the case of repeatedly short-time technological modes.

4. The choice of the most advantageous parameters c_i $(i = 1, \dots, n-2)$, connected by means of the formula (67) with the coefficients of the differential equation (64), will lead to the lowest values of the amplification factor of the elastic links.

5. Conclusions

Considering the row matrix (78) as the coordinates of the n-dimensional Euclidean vector, that is, $x_0^T \in E^n$, and $\tilde{x} \in E^n$ – as an alternating vector of the same space, we can state that the scalar product (80) is generated by the vector (78). If we fix x, that is the vector (79), then we can form the norm of the vector x_0^T, which generates the scalar product (80) or the bilinear function of x_0^T and $\tilde{x}$. In this case, it is assumed that the norm of the vector x_0^T is the maximum of the values (80) on the ordinary sphere $\|\tilde{x}\| \le 1$, i.e.: $\|x_0^T\| = \max\limits_{\|\tilde{x}\| \le 1} x_0^T \tilde{x}$.

As the vector items x_0^T depend on external forces and system parameters, one must strive to choose their lowest values, which correspond, in general, to the smallest forces. However, the desire to define small forces should not worsen the technical and economic performance of the machinery.

According to the generalized input principle, the optimization of the power mode can be achieved by the variation of machinery design parameters. In this case, the maximum value of external forces and their duration, especially the small, creating a large dynamic effect, become less noticeable.

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Simulation of the tribological properties of motor oils by the results of laboratory tests

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Abstract: The purpose of this paper is to present a study aimed at creating a calculation-experimental method for calculating the wear of lubricated friction units of machines based on a two-factor wear model (contact pressure – sliding velocity) with identification of their wear resistance parameters. To achieve this purpose it was necessary to obtain theoretical dependences for identification of wear resistance parameters in the wear models based on laboratory tests with various geometrical contact diagrams of lubricated samples. Analysis of known studies has shown that existing approaches required solution of complex systems of integral-differential equations or numerical methods that are unacceptable in the engineering practice. In this study a model of the wear of lubricated friction units of machines in conditions of boundary friction was obtained in a form of dependence of the wear rate on the dimensionless complexes of contact pressure and sliding velocity. The basis was the solution of the inverse wear of the contact problem for various geometrical schemes of contact. The contact diagrams corresponded to the actual forms of contact of the friction units of the machines: rolling bearings and sliding bearings, gears and others. The following equations were taken as the defining equations: the equilibrium equation in the contact, the continuity equation in the contact, and the approximating experimental dependence for the wear of materials. As a result of the solution, simple algebraic formulas for calculating and identifying the parameters of the patterns of wear have been obtained. It was found that the installation has been developed for tests by means of program Solid Works and the numerical algorithm of the decision of a task on the basis of program MathCad. The findings of the study contribute explain the influence of determining factors of sliding velocity and load on bearing wear. The practical value of the research is that the obtained results were recommended for predicting wear of lubricated friction units of engines at the design stage and optimizing their design and operational parameters.

Keywords: wear, lubrication, laboratory testing scheme, problem of contact wear, contact pressure, engine.

1. Introduction

The main reason of the breakage of the units of friction of the machines is wear process. The lubrication is the most effective way to increase wear resistance of friction units of machines. Therefore the first basic task of the researchers, designers and technologists is the creation of conditions of preservation and restoration of lubrication in contact. The success of researches of wear process of the lubricated surfaces is determined by test methods. Among known test methods of friction units with lubrication the most perfect are tests which are under the four-ball scheme. This is standard method

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and it is widely applied all over the world [1]. The main defect of the test is absence of the mathematical description of the wear process on this scheme. It brings only to qualitative description of the process. Besides four -ball test it has been used only standard material from become 52100 steel balls. But scheme of the external contact two balls not adequately prototypes the contact of the real interfacing the of friction units of the machines. In this connection it was put problem in given work to give the quantitative description of the wear process samples for different schemes of the tests and materials. The base of the decision of the problem there is decisions direct and inverse war contact tasks for contact and wear samples of the different form [2-4]. And as a result it was received the mathematical models of the wear process with using the accounting programs.

In work [2] analysis of variation of the contact pressure during wear was carried out at a nonlinear form of the wear. It was taken the dependence of wear rate on the factors of velocity and contact pressure. As a result it has been proposed the algorithm for solving the wear-contact problem for the thrust bearing.

It has been made in the solution of an inverse wear-contact problem for identifying parameters of the wear rate on contact pressure and sliding velocity [3]. It was derived the expressions for determining wear parameters on the basis of experimental dates of wear. But the assumption of permanence of the wear according to the test didn`t let us use this solution for the test schemes with a variable contact.

In paper [4] it has been carried out the theoretical analysis of kinetics of wear of spherical specimens on a four-ball tests friction machine. It was made the equation of wear kinetics corresponds to differential equation. But the described kinetic model has a phenomenological character with the principles of open thermodynamic systems.

In work [5] it is presented the theory of ball wear for a four-ball wear testing scheme While this work it has been solved the direct problem of determining the dimensions of the worn place depending on the sliding distance and the inverse problem of determining the parameters of the wear model based on the data of wear tests. Solutions have been obtained for the initial zero and nonzero contact patch and they are based on the assumption of a uniform distribution of the pressures over the contact area. It has been provided the examples of numerical solutions of the problem of contact wears under consideration.

In work [6] it was considered the problem of developing a calculation-experimental method for calculating wear of a sliding bearing based on a two-factor wear model with identification of wear resistance parameters To identify parameters of wear resistance in the wear model, a calculation-experimental method for determining calculated dependences of wear resistance parameters was developed on the basis of the wear test by the "cone - three balls" scheme.

The task of this work was to create a calculation-experimental method for calculating the wear of lubricated friction units of machines which were based on a two-factor wear model (contact pressure – sliding velocity) with identification of their wear resistance parameters. As a result, it was necessary to obtain theoretical dependences for identification of wear resistance parameters in the wear models based on laboratory tests with various geometrical contact diagrams of lubricated samples.

2. Technique of construction of models of wear process on an example of the four-ball scheme

The scheme of tests is considered at which top sphere rotates and bases with effort Q to three motionless bottom spheres (Fig. 1). As a result of tests a is formed for the bottom spheres the circular platform of wear process of radius. It is neglected the influence of elastic deformations of spheres on formation of a platform of contact. The zone of contact top and the bottom spheres is filled by the lubricant material.

The model in the form of dependence of intensity of wear process on two parameters is accepted for the description of the wear process of the bottom spheres under the accepted scheme of test. These parameters are loadings and speeds of sliding:

$$I = \frac{du_w}{dS} = k_w \left(\frac{\sigma}{E^*} \right)^m \left(\frac{VR^*}{\nu} \right)^n , \quad (1)$$

where σ – contact pressures; E^* - the resulted module of elasticity of materials of contacting spheres; V - the relative speed of sliding; R^* - the resulted radius of contacting spheres; ν - the kinematic viscosity of a lubricant (at 100°C); u_w - the linear wear of the bottom spheres; S - the way of friction for the bottom spheres; k_w, m, n – the parameters of model of wear process.

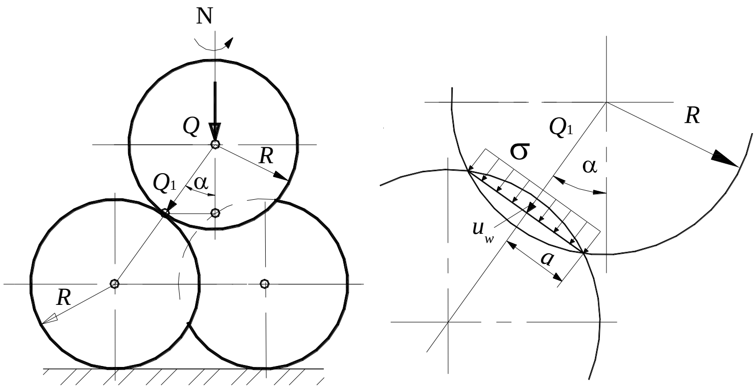


Figure1. Scheme of four-ball wear test.

Dependence of linear deterioration u_w on radius of a platform of wear process a of the bottom spheres is defined from geometry of crossing of spherical surfaces (Fig. 1):

$$u_w(S) = \frac{a(S)^2}{2R}. \quad (2)$$

From tests it is possible to receive the dependence of radius of a circular platform of wear process on a way of friction in the form of sedate approximation:

$$a(S) = cS^{\beta}, \quad (3)$$

where c, β – the parameters of approximation.

At uniform distribution of contact pressure on a platform of contact from a condition of balance in contact of spheres it will be received such formula:

$$\sigma = \frac{0{,}4082Q}{\pi a^2}. \quad (4)$$

After substitution (2-4) in (1) and integration, we shall receive:

$$\frac{c^2 S^{2\beta}}{2R} = K_W \left(\frac{0,4082Q}{c^2 \pi E^*}\right)^m \left(\frac{VR^*}{\nu}\right)^n \frac{S^{1-2\beta m}}{1-2\beta m}. \quad (5)$$

Whence m from a condition of feasibility of the equation (5) at any S it will be determined:

$$m = \frac{1-2\beta}{2\beta}. \quad (6)$$

For a finding of parameter n tests are spent at two values of speed of sliding V_1 and V_2 and two groups of data with parameters receive:

$$a = c_1 S^{\beta_1}; \quad a = c_2 S^{\beta_2} \quad (7)$$

It has been considered the problem of determining parameters of wear according to the results of testing specimens with the contact area changing in the process of wear. The change of the wear area causes the change of the contact pressures. The parameter m in expression characterizes the rate of change of contact. It is related to the parameter β of the experimental dependence (3) which is characterized by the of change of the contacting area during wear. The relationship between m and

β in the model of wear (1) is uniquely described by relation. Since the sliding velocity V in the considered ratios it does not depend on the friction path S, it does not affect parameters n and β during the tests. In this case, the change in the slip velocity V affects just the scale factor c in expression (1). The above reasoning is confirmed by the test results.

At constant test specifications for the wear process $\beta_1 = \beta_2 \approx \beta$ is accepted. Substituting expressions (7) in (5), we shall receive system of two equations:

$$\left.\begin{aligned} \frac{c_1^{\,2} S^{2\beta}}{2R} &= K_W \left(\frac{0,4082Q}{c_1^{\,2}\pi E^*}\right)^m \left(\frac{V_1 R^*}{\nu}\right)^n \frac{S^{1-2\beta m}}{1-2\beta m} \\ \frac{c_2^{\,2} S^{2\beta}}{2R} &= K_W \left(\frac{0,4082Q}{c_2^{\,2}\pi E^*}\right)^m \left(\frac{V_2 R^*}{\nu}\right)^n \frac{S^{1-2\beta m}}{1-2\beta m} \end{aligned}\right\} \quad (8)$$

For definition of parameter n we shall divide the first equation into the second and after transformations we shall receive:

$$n = (2m+2)\frac{\lg(c_1/c_2)}{\lg(V_1/V_2)}. \quad (9)$$

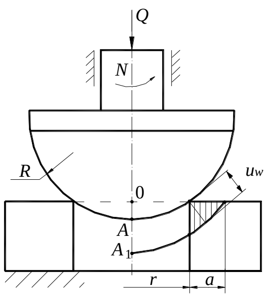
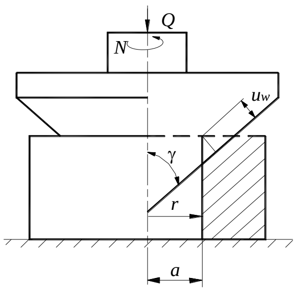
For a finding of factor K_w we shall take advantage of one of the equations (8):

$$K_w = \frac{\beta c_1^{2m+2}}{R}\left(\frac{2\pi E^*}{0,4082Q}\right)^m \left(\frac{\nu}{V_1 R^*}\right)^n. \quad (10)$$

As a result of the solution, simple algebraic formulas for calculating and identifying the parameters of the patterns of wear have been obtained.

3. Results of modelling of wear process at tests under schemes: a sphere-ring, a cone-ring

Table 1. The schemes of tests and parameters of models of wear process.

Parameters	Ball – ring	Cone – ring
		
m	$m = \frac{1-\beta}{\beta}$	$m = \frac{1-\beta}{\beta}$
n	$n = (m+1)\frac{\lg(c_1/c_2)}{\lg(V_1/V_2)}$	$n = (m+1)\frac{\lg(c_1/c_2)}{\lg(V_1/V_2)}$
K_w	$K_w = \frac{\beta c_1^{m+1} r^{m+1}}{R}\left(\frac{2\pi E^*}{Q}\right)^m \left(\frac{\nu}{V_1 R^*}\right)^n$	$K_w = \beta c_1^{m+1}\cos\gamma \left(\frac{2\pi r E^*}{Q}\right)^m \left(\frac{\nu}{V_1 R^*}\right)^n$

The scheme of contact of four spheres is used for test interfaces of non-similar form from steel materials (gearings, cam mechanisms, bearings, etc.) Using testing materials of sliding bearings, including polymeric for interfaces of the similar form (sliding bearings, hinges, etc.) the sphere - a ring is offered to use for tests the scheme. The third scheme of tests a cone - a ring is offered for expansion of types of tests of constructional materials Manufacturing of the conic sample more simple, than manufacturing of a sphere. It has been used the form (1) as the general form of model of wear process

The schemes for calculation and results of definition of parameters of models of wear process are shown in Table 1.

4. The device for tests

Wear tests can be performed for a variety of purposes, in particular: a qualitative comparison of lubricants and construction materials for wear; study of the mechanism and type of wear; definition of model parameters which describe the quantitative laws of the process. Here we consider the methods of laboratory testing for wear with the determination of the parameters of wear models, with the help of which in the future it becomes possible to estimate the estimated wear of real lubricated friction units of a car.

For quantitative definition of parameters of models of wear process by results of laboratory researches the device for tests on the basis of four - ball machines of friction has been designed by means of program Solid Works (Fig. 2). The basic unit of the device is the working unit (Fig. 2). The top sphere 1 is based on the aperture of the end of a spindle. It does not suppose palpation of a sphere at rotation and increases rigidity of unit. The bottom three spheres in 2 diameter of 12.7 mm are installed on tempered surface of a support 4.

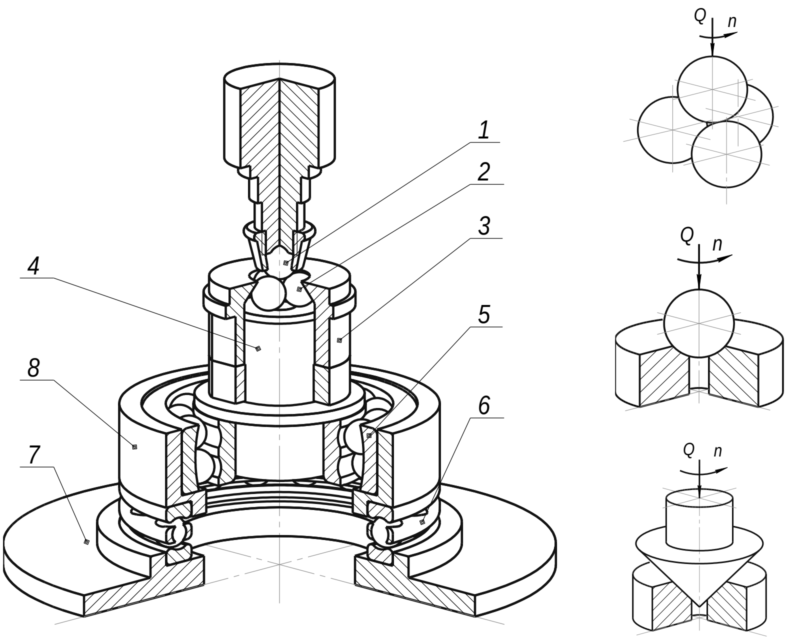


Figure 2. The device for tests (Solid Works).

The top plane of a nut 3 is used as measuring base for measure size of wear. The wear is measured without disassembly of the device. The microscope MPB-2 with by division of 0.05 mm is used for measurement of the sizes of spots of wear process on the bottom spheres. After measurements of wear process of test proceed under the accepted program. Exception of skews and self-installation at contact of spheres is provided with spherical bearing 5. The persistent bearing 6 is used for measurement of the moment of friction. The top sphere is loaded by means of the lever with the transfer attitude k =3.25. The thermometer of it is applied to the control of temperature to a zone of friction of spheres. A sensitive element of the thermometer (pos. 9, Fig. 2) is placed in a support under the bottom spheres. During these tests it has been carried out the continuous control of temperature of greasing over a zone of friction.

5. Results of tests of lubricant and constructional materials

Initial data:
The scheme 1. Four balls.

1. $R = 6{,}35$ mm.
2. $Q = 65$ N .
3. N_1 =200 rev/min ($V_1 = 0{,}077$ m/s), N_2 =600 rev/min (V_2 =0,19 m/s).

4. A material of balls: steel 52100.
5. A lubricant - motor oil Formula Q8, ν =12 mm²/s (API- SJ/CD, SAE - 15W/40).

The scheme 2. Ball-ring.

1. $R = 6{,}35$ mm, $r = 3$ mm
2. $Q = 65$ N
3. N_1 =200 rev/min (V_1 =0,063 m/s), N_2 =600 rev/min (V_2 =0,19 m/s).

4. A material of a ball - steel 52100; rings - aluminium.
5. A lubricant - motor oil Formula Q8, ν =12 mm²/s (API- SJ/CD, SAE - 15W/40).

The scheme 3. Cone-ring.

1. $\gamma = 30^0$, r =3 mm.
2. $Q = 65$ N .
3. N_1 =200 rev/min (V_1 =0,063 m/s), N_2 =600 rev/min (V_2 =0,19 m/s).

4. A material of a cone - steel 45; rings - bronze CuSn10P.
5. A lubricant - motor oil Formula Q8, ν =12 mm²/s (API- SJ/CD, SAE - 15W/40).

After tests under three specified schemes the results presented in table 2 have been received.

Table 2. Dependence of the sizes of a platform wear processes *a* (mm) from duration of tests (numerator-200 rev/min, a denominator-600 of rev/min).

Scheme	30 min	60 min	90 min	120 min	150 min	180 min
1	0.35	0.4	0.43	0.48	0.5	0.51
	0.48	0.54	0.63	0.65	0.67	0.68
2	0.125	0.2	0.25	0.275	0.35	0.4
	0.25	0.35	0.4	0.475	0.5	0.5
3	0.125	0.2	0.225	0.25	0.275	0.3
	0.225	0.325	0.375	0.4	0.425	0.45

Results of tests have been processed by means of programs Excel and MathCad. The calculated parameters of models of wear process for three schemes of tests are presented in Table 3.

Table 3. The models of wear.

Four balls	$I = 0{,}025\left(\frac{\sigma}{E^*}\right)^{1{,}62}\left(\frac{VR^*}{\nu}\right)^{0{,}135}$
Ball - ring	$I = 4{,}7\cdot10^7\left(\frac{\sigma}{E^*}\right)^{4{,}19}\left(\frac{VR^*}{\nu}\right)^{0{,}441}$
Cone - ring	$I = 2{,}19\cdot10^8\left(\frac{\sigma}{E^*}\right)^{4{,}37}\left(\frac{Vr}{\nu}\right)^{0{,}403}$

In Fig. 3 it is shown the dependences of intensity of wear process on contact pressure (1) and speed of sliding (2) for three schemes of the tests, which were constructed on models (Table 3).

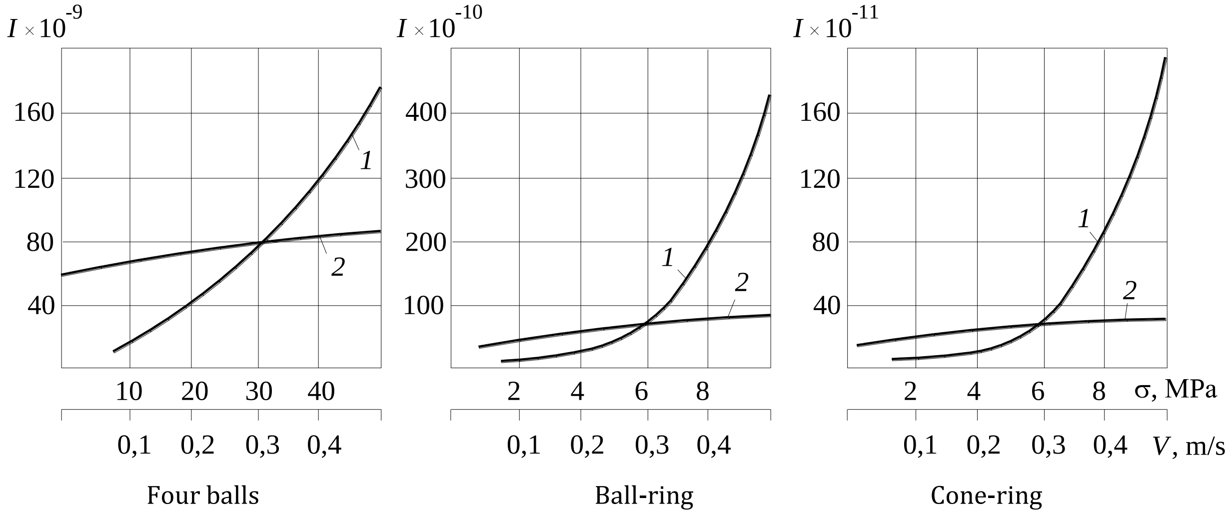


Figure 3. Dependences of intensity of wear process on contact pressure – 1 and speed of sliding – 2.

The received technique of construction of models of wear process can be used for designing units of friction and optimization of their parameters.

6. Conclusions

Test of lubrications by the four-ball machine without definition of models of wear process, has qualitative character. Also it can be used only for the limited types of materials and forms of interfaces.

The wear test methods are offered to three schemes with definition of parameters of multifactorial models of wear process. It is designed by means of program Solid Works the device for tests.

The numerical algorithm is developed for calculation of parameters of models and comparison of properties of lubricants for units of friction by means of program MathCad.

The obtained patterns of wear allow us to quantify the value of the intensity of wear depending on: load characteristics, properties of structural and lubricant materials, kinematic and design parameters. Quantitative values of the wear rate allow you to optimize the values of the specified parameters and operating conditions of tribo interfaces by the criterion of maximum durability.

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The tribology of the car: Research methodology and evaluation criteria

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Abstract: From a position of structural and power theory of friction and wear, it is possible to apply the method of Contact Electrical Resistance (CER) for a complex research of the processes in a-zone of frictional contact. The purpose of this paper is to present a construction of friction node and drive mechanism of friction machine. As a result of the reported study the regularities of changes the CER and tribomechanical indices for non-metal friction couples in dependence on loading parameters and lubricating media were received. Also, the method of determination the range and level of normal wear and critical points of transmission to damage in accordance with kinetics of wear changes is proposed. The interrelation between geometrical, physical and mechanical properties, processes of formation, transformation and destruction of secondary structures, tribotechnical indices and CER in dependence on operation regimes of friction couples.

Keywords: friction, wear, adaptability, secondary structures, electric resistance.

1. Introduction

The range of normal mechanochemical wear characterized by dynamic equilibrium of the processes of secondary structures (SS) formation and destruction - the range of structural adaptability (SA) - is the most important for the theory and practice of friction and wear. SS appearance is the thermodynamic basis of fundamental regularities of friction, lubricating action and wear, and the formation of a great SS gamma - the Science of Materials basis [1].

As the investigations [2] have shown, the criterion of contact electrical resistance of friction couple (CER) meets such demands. As the physical basis of the given criterion for the estimation of friction and wear processes served that, as investigations have shown, the SS films forming on the friction surface are non-conducting and minimize the surface destruction Values of resistance and wear depend on their type, structure and properties. The distinctive feature of friction geo modifiers from other additives consists in adding some substances to the samples tribomating which launch the self-organization processes [3-6]. Different types of additives of synthetic and natural origin change the oil physical thermal-oxidative ability due to the formation of materials surface layers enabling to decrease the friction coefficient and additional dissipation of friction energy [7-9], resulted in increased oil lubrication ability but wear resistance does not change greatly. That why it is necessary to seek for some new compositions with more positive characteristics for tribomating. A wide range of tribological characteristics and repairing compositions with additives of natural origin which are based on serpentinite-based powder properties have been studied in the papers [10-12].

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The aim of this work was to examine CER criterion application to study surface destruction (wear, damage) mechanisms, to reveal correlative dependence between structural state of friction surfaces (SS type and properties) and tribotechnical indices and CER. For the purpose, an electrical scheme for CER measuring has been developed which makes it possible to measure its value in the range 0-1,0 K Ω with the solving capability of 0,1 Ω.

2. Materials and Methods

Materials and Methods should be described with sufficient details to allow others to replicate and build on published results. Please note that publication of your manuscript implicates that you must make all materials, data, computer code, and protocols associated with the publication available to readers. Please disclose at the submission stage any restrictions on the availability of materials or information. New methods and protocols should be described in detail while well-established methods can be briefly described and appropriately cited.

Research manuscripts reporting large datasets that are deposited in a publicly available database should specify where the data have been deposited and provide the relevant accession numbers. If the accession numbers have not yet been obtained at the time of submission, please state that they will be provided during review. They must be provided prior to publication.

Interventionary studies involving animals or humans, and other studies require ethical approval must list the authority that provided approval and the corresponding ethical approval code.

3. Results

The measuring of wear intensity (№) was being carried out by a traditional means. As a control value of given parameters, their stabilized value after each loading stage of friction node were taken. The structure of friction surfaces of specimens was investigated on a scanning electronic microscope Cam Scan, SS chemical composition was determined on a microanalyzer of Cam Scan system and an attachment Link 860.

The experiments were carried out on serial machines and specially created friction machine [13-15] with the different schemes of contact in the ranges of sliding velocity V=0,2 –12 m/s. On the specially created friction machines sliding velocity and unit load were changed fluently (see Figure 1) with a help of hydraulically driven (it is shown in Figure 1).

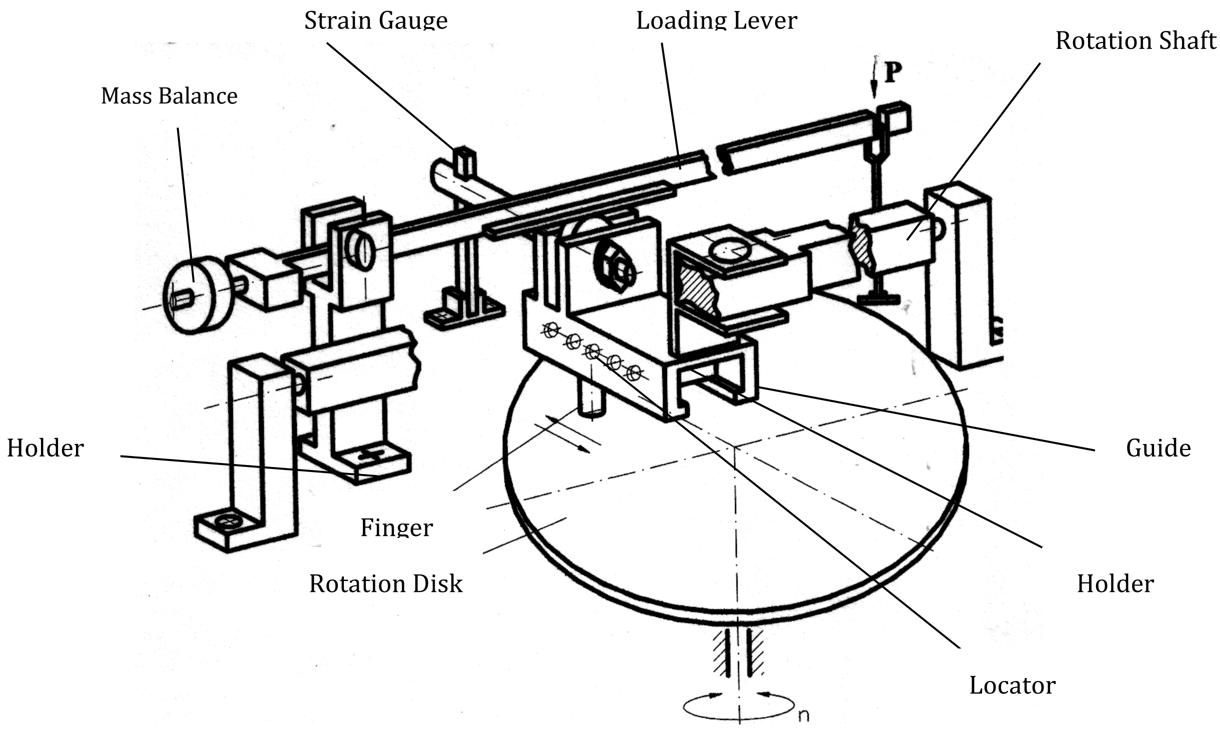

Figure 1. General appearance of friction node and loading mechanism.

The specimens made of steel 45 (42...45 HRC, Ra -0,125μm) were investigated. The specimen diameter - 6 mm. The disk material - steel 40H (48...50HRC, Ra - 0,125μm). Disk diameter 250 mm. The chemical composition of researched steels are shown in Table 1 and Table 2. As a working medium an inactive lubricant – petroleum jelly with "Anglamol-99" addition (3.2% S; 1.8% P; 0.7% N) of concentration was used.

Table 1. Chemical composition of steel 45, %.

C	Si	Mn	Cr	Cu	Ni	P	S	Fe
0.42…0.45	0.17…0.37	0.50…0.80	0.25	0.3	0.3	0.035	0.040	Rest

4. Discussion

The results of wear and CER measuring are shown in Figure 2. The data of investigation of friction surfaces chemical composition are given in Table 3.

Table 2. Chemical composition of steel 45, %.

C	Si	Mn	Cr	Cu	Ni	P	S	Fe
0.36-0.44	0.17-0.37	0.50-0.80	0.80-1.10	0.30	0.30	0.035	0.035	Rest

Table 3. Elemental analysis of friction surfaces, %.

<table>
<tr><td rowspan="2">Element</td><td colspan="6">Investigation section in Figure3</td></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">uninstalled processes</td><td>SS-1</td><td>SS-2</td><td rowspan="2">setting the second type</td><td rowspan="2">thermo-chemical processes</td><td rowspan="2">destruction</td></tr>
<tr><td>mechano-chemical</td><td>processes</td></tr>
<tr><td>S</td><td>1.314</td><td>0.111</td><td>0.973</td><td>0.109</td><td>0.474</td><td>0.009</td></tr>
<tr><td>P</td><td>0.496</td><td>0</td><td>0.288</td><td>0</td><td>0.381</td><td>0</td></tr>
<tr><td>Mn</td><td>0.356</td><td>0.264</td><td>0.452</td><td>0.409</td><td>0.412</td><td>0.440</td></tr>
<tr><td>Si</td><td>0.234</td><td>0</td><td>0.126</td><td>0.063</td><td>0.220</td><td>0.141</td></tr>
<tr><td>Fe</td><td>93.29</td><td>99.01</td><td>950.06</td><td>94.47</td><td>960.81</td><td>98.02</td></tr>
</table>

As Figure 2 reveals, there are the ranges of loading parameters sliding velocity V (SA regime) in which the value W is minimum and stable, R - maximum and stable (sections 2, 3, 5). On reaching the critical loads (damage regime) the wear speeds to maximum, R - to zero (sections 4, 6; W and R unstable value at the transition from mechanochemical processes to thermochemical (section 4) are explained by the intensive destruction of surface films, the deterioration of their mechanical, physical and chemical and geometrical characteristics. In the volumetrical destruction regime (section 6) the layers of the initial metal begin to contact. The received analogical regularities for the other friction couples prove that there is a correlative dependence between W, R parameters and SS type in SA range. This dependence is explained W, R parameters as characteristics of one and the same process (SA), one and the same object (SS).

Determination method of range and level of friction couples normal wear became possible due to the strict devision of processes into normal wear processes and damage processes (Figure 3). The method consists in that SA range (Figure 3 CD) is equalled to the range of maximum and stable value CER (Figure 3 AB). The normal wear level (Figure 3 point E) is determined by the measuring of wear value at any value of loading parameters (Px, Vx) from SA range by a traditional means

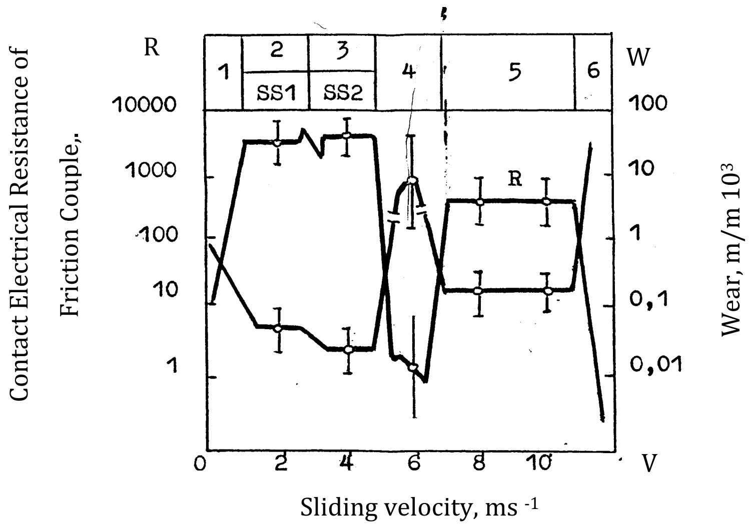

Figure 2. Diagram of dependence of wear and contact electrical resistance of friction couple on sliding velocity in friction of 45 steel specimen over 40H steel disk (P=8MPa, lubricant petroleum jelly with "Anglamol-99" addition).

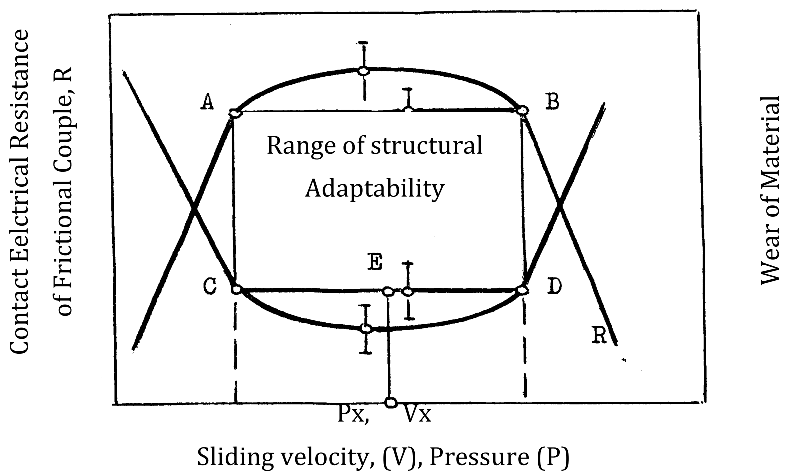

Figure 3. Method of definition the range and level of materials structural adaptability in friction.

Proposed method possesses the high resolving power and sensitivity, permitting in SA range to fix transitional processes from SS the first type to SS the second type and to damage processes. By the CER quantity and nature change the leading type of wear is determined.

In the SA range SS propertied are changed in wide limits under the effect of external parameters. That shows the great possibilities of their internal reconstruction. To estimate SS state and properties, thé criteria R R_{in}^{-1}, *t* are proposed. These criteria are based on the measuring of CER and the time of its stabilization (Fig. 4).

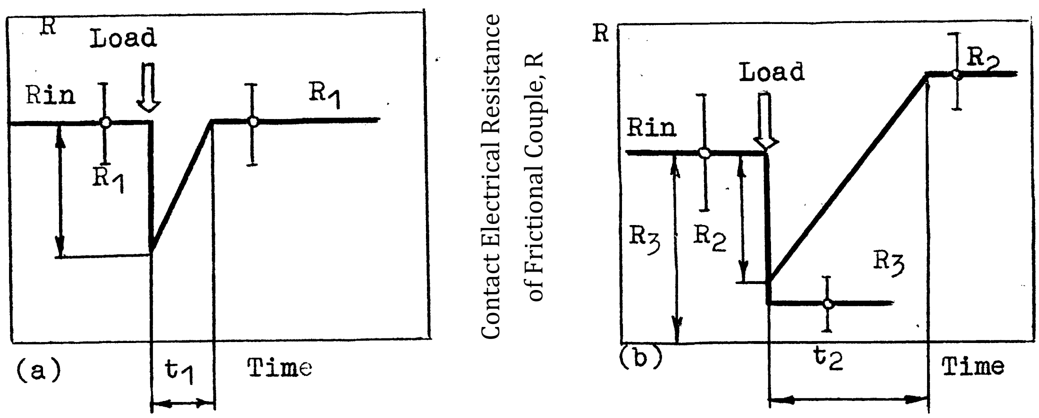

Figure 4. The nature of change of contact electrical resistance initial value (Kin) and the determining of parameters AR R_{in}^{-1} and t in friction in regimes of structural adaptability (a), (b) run-in (R_p) and passage to damage (R_3).

After each loading stage (P, V) the fall of CER initial value (R_{in}) on the value ΔR and in a time t its stabilization on a new level occurred (R_1, R_2, R_3). In SA range (Figure 4(a) the criteria ΔR R_{in}^{-1} and *t* are stable and minimum (durable, stable SS), in run-in regimes (Figure 4(b) – R_2) and volumetrical destruction (Figure 4(b) - R_3) their values are maximum and unstable. For the researched friction couple the values of given criteria: SA regime - ΔR_1 R_{in}=0,15…0,40; t_1=7…15 min; run-in regime - ΔR_2 R_{in}^{-1} =0,45…0,85; t_2=20…40 min; volumetrical destruction regime ΔR_3 $R_{in}^{-1}\approx 1$; $t\to\infty$.

Friction and wear regimes are determined by the relation of velocity of formation V_f and destruction velocity of SS. In SA regime, V_f and V_d are equal and equality of forming time t_f and destructing time td of SS attests about this (Figure 5(a)). In the regime of transition to damage V_f, V_d (t_f, t_d) (Figure 5(b)). t_f, t_d and R_{ss} values are determined while decoding the cyclogram of CER changes through the time in the regime of normal friction to its average value - R_a relatively.

SS lifetime $t=t_f + t_d$. In SA regime R_{ss} in the function of SS thickness. The revealed dependence allows to determine the parameters V_f and V_d of SS as the relation of R_{ss} to t_f or to t_d in the testing process directly. For SS forming on the friction surface of a specimen made of steel 40 t=40…120 min; SS thickness – 20…100 A; ΔR_{SS}=30…120Ω.

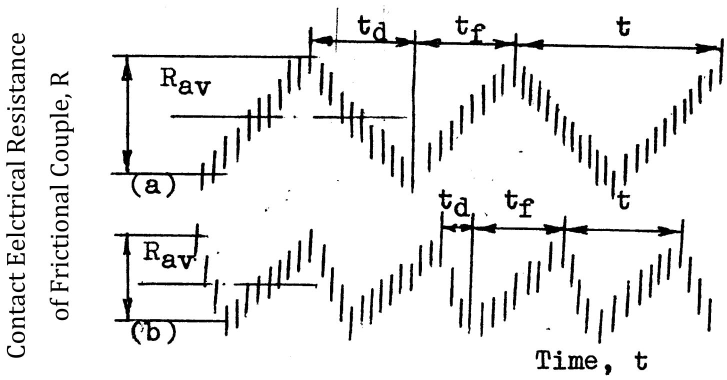

Figure 5. The determining of formation time (t_f), destruction time (t_d), lifetime (t) and geometrical characteristics (R_{ss}) of secondary structure using cyclograms of contact electrical resistance of friction couple change in time in structural adaptability regime (a) and passage to damage (b).

The proposed criteria are the structural-sensitive parameters, that characterized the SS state and properties. The capability to carry out the continuous control on friction and wear processes with the investigation of kinetics of SS formation, transformation in the testing process directly occurred. In community with the metallographycal analysis of friction surface they allow to control the friction and wear processes revealing the nature of tribological interactions.

5. Conclusions

From a position on structural and energy theory of friction and wear, a comprehensive methodology for the study of heavy-loaded friction pairs of the car has been developed and tested.

The universal friction machine has been designed and manufactured, a measuring complex for registration of contact electric resistance of friction pairs, wear intensity and coefficients of friction.

The wide complex has been conducted on the study of processes in the zone of frictional contact for different materials of friction pairs, lubricating media, and power load parameters. The character of relationship between the main tribotechnical showing, the contact electrical resistance and the structural state of the friction surfaces (type of secondary structures) was revealed and substantiated.

An express method for determining the range and level of the process of normal mechanical wear, the nature of the transition processes, kinetics of formation, transformation and destruction of secondary structures is proposed.

The complex for systematic control and analysis of the kinetics of tribological interactions processes, the obtaining of objective data in the process of their synergistic interaction, expansion of the data bank to create a unified theory of friction and wear, was created.

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Efficiency of managing the production capacity of service enterprises, taking into account customer motivation

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Abstract: This paper presents a methodology that has been developed for analyzing the production activities of posts, which allows to identify customers by their categories and territorial "affections", the emergence of which should be activated by a specific service enterprise. An algorithm has been developed for finding solutions for improving the quality of services and customer service conditions for a car service center. The practical implementation of the methodology was carried out on the basis of existing service enterprises for servicing trucks. Measures were found to increase the capacity of the production of service enterprises, which allows a particular enterprise to maintain its economic stability in a competitive environment. The criteria reflecting the production activities of the auto service enterprise are selected in accordance with justified principles. It is established that regular customers who apply for services more than three times, bring more revenue.

Keywords: service enterprise, production activity, customer, quality of services.

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1. Introduction

Modern stage of countries' economic upturn characterized by growing of automobile park and rapid development of technical services. Competitive struggle, which appears in these circumstances, it took a problem of economic survival of service enterprises (SE) into the front view, cause to technical positions it is rely upon rational management of potential for production assets [1].

In the literature, the questions of the indicators of the efficiency of service enterprises, because they are not relevant in the condition of the development of the company as a business without any analysis of its impact on the efficiency of the economy or social status of society, are poorly covered. The only question of evaluation of efficient activity of SE was sufficiently developed and covered. The plenty number of works are devoted to competitiveness of business, customer acquisition and estimation of level of their satisfaction, expenditures on auto-care service activity and guarantee of its profitability. It concerns to estimation of auto-care service as social-economic system and provision of their efficiency from the point of living standards, this issue do not have appropriate attention [2, 3].

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2. Literature review

Wide range of production processes on the enterprise for automobile transport drives technical service of SE to conduct a number of planning functions, organization and regulation of motor vehicle flow (MV) for maintenance and repair (M and R). The complex of such problems arises in connection with the fact, which a decrease in the total number, for example, of municipal buses and the equipment of posts and stations are complicated and correspondingly increase their value is recorded. Expensive equipment is not economically expedient to have on each SE, so it is advisable to create specialized production or create SE with full load of its capacities [4, 5].

However, in traditional methods of planning and managing the production of M and R of buses, production areas are used irrationally through the spontaneous, unregulated formation of "queues" by posts and individual performers [6].

Exploring the experience of the formation and development of industrial structures of motor transport, which provide the appropriate activities, we can conclude that the combination of the latter is not the only acceptable. A large part of production structures of automobile transport engage only in one type of activity, transferring others to the execution of outside entities. At the same time, a number of organizations combine these types of activities in certain combinations based on basic or auxiliary [7,8].

In Ukraine, in spite of the economic crisis, there is a gradual increase in passenger transportation, forwarding services and services in the field of M and R MV, provided by organizations specializing exclusively in these types of activities. This situation can be to some extent considered an objective process, which also corresponds to the general tendency that in the world economy it has observed in recent decades - economic organizations of various sectors of the economy tend to increase their competitiveness, concentrating on the main activity [9].

Functions that the SE had to provide decisive option for possible strategic directions for its further development in the transition to market relations. The MV's structural units, which were engaged in main and auxiliary activities, in many cases they transformed into strategic business units or independent specialized enterprises [10].

In modern conditions, with a decrease in the average number of MVs in carriers' parks, significant reduction of volumes of transportation by large carriers, an increase in the number of MV models, including foreign production, etc., can be expected to gradually increase maintenance and repair work, which can be passed on «to a third party». At the same time, car service companies themselves can act as logistic providers of economic organizations that provide transportation services. In fact, average annual output of post maintenance and repair was in 30% lower then it's planned. In order to ensure the economic stability of car-care service support or increase the demand for their services [11].

Along with this we noticed that issues were considerably less examined, especially those which related to influence of service quality, that're provided, on clients' decisions to repeat their requests to use services of particular enterprise [12].

Satisfaction of consumers with high-quality service will bring substantial contribution info economic growth of enterprise [19, 20]. In the companies, that had highest rates of quality of performed works, growth rate in annual volume of realization of services was in 9% higher, and profitability of sales was in 11% higher, then in those companies, which were worse according to these indicators [13].

Existing structure of service enterprises' (SE) assets is not workable in case of qualitative development. Absence of evidence-based methods for management of their development was not create real preconditions for establishment of promising sphere of auto-care in the face of competition. In a view of above a problem of appropriate development of auto service system has gained special importance for our country [14].

To provide with high quality of prevention and repair growing quantity of vehicles are to formulate service enterprises' production activity on scientific bases [6].

Methods of determination of rational part of enterprises with different capacities in auto service system are absent. That's defined the priority of solving the tasks made with theoretical foundation and mathematical formulation of an optimal balance between quantity of big, medium-sized and small enterprises in auto service systems of city, districts, regions and sub-regions.

A purpose of this work is increasing efficiency of service enterprises' work by rational choice of directions concern to improving the quality of services.

In the article [17, 18] describe that despite the importance of trust and commitment in relationship marketing, the scholarly inquiry on the issue is rather impeded in several ways. Also was describe that when it comes to the marketing of services and specifically for business-to-business (B2B) markets, the empirical documentation is even slimmer despite the fact that services are increasingly becoming a vital component of the product that the customers buy even when it comes to tangible goods such as computers or cars.

A tasks of this work:

To analyze research works in the area of maintenance and select the criterias, that will reflect production activity in service enterprises.

To develop methods of analysis of posts' production activity and make survey among customers of service enterprises.

To develop solving algorithm due to improve quality of services and service conditions.

To implement methods based on existing service enterprises foe servicing trucks in practice.

3. Research methods

Methodology of investigation based on statistical inference mathematical modelling with applying sociological methods.

Methodology of analysis of production activity on maintenance and repair and questionnaire of clients let us to receive mentioned indicators of service quality.

Repeatability of clients' services demand increases production program, confirms hypothesis and quantitative assessment of economical benefit for enterprise, which provides services through improving quality of service provisioning.

The algorithm of finding the solutions with aim to improve a quality of services and condition of relation customer care it forms analytic expression for improving a potential of production capacity of enterprises, as follows they are increasing quality and effectiveness of service provisioning.

In regime of current time it founds out the information for making the decisions on improving work of service enterprise according to indicators, which are characterize its work.

4. Research results

At the revising and valuation of quality system and separate components it was checked an ability to ensure compliance with the requirements throughout analysis of design, technology and normative and other documents analysis in respond to status of technical equipment, controlling means for measuring the parameters of the processes, appropriate staff. Quality system is determined by relative standard if there are no significant discrepancies or there are not more then 10 significant discrepancies.

Standards of ISO 9000 are establishing requirements to quality management system for internal use by enterprise. They were focused on application "process approach" at the design, the results were implemented and improved with aim to satisfy consumers through meeting their requirements (Fig. 1).

It is to analyze direct and cross-cutting connections between intentions and wills of customers to purchase an auto of that supplier, including re-purchase, and intentions to use services of dealer service enterprise (Figure 2). The basis of study was database about 5206 owners of cars (service customers). In a capacity of the most important factors, that have an impact on satisfaction and behavior intentions for automobile, that's became auto capacity, brake system and transmission, additional equipment. Analogous to service enterprise – wait for appointment to TS and R, the period of execution of works and quality of work, politeness of staff.

The result of work became estimation of the impact on level of customers' satisfaction with auto and their intentions to use dealer service enterprise and, in contrast, estimation of impact level of customers' satisfaction using service of SE on intentions to re-purchase them particular automobile model.

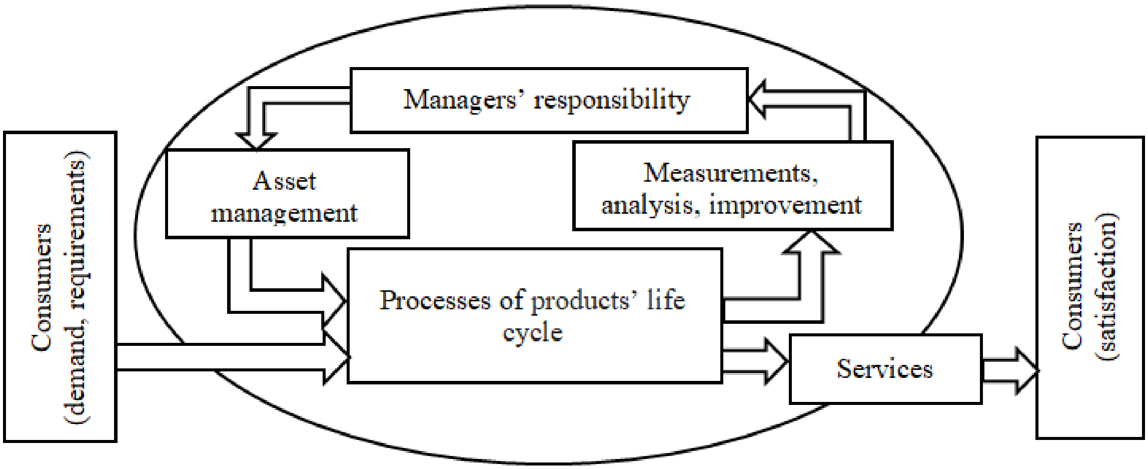

Figure 1. Quality product and service management, that's grounded base on process approach.

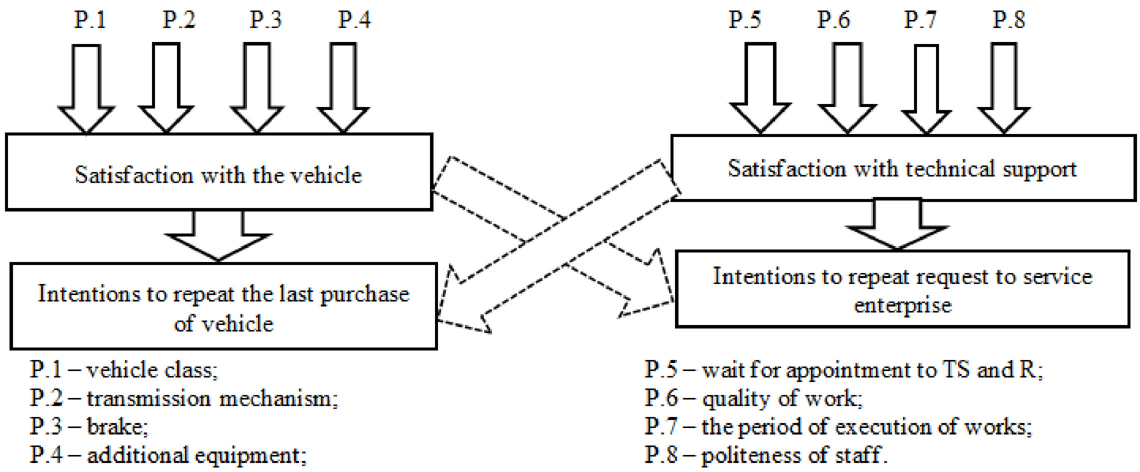

Figure 2. A model of interaction between intentions under power of considerable factors.

One of key feasible indicators of work performance on service enterprise and realization of potential is coefficient of using production capacities:

$$K_{PC} = \frac{T_{RPC}}{T_{MPC}}, \quad (1)$$

where T_{RPC} - real production capacity of enterprise; T_{MPC} - maximum production capacity of enterprise.

In clients' structure, what was using for auto-care center services, presented clients, which relevant to loyal category, or to new added category, entering flow of request on services and production programs are described by further calculations:

$$\begin{cases} T_{NEW_{1i}} \cdot C_{NEW_{1i}} \cdot K_{NEW_{1i}} + T_{LOYAL_{1i}} \cdot C_{LOYAL_{1i}} \cdot K_{LOYAL_{1i}} = T_{RPC_{1i}} \\ T_{NEW_{2i}} \cdot C_{NEW_{2i}} \cdot K_{NEW_{2i}} + T_{LOYAL_{2i}} \cdot C_{LOYAL_{2i}} \cdot K_{LOYAL_{2i}} = T_{RPC_{2i}} \end{cases}, \quad (2)$$

where *i* – is an index of workshop (area) auto service; *1,2* – the indexes of real and planned indicators respectively; T_{NEW}, T_{LOYAL} - labor input of new and loyal customers' satisfaction respectively;

C_{NEW}, C_{LOYAL} - quantity of new and loyal clients; K_{NEW}, K_{LOYAL} - frequency of requests on services from new and loyal clients.

Reserve of increasing a capacity utilization rate for enterprise caused improving level of service quality on *i* workshop:

$$\Delta K_{PC}(i) = P_i \cdot K_{PC_i} \cdot \left[\frac{K_{ADDIT_i} \cdot K_{CLIENT_i} \cdot \left[1 + D_{LOYAL\,i}^{\;n} \cdot \left(K_{ORDER_i} \cdot K_{FREQ_i} - 1\right)\right]}{\left[1 + D_{ADDIT\,i}^{\;r} \cdot \left(K_{ORDER_i} \cdot K_{FREQ_i} - 1\right)\right]} - 1 \right] \tag{3}$$

Taking into account the fact, that at the same time service has technical and consumer features, the calculations of indicators with applying multiplicative method:

$$П_j^{TECH} = K_j^{TECH} \cdot K_{l\,j}^{\;TECH}, \tag{4}$$

$$П_j^{EQUIP} = K_j^{EQUIP} \cdot K_{l\,j}^{\;EQUIP}, \tag{5}$$

$$П_j^{PERF} = K_j^{PERF} \cdot K_{l\,j}^{\;PERF} \tag{6}$$

where $П_j^{TECH}, П_j^{EQUIP}, П_j^{PERF}$ - corresponding to average quality indicators, that are characterized technology, equipment and performers concerning *j*-type of works (services).

Considering last formulas a quality consensus representative of *j*-service investigated *i*-workshop (area) will be determined next way:

$$П_j = П_j^{TECH} + П_j^{EQUIP} + П_j^{PERF}. \tag{7}$$

Algorithm of solution search concerns with quality and terms of service for customers of service enterprise are including five phases, the results shown up on Figure 3.

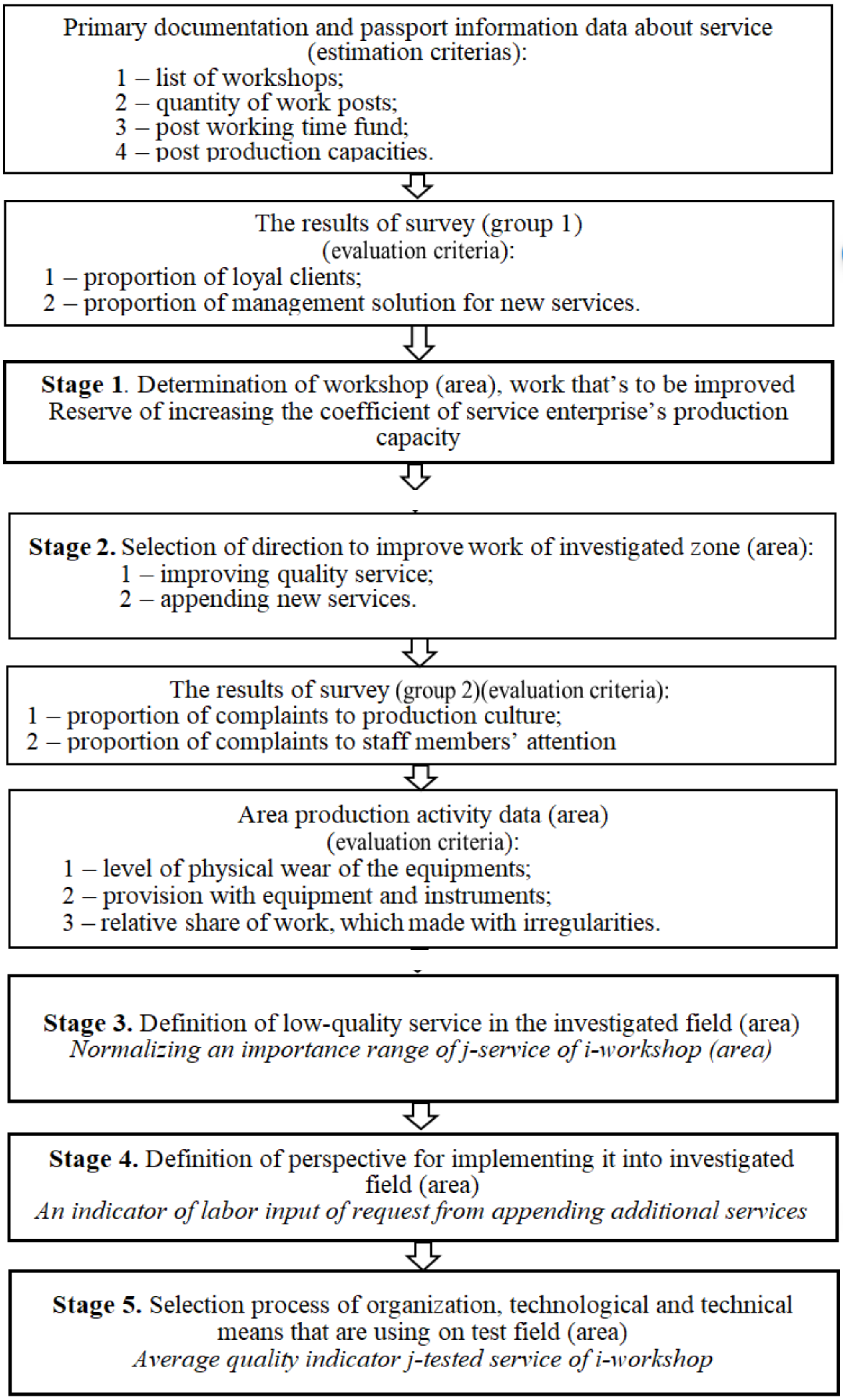

Figure 3. Searching means algorithm with aim to improve quality of service and their terms for service enterprise' consumers.

Phase 1. Determination of production field (area) of auto service, work that's should developed, it's made in respond to amount of reserve of increasing capacity utilization rate for service enterprise from improving quality services in *i*-workshop $\Delta K_{PC}(i)$.

An amount of reserve of increasing capacity utilization rate in service enterprise was defined $\Delta K_{PC}(i)$ with aid of improving quality of esistng and appending additional service on each enterprises' production areas.

In fact a maximum figure of indicator $\Delta K_{PC}(i)$ have got priority № 1 rang, and *i*-production zone is finding as the problem respectively. In case of equality distribution of indexes $\Delta K_{PC}(i)$ on two production areas (districts) selection is established on the account of another area, in such reserve coefficient rising $\Delta K_{PC}(i)$ cause to improving higher quality of services.

Following analysis will be done only for particular *i*-workshop (area) of auto service.

Phase 2. Selection process of the direction aimed to improve the workshop (area) includes: increasing the quality of existing areas or organization of additional services, it's determined when there is maximum reserve of increasing a capacity utilization rate for service enterprise from improving quality of services in *i*-production area:

$$\Delta K_{PC}(i) \rightarrow MAX\,. \tag{8}$$

In case of equality of indicators $\Delta K_{PC}(i)$, which were obtained separately from the quality improvement and implementation of additional services, an advantage was taken to quality growth, as this direction of improvement of this activities, as follows references have shown, that it's the most relevant to modern auto-care service in competitive conditions.

Phase 3. Identification of low-quality service under investigated workshop (on the field) of quto service was done in condition of maximum normative range indicator of importance:

$$\Pi^{N}_{i\ j} \rightarrow MAX\,. \tag{9}$$

Phase 4. Determination of future area for application in investigated auto service workshop conducted in condition of maximum indicator of labor-intense from introduction additional services:

$$K_{ADDIT_i}(j) \rightarrow MAX\,. \tag{10}$$

It is determined an indicator of labor-intense of order $K_{ADDIT_i}(j)$ from taking additional service in the investigated workshop (on the field) of auto service. Meanwhile, a maximum value of indicator $K_{ADDIT_i}(j)$ has gotten № 1 rang of priority, and responding *j*-service was found perspective as well.

Phase 5. Selection of organizational, technological and technical measures on improving types of services, which were provided on this area, it's complied in the occasion of minimum average indicator of quality of *j*-services investigated *i*-workshop (area):

$$\Pi_{j} \rightarrow MIN \tag{11}$$

Selection of «weak link» in algorithm resulting from high importance of holding the clients by service staff member, that's why a necessity appears in looking for and erasing trivial defects in service process, they may lead to loss of clients and incomes. Furthermore to cut «weak link» is not reasonable way.

Service enterprise provides customers with complex services and cutting some type of works, it will cause to dissatisfaction with their needs in complex servicing for auto mobiles. This, as follows, will bring to loss of clients and incomes.

The main obstacles in applying proposed methodology lies in:

- methodology is focused on small and middle-sized service enterprises;
- reserve of increasing a capacity utilization rate for enterprise calculated only based on improving the quality and service range;

- organization of new types of works (services) in the workshops (on the fields) of auto service relavant to aspect of rebuilding (reconstruction) PTB auto service enterprise.

Found data set is a subject to statistical processing, the results are performed. The composition of clients in groups starting from 1 to 6th applications were heterogeneous. At the determination of the average weighted workload, as a mileage has taken a mileage between the customer's call to the service company.

The analysis of data of the primary documentation of truck service enterprises.

Repeat application from clients (more than 3 times) on services in the investigated truck service centers come along with double growing in labour-intense order (Figure 4).

There are not no noticeable changes in the frequency of customer referrals to a service facility and inter-repair mileage – most of clients using services with monthly periodicity.

The histogramme of general mileage on car starting from exploitation and age of the car at the moment of 1st -6th clients' appeal to service facility was designed (Figure 5, 6).

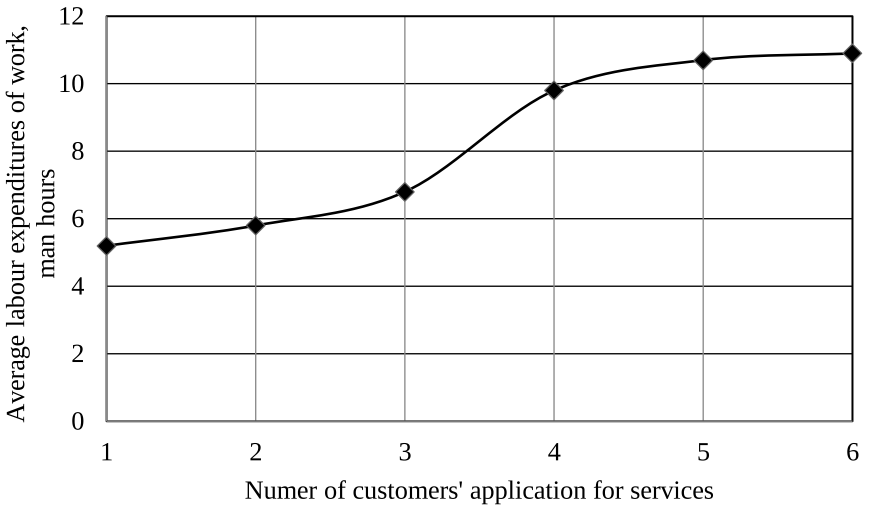

Figure 4. Variation of labour-intense of services in relation to number of customer's application to service enterprise.

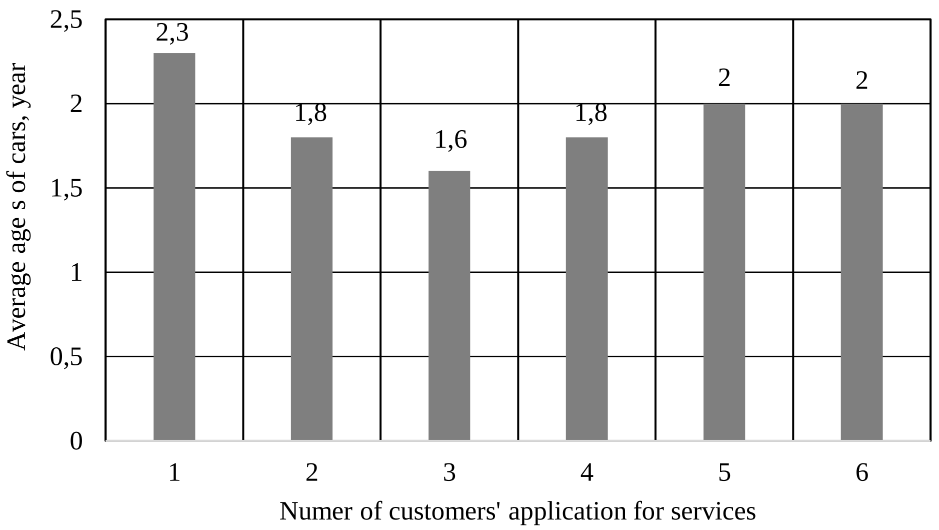

Figure 5. Age structure of clients' auto park divided into groups.

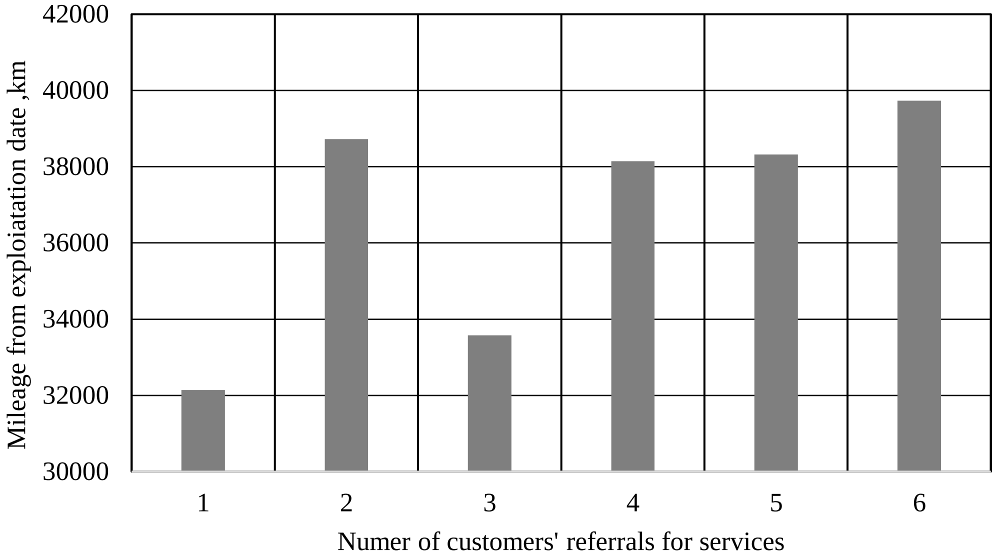

Figure 6. Allocation of mileages on cars from the beginning of exploitations divided into groups.

Income (hrn/km of mileage) or average weighted labour-intense of complied world on auto mobiles' work (man hours /1000 km) it's increasing along with growing clients' referrals to service enterprise (Figure 7). Average weighted labour-intense of services, that required by loyal clients, in average in 2 times higher, than in primery clinets and concludes approximately 3-3.3 man hours / 1000 km. For this reason holding and loyal customers are more profitable for service enterprise.

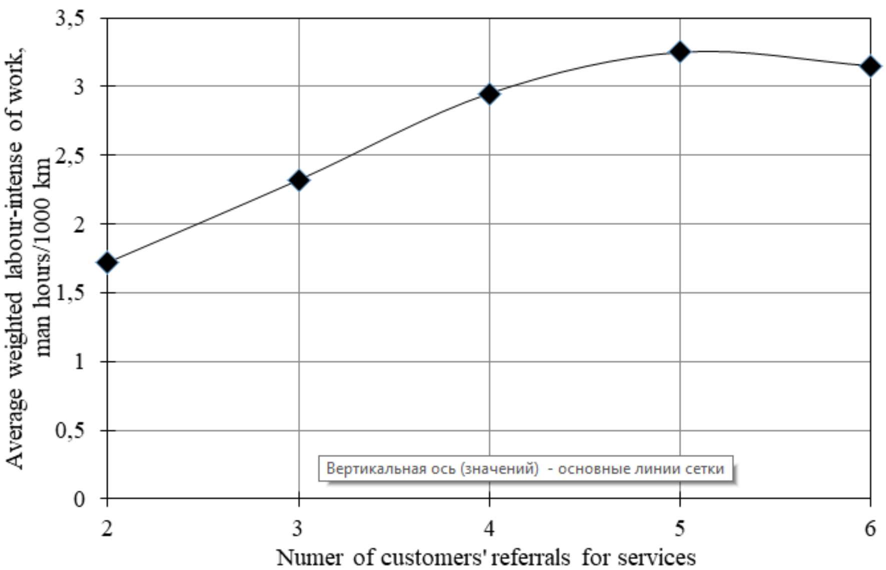

Figure 7. Change of average weighted labour-intense of services in dependence of number of customers' referrals to service enterprise.

Assuming the findings from analysis of age structure of auto park and mileages starting from exploitation of the clients' automobiles from various groups of referrals, they weren't disclose strong pattern of index changing at the re-referrals. We can come to conclusion that: single-use and average weighted labour-intensity of services, which are required by clients, that's caused by building trust to firm, it occurs in case of repeat application for services.

Increasing confidence in work quality for those investigated truck service enterprises (from 3-rd, 4-th appliances) goes with growing a volume of order due to inclusion of some ancillary, that client accepts, and appearance of a large-volume work order, which client did himself before or in another auto service. As a result single-use and average weighted labour work have risen.

The empirical values of the criterias $K_{ЗАК_i}, K_{ЧАСТ_i}$ for the management potential of the production capacity of freight service enterprises have such figures, as $K_{ЗАК_i}$ = 2, $K_{ЧАСТ_i}$ = 1.

Experimental studies carried out on freight service enterprises, they show that: loyal clients of auto service, who applied more that 3 times, they took bigger profit; for service enterprise it's reasonable holding customers on service in connection with higher economical upturn from loyal clients.

The empirical values of the criterias $K_{ЗАК_i}, K_{ЧАСТ_i}$ are management functions of production capacity potential of service enterprise using the solving algorithm for improving client servicing.

The main customer of car-care service is private companies, which have got up to 14 automobiles (Figure 8). Relative weight for those customers is - 78%. The majority of them have got auto park of up to 4 items.

Adjustment factor takes into account seasonality of receipt of applications for repairs. In the frames of TS and TR have taken place dispatch center for co-operation with customers. Reception and registration of order for repair is complied with dispatcher in agreement with foreman of production area or master of the reception. Dispatcher is making a description of a car, an external inspection, receipt paperwork, calculations on the cost of services.

Service receptionist agrees with customer a volume of work, spare parts, time for accomplishment and release of order date, and he provides consultations on the question of maintenance and repair of car.

After placing the respective values:
- in conditions of increasing of work quality, provided
1. Area for diagnostic of engine: = 5%;
2. Areas TS and TR: = 2%;
3. Area for repair of aggregates: = 1%;
- in condition of new type of services organization:
1. Area for diagnostic of engine: = 1%;
2. Areas TS and TR: = 1%;
3. Area for repair of aggregates: = 1%.

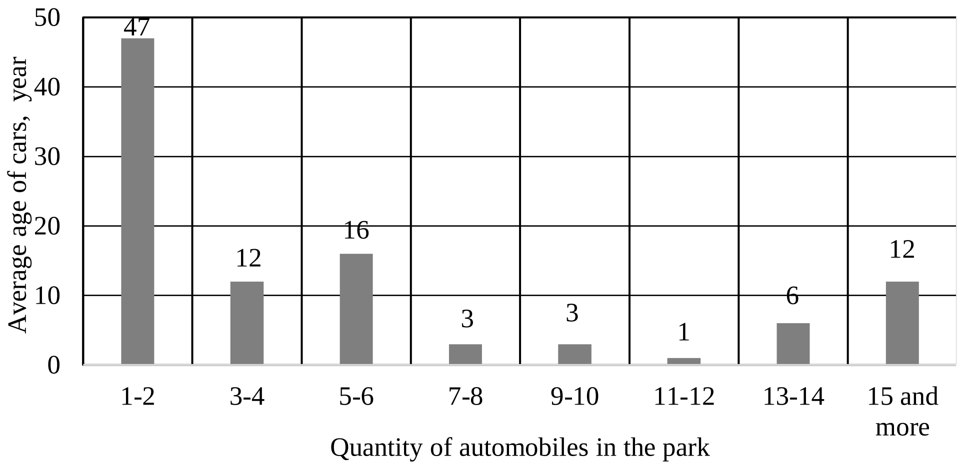

Figure 8. Customers' distribution by quantity of automobiles in the park.

On Figure 9, 10 have shown graphic interpretation of service quality on diagnostic of engine. The resulting quality feature obtained by general data of the questionnaire of clients and the data on the production activities in the areas.

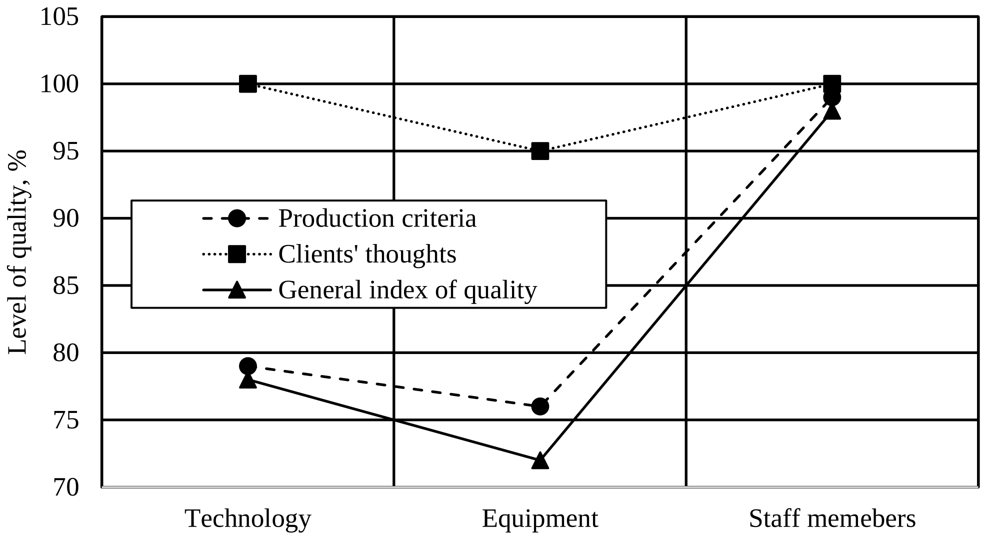

Figure 9. Tests of low level quality of diagnostic and inspection works.

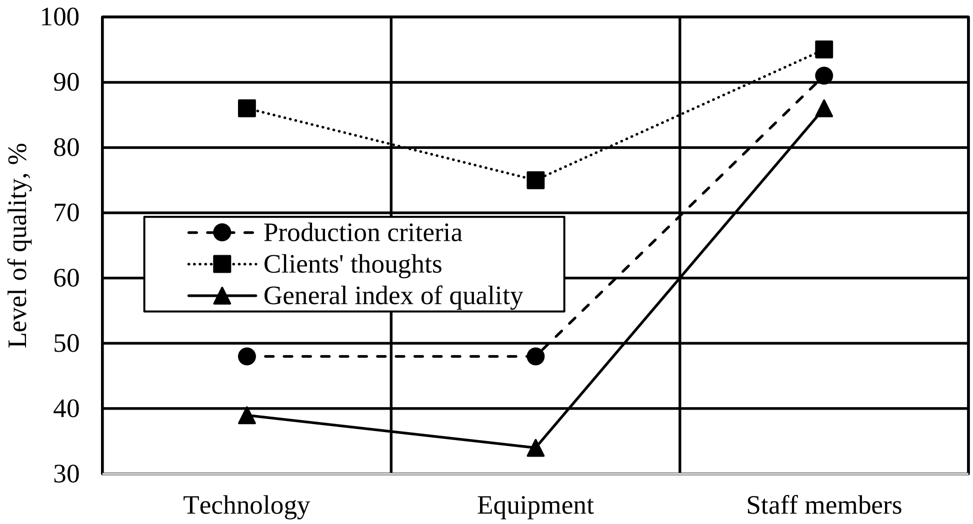

Figure 10. Investigation of low level of work quality with servicing the fuel equipment.

In order to increase a quality of work of fuel systems (Figure 4, 5, critarias «Technology», «Equipment») is technological equipment for working place in respond to typical requirements and insertion of main technical equipment on needed technical conditions.

Realization of methodology of managing a potential of production activity on particular facility allows to increase a coefficient of $K_{BП}$ to 5%.

5. Discussion of the results

Today is given attention to principles of design and building of service enterprises, optimization of location, valuation methods and indicators of production-technical base (PTB), feasibility studies on volume and capacities of SE, but also on design issues [16].

The key factor of market successes of the companies are bringing in and holding of clients, taking into account effective measures done to satisfy their needs. The main directors of increasing power on the market are developing of cooperation service centers with dealers in proving services for clients' automobiles, «information service», «off-premise service», «exchange of appliances service», «service in terms of contract with enterprise» [13].

Apart from this, it's assumed, that enterprise conducted maintenance services according to technologies and SE standards, the results of work was handled by responsible representative from auto center. Oral complaints, that were raised from clients to staff members, it's not paid particular attention, meanwhile they quantity is increasing quantity of written complains in 10 times [1].

6. Conclusions

Analysis method for posts' production activity and questionnaire of service enterprises' customers was done. A survey of revised enterprises let to discover clients according to their categories and territorial affiliation, appearance of those should be activated in particular service enterprise. For instance, on checked service facility is to activate customer appearance, who are in radius of 7 km from SE.

The algorithm of solution seeking on improving quality and terms of services was designed. Modeling allows to intentify main solutions aimed to develop working process in the enterprise with high profitability in amount of 90% and relative mistake in amount of 5%.

Practical realization of methods based on existing service enterprises for managing trucks was done.

The measures to increase a potential of production capacities of service enterprises were found, and the conclusion of this it allows a separate enterprise keeping its economic strength in competitive conditions.

The factors, which describing production activity of auto service enterprise were selected and grounded.. In fact, a key factor is share of loyal auto service customers. In order to maintain stable work of enterprise this factor must be no lower than 60%.

It was found, that loyal consumers, which have applied for the services more than 3 times, they brought higher income. Average weighted labour-intense of services (man hours /1000 km), required by loyal customers approximately in 2 times higher, that the same indicators fist clients have. It brings into the front view the measures for holding existing clients.

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Evaluation of strength, fatigue, durability and damage to the material in the machine elements using physical parameters and criteria

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Abstract: This paper presents the main physical parameters, dependencies, calculation methods in the physical structural-energy theory of the strength of a deformed solid. The initial physical and mechanical parameters of the strength of steel 45 were determined analytically. The physical methods were used to calculate the durability, fatigue, and steel damage for non-stationary mechanical and thermal loads. The relationship between physical and mechanical strength parameters is analytically determined. The results of calculations of the modified characteristics of the strength of the damaged material are presented, plastic deformations, cyclic stresses of arbitrary shape, and temperature conditions are taken into account. The originality of the study consists in that we used our own program for calculating the new characteristics of the damaged material for different stress functions. The application value of the research is that the physical method allows to analyze the data of load sensors, indentation according to ISO 14577 in the elements of machines. The physical parameters of the material and the new theoretical calculation methods can be used to control the state of the strength of the machinery mechanisms during operation.

Keywords: stress, strain, strength, physical equation, calculation.

1. Introduction

The purpose of the article is to show the main physical parameters, dependencies, calculation methods in the physical structural-energy theory of the strength of a deformed solid (hereinafter DS). The basic equation of physical theory. The relationship of physical molar state parameters and the usual mechanical properties and parameters of materials. Examples of using the physical method for the theoretical determination of the initial physical parameters and ordinary mechanical parameters of steel 45 according to the rheological diagram of the material test. Analytical evaluation of the standard mechanical characteristics of the initial physical parameters of the material, using a generalized rheological deformation diagram of tension. Theoretical assessment of the parameters of strength, durability, fatigue of steel 45, examples for different cyclic loads and temperature conditions. The direction of the practical application of the physical approach to assess the strength and damage of machines and mechanisms.

Using the equations and formulas of the physical theory, an objective relationship is established between the physical structural and energy parameters and the usual mechanical properties of strength and deformation characteristics of the material. To this end, an analysis was made of the properties of the rheological functions of stresses and strains obtained experimentally at a low rate of steel

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deformation under tension before fracture. Using the deformation rheological diagram of the uniaxial tension of the material, the properties of the functions of speed and acceleration of the relative irreversible plastic deformations of the form change of the body are analyzed analytically. As a result, generalized formulas are obtained analytically for estimating the initial values of the structural physical parameter and the activation energy of material destruction.

Using the developed theoretical methods, stationary creep equations, physical equations and the dependences of the structural-energetic theory of strength, a theoretical estimate of the initial structural-energetic physical parameters of the strength of a structural material was made. The initial structural parameter γ_o, the activation energy of destruction U_0 of carbon steel are determined.

Using recognized experimental data, physical theoretical methods, using carbon steel as an example, a generalized analytical physical model of mechanical tests was developed. A generalized rheological function was obtained simulating tests according to ISO 6892-84, which allows virtual tests of uniaxial stretching of a material before fracture.

Thus, having data on the body temperature T, the rheological function $S(t)$ of the actual load in true stresses, the initial physical parameters of the material γ_o, U_o, using analytical methods of the physical theory, it is possible to determine the values of plastic deformations, damage, the predicted time to failure, etc.

In the physical theory, additional important physics mechanical parameters and properties of the process of irreversible deformation up to the state of material destruction are also considered.

A theoretical analysis and generalization of the properties of force and deformation rheological diagrams of uniaxial stretching of a material are applied. A method for constructing a generalized rheological diagram $S(t)$ of a standard process was obtained, using which physical methods can determine standard characteristics of the limit of proportionality σ_{02} (plastic deformation = 0.02%), tensile strength $\sigma_в$, time to failure t_*, residual deformation ε_{r*}, plastic deformation rate and other physical and mechanical characteristics of the material for this process.

A theoretical method is proposed for solving an inverse physical problem – calculating the mechanical standard characteristics of steel using physical parameters of strength and a rheological generalized tensile test model according to a standard.

Physical and analytical methods are proposed that allow the theoretical calculation of fatigue characteristics at different frequencies and instrumental temperatures, using the initial physical parameters of the material, the dependence of the theory, the developed algorithms and programs. An example of theoretical calculations of simple mechanical characteristics of carbon steel, the possibility of a physical theoretical method for studying the processes of deformation and destruction of solids is shown.

2. Materials and Methods. Physical parameters and dependencies

The physical structural-energetic theory of strength (SET) is the result of the theoretical development of the kinetic concept of strength (KCS) of solids [1]. The concept is well known as the Zhurkov formula (1), which determines the time to brittle material failure (durability) for constant stresses and temperatures:

$$\tau_* = \tau_o \exp\,(U_o - \gamma_o\sigma)/RT \tag{1}$$

where, τ_* is the durability; γ_0, m^3/mol - is the structural parameter of the material; τ_o is the period of associated thermal vibrations of the atoms of the body; U_0, J/mol - is the activation energy of destruction; σ, Pa - is the constant tensile stresses; R, $J/mol \cdot K$ - is the gas constant; T, K, constant temperature; $\gamma_o\sigma$ - the product is the molar energy density, according to one of the three components of the main stresses DS: $W_{Lo} = \gamma_o \cdot \sigma$, J/mol.

Formula (1) is confirmed for different solid materials in a wide range of stresses and temperatures. Zhurkov's concept is fundamentally different from the previous DS mechanics. The duration of the voltage, temperature, microstructure parameters of the DS structure, etc. are taken into account. The concept uses the DS molar physical characteristics. Previously, the molar parameters, the kinetics of their changes, were considered exclusively in calculations of chemical reactions, materials science, etc. In the concept, the fluctuation of the energy of the atomic bond is considered to be the cause of the elementary damage. It is assumed that the accumulation during the time τ_* of the elementary destruction of bonds in the material, up to a critical level, creates conditions for macroscopic spontaneous brittle destruction of the body [1].

The concept has been successfully applied in calculating the strength of structural elements with cyclic and static voltages [2], shock, pulsed laser loads, earth crust strength, and a number of others [3,4]. But in these methods there is no physical and theoretical justification for the use of molar characteristics, sound methods for calculating the complex stress state and variable voltages. In (1), the main parameters were taken as empirical.

In the structural-energetic kinetic theory of solid strength (SET), a theoretical substantiation of the formula and Zhurkov parameters (1) was obtained, a physical wave-particle model of destruction and irreversible deformation of the DS [5] was substantiated. The physical theory of strength was obtained from the standpoint of statistical physics and wave theory, analysis and theoretical substantiation of experimental results and empirical formulas of the kinetic concept of the strength of solids. Destruction is considered as an elementary wave-wave process of periodic energy exchange, in small volumes of a solid body, occurring with a characteristic high frequency. This process may be reversible and irreversible. In classical mechanics, phenomenological models of the destruction of hypothetical atomic bond forces in solids (pair potentials, etc.) are considered. The physical theory considers a microscopic process of interaction of elementary kinetic energy flows of de-Broglie wave-quasiparticles, resulting from fluctuations of the interaction of these quasiparticle waves in elementary small DS volumes. The elementary energetic associated volume wave-particle wave interactions of elementary structural units of a macroscopic medium (in terms of mechanics are atomic bonds) are considered. The physical generalized model of the volume interaction of structural units is applicable for solids of different nature, it reasonably replaces the empirical model of "mechanical" atomic binding forces.

In the structural-energetic kinetic theory of solid strength (SET), a theoretical substantiation of the formula and Zhurkov parameters (1) was obtained, a physical wave-particle model of DS destruction was substantiated, a number of fundamental issues of applying physical methods in the concept and theory of strength were solved [5].

In SET, new generalized physical parameters of the DS state, derivatives of these quantities, are proposed, functions are obtained, from which formula (1) follows. The relationship between the physical molar parameters and the mechanical parameters of the theory of elasticity is shown, a number of well-known experimental dependencies of DS mechanics and the equation of state of an ideal gas (theoretically as a case of the wave-particle thermodynamic system) have been theoretically obtained [6]. Consider the basic physical molar values in SET.

For simplicity, we consider DS as a heterogeneous single-phase (three-dimensional phase) one-component thermodynamic system in a quasi-equilibrium state. Let the function of principal stresses $\sigma_1(t)$ be given for one component of the tensor $\sigma_1(t) = \sigma(t), |\sigma| > 0$, Pa. In this case, DS can be characterized by generalized physical characteristics.

$Sh(\sigma, t), m^3/mol$ - is the molar volume of quasiparticles of strength. The volume DS in which for each elementary small characteristic period of time τ_o, occurs N_A characteristic periodic fluctuations of the energy of the interaction of quasiparticle de Broglie waves. Avogadro number $N_A = 6{,}022 \cdot 10^{22} un/mol$.

$$W_L = W_\sigma \cdot Sh, \quad J/mol; \qquad W_\sigma = \frac{\sigma^2}{2E}, \quad J/m^3,$$

where $W_L(\sigma, t)$ is the molar energy, the state function of DS; E is the modulus of elasticity.

$$Gr = \sigma \cdot Sh(\sigma, t), \quad J/mol.$$

where, Gr is the structural-energy potential, the physico-mechanical characteristic of the state of a solid body.

$$Gr(t)=0.5E\cdot\gamma_r(t)\,;\quad Gr_o=0.5E\gamma_{ro}\,;\quad \gamma_o=Sh(t=0,\sigma=E)$$

$\gamma_r(t,\sigma)$ - the root molar volume DS, the structural function of the material [6,7]. The state function $Gr(\sigma,T,U_o,Gr_{o,}t)$ reflects the process of the influence of mechanical, heat load on irreversible changes in the material [6, 7]. The initial value Gr_o, for pure metals, of many solids is determined by the Zhurkov method [2, 3]. For structural materials Gr_o, the value is determined in SET by analytical methods, by processing the rheological diagrams of uniaxial tension of the material or indentation data according to ISO 14577 [7].

The relationship between physical parameters and mechanical properties of materials. In SET, dependences (3) (4) are obtained, which allows determining plastic deformations of a material at any time instant if the function of true stresses and the initial physical parameters of the material are given:

$$\varepsilon_r(t)=\int_0^t \frac{RT}{\tau_*(W_L)W_L(t)}dt\,, \tag{3}$$

$$\dot{\varepsilon}_r(t)=\frac{RT}{\tau_*(W_L)W_L(t)}\,,\quad 1/s\,. \tag{4}$$

ε_r - accumulated true irreversible deformations; $\dot{\varepsilon}_r$ - strain rate for uniaxial deformation. Dependencies (3, 4) are confirmed experimentally [8].

In SET, a dependency is obtained that allows you to find the current value of the parameter $\gamma_r(t)$ for structural materials by processing experimental rheological diagrams $\varepsilon_r(t)$ [7].

$$\gamma(t)=\frac{RT\partial(Ln\alpha\dot{\varepsilon}_r)}{\partial\sigma}\,, \tag{5}$$

α is the normalization factor.

A simple formula is obtained for the analytical evaluation of the initial value of the structural parameter of a structural material according to the analytical processing of rheological diagrams, as a result of uniaxial tension of the sample material.

In SET, a number of other dependencies of the relationship of physical, thermodynamic, and mechanical parameters are obtained, which allow solving problems of DS mechanics by physical methods, confirmed by experimental data. For example, the calculation of the specific number of dislocations, the amount of heat generated during irreversible processes, etc. [5, 6].

The basic equation of physical theory.

The SET obtained physical equations and dependencies for the calculation of durability under non-stationary and complex loads, with respect to different molar functions of the DS state [5]. Differential equation (5) is written for a structural function $\gamma_r(t,\sigma)$, a single-component structurally homogeneous, stable material, the true stress function $\sigma(t)$ is given. The equation was obtained by the author of the article on the basis of the analysis and generalization of two recognized independent fundamental experiments KCS [9].

$$\frac{\sigma d\gamma}{dt}=\frac{RT}{\tau_0}\exp\left(\frac{\gamma_o\sigma-Uo}{RT}\right),\quad j/s\cdot mol, \tag{6}$$

Border conditions: U_o,γ_o. Condition of destruction:

$$U_0-\gamma(t)|\sigma(t)|=0\,,\qquad T=const\,.$$

In the ETS, further physical methods are developed for taking into account the influence on the strength and durability of the factors of all-round pressure, radiation, electric current, a number of formulas are obtained for assessing these factors on the durability, etc. Using the example of analyzing the properties of an experimental carbon steel rheological diagram, we show the possibilities of a physical theory to solve analytically the problems of estimating standard mechanical characteristics, material damage, determine modified standard characteristics of a damaged material, fatigue properties, durability, etc. for alternating stresses, material temperature. We use equations, theory dependences, developed programs for solving equations of physical theory. These programs allow you to see the values of physical parameters of strength, the speed of their change under different loads, etc.

3. Results

3.1. The method of theoretical determination of the initial physical parameters of steel 45

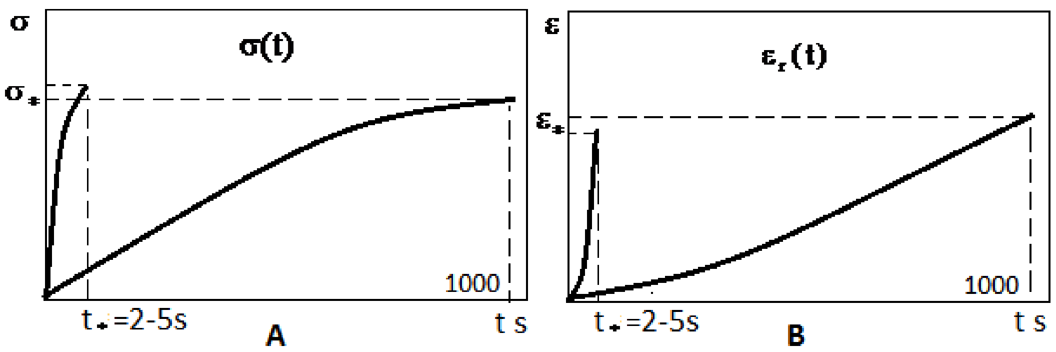

Figure 1. Conditional rheological diagrams of the sample stretching to failure t_*, the standard process time to failure is 2-5s: (A), $\sigma(t)$ force diagrams; (B), $\varepsilon_r(t)$ deformation diagrams.

We use rheological diagrams of slow stretching $\sigma(t)$ of the sample, force, Figure 1 (A) and deformation, Figure 1 (B). They were obtained on a special testing machine [10]. The strain rate in the initial section $\dot{\varepsilon} = 0{,}53 \cdot 10^{-4}, s^{-1}$. The duration of the deformation process is about 1000 s. The process is isothermal. For comparison, the usual rheological curves $\sigma(t)$, $\varepsilon(t)$,obtained by the method ISO6892-84 are shown schematically alongside, recorded in time, until the specimen was destroyed. The standard process time is 2-5 seconds to failure. Test parameters are recorded in digital form and Excel spreadsheets against time.

Using these experimental results, equations (3, 4), physical equation (5), and dependence (6), a theoretical estimate of the structural-energetic physical parameters of the strength of steel 45 was made. The initial structural parameter $\gamma_o = \gamma(t_{02}) = 1{,}23 \div 1{,}28 \cdot 10^{-4}$ m3/mol was determined. The activation energy of destruction $U_{o1} = 1{,}38 \cdot 10^5$ j/mol - to the yield point, $U_{o2} = 2{,}05 \cdot 10^5$ j/mol - to the limit of strength. Using the obtained physical parameters, the inverse problem was theoretically solved, the initial deformation diagram was constructed, the basic parameters of deformation by tensile steel 45 were determined to failure for a given stress function according to ISO6892-84 [11]. Thus, the verification of the first stage of calculations.

3.2. Evaluation of standard mechanical characteristics of ISO6892-84 using the initial physical parameters of the material

The physical theory was used to estimate the limits of proportionality and strength, residual deformations of steel 45. The analytical relationship between the mechanical characteristics of strength and the physical parameters of the strength of steel 45 was used. The initial physical structural and energy parameters γ_o, U_o obtained earlier were used. A generalized model of the rheological stress diagram for uniaxial tension of steel to failure, which provides the necessary average rate of relative deformations of the material $\dot{\varepsilon} = 1{,}375 \cdot 10^{-3}$, $1/s$, is applied according to ISO6892-84. Calculation results: $\sigma_{02} = 449$, MPa, limit of proportionality; t_{02}=1.56, s; 0.0021 (0.21%); $S_* = 1060 \div 1200$ MPa, Pa true tensile strength; $t_* = 3.7...4.4$ s, time to failure; $\varepsilon_{r*} = 0.16...0.22$, residual deformations at fracture; $\sigma_B = 778$ MPa, conditional tensile strength.

Experimental characteristics of carbon steel 45, in the state of delivery [12]; $\sigma_B = 748$, MPa, $S_* = 1173$ MPa; $\sigma_{02} = 412 \cdot 10^6$ Pa. Residual elongation 19%.

3.3. Theoretical estimation of steel fatigue parameters 45, for given various cyclic stresses, temperature regimes

Using the dependences of the physical theory (2-5), the initial molar physical parameters of steel 45, the fatigue tests of the material ISO 14577-1: 2002 [14] were analytically simulated, and the fatigue limit σ_{-1p} of carbon steel 45 was determined [7]. The influence of load frequency, temperature on durability, endurance limit has been estimated. The results are consistent with the reference characteristics of the material, confirm the adequacy of the proposed physical model of fatigue failure. Reference characteristic of the endurance limit of steel 45 (GOST 1497-84) 190-250, MPa (tensile pulsations) (Figure 2).

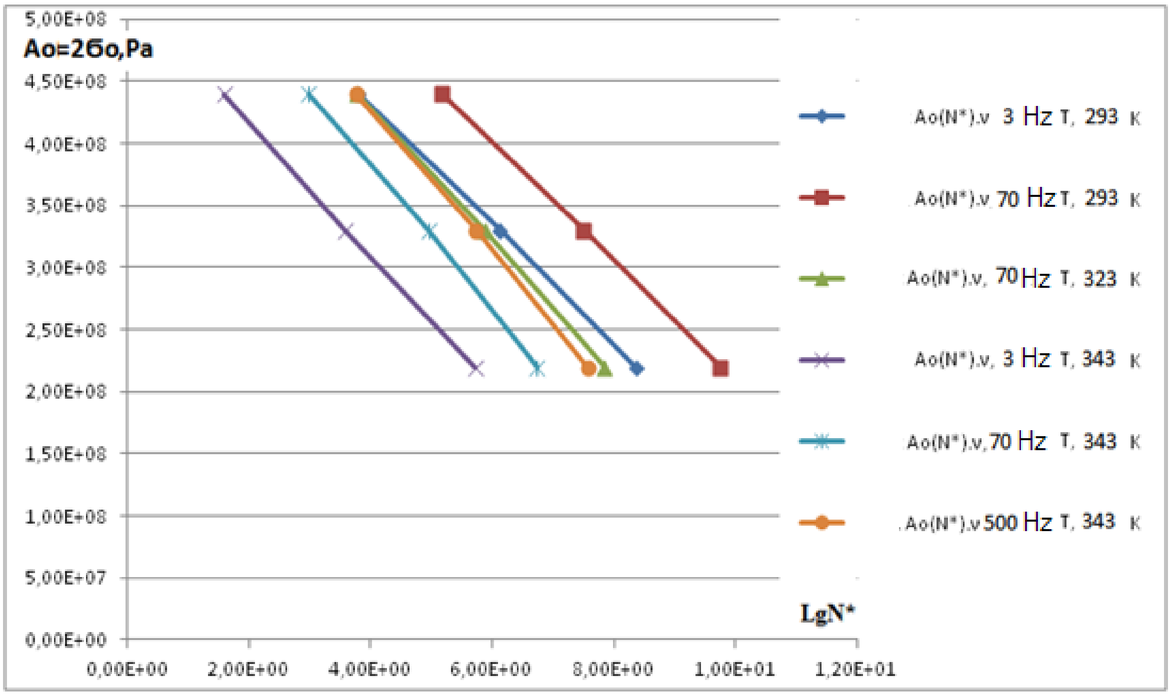

Figure 2. The dependence of the amplitude of the magnitude of the cyclic tensile stress A_0 on the number of cycles to the destruction of the material N_*. 1. Frequencies 3, 70, 500 Hz. Temperature: 293 (20), 323 (50), 343 (70), Celsius temperature in brackets. Form of uniaxial tension cycle stress: $\sigma(t) = \sigma_0(1.001 - \cos B_S t)$.

3.4. Indentation

Using rheological indentation diagrams, the SET made physical calculations of the physical and standard mechanical characteristics of the strength of 45, 15Х2НМФА (15KhNMFA) steel. The methods of physical theory were used, additional physical parameters of the process were taken into account, based on the data of instrumented indentation according to ISO 14577-1.2002. Experimental data obtained at the UTM-20HT installation [13] for Brinell and Vickers indenters are used in the work. A general physical analytical method for analyzing and processing test results, with various tools and indentation efforts, is proposed. The method is intended for an approximate assessment of the physical parameters of the material and standard mechanical characteristics of strength. By this method, using the simplified DS model, the ultimate strength and yield strength of steel 45, 15Х2НМФА (15KhNMFA) were determined.

4. Discussion

The DS model as a physical medium of CFL molar energy consisting of quasiparticles allowed to simultaneously form the concept of internal and external physical surface, physical external and internal boundary of the body, they allow analytically describe the processes of irreversible deformation (plastic deformation), the formation of a free surface (defect, crack, rupture)), heat generation, up to the brittle destruction of the body [5, 6]. The dependences of the theory are confirmed by the well-known empirical formulas of DS mechanics and the kinetic concept of strength. The physical properties of the molar structural-energetic model of deformation and destruction of the body are, in a certain sense, universal, applicable to describe the destruction of bodies of different physical nature (amorphous, crystalline, etc.). To describe the processes in DS, the physical equilibrium equation of molar energy is used. In theory, the connection of physical parameters with the parameters of DS mechanics is established. Physical energy characteristics are considered: the molar energy (molar thermodynamic potential), the molar volume, the change in the molar volume, their derivatives, the power, the speed of the process, and other physical parameters DS. The well-known experimental physical kinetic equations and dependences characterizing the state of an ideal gas and an ideal solid follow from the wave equilibrium equation of molar energy. The theory considers the rheological (in time) characteristics of the processes. The connection of macro parameters of stress, pressure, temperature, volume, free surface area, with microscopic statistical energy physical parameters of the atomic level has been established.

The performed calculations show the physical picture of the connection between the mechanical parameters of plastic deformation of the material and the physical parameters of the deformed solid. It is shown that it is possible in principle to apply new physical methods, instead of phenomenological approaches, when solving problems of DS mechanics. A more accurate and detailed calculation of the mechanical parameters and physical characteristics of DS is possible. To do this, it is necessary to calculate the physical parameters over the entire deformation diagram, to use other more complex methods of numerical solution.

5. Findings

With the rheological diagrams of the true stresses S (t) and deformations ε (t), the process of stretching a sample of a material (by oscillogram, table, etc.) before failure, or the results of indentation according to ISO 14577-1.2002, it is possible to determine the initial physical parameters using physical methods, then we determine the standard characteristics of strength and fatigue, simulating the standard test procedures. Physical methods can theoretically estimate the parameters of strength, fatigue, material durability for an arbitrary given function of stress and temperature. A theoretical account of the influence of additional physical factors on the process of damage accumulation in the material is possible. The developed theoretical and programmatic methods allow the rapid assessment of the state of the physical and mechanical parameters of the material directly in the structural elements of existing machines and mechanisms. For this purpose, you can use the appropriate sensors to control the parameters of deformation, temperature, etc. Data can be accumulated and stored, use the communication mode with information processing devices provided by the appropriate software algorithms for physical calculations of material state parameters. For interested organizations, we propose a joint further development, the use of the proposed physical calculation methods, programs for analyzing and monitoring the state of strength, damage to structural elements of dynamic devices, machines in complex non-stationary conditions and operation.

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The influence of the cinematic parameters of movement and sprung mass vibrations of wheeled vehicles on the move along the curvedlinear sections of the way

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Abstract: This paper presents a study outcome whereby the method of analyzing the stability with regard to the skid of wheeled vehicles with the consideration of variable velocity value along the curvilinear sections of the way and longitudinal angular oscillations of the sprung part has been developed. The longitudinal - angular oscillations of the sprung part reduce the critical speed value of steady motion; accelerated movement of the vehicle along the curvilinear section of the way for larger values of acceleration of the front axle skid occurs at lower velocity values (rear for the larger ones), for slow motion on the contrary. As for the impact of the power characteristics of the sprung system, then for the same values of all other parameters (amplitudes of longitudinal - angular oscillations, static deformations, acceleration (deceleration)), the progressive characteristic of the sprinkler system corresponds to the greater value of the critical speed of the stable motion as a regressive one. The theoretical contribution of the reported study in that the obtained results can serve as a base for study the influence of the kinematic parameters of the vehicle's motion on its controllability.

Keywords: steady motion, sprung and unsprung parts, critical speed value, longitudinal - angular oscillations.

1. Problem statement

Steerability, soft riding and steady motion are one of the most important running quality of wheeled vehicles (WV). And they are to some extent dependent on the external factors (inequality and curvature of the way, the state of its coverage). At the same time, they determine the kinematic parameters of WV movement and the relative oscillations of the sprung and unsprung parts. Regarding to the relative oscillations of the indicated parts, they, in addition to external factors (which are the main causes of their occurrence), are additionally determined by the power characteristics of the sprung system (SS) and the elastic tires. The dynamics of the sprung and unsprung parts of WV, and thus, power characteristics PH, greatly affect into the steady motion along the curvilinear sections of the way reducing the critical speed value of steady motion. If for the case of linear and partially for the nonlinear power characteristics PH in terms of vertical or transverse angular oscillations, the problems of the impact of the dynamics of the WV sprung part on the stability motion have been considered, then they did not find proper development for longitudinal - angular oscillations. The last one, to a lesser

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extent, have no effect on the stability of the movement both vertically and transversely - angular oscillations. In addition, the variable speed velocity of WV along the curvilinear sections of the way also affects into its steady motion. The study has been devoted to the partial development of this problem.

In the main publications concerning the steady motion of WV taking into account the dynamics of the SS, cases of linearly elastic characteristics of shock absorbers and simplest power characteristics of damper devices have been considered [1-5]. However, the SS with linear power characteristics does not fully ensure, first and foremost, ergonomic conditions of WV running [6]. In studies [7-12] an attempt was made to analyze the influence of some classes of SP with the nonlinear power characteristics of shock absorbers on SM dynamics for the simplest cases of oscillations of the sprung part (SP). At the same time, it has been noted that the longitudinal - angular oscillations of WV and variable speeds play very important role in the steady motion as transverse angular and vertical one. For the indicated oscillations, there is a need to consider more complex physical, but on the contrary, mathematical models. The research urgency of the steady motion increases primarily with the growth of the WV speed and the use of suspension brackets with a nonlinear (including controlled) characteristic of the change in the restoring force.

2. Task assignment

Three mass mechanical system as a physical model of the study object has been chosen to study the complex influence of variable speed and nonlinear longitudinal - angular fluctuations of the SP, on the WV steady motion along the curvilinear sections of the way. It includes the sprung (front and rear axles) and unsprung parts. They interact with each other through the elements of the suspension system - elastic shock absorbers and dampers.

Basic assumptions about external factors of motion during the KTZ movement along the path with inequalities:

- the inequalities of the road under the right and left wheels have the same vertical section;
- reaction forces of the skid of the front left ($Q_{1l.}$) and right ($Q_{1r.}$) and rear left ($Q_{2l.}$)and right $Q_{2r.}$ the rights of the rear axle are proportional to the normal dynamic forces of pressure $N_{il.}$ or $N_{ir.}$ on the support surface of the road (($i=1$ for the front and $i=2$ - for rear axles);).

As for the power characteristics of the right and left sides of the sprung system it is obvious that they are identical, but, taking into account the above mentioned statements, follows that the SP of the WV, through the onset of the inequality of the road, carries longitudinal-angular oscillations. The values of the forces of the right and left sides of the sprung system are described by the dependencies:

- Elastic forces of shock absorbers of the front ($F_{1r.}$ and $F_{1l.}$) and rear ($F_{2r.}$ and $F_{2l.}$) suspensions $F_{il} = c_i \Delta_{il}^{\nu+1}$, $F_{ir} = c_i \Delta_{ir}^{\nu+1}$ ($c_{i,}$ ν - stable, $\Delta_{ir.}$ - deformation of the elastic element of the right side, $\Delta_{il.}$ - deformation of the elastic element of the left side
- the resistance forces of damper devices of the right R_{ir} and left $R_{ir} =$ sides as speed functions of their deformation $R_{il} = \alpha_i \dot{\Delta}_{il}^s$, $R_{ir} = \alpha_i \dot{\Delta}_{ir}^s$ (α_i, s - stable), $\dot{\Delta}_{ir}$ and $\dot{\Delta}_{il}$ - deformation rate corresponding to the left and right dampers.

The task is to find the critical speed velocity V stable motion along the curvilinear sections of the way with a radius of curvature ρ as functions of the amplitude of longitudinal - angular oscillations, the main parameters that describe the power characteristic of SS and acceleration (deceleration) of WV motion.

3. Method of solving

The basis for solving the problem will be the kinetic-statics equation of the system, which is not sprung and unsprung parts of the WV, for the case of its movement along the curvilinear sections of the way [13].

$$\begin{aligned} &\vec{F}^e + \vec{\Phi} = 0, \\ &\vec{M}_O^e + \vec{M}_O^{\Phi.e} + \vec{M}_O^{\Phi.r} = 0, \end{aligned} \tag{1}$$

n which respectively $\vec{F}^{e}, \vec{\Phi}$ - the main vectors of external forces and forces of inertia considered by the three mass systems, but $\vec{M}_O^e, \vec{M}_O^{\Phi.e}, \vec{M}_O^{\Phi.r}$, - the main points of a relatively arbitrary center O external ($\vec{M}_O^e$) forces and forces of inertia in relative ($\vec{M}_O^{\Phi.r}$)and figurative ($\vec{M}_O^{\Phi.e}$) movement. As for the first of them, it is the active forces of weight: front ($\vec{P}_1$), rear ($\vec{P}_2$) axles (unsprung part), sprung part - ($\vec{P}_3$); driven by the driving force" of the rear left $F_{a2l.}$ and the rear right $F_{a2r.}$ wheels.

Passive forces: normal reaction of road surface acting on front tires ($\vec{N}_{1r.}, \vec{N}_{1l.}$) and rear $\vec{N}_{2r}, \vec{N}_{2l.}$ axles; skid reaction forces of the front left ($Q_{1l.}$) and right ($Q_{1r.}$) and rear left ($Q_{2l.}$)and right $Q_{2r.}$ and rear axles; forces of resistance to rolling of front right $F_{1or.}$ and left $F_{1ol.}$ wheels.

The forces of inertia of the portable (curvilinear) motion are reduced to the main vector of forces of inertia of the front $\vec{\Phi}_1^e$, rear $\vec{\Phi}_2^e$ axles and sprung mass - $\vec{\Phi}_3^e$. They are determined by correlation: $\vec{\Phi}_i^e = \vec{\Phi}_i^{e.\tau} + \vec{\Phi}_i^{e.n}$ $\Phi_i^{e.n} = \frac{P_i}{g}\frac{V^2}{\rho}$, $\Phi_i^{e.\tau} = \frac{P_i}{g} w$, w - the value of acceleration (deceleration) of the WV motion. The vectors $\vec{\Phi}_i^{e.n}$ are directed toward the convexity of the trajectory of motion, a $\vec{\Phi}_i^{e.\tau}$ - in the opposite direction to the velocity vector of the center of mass of the WV (for accelerated motion) and to the side of the velocity vector - for the slowed motion.

Notes 1:

1. In the work, it is considered that the WV is moving along the curvilinear sections of the road with the constant acceleration in magnitude, therefore V is the meaning of the speed of the WV at the given time;
2. The change of the radius of the trajectory curvature to the points which coincide with the centers of the masses of the sprung part, as well as the front and rear axles are not taken into account;
3. The influence of the road inequalities on the vertical fluctuations of the WV may be the subject of separate investigations, and fluctuations of the SM are considered to be due to initial disturbances.
4. As for the forces of inertia in relative motion (longitudinally - angular oscillations) then their relative transverse axis, passing through the center of mass C can be reduced to the moment of inertia forces $M_C^{\Phi.r}$, the value of which is equal $M_C^{\Phi.r} = -I_C \varepsilon$, where I_C - moment of inertia of the sprung mass relative to the axis indicated above, but ε - angular acceleration of the SM movement. The basis for determining the angular acceleration of the SM may be longitudinal differential equation - angular oscillations of this part and the relevant initial conditions. The differential equation of the specified part of the WV, more precisely, its right-hand side is determined by the forces acting on it (see Fig. 1).

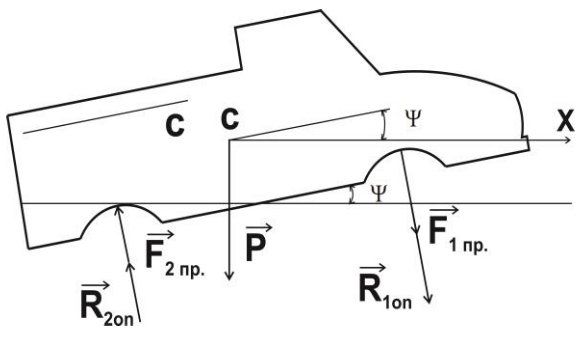

Figure 1. Scheme for studying the dynamics of the SM of the WV

On the given figure $\vec{F}_i = \vec{F}_{ir.} + \vec{F}_{il.}$, $\vec{R}_i = \vec{R}_{ir.} + \vec{R}_{il.}$ are the superficial forces of shock absorbers or damping devices of the right and left side of the front ($i=1$) and ($i=2$) rear suspension, as well as $\psi(t)$ - value of the rotation angle of the SP at an arbitrary time. Thereby, $M_C^{\Phi.r} = -I_C \frac{d^2\psi}{dt^2}$, namely, the differential longitudinal-angular oscillation takes the form

$$I_C \frac{d^2\psi}{dt^2} = -c_1 a\left(a\psi(t) - \Delta_{cm.}\right)^{\nu+1} - c_2 a\left(b\psi(t) + \Delta_{cm.}\right)^{\nu+1} - \alpha_1 a\left(a\frac{d\psi}{dt}\right)^{s} - \alpha_2 b\left(b\frac{d\psi}{dt}\right)^{s} \quad (1)$$

where a, b - parameters that determine the position of the center of mass of the SM, $\Delta_{cm.}$ - the static deformation of elastic shock absorbers.

In order to determine the critical value of the velocity of steady motion, taking into account the fluctuations of the Sm, it is not necessary to have the law of changing these oscillations of the specified part of the WV, but only their amplitude, for example, the amplitude of the initial perturbation. Then max $M_C^{\Phi.r}$ =max $I_C \frac{d^2\psi}{dt^2}$, but max $I_C \frac{d^2\psi}{dt^2}$ = max $G(\psi,\dot\psi)$, where $G(\psi,\dot\psi)$ - right part of the equation (2). In addition it is known that the resistance forces of the damping devices cause the PM to decay the oscillations of the specified part of the WC, so the right-hand side of equation (2) assumes the maximum value at the moment of maximum amplitude, that is, at the "initial" time point for which $a_{\psi}|_{t=0}=\bar a_{\psi}$.

Thereby, max $M_C^{\Phi.r}$ =max $\left[c_1 a\left(a\psi(t)-\Delta_{cm.}\right)^{\nu+1}+c_2 b\left(b\psi(t)+\Delta_{cm.}\right)^{\nu+1}\right]$. Considering the above, it can be argued that the maximum value of the inertia forces moment of the PM in relative motion relative to the axis $C\zeta$ takes the value

$$\max M_C^{\Phi.r} = \bar M_C^{\Phi.r} = \left(c_1 a(a\bar a_{\psi}-\Delta_{cm.})^{\nu+1}+c_2 b(b\bar a_{\psi}+\Delta_{cm.})^{\nu+1}\right) \tag{2}$$

The above considerations allowed to avoid time-consuming procedures for integrating the nonlinear differential equation (1), and hence, go directly to the procedure for finding the critical speed of steady motion taking into account longitudinal - angular oscillations of the WV and the variable at the speed of movement. To do this, let's turn from the vector relations (1) to their scalar counterparts

$$\begin{aligned}
&F_{2lppy.}+F_{2rppy.}-F_{1loo.}-F_{1roo.}-\Phi_1^{e.\tau}-\Phi_2^{e.\tau}-\Phi^{e.\tau}=0,\\
&Q_{1r.}+Q_{1l.}+Q_{2r.}+Q_{2l.}-\Phi_1^{e.n}-\Phi_2^{e.n}-\Phi^{e.n}=0,\\
&N_{1r.}+N_{1l.}+N_{2r.}+N_{2l.}-(P_3+P_1+P_2)=0,\\
&\left(\Phi_1^{e.n}+\Phi_2^{e.n}\right)R+\Phi^{e.n}(R+h)+\left(N_{1r.}+N_{2r.}\right)d-(P_3+P_1+P_2)\frac{d}{2}=0,\\
&P_3 a+P_2(a+b)-(N_{2r.}+N_{2l.})(a+b)+\left(\Phi_1^{e.\tau}+\Phi_2^{e.\tau}\right)R+\Phi^{e.\tau}(R+h)-\overline{M}_y^{\Phi.r}=0,\\
&(Q_{2r.}+Q_{2l.})(a+b)-\Phi_2^{e.n}(a+b)-\Phi^{e.n}a-(\Phi_1^{e.\tau}+\Phi_2^{e.\tau}+\Phi^{e.\tau})\frac{d}{2}+(F_{2lppy.}-F_{1loo.})d=0.
\end{aligned} \tag{3}$$

where R, h, d - in accordance: tire radius; the parameter characterizing the height of the masses center placement of the SP over the axels, the distance between the axles of the front (rear) wheels. If it taken into account that the anti-skidding forces $\vec Q_1$, $\vec Q_2$ are determined by dependencies $Q_1=Q_{1r}+Q_{1l}=k_1\left(N_{1r.}+N_{1l.}\right)$, $Q_2=Q_{2r}+Q_{2r}=k_2\left(N_{2r.}+N_{2l.}\right)$, and the main vectors of inertial forces take the above values, then the system of equations (3) has been transformed into a form

$$\begin{aligned}
&F_{2lpyu.}+F_{2rpyu.}-F_{1lon.}-F_{1ron.}=\frac{P_3+P_1+P_2}{g}w,\\
&k_1(N_{1r.}+N_{1l.})+k_2(N_{2r.}+N_{2l.})=\left(P+P_1+P_2\right)\frac{V^2}{\rho g},\\
&N_{1r.}+N_{1l.}+N_{2r.}+N_{2l.}=P+P_1+P_2,\\
&P_3 a+P_2(a+b)-(N_{2r.}+N_{2l.})(a+b)=\bar M_y^{\Phi.r}-\left[\frac{P_1+P_2}{g}R+\frac{P_3}{g}(R+h)\right]w,\\
&(P_3+P_1+P_2)\frac{d}{2}-\left(N_{1r.}+N_{2r.}\right)d=\frac{P_1+P_2}{g}\frac{V^2}{\rho}R+\frac{P_3}{g}\frac{V^2}{\rho}(R+h),\\
&k_2\left(N_{2r.}+N_{2l.}\right)(a+b)+(F_{2lpyu.}-F_{1lon.})d=\frac{P_2}{g}\frac{V^2}{\rho}(a+b)+\frac{P_3}{g}\frac{V^2}{\rho}a+\frac{P_3+P_1+P_2}{2g}dw.
\end{aligned} \tag{4}$$

Notes 2.

1. Equations (4) have been written in projections on a Cartesian system with a start at the point of contact of the right front wheel to the road, and two axles are directed along and across of the WV;

2. The critical speed does not depend on the reference system choice, and the form of the equation (4) changes with the coordinate system.

In the above dependencies $\bar{M}_y^{\Phi.r}$ - the moment of the inertial forces of relative motion relative to the transverse axis and the point of contact of the left front wheel to the road, takes the following value $\bar{M}_y^{\Phi.r}=I_y\frac{\left(c_1 a(a\bar{a}_\psi-\Delta_{cm.})^{\nu+1}+c_2 b(b\bar{a}_\psi+\Delta_{cm.})^{\nu+1}\right)}{I_C}$, I_y - the inertia moment of the absorbed mass relative to the transverse axis, which passes through the contact point of the front left wheel and the road. The indicated value in accordance with the Huygens-Steiner theorem is determined by the relation $I_y=I_C+\frac{P_3}{g}\left(a^2+(R+h)^2\right)$.

After simple transformations from it critical values in view of the drift of the front V_1 and rear V_2 axles of WV can be done

$$V_1=\sqrt{\left(k_1 g-\frac{k_1\left[\left(P_1+P_2\right)wR+P_3 w\left(R+h\right)+g\bar{M}_y^{\Phi.r}\right]+(P_1+P_2+P_3)\frac{d}{2g}w-(F_{2lpyu.}-F_{1lon.})d}{P_1\left(a+b\right)+P_3 b}\right)\rho},$$

$$V_2=\sqrt{\left(k_2 g+\frac{k_2\left[(P_1+P_2)Rw+P_3(R+h)w-g\bar{M}_y^{\Phi.r}\right]-\left(P_3+P_1+P_2\right)\frac{d}{2g}w+(F_{2rpyu.}-F_{1ron.})d}{P_2\left(a+b\right)+P_3 a}\right)\rho}. \tag{5}$$

In the specified ratios, the summands $(F_{2lpyu.}-F_{1lon.})$ and $(F_{2rpyu.}-F_{1ron.})$ describe the forces acting in the longitudinal direction of the WV on the tires and force it to accelerated (or slowed) motion. If further consider that $F_{1lon.}=F_{1ron.}$ and $F_{2lpyu.}=F_{2rpyu.}$, then the acceleration of the WV motion is determined by the ratio $w=\frac{F_{2lpyu.}+F_{2rpyu.}-F_{1lon.}-F_{1lon.}}{P_3+P_1+P_2}g$. The above gives the critical values for the introduction of the front and rear axles in the form

$$\tilde{V}_1=\sqrt{\left(k_1 g-\frac{k_1\left[\left(P_1+P_2\right)wR+P_3 w\left(R+h\right)+g\bar{M}_y^{\Phi.r}\right]}{P_1\left(a+b\right)+P_3 b}\right)\rho},$$

$$\tilde{V}_2=\sqrt{\left(k_2 g+\frac{k_2\left[(P_1+P_2)Rw+P_3\left(R+h\right)w-g\bar{M}_y^{\Phi.r}\right]}{P_2\left(a+b\right)+P_3 a}\right)\rho}. \tag{6}$$

In this manner, critical $\tilde{V}$ taking into account the fact that the value of the speed of steady motion along the curvilinear section of the road is equal $\tilde{V}=\min\left(\tilde{V}_1,\tilde{V}_2\right)$. It should be noted that in the equations for $\tilde{V}_1$ and $\tilde{V}_2$ before $\bar{M}_y^{\Phi.r}$ is sign "–". This is due to the fact that SP performs relative longitudinal - angular oscillations, and the moment of inertia forces in the specified motion changes its size and direction. The most dangerous because of the steady motion will be the case, when the moment of inertia forces reduces the force of pressure on the road surface, and therefore the critical value of the speed corresponds to the minimum value of the moment of inertia forces.

A special case of the above dependencies for $w=0$ is the critical value of steady motion speed, provided by constant speed value, and for $w<0$ the results refer to the slow motion, i.e.

$$\tilde{\tilde{V}}_1=\sqrt{\left(k_1 g+\frac{k_1\left[\left(P_1+P_2\right)wR+P_3 w\left(R+h\right)-g\bar{M}_y^{\Phi.r}\right]}{P_1\left(a+b\right)+P_3 b}\right)\rho},$$

$$\tilde{\tilde{V}}_2=\sqrt{\left(k_2 g-\frac{k_2\left[(P_1+P_2)Rw+P_3\left(R+h\right)w+g\bar{M}_y^{\Phi.r}\right]}{P_2\left(a+b\right)+P_3 a}\right)\rho}. \tag{7}$$

4. Conclusions

The obtained analytical dependencies show that the critical value of the steady motion along the curvilinear sections of the road:

- without taking into account longitudinal - angular oscillations of the SM is significantly overestimated;
- the greater e value of the oscillations amplitude corresponds the less value of the critical velocity;
- for the progressive power characteristic of the sprung system at small amplitudes of oscillations is greater than for the linear power characteristic (provided that the static strain is equal), and for the "big" ones - on the contrary;
- for higher values of the parameters of the WV base is smaller;
- critical velocity value is greater for the progressive characteristic of the sprung system at higher values of the static deformation of the sprung system, and for regressive - on the contrary.

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Modeling of hazardous situations on vehicles for estimation the occupational risk of drivers

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Abstract: This paper provides an analysis of the complexity of factors related to road transport. The most significant of them are outlined and occupational risk on motor transport is estimated, depending on the conditions of carrying out transport work and the duration of operation of the vehicle. Models of the onset of hazardous situations are developed during separate motor transport works. It is established that the reliability of the modeling is significantly influenced by the insufficient reasonableness of the causes of road traffic accidents and the large number of impacts on the occupational risk of individual elements of the "driver-car-environment" system. It has been shown that the procedure for the determination of occupational risks should be based on statistically significant data on the causes of accidents and the results of monitoring the technical condition of the vehicle systems that determine its accident rate. To evaluate the occupational risk of truck drivers, the SAPHIRE computer program was used, which allows using the Fusel-Veseli and Birnbaum criteria to calculate the probability of a hazardous situation occurring on the basis of a plurality of probabilities of basic events. As a result of the study, the professional risk of drivers in case of nonobservance of norms of occupational safety and the presence of defects in the responsible parts of the system (units) of the truck has been calculated, as well as the degree of risk reduction of emergency transport situations after the introduction of appropriate measures of safety, in particular after removal of defects in the technical condition of the truck. The value of the study is that the application of this approach to the assessment of drivers' occupational risk factors makes it possible to compare the impact of hazardous factors of different kinds and to determine the overall degree of danger, taking into account the contribution of each individual factor.

Keywords: road accident, modeling of hazardous situations, occupational risk, tree failure, technical condition of a truck.

1. Introduction

Road transport accidents (RTA) with various consequences may occur during road transportation, in particular with injuries to road users. For the most part, among the causes of RTA indicate unsatisfactory covering of motor roads, neglect of drivers of the traffic Rules, lack of control of the heads of motor transport enterprises (subdivisions) by the technical condition of motor vehicles, etc. [1]. These reasons are manifested comprehensively and predetermine the high level of occupational risk of truck drivers, not only during the transport of dangerous goods [2], but also in case of, for example, exceeding the load-carrying capacity of a vehicle or the transportation of oversized agricultural machinery.

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In order to develop measures to prevent road traffic accidents of truck transport, it is necessary to analyze the complex of factors related to road transportations, to isolate the most significant and to assess the occupational risk on road transport depending on terms of performance of transportation works [3]. For such an analysis, mathematical modeling of hazardous (emergency) situations on motor transport with the involvement of logical operators and the probability theory apparatus is effective [4, 5]. However, the insufficient reasonableness of the magnitudes of the probabilities of manifestation the causes of accidents which are in the calculations by the basic events, and the large number of impacts on the occupational risk of individual elements of the system "driver-car-environment" ("D-C-E") now limits the authenticity of modeling [6, 7].

Nowadays, different approaches to describing links within the framework of developed models are used to simulate hazardous situations [8, 9]. In most of the work published over the past 10 years and devoted to the problem of assessing occupational risks, not only discuss the definition of occupational risk, but also offer methods for taking into account the influence of numerous circumstances of dangerous situations [10, 11]. But, despite the large number of risk assessment algorithms in production, there are currently no acceptable methods for assessing the risk on technology processes using technical means, especially for the automotive branch in Ukraine. Often the recommended methods are characterized by significant disadvantages in terms of their practical application (due to the complexity, incorrectness of input the initial data in the calculations, do not take into account the duration of the influence of dangerous factors).

The assessment of the risks of hazardous situations on motor transport should be based on the results of monitoring the technical condition of vehicles, statistics on the causes and circumstances of accidents, as well as on the results of simulation of hazardous events, their impact on the level of occupational injuries [12–14].

2. Materials and methods

In this paper a methodology for calculating the occupational risks of truck drivers, which provides for the possibility of taking into account the organizational, technical and psycho-physiological causes that lead to injuries in the branch is developed. The method is based on Event Tree Analysis. The application of this approach for assessing occupational risk indicators on motor transport allows us to compare the impact of hazardous factors of different nature and species, and to determine, taking into account the contribution of each individual factor, the overall degree of danger.

To calculate the occupational risk of truck drivers, an adapted SAPHIRE computer program, which allows with using the Fusel-Veseli and Birnbaum criteria to calculate the probability of a traumatic situation occurring on the basis of a plurality of probabilities of basic events, was used [15].

In the developed models of the accident, the probability of the basic events, which corresponds to the organizational, technical and psychophysiological causes of occupational injuries, asked according to statistical indicators of the causes of accidents on motor transport [16], and the assessment of the impact of technical malfunctions of the truck on the probability of an accident provide taking into account the length of operation of the car.

Models of occurrence of dangerous situations were constructed for typical accidents: rollover of the car as a result of skidding on the turn on unfavorable weather conditions; rollover of the car while driving on a slope; collision of a car with a moving (immovable) obstacle or riding from the road in a ditch.

3. Results and discussion

In models that describe the circumstances of an accident should take into account the risk factors that affect to the probability of getting into an accident and possible severity of the accident (excess speed, the presence of alcohol or drug intoxication, fatigue or bad driver's eyesight, dark time of day or insufficient visibility through weather conditions; unsatisfactory overall technical condition of the vehicle or separately defective braking system condition; non-compliance with periodicity of technical reviews; unsatisfactory road conditions; insufficient fastening of the cargo, non-use of safety belts, etc.). Determining the significance of each of the risk factors is a difficult task.

The degree of gravity of the consequences of an accident will increase, for example, in case of emergence of a fire after an accident, leakage from the car of flammable liquids, delays in providing medical care to the victim, and the difficulties in saving the victims. These dependencies are not linear. Thus, according to research [17, 18], the risk of traffic accidents with injuries to road users is proportional to the square of speed of the vehicle's; the probability of a serious traffic accident is proportional to the speed in the cube; the likelihood of an accident with a fatal outcome - to the speed in the fourth degree.

The psycho-physiological state of the driver, namely the feeling of internal discomfort, the fatigue, reaction speed, culture and driving skills, in particular observance of the established speed mode of movement, the use of safety belts, the presence of alcohol or drug intoxication, etc. is essentially effects on the safety of the traffic.

These and other circumstances of the accidents can be fully reflected in the multi-factor models creating of hazardous situations, but in order to quantify the risk of an accident occurrence, the calculation model must include certain values of the determining parameters which must be substantiated. So in the developed method of calculation of professional risk it is proposed to display in the models of the Event tree as the main causes of road accidents those, which are contained in the acts of investigation of accidents in motor transport and quantitatively statistically estimated in the annual sectoral reporting.

Among the main (common) causes of accidents most often indicate the following:

- unsatisfactory technical condition of vehicles;
- violations of labor and production discipline by road users;
- violation of traffic rules;
- violation of safety requirements during operation of vehicles;
- violation of the technological process of cargo transportation;
- psycho-physiological reasons connected with fatigue or painful state of the driver, etc.

The comparison of the definitions of these causes and the causes of occupational injuries, indicated in [16], shows that their conformity is not complete. Just as the basic events for the calculation models were introduced by nearest equations for the reasons indicated in [16], for which the statistical coefficients (indicators of the risk of injury) are known. The sum of these coefficients, as according to statistics [16], was to be equal to units.

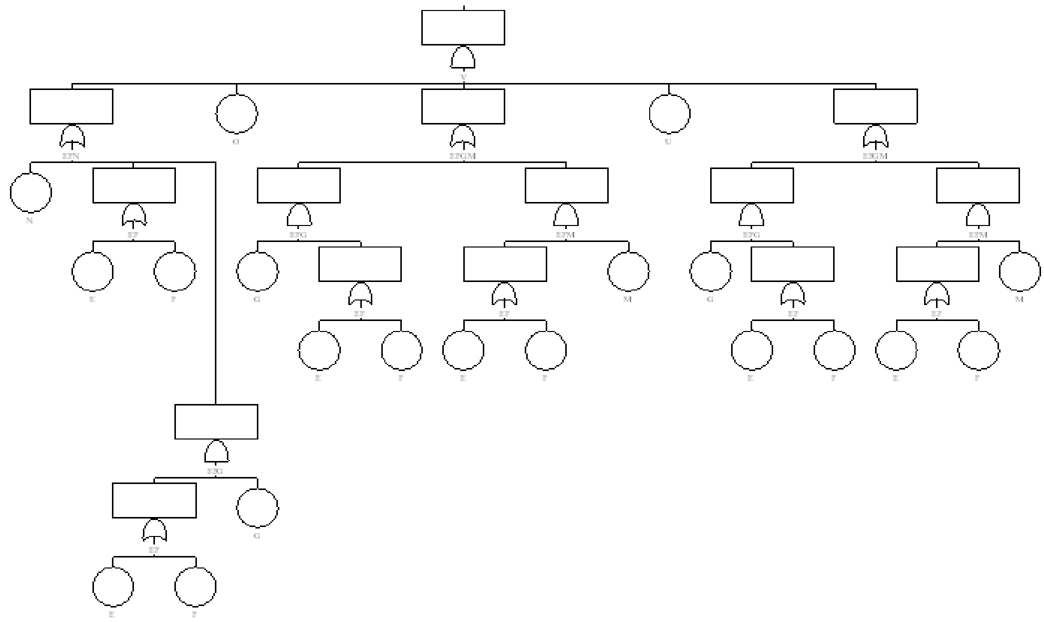

Figure 1. Block diagram of the logic-simulation model of a dangerous situation "the rollover of a car (tractor) as a result of skid on the turn".

As an illustration of this approach, in this paper, the calculation of the risk of rollover of a vehicle (tractor) as a result of skid in adverse weather conditions is presented. Such accidents occur, in particular, on roads outside settlements, where small radius of turns are arranged and there are other road traffic problems. The logic-simulation model of such a traumatic situation is presented in Figure 1.

The meaning of the elements of the logic-simulation model of a dangerous situation "the rollover of a car (tractor), as a result of skidding on the turn" presented in Table 1, where the quantitative values of the basic events are given. The quantitative values of the probability of the basic events were combined in Table 1 in order to keep compliance with the data of statistical bulletins "Traumatism in the production in 20_ _", prepared by the State Statistics Service of Ukraine on the basis of the data of forms of state statistical observation № 7-tnv "Report on injuries on production in 20__ year ".

Table 1. Semantic meaning of the elements of the logic-simulation model of the road accident.

Elements symbol (basic events)	Brief description of elements (basic events)	Quantitative value of probability of basic events
E	Disadvantages during the training of drivers the safe working methods (in the actual absence of occupational safety and health at the enterprise)	0.15
F	Absence or poor quality of a medical examination or professional recruitment of drivers (unsatisfactory activity of occupational safety and health)	0.1
EF	Unsatisfactory condition of occupational safety and health at the enterprise	
G	Violation of the technology of cargo transportation (due to the lack of respectively prepared drivers able to drive a vehicle under difficult conditions)	0.25
EFG	Low professional level of employees hired to work	
N	Unsatisfactory technical condition of vehicles (due to insufficient funds for updating the material and technical base of the enterprise)	0.2
EFGN	Operation of a tractor (car) with worn-out tread of the wheels above the permissible level or presence of defects in details of the steering system and the braking system	
O	Unfavorable atmospheric phenomena on the road or performance of work in the dark time of day	0.15
M	Low level of labor discipline and driver's work culture (use of alcohol, psychotropic or narcotic substances during work)	0.1
EFM	Driver's stay while working in alcohol or drug addiction	
EFGM	Violation of traffic safety rules - exceeding the permissible speed of the tractor (car)	
$EFGM^1$	Sudden (emergency) braking	
U	Imperfection of the technological process, its non-compliance with safety requirements (presence of steep turns on roads or defective road cover)	0.05
V	Rolling over the car as a result of skidding on the turn	$6.561 \cdot 10^{-4}$

As an example, in the work, the risk of a dangerous situation (overturning a vehicle) was calculated for two discrete cases that characterize the impact of a dangerous manufacturing factor: virtually no action of a dangerous factor (probability of influence of 0.01) and its defining action (probability of influence 0.5). In Table 2 shows how the risk of rollover of a vehicle has changed due to the predominance of certain elements of the model, in particular after a significant deterioration of the technical condition due to the presence of defects in the responsible parts of the vehicle systems.

Table 2. Changes of risk indicators for the logic-simulation model of the dangerous situation "roll-over of a car (tractor) due to skidding on the turn".

Dangerous factor (action, event, situation)	Quantitative value of probability of basic events	Calculated risk indicator, P	Change in the risk indicator in the presence of danger, times
E	0.01	$2.887 \cdot 10^{-4}$	–
	0.5	$1.574 \cdot 10^{-3}$	5.45
F	0.01	$4.2 \cdot 10^{-4}$	–
	0.5	$1.705 \cdot 10^{-3}$	4.06
G	0.01	$2.062 \cdot 10^{-4}$	–
	0.5	$1.125 \cdot 10^{-3}$	5.45
N	0.01	$3.432 \cdot 10^{-4}$	–
	0.5	$1.268 \cdot 10^{-3}$	3.69
O	0.01	$4.375 \cdot 10^{-5}$	–
	0.5	$2.186 \cdot 10^{-3}$	49.97
M	0.01	$4.874 \cdot 10^{-4}$	–
	0.5	$1.406 \cdot 10^{-3}$	2.88
U	0.01	$1.312 \cdot 10^{-4}$	–
	0.5	$6.548 \cdot 10^{-3}$	49.91

In Table 3 presents the risks of occurrence of a dangerous event (probability of influence 0.5) in the form of a diminutive row, which allows to assess the most significant risks.

Table 3. The row of risk increases of a dangerous event in the logic-simulation model.

The model element	M	N	F	E	G	U	O
The estimated risk indicator	2.88	3.69	4.06	5.45	5.45	49.91	49.97

Important, demonstrative and necessary for further analysis are not the absolute values of the calculated risk, which depend on the structure of the proposed model of the onset of the emergency situation, changes in risk indicators, which characterize the impact of a certain production factor. Before consideration it is necessary to take a given on the basis of statistics the significance of the factor taking into account the change of risk within the closed system of basic events.

By analyzing the calculation of the relative importance of the underlying events by the Fusel-Vesely criterion, it can be noted that in all variants of the risk-taking situation events take part in events O and U which are the most significant among all other events and have the same coefficients of significance (Table 4).

Table 4. Indicators of the relative importance of primary (basic) events by the Fusel-Veseli criterion.

Event name	Number of variants of process development	Probability of basic event	Fussell-Vesely importance	Risk reduction ratio	Risk increase ratio
O	4	$1.5 \cdot 10^{-1}$	1.0	-	6.65
U	4	$5.0 \cdot 10^{-2}$	1.0	-	19.91
G	2	$2.5 \cdot 10^{-1}$	$7.142 \cdot 10^{-1}$	3.499	3.142
E	2	$1.5 \cdot 10^{-1}$	$5.999 \cdot 10^{-1}$	2.50	4.398
F	2	$1.0 \cdot 10^{-1}$	$3.999 \cdot 10^{-1}$	1.666	4.597
M	2	$1.0 \cdot 10^{-1}$	$2.856 \cdot 10^{-1}$	1.40	3.57
N	2	$2.0 \cdot 10^{-1}$	$1.934 \cdot 10^{-1}$	1.286	2.842

Analyzing the calculation data of the absolute significance of the underlying events according to the Birnbauom criterion, one can also note that events O and U take part in all variants of a risk-taking situation events, while the coefficient of significance of the event O is much smaller than the coefficient of significance of the event U (Table 5).

Table 5. Indicators of absolute significance of primary (basic) events by the Birnbaum criterion.

Event name	Number of variants of process development	Probability of failure	Birnbaum importance measure	Risk reduction difference	Risk increase difference
O	4	$1.5 \cdot 10^{-1}$	$1.307 \cdot 10^{-2}$	$6.561 \cdot 10^{-4}$	$1.241 \cdot 10^{-2}$
U	4	$5.0 \cdot 10^{-2}$	$4.368 \cdot 10^{-3}$	$6.561 \cdot 10^{-4}$	$3.712 \cdot 10^{-3}$
G	2	$2.5 \cdot 10^{-1}$	$2.623 \cdot 10^{-3}$	$3.936 \cdot 10^{-4}$	$2.229 \cdot 10^{-3}$
E	2	$1.5 \cdot 10^{-1}$	$2.623 \cdot 10^{-3}$	$2.624 \cdot 10^{-4}$	$2.360 \cdot 10^{-3}$
F	2	$1.0 \cdot 10^{-1}$	$1.87 \cdot 10^{-3}$	$4.686 \cdot 10^{-4}$	$1.405 \cdot 10^{-3}$
M	2	$1.0 \cdot 10^{-1}$	$1.87 \cdot 10^{-3}$	$1.874 \cdot 10^{-4}$	$1.686 \cdot 10^{-3}$
N	2	$2.0 \cdot 10^{-1}$	$1.67 \cdot 10^{-3}$	$1.782 \cdot 10^{-4}$	$1.596 \cdot 10^{-3}$

The indicated results of the conducted studies give the opportunity to focus attention on the riskiest primary (basic) events for the development of effective preventive measures to prevent such and similar accidents.

4. Conclusions

The assessment of the risks of hazardous situations in motor vehicles should be based on statistical data on the causes and circumstances of accidents, the results of monitoring the technical condition of vehicles, as well as the results of simulation of hazardous events, their impact on the level of occupational injuries.

The results of the calculation of the elements of the logic-simulation model allow to estimate the risk of an accident during a traffic accident as a result of a certain correlation of reasons of an organizational, technical and psycho-physiological nature, in particular due to the accumulation of defects in the responsible parts of the nodes. The obtained values, which correspond to unacceptable occupational risk, should be the basis for observance of normative terms of technical maintenance of vehicles and replacement of damaged parts.

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Suspension of a car with nonlinear elastic characteristics based on a four-link lever mechanism

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Abstract: This paper shows the possibility of creating a suspension of a car with a nonlinear elastic characteristic based on a four-link lever mechanism. It also presents the kinematics and dynamics of the mechanical suspension system. As a result of the study, the kinematic laws and distribution of forces in the nodes of the suspension have been found. The dependence of general rigidity on the stiffness of the main and additional elastic elements have been determined for obtaining the required nonlinear elastic characteristic. An example of a given nonlinear elastic characteristic is presented.

Keywords: suspension of a car, nonlinear elastic characteristic, four-link lever mechanism.

1. Introduction

During operation of cars periodically its sub sorted mass as a result of change of payload. Most significantly this is noticeable for the rear axle. If for cars the change of load on the rear axle is 45-60%, for buses – 200-250%, then for trucks the change of load reaches 250-400%.

Suspension of a car with a linear elastic characteristic is not able to provide the proper smoothness of the course, as when changing the load, the static arrows of the deflection and, as a result, the frequency of oscillations change.

From the theory of the automobile it is known that in order to maintain the required level of internal frequency of oscillations with variable load, it is necessary to ensure the stability of the static deflection z_0 change in the stiffness of the suspension.

Such a requirement is satisfied by the nonlinear elastic characteristic of the suspension, which corresponds to the condition [1,2,6]:

$$\frac{R_z}{c_p} = z = z_0 = const \qquad (1)$$

,

where R_z – dynamic load of the suspension; c_p – the rigidity of the suspension is given; z– vertical displacement of the submerged mass.

In turn, this condition will be fulfilled, as is known [1], if the characteristic of the suspension changes according to the law of the indicator function:

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$$R_z = R_{z0} \cdot e^{(\frac{z}{z_0} - 1)}, \qquad (2)$$

where R_{z0} – static load of the suspension *N*.

It should be noted that ensuring these conditions will lead to constant frequency fluctuations, regardless of the load change, with the following assumptions:

- all the payload falls on the rear axle, which is almost performed for trucks and passenger cars;

- the oscillations of the submerged mass above the front and rear axles do not depend on each other. This is possible with the mass distribution factor $\varepsilon = 0,85 \div 1,2$ [1,2,4-6].

Known ways to achieve non-linearity by using in the spring suspensions or additional elastic elements with a progressive characteristic [1,3,4]. But such systems do not provide a constant level of smoothness at various values of the submerged mass. Systems with additional elastic elements connected at the values of the submersible mass close to the nominal load-carrying capacity have poor smoothness at the unloaded condition of the car.

To the fullest extent, condition (2) can provide an adaptive suspension in which the damping degree of the shock absorber is given in accordance with the road surface condition, the parameters of motion, and may also change to the current value of the submersible mass [7-12]. In adaptive suspensions used in modern cars, the degree of damping of the shock absorber varies in two ways: by means of electromagnetic valves or by means of magnetorheological liquids.

By the first way work the well-known suspensions Adaptive Variable Suspension, AVS from Toyota; Continuous Damping Control, Opel CDS; Adaptive Chassis Control, DCC from Volkswagen; Electronic Damper Control, EDC from BMW (active suspension Adaptive Drive); Adaptive Damping System, ADS from Mersedes-Benz (Airmatic Dual Control Pneumatic Suspension) [13-17].

Shock absorbers based on magnetorheological fluids are used in MagneRide suspensions from General Motors (cars Cadillac, Chevrolet); Magnetic Ride by Audi [18].

With significant advantages, the adaptive suspension due to the complexity of the design of the shock absorber, the presence of trace elements (sensors), computer control has a high cost, both its own and maintenance, of course, restricts its use.

That is why occurs the task of designing simple, relatively cheap suspensions with a nonlinear characteristic, close to the condition (2) for cargo and passenger cars of class N1, B1.

2. Materials and Methods

To obtain a nonlinear elastic characteristic we use the kinematic scheme of the suspension on the basis of a four-link lever mechanism (Figure 1) [19, 20].

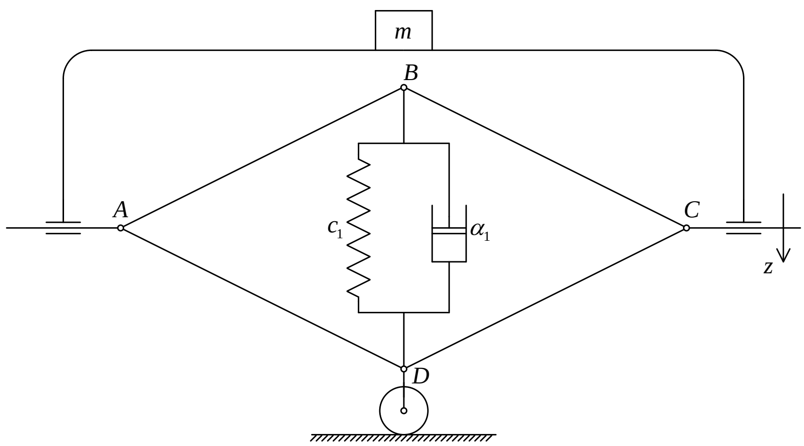

Figure 1. Kinematic scheme of the suspension on the basis of a four-link lever mechanism.

Under this scheme the sprung mass rests through longitudinal guides on the side hinges A and C of the four-link lever mechanism ABCD. The elastic and damping elements are fixed between the upper B and the lower D joints of this mechanism. In this case, the lower hinge is based on unscattered mass.

Let's consider the kinematics of such a scheme.

If you immediately fix the lower hinge D of the four-link lever mechanism and, for the submersible mass, set the vertical displacement *z* (Figure 2), then the upper hinge B moves to *2z*, since each of the vertical half diagonals of the diamond ABCD will deform to *z*.

This leads to the fact that the magnitude of the oscillations of the submerged mass will be doubled between the upper and lower hinges of the quadrilateral lever mechanism, and, therefore, the elastic element will be perceived as a double deformation *ΔBD = 2z*. This allows you to use an elastic element with less rigidity in the suspension while maintaining the same level of internal frequency of oscillation of the submerged mass.

Let's find the horizontal displacement *y* of the side hinges in relation to the vertical displacement of the sub-mass *z*. Consider the scheme in Figure 2.

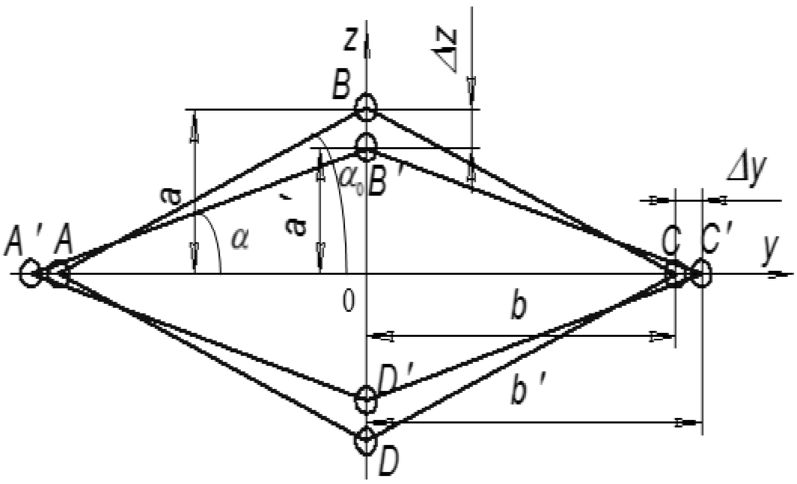

Figure 2. The scheme of finding the horizontal displacement y of the side hinges relative to the vertical displacement of the sprung mass *z*.

The ABO triangle (Figure 2) formed by the joints A and B of the lever quadrilateral ABCD and the point O of the intersection of the diagonals of the diamond corresponds to the state of the static deflection of the suspension. The A1B1O triangle corresponds to the current suspension condition with oscillations. The value BB1 corresponds to the deformation of the vertical semia dionon of the diamond and is equal to *z*. The value A1A is the horizontal displacement of the side hinge Δy. The angle α_0 is the angle between the horizontal diagonal of the diamond AC and the side AB and corresponds to the state of the static deflection z0, $< \alpha =< OA_1B_1$ which is the angle corresponding to the state of the deformed suspension by the value of z. Indicate the semi-diagonal $OB = a_0$, $OB_1 = a$, $OA = OC = b_0$, $OA_1 = OC_1 = b$, side of the diamond $AB = l$.

From the triangle ABO: $\alpha_0 = l \cdot \sin \alpha_0$, $в_0 = l \cdot \cos \alpha_0$.

From the triangle A1B1O: $\alpha = l \cdot \sin \alpha$, $в = l \cdot \cos \alpha$.

Then $$z = \alpha_0 - \alpha = l(\sin \alpha_0 - \sin \alpha), \quad (3)$$

from which occurs $$\sin \alpha = \sin \alpha_0 - \frac{z}{l} \quad (4)$$

$$y = в - в_0 = l(\cos \alpha - \cos \alpha_0). \quad (5)$$

Using equation (4), we find $cos\alpha$ and substitute in equation (5):

$$y = l(\sqrt{1-(\sin\alpha_0 - \frac{z}{l})^2} - \cos\alpha_0) \quad (6)$$

Expression (6) is a nonlinear functional dependence of the horizontal displacement in the side hinges A and C of the ABCD diamond from the vertical deformation of the suspension *z*.

The nonlinearity of the function $y = f(z)$ allows the use in the suspension of additional elastic elements with rigidity c_2, placed horizontally along the axis of the displacement of the side hinges of the four-link lever mechanism (Figure 3) to obtain a nonlinear elastic characteristic.

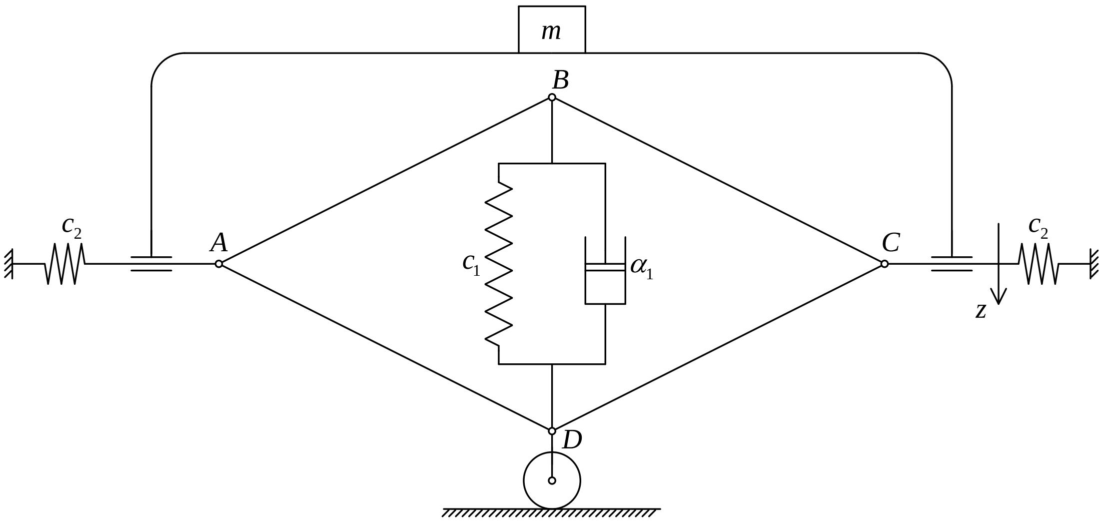

Figure 3. Kinematic scheme of the suspension on the basis of a four-link lever mechanism with additional elastic elements.

3. Discussion

Consider the dynamics of the car suspension on the basis of a four-link lever mechanism with the additional elastic elements c_2 shown in Figure 3.

On Figure 4 are shown the forces acting in the suspension arrangement, assuming that there is no friction in the kinematic pairs.

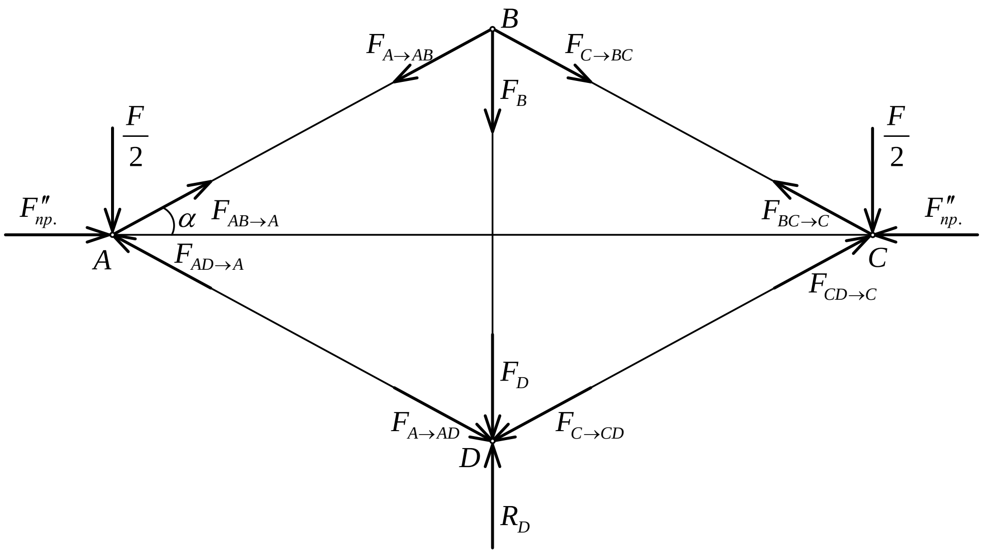

Figure 4. Forces acting in the device suspension.

External force $F = c \cdot z$, where c – overall rigidity of the suspension. Force F, given the symmetry of the circuit, it is transmitted to the side hinges A and C, as a force $\frac{F}{2}$. At the same time, as a result of the action of the nodes A and C, respectively, on the rods AB and BC there are reactions $F_{AB \to A}$ and $F_{BC \to C}$, but in the rods AD and CD – the reaction $F_{AD \to A}$ and $F_{CD \to C}$. F_c' and F_c'' – forces of the strength of the elasticity of the main vertical, located between the joints B and D, and additional horizontal elastic elements with stiffenings c_1 and c_2 accordingly.

Having considered the equilibrium of the hinge A (Figure 5), we find that

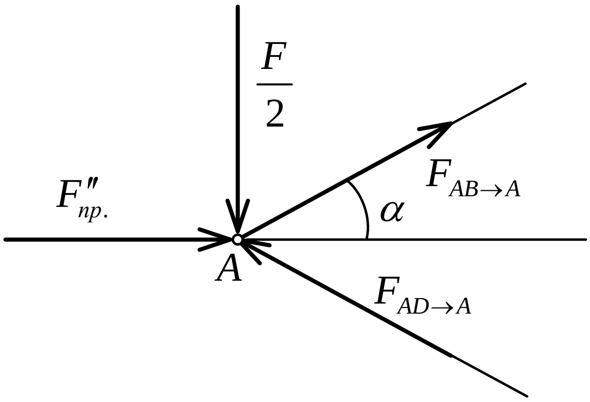

Figure 5. The equilibrium of the hinge A.

$$F_{AB \to A} = \frac{\frac{F}{2} - F_c'' \cdot tg\alpha}{2 \cdot \sin\alpha} \tag{7}$$

Taking into account that $\bar{F}_{AB \to B} = \bar{F}_{A \to AB} = -\bar{F}_{AB \to A}$ from the equilibrium of the hinge B (Figure 6) we have:

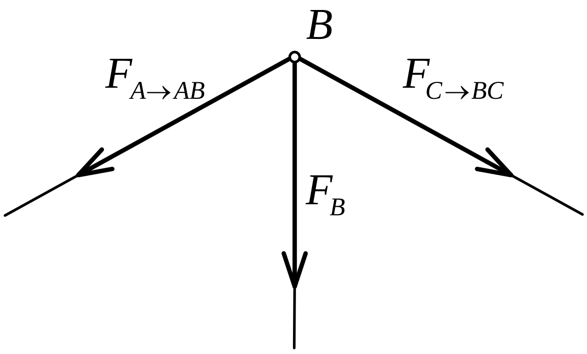

Figure 6. The equilibrium of the hinge B.

$$F_c' = 2 \cdot F_{AB \to A} \sin\alpha \,. \tag{8}$$

By substituting (7) into (8), we obtain:

$$F_c' = \frac{F}{2} - F_c'' \cdot tg\alpha \,, \tag{9}$$

where

$$\frac{F}{2} = F_c' + F_c'' \cdot tg\alpha .$$

Taking into account that at a static deflection of suspension brackets $F = cz_0$, $F_c' = c_1 \cdot 2z_0$, $F_c'' = c_2 y$, we have:

$$\frac{cz_0}{2} = c_1 2z_0 + c_2 y \cdot tg\alpha$$

$$c = 4c_1 + \frac{2c_2}{z_0} y \cdot tg\alpha , \quad (10)$$

where *y* is based on formula (6).

Dependence (10) is a nonlinear dependence of the total stiffness of the suspension on its vertical deformation *z*.

On Figure 7 is shown an example of an elastic characterization of a suspension on the basis of a four-link lever mechanism with additional elastic elements, obtained for the parameters: sprung mass m = 100 kg, c1 = 3600 N/m, c2 = 8000 N/m.

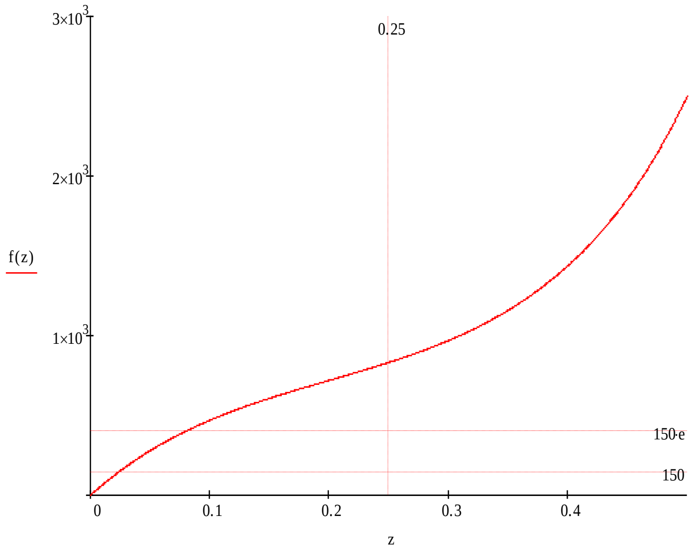

Figure 7. Elastic characterization of a suspension on the basis of a four-link lever mechanism with additional elastic elements.

4. Conclusions

The scheme of a suspension of a vehicle on the basis of a four-link lever mechanism is investigated, which involves the use of a main elastic element that perceives the double vertical movement of the sprung mass and additional elastic elements that perceive the horizontal deformation of the lever mechanism. On the basis of the kinematic analysis of the scheme, a nonlinear relationship between vertical suspension deformation and horizontal deformation of the four-link lever mechanism is established.

On the basis of dynamic analysis, the distribution of forces in the scheme is determined and a nonlinear dependence of the general stiffness of the suspension and its vertical deformation is established. This allows to obtain a nonlinear elastic characteristic of the suspension and, in turn, can provide a constant smoothness of motion in the variable sprung mass.

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Choosing the best available techniques of using the alternative engine fuels in automotive engineering

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Abstract: Purpose: The aim of our research work was to choose the best available technology of using the alternative engine fuels in vehicle and tractor technique use. Methodology: The methodology of multicriterial optimization was adopted for the purpose of the research. Results: There are given the results of calculating researches related to the choice of the best available techniques of the alternative engine fuels in vehicle and tractor technique use by the method of complex evaluation of fuel and power indexes of alternative fuels and engine, ecological safety and economic feasibility of vehicle exploitation. Fuel and power indexes of the fuels and of the engine are estimated by the criterion of adaptation, which is calculated by the method of hierarchies, ecological safety is evaluated taking into consideration the number of pollutant emissions with exhaust gases, their maximum permissible concentrations and safety class, economic feasibility of technique exploitation is estimated by the economic feasibility criterion which is calculated taking into account the economy of exploitation charges while using alternative fuels and placement of funds for technique re-equipment. The highest value of general criterion of the choice of suitable technique of fuel use which integrates the listed criteria, belongs to the technique of natural gas using in the gas engine re-equipped from the diesel one, petrol diesel fuel has the lowest value. The theoretical contribution: is The research findings have contributed to the development of a common methodology of estimating the factors of vehicles functioning on alternative fuels on criteria of technical suitability, environmental safety and economic efficiency of operation. Practical implications: The proposed methodology allows to estimate the technique indexes while its functioning on different types of fuel by one general criterion, which simplifies a lot the choice of technique of rational type of fuel use.

Keywords: alternative engine fuels, vehicle and tractor technique, the best available techniques.

1. Raising the problem

A term «The Best Available Techniques» (BAT) appeared for the first time in Directive of the working group on air framework (Air Framework Directive – AFD) in 1984. The BAT are techniques of goods (commodities) production, implementation of works, granting of services, determined on the basis of modern achievements in science and techniques and the best combination of criteria for achievement of the environment protection aims at condition of availability of any economic feasibility and technical viability of its application. In the countries of post-soviet space, in particular Russian Federation, there were made some attempts to implement the researches concerning introduction of BAT in chemical industry [1].

As of today there is a large park of the wheeled transport vehicles and mobile agricultural technique in our country, the work of which is based on petroleum origin fuel. But the cost of fuel grows continuously; the ecological situation in the country is getting worse too. One of the basic exit ways

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from this situation is transfer of the equipment to the work which is based on the alternative engine fuels (AEF). Thus, separate technologies of AEF use may be considered as the BAT.

In the European Union there are 33 reference books of EU for BAT meant for different industries, taking into account all the technological features and hardware-controlled equipment of the processes with consideration for ecological influences and economic charges. However, the direct use of the European BAT reference books at home enterprises is hardly possible, having regard to present differences, including specifics of all the types of resources, features of raw materials, availability of different energy types, natural conditions, ecological descriptions of territories and technological culture of production.

In this connection the development of scientifically - reasonable methodical providing of transition for AEF is necessary, the first stage of which is a decision of the task: choice of techniques as BAT taking into account its technological possibility to be realized, ecological safety and financial viability.

Use of system approach and information technologies possibilities is the necessary condition of this problem solving, taking into account its complexity and multidimensionality.

2. Analysis of the recent researches and publication

A considerable contribution to the development of system analysis and theories of making decision was brought in by: V.N. Volkova, A.A. Denysov [2], A.V. Kostrov [3], O.I. Lerichev [4], S. Optner [5], F.I. Peregudov [6], V.V. Podinovskyi [7], D.A. Pospelov [8], T. Saati [9]. Among the best known researchers of the problems of alternative fuels in transport vehicles use are worth to be mentioned the scientists from Ukraine and post-soviet space countries Y. Gutarevych [11], F. Abramchuk [11], S. Gusakova [12], S. Devianina [13], V. Yerokhova [14], V. Lukanina and A. Khachiian [15], V. Markov and A. Gaivoronskyi [16], A. Ukhanov [17], G. Saveliev [18] and others. In particular, Gutarevych Y.F. [10] studied the influence of using the natural gas, biodiesel fuels, non-alcohol mixtures on the energetic and ecological indexes of engines and vehicles. Abramchuk F.I. [11] explored the influence of natural gas on the similar indexes of gas engine re-equipped from diesel one. S.Gusakov [12] and S. Devianin and S. Markov [13] examined the influence of biological fuels on the engine indexes. V.Yerokhov [14] has devised a methodology of making a specific complex program of using the alternative fuel types in the automobile transport.

These problems solving are covered in lots of works of western scientists, among them P. Hamling, 2002 [18], N. Nuland, 2002 [19], M. Karabektas, 2008 [20], A. Murugesan, 2009 [21]. The most widespread questions investigated in works of home and foreign scientists were indexes of engines and cars work while working at alternative fuels. However, the approaches expounded in-process do not give clear rules for determination of BAT in a concrete situation.

3. Aim and task of the article

The aim of our research work is to choose the best available technology of using the alternative engine fuels in the automotive engineering.

Research tasks:

- developing of the method of choosing the best available technology of using the alternative engine fuels in the automotive engineering;
- determination of the criteria of adaptedness, ecological compatibility, economical efficiency of using the alternative engine fuels and the general criterion of choosing the best available technology.

4. Materials and methods of researches

For determination of BAT it is necessary to choose such techniques (technical measures, management decisions), which are the most effective from the point of view of achievement the general high level of environment protection. In practice while realization of this principle, there could appear the situations in which it is not clear, which one of the techniques would provide the highest level of environment (E) protection and the highest economic effect (Figure 1). Therefore there is a necessity to conduct the preliminary estimate of technologies for identification of the exactly best technique.

The materials above characterize initial data for authentication of a technique as BAT as exceptionally compound because of system factors and measurable indexes heterogeneity, bound by heterogeneous criteria, as well as requirements and limitations, partitioned character of a control object - natural environment and elements of the technological system, different degree of studied current processes and necessity of participation in all the stages of techniques life cycle for different profile specialists (technologists, environmentalists, economists) for solving of the integrated task.

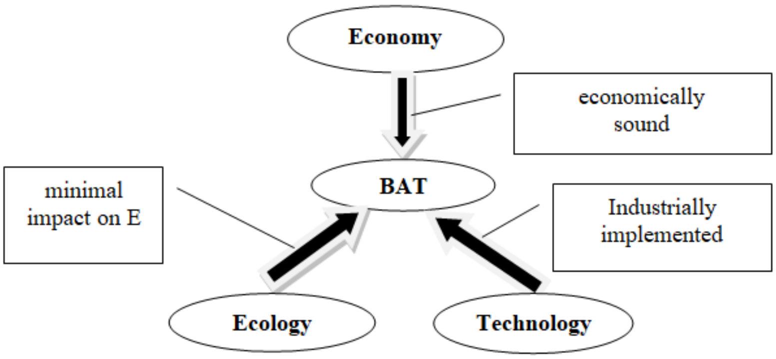

Figure 1. System factors of authentication of techniques as BAT.

Possibility of application of certain type of AEF is determined by many factors: its regional resources, correlation of prices between alternative and traditional fuels, charges on engines adaptation for working on AEF, on the delivery infrastructure, on storage and filling up of technique.

In such conditions, the effective methodological basis is a system approach. The system approach allows to lead the complex task (or difficult systems) of high dimension to more simple tasks (accordingly - subsystems or blocks) linked (united) by certain rules. Thus in each of subsystems can be arrived at not all, but only some aims (criteria), while others - in other subsystems; then a general result is reached on the basis of the results of partial tasks component decision.

In the process of making decision it is necessary to find a compromise between the most conflicting aims, taking into account plenty of criteria. For the efficiency increase of administrative decisions there were elaborated a lot of methods of multicriterion analysis and optimization.

Methodology of BAT choice of AEF use includes the determination of criterion of adaptation K_a of system «fuel-engine-vehicle» to the alternative engine fuels, criterion of ecological safety K_e of the vehicle (V) and criterion of economic efficiency of exploitation.

The adaptation criterion takes into account the technological possibilities of introduction. For determination of system adaptation criterion to different fuels (petroleum diesel fuel, natural gas, biodiesel fuel) there was worked out a methodology on the basis of hierarchies analysis method (HAM) of T. Saati [9]. By means of HAM it is possible to solve the task of multicriterion optimization with enough of optimality criteria. The next principles form the basis of HAM: decomposition (structuring of a problem into the hierarchic system of easier tasks); paired comparison (comparison of all possible combinations according to the results of determined priorities or weight coefficients); hierarchic composition (determination of a priority in each group on all the levels of hierarchy). The advantage of given method is a possibility of taking into consideration the non-numerical indexes.

During the estimation of ecological safety of the vehicle are taken into account the amount of pollutant (P) emissions with discharge gases (DG), their toxicity and danger class. The vehicle danger category which works on a traditional or alternative fuel

$$HCV = \sum_{i=1}^{n} HCS_i = \sum_{i=1}^{n} \left(\frac{M_i}{MPC_i} \right)^{\alpha_i}, \quad (1)$$

here *HCS* – is the hazard category of the i-th substance, m^3/s; M_i – is the amount of emissions of the i-th substance, g/m^3, values of which are obtained on the basis of records of the travel emissions of harmful substances (HS), g/km, obtained by calculations using mathematical models; *MPC* – is the daily average maximum permissible concentration of i-th substance, g/m^3; α_i – is the dimensionless constant, allowing us to relate classes of hazard of i-th substance and sulphur dioxide (III hazard class); *n* – is the amount of harmful substances in the exhaust.

It is advantageously to carry out an assessment of the environmental parameters of the vehicle, working on basic and alternative types of fuel, with the sanitary norms. Pollutant emissions with exhaust gases (g/s) during the engine work using different fuel types were determined by a mathematical modelling of a running cycle of the vehicle according to the methodology of prof. Y. Gutarevych [10]. In addition to that, the results of experimental researches of exhaust gases toxicity of a given engine on different speed and loading modes were taking into account.

In the first stage it is performed according to EA criterion that is the environmental adaptability of the ICE (internal combustion engine) to alternative fuels:

$$EA = \frac{1}{n}\sum_{i=1}^{n}(K_i)^{\alpha_i} = \frac{HCV}{HCV_b}, \tag{2}$$

here HCV – is the hazard category of the vehicle running on alternative fuel, m^3/s; HCV_b – is the hazard category of the vehicle running on a basic fuel, m^3/s.

On the second stage the index of environmental hazard of the vehicle running on alternative fuel is determined

$$K_{eh} = EA \cdot K_b, \tag{3}$$

here K_b – is the index of environmental hazard of the vehicle running on the primary fuel.

The criterion of environmental safety

$$K_e = \frac{1}{K_{eh}}. \tag{4}$$

The most effective decision from the economic point of view in relation to the choice of fuel will correspond to a minimum of the annual resulted charges:

$$B_{yi} = C_i - i \cdot K_i \rightarrow \min, \tag{5}$$

here C_i – is a cost price with the usage of i-type of fuel, UAH; i – is a permanent norm of discount.

Economic efficiency of the use of AEF is estimated by the criterion of economic efficiency:

$$K_{ee} = \frac{B_{yi}}{B_{p\max}}. \tag{6}$$

Natural gas has the highest value of economic efficiency criterion, biodiesel fuel has a little less value.

Thus, three criteria of choice of rational type of fuel are chosen for transport vehicles. A multicriterion task will be simplified to the onecriterion one by the method of rolling up. The integration of separate criteria in one general criterion of rational type of fuel is effectuated as follows:

$$K = \varphi_1 \cdot K_a + \varphi_2 \cdot K_e + \varphi_3 \cdot K_{ee}, \tag{7}$$

here φ_1, φ_2, φ_3 – are the significance coefficients of indexes of system adaptation to AEF, of ecological safety and economic efficiency of technological vehicles exploitation on different types of fuel ($\sum \varphi_i = 1$).

For the estimation of significance of separate criteria there were taken the results of expert estimations. The ecological safety criterion has the biggest meaning (0.4), the adaptation criterion and the criterion of economic efficiency of exploitation have some less values (0.3). To make a decision about the BAT choice of the AEF use there was formed an objective function.

5. Results

Using the method of hierarchies analysis (MHA) and mathematical matrix model it is carried out a comprehensive assessment of operating characteristics of the alternative motor fuels and of the performance of engine at each level of the system with a hierarchical structure. The estimates of motor fuels are given in a Table 1.

Table 1. Estimates of motor fuels.

Parameter	Fuel		
	Diesel	**Biodisel**	**Natural gas**
The adequacy of resources and the possibility of mass production	-	+/-	+/-
The lowest calorific value MJ/kg (MJ/m^3)	42.5	38.3	38.0
Knock resistance (octane number) or propensity to self-ignition (cetane number)	45.0	49.0	110-125
Environmental quality (environmental impact)	-	+	+/-
Energy production	-	+	+
Security applications	+/-	+	+/-

Note: «+» – is the presence of advantages in comparison with petroleum diesel; «-» – is the lack of advantages in comparison with petroleum diesel; «+/-» – is the combination of advantages and disadvantages.

The performances of fuels and engine shown in a Table 2 are the assessment criteria of fuel and energy properties: A1 – is the adequacy of resources and the possibility of mass production of fuel; A2 – is the energy performances of the engine when operating on this fuel; A3 – is the knock resistance of fuels and the propensity for self-ignition; A4 – is the price of fuel; A5 – is the specific effective engine fuel consumption in power units; A6 – is the energy consumption of fuel production; A7 – is the safety of an application.

A track fuel consumption and travel emissions of a tractor, being operated on different fuels, are defined by mathematical modeling. The calculations showed that the tractor with a diesel engine, being driven on the adopted driving cycle, consumes (accordingly, on average) 22% less fuel, and its CO emissions are 47% less and CH emissions are 90% less than of the tractor with a gas engine.

This is due to the fact that the gas engine in all modes runs on richer fuel-air mixtures. A tractor with the diesel engine emits nitrogen oxides NO_x 4% more. It also emits soot unlike the tractor with the gas engine. Comparing the total specific emissions of harmful substances (HS), converted to carbon monoxide ΣCO, taking the relative aggressiveness, it is clear that the tractor with a diesel engine is (36%) more toxic. The total toxicity of a tractor engine running on biodiesel fuel is also lower than of an engine on oil fuel. But the number of emissions of harmful substances in the exhaust gases does not allow to analyze the environmental safety of the tractor.

Table 2. The pair comparison of the estimates of motor fuels.

Criteria of evaluation	A1	A2	A3	A4	A5	A6	A7	The vector of priority (x_i)
A1	1	1/5	6	4	1/7	1/6	1/6	0.14
A2	5	1	1/3	6	1/2	1/4	1/5	0.14
A3	1/6	3	1	3	5	1/4	1/3	0.14
A4	1/4	1/6	1/3	1	1/6	1/3	1/4	0.11
A5	7	2	5	6	1	5	1/2	0.16
A6	6	4	4	3	1/5	1	1/5	0.15
A7	6	5	3	4	2	5	1	0.16
ΣC_i	25.42	15.37	19.66	27	9.01	12	2.65	$\sum_n \approx 1.0$

The compressed natural gas has the maximum value of criterion according to the results of calculations of the fuel and energy criterion of different fuels (Table 3).

Table 3. Estimated values of the fuel and energy criterion for different fuels.

	A1	A2	A3	A4	A5	A6	A7	The energy criterion
$\Sigma(x_i)$	0.14	0.14	0.14	0.11	0.16	0.15	0.16	
Diesel	0.26	0.40	0.24	0.27	0.25	0.27	0.36	0.29
Biodiesel	0.43	0.34	0.34	0.27	0.32	0.33	0.36	0.34
Natural gas	0.31	0.25	0.42	0.46	0.43	0.38	0.28	0.36

The results of comprehensive assessment of ecological danger of exhaust gases of an MTZ-80 tractor based on the hazard category HCV for the maximum permissible concentrations and hazard class of harmful substances are given in the Table 4.

The hazard category of a tractor running on biodiesel is 1.11 times less, and on natural gas is 1.26 times less than on diesel fuel. And on average 90% of environmental hazards of exhaust gases for all fuels consist of danger of nitrogen oxides NO_x, the contents which are in exhaust gases weight is not very significant.

Table 4. The hazard category of exhaust gases of a wheeled tractor with an engine running on different fuels.

Fuel	Hazard category of harmful substances of exhaust gases								Hazard category of a tractor (HCT)	
	NO_x		CO		CH		soot			
	m³/s	%	m³/s	%	m³/s	%	m³/s	%	m³/s	%
Diesel	2789.1	87.8	9.1	0.29	1.9	0.06	377.5	11.9	3177.6	100
Natural gas	2599.8	98.7	15.1	0.57	17.4	0.66	–	–	2632.9	100
Biodiesel	2694.1	89.8	12.8	0.42	4.5	0.15	288.2	9.6	2999.6	100

The determination of the index of environmental hazard and of the level of ecological safety of the MTZ-80 tractor running on different fuels according to the K_{eh} criterion (Table 5) was the next step. The Table 5 shows that the best value of the criterion of environmental safety is inherent to the tractor, running on natural gas. The results of calculation of indicators of economic efficiency are summarized in Table. 6.

Table 5. The assessment of environmental safety of the MTZ-80 tractor running on different fuels.

Fuel	The index of environmental hazard K_{eh}	The criterion of environmental safety K_e
Diesel	2.98	0.33
Natural gas	2.38	0.42
Biodiesel	2.7	0.37

The operation of the MTZ-80 tractor as a technological vehicle on gas fuel in comparison with that on diesel fuel provides an annual economic effect of EUR. 202.6; and the payback period of the cost of conversion to run on gas is 1.41 year. When it is operated on biodiesel the annual economic effect is EUR. 5.91; and the payback period of the cost of conversion is 4.9 years.

Table 6. The economic efficiency of tractor operating on alternative fuels.

№ i/s	Parameter	Unit of measure	Fuel	
			Natural gas	Biodiesel
1.	The capital cost of tractor conversion to run on AMF	EUR.	363	108.8
2.	The saving of operational costs	EUR.	257	22
3.	The payback period	years	1.41	4.9
4.	The annual economic effect from the use of alternative fuels	EUR.	202.6	5.91
5.	The criterion of economic efficiency	–	0.71	0.2

It is established as a result of researches that the natural gas in case of its use in gas engine converted from diesel one has the greatest value of the general criterion for the selection of the appropriate type of fuel; and the petroleum diesel fuel has the smallest value of this criterion. The results of the calculations are summarized in the Table 7.

Table 7. The value of the general criterion for the selection of the appropriate type of fuel for the MTZ-80 tractor.

Fuel	The general K criterion for selection of appropriate type of fuel
Diesel	0.221
Natural gas	0.479
Biodiesel	0.31

The general criterion of BAT choice of AEF use, for the tractor MT3-80 used as a technological transport vehicle, is determined, that means that a multicriterion task is simplified to the onecriterion. As a result of researches, there was set that natural gas has the greatest value (0.479) of general criterion of rational type of fuel choice in a case of its use in gas engine that was reconstructed from a diesel engine D-243, a petroleum diesel fuel has the least value (0.221), a biodiesel fuel – 0.31. As it is evident from the given results, while determining a general criterion of BAT choosing, its biggest value for natural gas is naturally determined. However the value of criterion of ecological safety and economical efficiency of machines operation is the biggest exactly for natural gas.

6. Conclusions

A method of many criteria choosing of the best available technology of using the alternative engine fuels in the automotive engineering was developed.

The model representations of operating of automotive and tractor vehicles, running on different fuels, allowed us to reduce the problem of the choice of fuel to the optimization of the parameters of the operating "fuel-engine-vehicle" system according to the fuel-energy criterion, to the criteria of environmental safety and of economic efficiency of operation. The proposed methods allow to evaluate the performance of automotive and tractor vehicles running on various fuels according to a single composite index (general criterion), which it greatly simplifies choosing of fuel.

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Development and application of composites based on polytrifluorochlorethylene

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Abstract: This paper provides results of an analytical study on the influence of the content of organic fiber Tanlon of the brand T700 on the physico-mechanical and tribological properties of organoplastics based on polytrifluorochlorethylene. As a result of the analysis it was found that introduction of 5-20 wt. % fiber Tanlon T700 leads to a positive effect: it increases modulus of elasticity, hardness and yield stress to 45-69, 30-60% and in 1,1-1,2 times respectively. It has been shown that, in conditions of friction without greasing implementation of filler, this solution positively affects on polymer: it reduces the coefficient of friction to 15-40% and wearing by two orders of magnitude (from 91.75 to 0.15). The practical value of these findings is that the developed composition can be used for production of mobile joints elements of machines and mechanisms that are used in various spheres of industry.

Keywords: organoplastic, polytrifluorochlorethylene, polysulfonamide, physico-mechanical, tribological characteristics

1. Introduction

Automobile transport of the XXI century cannot be provided without the use of polymer composite materials (PCM). Friction knots of vehicles in the process of operation are exposed to various external factors: increased loads, temperatures and humidity, the effects of aggressive environments, dust, vibrations, particles of abrasive (that cause deterioration of the surfaces of rubbing pairs) influenced by that in the material of structures develop deformations that lead to the destruction, that reduces the duration of their trouble-free operation [1,2].

The use of PCM will increase service life of aggregates, minimize costs during the operation to 50%, increase reliability, resistance to damage and cost-effectiveness (due to the simplicity of technological process of production and the possibility of automatization of the process) [3].

Fluoropolymers (FP) are one of the promising materials for the creation of PCM, capable to work in difficult conditions. FP are characterized by the row of properties that aren't inherent for other polymer materials: high thermal stability, inertia to aggressive chemical environments and oils that are kept in the wide temperature range. But these materials also have disadvantages, the main of them is low wear resistance (which is confirmed by the obtained experimental data) using it for the production of slide bearings [4].

Different fillers, including Organic Fibers (OF), are used to improve the tribotechnical characteristics of FP. The positive effect of reinforcement of the OF is due to the weakening of

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intermolecular bonds in the polymer, the formation of optimal structure of the material. Organic fibers, in comparison with carbon and fiberglass, are characterized by high adhesion to the matrix, strength-to-weigth ratio and hardness.

In view of the above, the purpose of this work was to research the physico-mechanical and tribotechnical characteristics of Organoplastics (OP) based on Polytrifluorochlorethylene (PTFCE) -reinforced by the fiber polysulfonamide brand Tanlon T700.

2. Objects and methods of researches

As a polymer matrix was chosen polytrifluorochlorethylene [-CF2-CFCl-] - solid white powdered product, which is characterized by high compressive strength, chemical resistance (which brings it closer to the resilience of polytetrafluoroethylene) and plasticity, is easy machining, which allows to give exact size to the product. Products based on PTFCE can be operated at temperatures from 78 to 403 K (elastic) or even up to 463 K (crystalline), depending on the regime of product formation.

Table 1. The main properties of polytrifluorochlorethylene [5]

Indicator	**Value**
Density, g/cm^3	2.1-2.16
The softening temperature for Vicka, K	403
Water resistance (growth in water), %	0.00-0.01
Degree of crystallinity at 293 K, %	40-70

However, in the production of products from it there are difficulties associated with the use of high temperatures, close to the temperature of decomposition of the polymer, and also with the need in some cases, the tempering of products for giving them elasticity. Therefore, the formation of products with PCTFE should be carried out at strictly controlled temperature, pressure and time of extinction.

As a filler, was used heat-resistant fiber (see Table 2.) polysulfonamide of the brand Tanlon T700 (China). To determine the optimal composition of PCM were produced samples with different ratios of component.

Table 2. Main properties of fiber [6]

Indicator	**Value**
Length, mm	3
Density, g/cm^3	1.42
Strength, MPa	650
Extension,%	20-25
Modulus of elasticity, MPa	7450

Preparation of compositions based on PTFCE containing 5-20 wt % of discrete fiber polysulfonamide Tanlon T700, carried out by the method of dry mixing in the machine with rotating electromagnetic field (0,12-0,15 Tl) using ferromagnetic particles taking out by magnetic separation.

Samples for tests were made in form of cylinders with a diameter 10 and a heigh 10 mm. The prepared mixture was tabletted at room temperature and 40 MPa. The resulting prepreg was charged in a mold heated to 423 K, after that the temperature in the mold increased to 510-515 K and kept at this temperature for 10 minutes, then gave pressure 40MPa. For fixation the product was cooled under pressure to the temperature 490-495 K and pushed from the mold in water for hardening.

Modulus of elasticity, yield stress and unit strain under compression determined according to the GOST 4651-78 on the machine FP-100. Hardness was found by the Rockwell method on the HRE scale according to the GOST 9013-59 on the hardness 2074 TPR.

The tribological characteristics were explored in conditions of friction without greasing the friction machine SMC by the scheme "disk-block" under the load 1 MPa, slip rate 1 m/s, friction path of 1000 m. As a counterbody was used steel 45 (45-48 HRC, R_a = 0.32 μm).

3. The results of researches

Important information on the elastic characteristics of material, nature and magnitude of plastic deformation, hardness and yield strength is given by the method of compression.

As it is shown in Fig. 1, the curves of the OP dependences of hardness (σ) - unit strain (ε) under compression, according to the classification of Herzberg [7], belong to the type V, which characterizes the elastic heterogeneous plastic behavior. At the section of curves up to 30 MPa, there is a completely elastic behavior of materials. Further, the shape of the curves is the result of the competitive development of two processes. The first process is characterized by plastic flow, due to the destruction of original structure of the polymer, resulting in usually a fall in of load. The second process is characterized by the restructuring of the destroyed structure into the new, due to accumulated deformation tensions. Such a structure is characterized by a high degree of orientation and hardness. It is due to the competition of these processes and there is a change in the angle of inclination of the curves σ-ε. Further elevation of the angle of inclination indicates the deformation strengthening stage: a large number of sections of the polymer acquires a new structure, which leads to an increase in the resistance of the material.

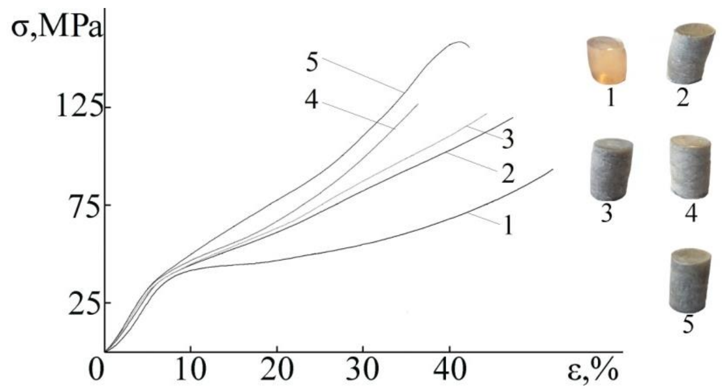


Figure1. Curves "tension -deformation" of polytrifluorochlorethylene (1) and organoplastics on its basis, reinforced 5 (2); 10 (3); 15 (4); 20 (5) wt % of fiber

The implementation of polysulfonamide fiber leads to the increase in modulus of elasticity and yield strengths to 45-69% and in 1.1-1.2 times, respectively, in comparison with PTFCE (see Table 3), which is a consequence of a decrease in the flexibility of macromolecules resulting in appear bonds between particles of filler and macromolecules of binder. During mixing component in the electromagnetic field, each fiber is covered with a layer of PTFCE, in which the macromolecules are oriented in such a way that their polar groups are turned to polar fiber groups.

Table 3. Influence of organic fiber on the properties polytrifluorochlorethylene

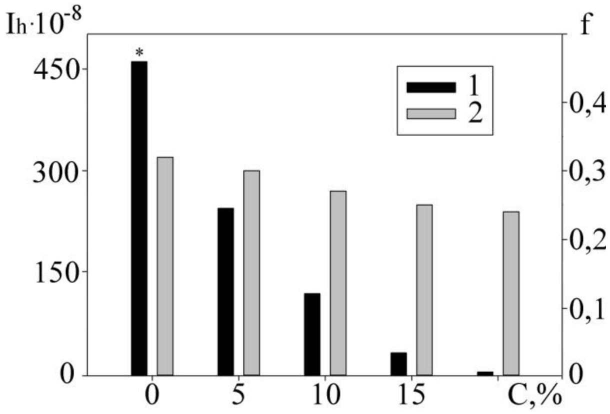
Indicator	Fiber content, wt %				
	0	5	10	15	20
Limit of proportionality (σ_{pr}), MPa	27	30.5	30.8	32	31.1
Relative lengthening of proportionality (ε_{pr}), %	5.4	5.2	5.1	5	4.2
Yield strengths low limit (σ_p), MPa	44	49.4	50	52.6	53.8
Relative elongation of yeld (ε_p), %	17	12.9	12	13.2	13.3
Ultimate strength (σ_s),MPa	-	119.5	121.5	126	152
Relative elongation of strength (ε_s), %	-	36	41	44.2	47.3
Modulus of elasticity (E), MPa	455	655	695	755	760
The shear modulus (G), MPa	194	267.7	281.7	304.3	307
Volume bulk density (K), MPa	220	394.4	435	485.3	482.8
Poisson's coefficient (ν)	0.16	0.22	0.23	0.24	0.24
Parameter Lame (λ), MPa	91	215.9	247.2	282.4	278.1

The growth of the shear modulus, bulk elasticity, the Lame parameter and the Poisson's coefficient of developed of OPs in 1.4-1.6, 1.8-2.2, 2.4-3.0 and 1.37-1.5 times respectively, in comparison with the basic material, it shows the increase in the material resistance to landslide deformations, which leads to the increase of the stability of the shape of parts during the transfer of load. Confirmation of the above can serve as sample images after compression (Fig. 1).

The coefficient of friction and the intensity of linear wear, are one of the important indicators used in the fulfilment of technical calculations and making decision, that characterize the frictional interaction of two bodies.

The results of tribological explores (Fig. 2) showed the following: in identical conditions, the organoplastic exceed the base polymer by the intensity of wear and the coefficient of friction in 1.9-85 times and 15-40% respectively.

Through friction of PTFCE on its surface appear deep furrows - roughness of more rigid surface (counterbody) and plough softer (Fig. 3, a), forming a friction path, indicating the adhesion mechanism of wear, when the molecular bonds of contacting surfaces under certain conditions are stronger than bond of the surface layer of friction. The distinctive feature of adhesion mechanism is the frictional transfer of the adhesive tapes of binder to the counterbody (see Fig. 3, b), which is due to the presence of local bonds between the contact surfaces.



*trekking trap 500 m

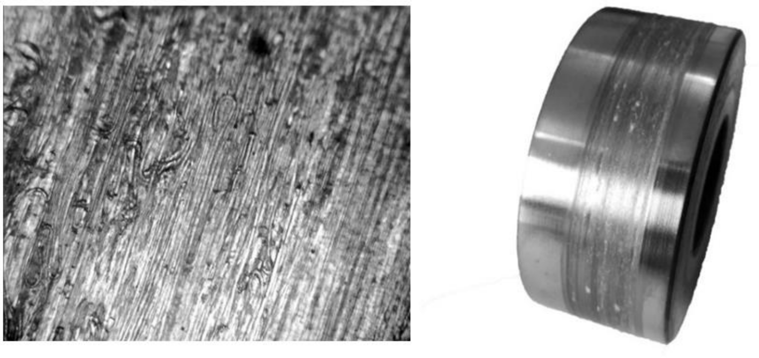
Figure 2. Influence of polysulfonamide fiber content on: the intensity of linear wear (1) and the coefficient of friction (2)

(**a**) (**b**)

Figure 3. Microstructure (× 100) of friction surface of basic polymer (**a**) and products of its wear (**b**)

Research of the friction surface of OP (Fig. 4, a) showed that during abrasion of samples is formed smooth glassy surface (occur increase the actual contact area), on which are clearly visible chaotic organic fibers. The superficial layer of ground-in sample is characterized by the low coefficient of friction and wear. These facts reflect the pseudo-elastic abrasion mechanism of organoplastics that is realized between sample and counterbody: transfer film is formed on the surface of counterbody (Fig. 4, b), and sample isn't rubbed on the steel, but on the products of wear, that results in the shear deformation localizes inside the film that has low shear resistance, which leads to the decrease of the frictional force [8].

It is known [9] that one of the important contributions to the overall enhancement of tribotechnical characteristics is the hardness, which measures the possible areas of application of PCM. Solid and durable PCMs can be used in the production details of machines and mechanisms working in heavily loaded knots of friction: gear wheels and crowns, bearings. From Fig. 5 it is seen that the implementation of fiber leads to the increase of hardness of polymer matrix to 30-60%, which can be explained as both the high stability of the filler and the transformation of the structure of polymer under the influence of fiber.



(**a**) (**b**)

Figure 4. Microstructure of friction surface **(a)** (× 100) and transfer film **(b)** of organoplastic containing 15 wt % of fiber

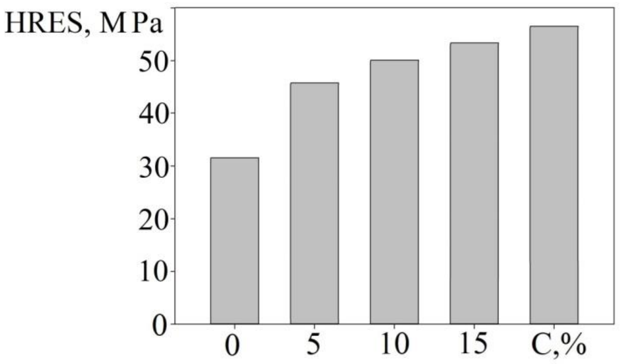


Figure 5. Influence of fiber on hardness of polytrifluorochlorethylene

Positive results of laboratory researches allowed us to proceed to production tests.

The safety of the operation of freight transport directly depends on the braking system: the simultaneous activation of all wheels. If this condition isn't implemented, then the freight transport can lead to the car accident, which can lead to fatal consequences. One of the main details of braking system of the car KamAZ (Fig. 6) is S-shaped brake expander.

During braking, the pads (7) are pushed apart by the S-shaped brake expander 12 and pressed against the inner surface of the drum. Between the expansion cam 12 and the pads there are rollers 13 that reduce friction and improve productivity of braking. The expansion cam scrolls in the bracket 10, attached to the caliper. The necks of the expansion cam are tucked together with the sleeves with bracket with the clearance, which provides the turn expansion cam [10].

The expansion cam of the car KamAZ works in difficult conditions: actions of aggressive environments, variable temperatures (especially in winter), high humidity and high contact tensions in the place of working profile of the brake expander, lead to quite intense wear of cast-iron rollers.

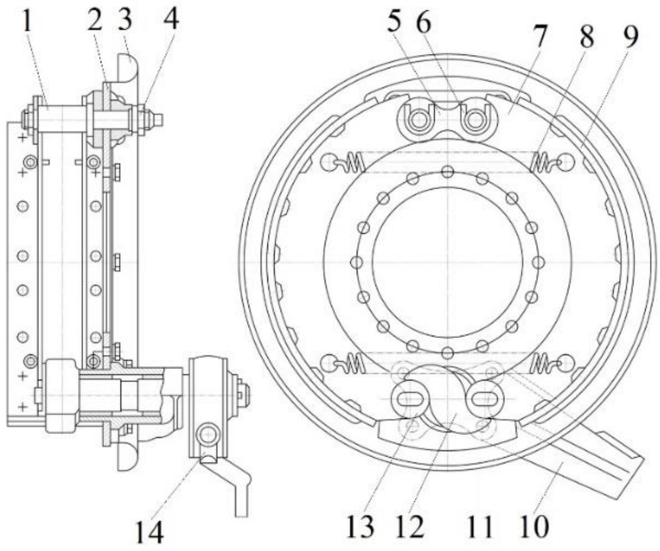


Figure 6. Brake mechanism of the car KamAZ 1-axis pad; 2- caliper; 3- flap; 4-nut axis; 5-lining of axes pads; 6- linchpin axis pad;7-brake pad; 8-spring; 9-friction pad; 10-bracket of the expansion cam; 11-roller's axis; 12- expansion cam; 13-roller; 14-regulating roller

5. Conclusions

In general, the analysis of the physico-mechanical and tribotechnical characteristics of the developed organoplastics shows that the use of organic fiber Tanlon T700 5-20 wt % , as the filler for polytrifluoroethylene is a promising way of increasing the modulus of elasticity, hardness and yield strength, respectively, to 45-69 30- 60 and 10-20%, while reducing the coefficient of friction to 15-40% and increasing the wear resistance in 1,9-85 times. Thanks to this, this organoplastic can be recommended for the production details of mobile joints of machines and mechanisms that can work in conditions of friction without greasing.

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Reduction of energy losses on car movement while using a combined electromechanical drive of leading wheels

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Abstract: This article addresses the problem that fluctuations in the torque of an internal combustion engine (ICE) lead to additional energy losses, as it causes fluctuations in the speed and kinetic energy of the car. These losses increase as the frequency of oscillations of the torque of the internal combustion engine approaches the frequency of free (natural oscillations) of the running gear of the car in the longitudinal direction. If there is an elastic connection between the traction force and the movement of the car, the movement of the latter can be represented as complex. At the same time, the portable movement is uniform, and the relative movement is oscillatory. This article presents the results of the study of these losses for cars with mechanical and combined electromechanical drive wheels. Analytical expressions are obtained, which allows to take into account additional energy losses including the tangential rigidity of the tire and the rigidity of the suspension in the longitudinal direction. When using a combined electromechanical drive of the drive wheels as well as in the case of a mechanical transmission of a car, the resonance is dangerous. But with the increase in the share of torque k_{em} on the wheel generated by the electric motor, the relative additional energy losses for the movement of the car are reduced.

Keywords: torque, internal combustion engine, fluctuations, energy consumption, speed, combined electromechanical drive wheels

1. Introduction

Fluctuations in the torque of an Internal Combustion Engine (ICE) lead to additional energy losses, as it causes fluctuations in the speed and kinetic energy of the car.

The work of [1,2,3] is devoted to the influence of the irregularity of the torque of the internal combustion engine on the additional energy losses during steady-state car movement.

In the work [4], the authors note that the achievement of energy efficiency, road safety, environmental and economic safety indicators becomes the main organizational goal of the functioning of the motor transport system and is considered as an ongoing process for managing the technical level of vehicles. The works of many authors [5,6,7] is devoted to the study of energy-transforming properties of automobiles.

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The stability of the characteristics of the vehicle's movement essentially depends on the work of the suspension of the car [8,9,10,11]. The suspension system acts as a bridge between the driver and the passengers of the vehicle and the road it is moving. It has two main functions [8]. One of them is to isolate the vehicle body from external inputs, which are mainly derived from non-ideal road surface. The other is to maintain a reliable contact between the road and the tires to ensure the stability of the trajectory. The best way in variable operating conditions is provided by adaptive active suspension systems [9]. The analysis of the influence of the traction properties of tires on the dynamic characteristics of vehicles the work [12] is devoted. Many authors emphasize the need to control the air pressure in car tires [12, 13].

The amplitude of the oscillations Apk of the traction force depends on the amplitude of the oscillations of the indicator torque Mi of the internal combustion engine [14].

2. Methodology

In the works [2, 3] it was determined that the additional energy losses due to fluctuations in torque and, accordingly, fluctuations in the tractive force on the wheels can be determined from the following relationship

$$\Delta W_s = \frac{A_p}{\pi} S, \qquad (1)$$

here A_p - is the amplitude of oscillations of the traction force (when simulating these oscillations by the harmonic law [2]); S - the path traveled by the car (controlled mileage).

Analysis of equation (1) shows that additional energy losses due to vehicle movement caused by fluctuations in traction force on the wheels when using a combined electromechanical drive. Received [1] an expression to determine additional energy loss

$$\Delta W_s = \frac{k_1}{2\pi} \cdot \Sigma P_r \cdot S \cdot \left(1 - \frac{M_{em} \cdot n_1}{r_d \cdot \Sigma P_r}\right), \qquad (2)$$

here k_1 - the coefficient of non-uniformity of torque [2, 3],

$$k_1 = 0.08 + \frac{14.44}{i_c}; \qquad (3)$$

i_c - the number of cylinders of the internal combustion engine; $\sum P_r$ - the total force of resistance to movement of the vehicle; M_{em} - torque from the electric motor, supplied to the wheel of the car; n_1 - the number of driving wheels of the car; r_d - the dynamic radius of the drive wheels.

In the works [3], a relative indicator of additional energy loss of the car with the combined electromechanical drive of the wheels and variations in the torque of the internal combustion engine was proposed

$$\eta_{\Delta W} = \frac{\Delta W_s}{S \Sigma P_r} = \frac{\Delta W_s}{A_r} = \frac{k_1}{2\pi}(1 - k_{em}) = \frac{0.04 + \frac{7.22}{i_c}}{\pi}(1 - k_{em}), \qquad (4)$$

where A_r - the total work force of external resistance to the movement of the vehicle; k_{em} - the proportion of torque on the wheels created by the electric motor,

$$k_{em} = \frac{M_{em} \cdot n_1}{r_d \cdot \Sigma P_r}. \qquad (5)$$

It can be seen from equation (4) that with an increase in the coefficient ked the relative additional energy loss decreases due to the ICE torque variation. When k_{em} = 1 value $\eta_{\Delta W}$ = 0.

However, in the well-known works [1 – 3], the effect of the elastic coupling between the tractive force and the movement of the car on the additional energy losses is not investigated.

The aim of the study is to increase the energy efficiency of cars by reducing the additional energy losses associated with the longitudinal flexibility of the chassis.

To achieve this goal it is necessary to solve the following task: determine the additional energy loss for the combined electromechanical drive of the driving wheels of the car.

If there is an elastic connection between the traction force and the movement of the car, the movement of the latter can be represented as complex [15]. At the same time, the portable movement is uniform, and the relative movement is oscillatory (Fig. 1).

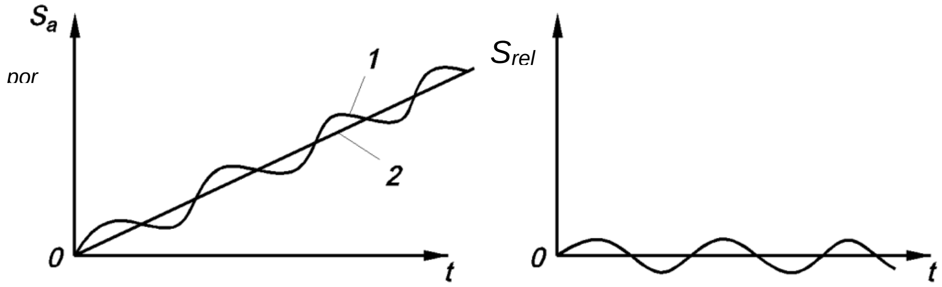

Figure1. The steady-state movement of the car with the elastic connection between the traction force and its movement: a - a graph of absolute (1) and portable (2) movements; b - relative motion graph

Portable movement of the car is described by the following equation

$$S_{por} = V_{por} \cdot t = \overline{V}_a \cdot t = S \,, \tag{6}$$

where V_{por} - the speed of the portable movement

$$V_{por} = \overline{V}_a \,; \tag{7}$$

$\overline{V}_a$ - the average speed of the steady motion of the car; t – time.

The equation of the dynamics of the relative movement of the car can be represented as the equation of the dynamics of the relative movement of the car can be represented as

$$m_a \cdot \ddot{S}_{rel} + \alpha_{lon} \cdot \dot{S}_{rel} + c_{lon} \cdot S_{rel} = P_w - \Sigma P_r \,, \tag{8}$$

where m_a - the mass of the car; c_{lon}; α_{lon} - coefficients of stiffness and viscous friction, due to the tangential flexibility of the tires and the longitudinal flexibility of the suspension; P_w - traction force of the car.

3. Determination of additional energy loss for the mechanical transmission of the car

Equation (8) can be represented as

$$\ddot{S}_{rel} + 2n \cdot \dot{S}_{rel} + k^2 \cdot S_{rel} = \frac{P_w - \Sigma P_r}{m_a} \,, \tag{9}$$

here $2n$ - the damping coefficient,

$$2n = \frac{\alpha_{lon}}{m_a} \,; \tag{10}$$

k - the frequency of free (natural) vibrations of the elastic system,

$$k = \sqrt{\frac{c_{lon}}{m_a}} \,. \tag{11}$$

The solution to the differential equation (9) is the sum of the total and particular solutions. Since with forced oscillations over time ($t \to \infty$), the general solution Sot tends to zero, then the general solution S_{rel} will be equal to the particular solution $(S_{rel})_0$. With the unevenness of the torque of the internal combustion engine, the total tractive force on the driving wheels of the vehicle can be represented by the following relationship:

$$P_w = \overline{P}_w + A_p \cdot \sin(\Omega_M \cdot t), \qquad (12)$$

where $\overline{P}_w$ - the average value of the traction force; A_p - the oscillation amplitude of the traction force; Ω_M - the circular frequency of the internal combustion engine torque.

At the steady state of the car movement

$$\overline{P}_w = \Sigma P_r. \qquad (13)$$

Equation (9) taking into account relations (12) and (13) takes the form

$$\ddot{S}_{rel} + 2n \cdot \dot{S}_{rel} + k^2 \cdot S_{rel} = \frac{A_p \cdot \sin(\Omega_M \cdot t)}{m_a}. \qquad (14)$$

The particular solution of a second-order inhomogeneous differential equation (14) is obtained in the form

$$S_{rel} = (S_{rel})_0 = \frac{A_p}{m_a \cdot (k^2 - \Omega_M^2)^2 + 4n^2 \cdot \Omega_M^2} \cdot \left[(k^2 - \Omega_M^2) \cdot \sin(\Omega_M \cdot t) + 2n \cdot \Omega_M \cdot \cos(\Omega_M \cdot t)\right]. \qquad (15)$$

Or, having made transformations, we will receive

$$S_{rel} = (S_{rel})_0 = \frac{A_p}{m_a \cdot \sqrt{(k^2 - \Omega_M^2)^2 + 4n^2 \cdot \Omega_M^2}} \cdot \sin(\Omega_M \cdot t + \varphi), \qquad (16)$$

where φ - the angle of phase shift between the oscillations of the traction force and the relative movement of the car S_{rel},

$$\varphi = arctg\left(-\frac{2n \cdot \Omega_M}{k^2 - \Omega_M^2}\right). \qquad (17)$$

From the expression (16) we determine the amplitude of oscillations of the relative movement of the vehicle

$$A_S = \frac{A_p}{m_a \cdot \sqrt{(k^2 - \Omega_M^2)^2 + 4n^2 \cdot \Omega_M^2}}. \qquad (18)$$

The speed of the relative movement of the car

$$V_{rel} = \frac{dS_{rel}}{dt} = \frac{A_p \cdot \Omega_M}{m_a \cdot \sqrt{(k^2 - \Omega_M^2)^2 + 4n^2 \cdot \Omega_M^2}} \cdot \cos(\Omega_M \cdot t + \varphi). \qquad (19)$$

Absolute vehicle speed

$$V_a = V_{por} + V_{rel} = \overline{V}_a + \frac{A_p \cdot \Omega_M}{m_a \cdot \sqrt{(k^2 - \Omega_M^2)^2 + 4n^2 \cdot \Omega_M^2}} \cdot \cos(\Omega_M \cdot t + \varphi). \qquad (20)$$

In fig. 2 shows a graph of the change in the absolute speed of the car. In fig. 2 shows a graph of the change in the absolute speed of the car.

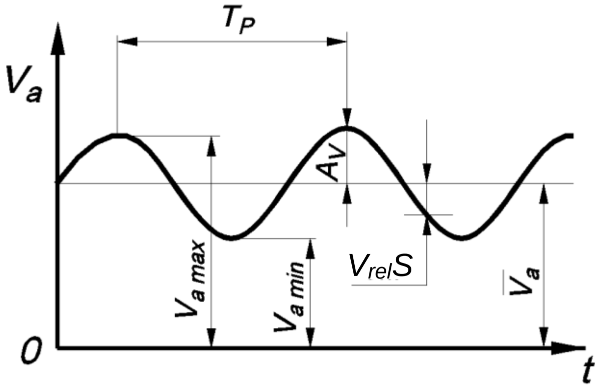

Figure 2. Tachogram of the complex movement of the vehicle when the traction force fluctuates

When the vehicle speed fluctuates, the level of its kinetic energy fluctuates. Compared with the uniform movement (portable), the additional energy consumption for the relative movement of the vehicle in one cycle of oscillation of the traction force will be equal (see fig. 2)

$$\Delta W_c = \frac{m_a \cdot \left(V^2_{a\max} - V^2_{a\min}\right)}{2} = \frac{m_a \cdot \left(V_{a\max} - V_{a\min}\right) \cdot \left(V_{a\max} + V_{a\min}\right)}{2} = m_a \cdot \Delta V_a \cdot \overline{V}_a = 2 \cdot m_a \cdot \overline{V}_a \cdot A_V, \quad (21)$$

where ΔV_a - the maximum change in vehicle speed in one cycle of change in tractive force, $\Delta V_a = V_{a\,max} - V_{a\,\min}$; $\overline{V}_a$ - the average speed of the steady movement, equal to the speed of the portable movement,

$$\overline{V}_a = \frac{V_{a\max} - V_{a\min}}{2}; \quad (22)$$

A_V – oscillation amplitude of the relative vehicle speed.

From the equation (19) we define

$$A_V = \frac{A_p \cdot \Omega_M}{m_a \cdot \sqrt{\left(k^2 - \Omega_M^2\right)^2 + 4n^2 \cdot \Omega_M^2}}. \quad (23)$$

After substituting the equation (23) into the expression (21), we obtain

$$\Delta W_c = 2A_p \cdot \overline{V}_a \cdot \frac{\Omega_M}{\sqrt{\left(k^2 - \Omega_M^2\right)^2 + 4n^2 \cdot \Omega_M^2}} \quad (24)$$

Additional energy consumption during t

$$\Delta W_t = \Delta W_ц \cdot \frac{t}{T_p}, \quad (25)$$

where T_p - the period of oscillation of the traction force,

$$T_p = \frac{2\pi}{\Omega_M}. \quad (26)$$

The expression (25) with (24) and (26) takes the form

$$\Delta W_t = \frac{A_p \cdot \overline{V}_a \cdot t \cdot \Omega_M^2}{\pi \cdot \sqrt{\left(k^2 - \Omega_M^2\right)^2 + 4n^2 \cdot \Omega_M^2}}. \quad (27)$$

Given that the path traveled by the car (its mileage) is determined by the dependence (6), we obtain the additional energy consumption depending on its mileage

$$\Delta W_S = \frac{A_p \cdot \Omega_M^2 \cdot S}{\pi \cdot \sqrt{\left(k^2 - \Omega_M^2\right)^2 + 4n^2 \cdot \Omega_M^2}} \quad . \tag{28}$$

The amplitude of oscillations of the traction force on the driving wheels is defined in [2, 3]

$$A_p = \frac{\overline{M}_i \cdot u_{tr} \cdot \eta_{me} \cdot \eta_{tr}}{2r_d} \cdot \left(0.08 + \frac{14.44}{i_c}\right) \cdot \left[1 - \frac{1}{\eta_{me} \cdot \eta_{tr} \cdot \left(1 + \frac{m_a \cdot r_k^2}{I_{red}^w}\right)}\right] \quad , \tag{29}$$

where $\overline{M}_i$ - the average indicated engine torque; u_{tr} - gear transmission ratio; η_{me}; η_{tr} - mechanical efficiency of the engine and transmission; r_k - the kinematic radius of the wheel; I_{red}^w - reduced to the wheels the moment of inertia of the transmission and the rotating mass of the engine.

The expression (28), after substituting equation (29) into it, transforms to the following form

$$\Delta W_S = \frac{\Omega_M^2 \cdot S}{\pi \cdot \sqrt{\left(k^2 - \Omega_M^2\right)^2 + 4n^2 \cdot \Omega_M^2}} \cdot \frac{\overline{M}_i \cdot u_{tr} \cdot \eta_{me} \cdot \eta_{tr}}{2r_d} \cdot \left(0.08 + \frac{14.44}{i_c}\right) \cdot \left[1 - \frac{1}{\eta_{me} \cdot \eta_{tr} \cdot \left(1 + \frac{m_a \cdot r_k^2}{I_{red}^w}\right)}\right] \quad . \tag{30}$$

Circular frequency of oscillation of torque [2, 3] Circular frequency of oscillation of torque [2, 3]

$$\Omega_M = \frac{\overline{\omega}_e \cdot i_c}{2} \quad , \tag{31}$$

where $\overline{\omega}_e$ - the average angular velocity of the shaft of the ICE,

$$\overline{\omega}_e = \frac{\overline{V}_a \cdot u_{tr}}{r_k} \quad . \tag{32}$$

In the equation (30)

$$\frac{\overline{M}_i \cdot u_{tr} \cdot \eta_{me} \cdot \eta_{tr}}{r_d} = \overline{P}_w \quad . \tag{33}$$

Transforming equation (30) into account the expressions (31) - (33), we get

$$\Delta W_S = \frac{S \cdot \overline{P}_w \cdot \left(0.04 + \frac{7.22}{i_c}\right) \cdot \left[1 - \frac{1}{\eta_{me} \cdot \eta_{tr} \cdot \left(1 + \frac{m_a \cdot r_k^2}{I_{red}^w}\right)}\right]}{\pi \cdot \sqrt{\left(\frac{k^2}{\Omega_M^2} - 1\right)^2 + \frac{16 \cdot n^2 \cdot r_k^2}{\overline{V}_a^2 \cdot u_{tr}^2 \cdot i_c^2}}} \quad . \tag{34}$$

Given the ratio

$$W_{por} = S \cdot \Sigma P_r = S \cdot \overline{P}_w \quad , \tag{35}$$

convert (34) to the form

$$\frac{\Delta W_S}{W_{por}} = \frac{\left(0.04 + \frac{7.22}{i_c}\right) \cdot \left[1 - \frac{1}{\eta_{me} \cdot \eta_{tr} \cdot \left(1 + \frac{m_a \cdot r_k^2}{I_{red}^w}\right)}\right]}{\pi \cdot \sqrt{\left(\frac{k^2}{\Omega_M^2} - 1\right)^2 + \frac{16 \cdot n^2 \cdot r_\kappa^2}{\overline{V}_a^2 \cdot u_{tr}^2 \cdot i_c^2}}} \quad , \tag{36}$$

where W_{por} - energy losses for the portable movement of the car.

In the equation (36), the value $\frac{m_a \cdot r_k^2}{I_{red}^w}$ can be expressed in terms of the coefficient δ_{rot} accounting for the rotating masses of the transmission and engine

$$\frac{m_a \cdot r_k^2}{I_{red}^w} = \frac{1}{\delta_{rot} - 1} . \quad (37)$$

The coefficient of accounting for rotating masses can be determined by the well-known [16] formula

$$\delta_{rot} = 1 + A_1 + A_2 \cdot u_g^2 , \quad (38)$$

where A_1 - the coefficient of accounting for the rotating mass of the transmission associated with the wheels with a constant gear ratio; A_2 - factor accounting for the rotating mass of the transmission and the engine associated with the wheels of a variable gear ratio; u_g - gear ratio.

The expression (36) with (37) and (38) takes the form

$$\frac{\Delta W_S}{W_{por}} = \left(1 - \frac{1 - \frac{1}{1 + A_1 + A_2 \cdot u_g^2}}{\eta_{me} \cdot \eta_{tr}}\right) \frac{0.04 + \frac{7.22}{i_c}}{\pi \cdot \sqrt{\left(\frac{k^2}{\Omega_M^2} - 1\right)^2 + \frac{16 \cdot n^2 \cdot r_k^2}{\overline{V}_a^2 \cdot u_{tr}^2 \cdot i_c^2}}} . \quad (39)$$

To estimate the additional energy losses caused by the oscillations of the traction force, when conducting a preliminary analysis, we can assume that the elastic coupling is $n = 0$ and there is no effect of rotating transmission masses, i.e. $\delta_{rot} \approx 1$. Subject to accepted assumptions, equation (39) will be simplified

$$\frac{\Delta W_S}{W_{por}} = \frac{0.04 + \frac{7.22}{i_c}}{\pi \cdot \left|\frac{k^2}{\Omega_M^2} - 1\right|} . \quad (40)$$

In fig. 3 and fig. 4 shows dependency graphs $\frac{\Delta W_S}{W_{por}} = F\left(\frac{k}{\Omega_M}\right)$ for different numbers of cylinders i_c of an internal combustion engine. The relative increase in additional losses $\frac{\Delta W_S}{W_{por}}$ as can be seen from fig. 3 and fig. 4, higher at $\frac{k}{\Omega_M} < 1$ than at $\frac{k}{\Omega_M} > 1$. Obviously, to reduce the ratio in accordance with the equation (11), it is necessary to increase the coefficient of tangential rigidity of tires and reduce the longitudinal compliance (increase the longitudinal rigidity) of the suspension.

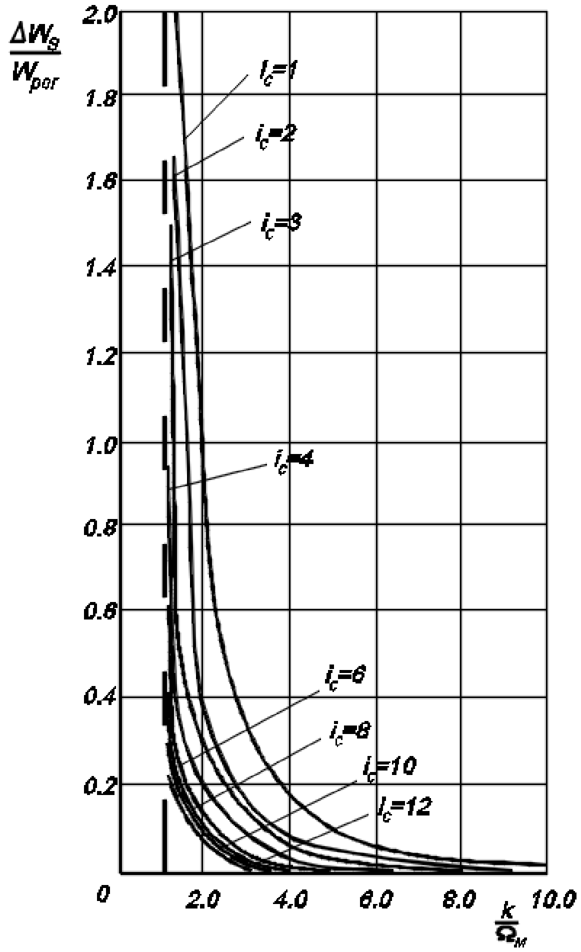

Figure 3. Dependence of relationship $\frac{\Delta W_S}{W_{por}}$ on relationship $\frac{k}{\Omega_M}$ with different values i_c and $\frac{k}{\Omega_M} > 1$

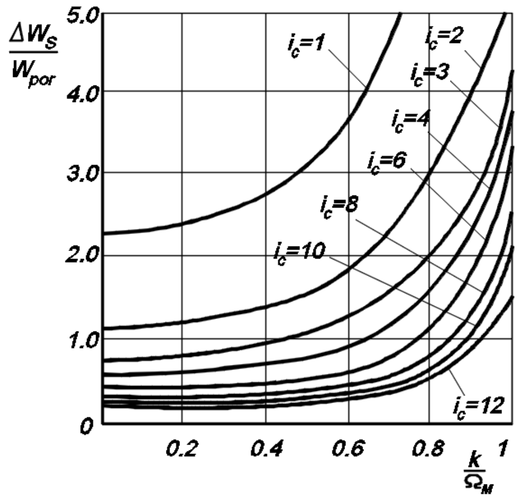

Figure 4. Dependence of relationship $\frac{\Delta W_S}{W_{por}}$ on relationship $\frac{k}{\Omega_M}$ with different values ic and $\frac{k}{\Omega_M} < 1$

From the equation (23) it can be seen that with absolutely rigid tires and suspension (κ = 0; n = 0) it will become (1), which corresponds to the result obtained earlier in the work [2].

4. Determination of additional energy loss for the combined electromechanical drive of the vehicle drive wheels

When using the combined electromechanical drive of the drive wheels, the amplitude of the oscillations of the traction force decreases [1]. In the work [1], the dependence was obtained to determine the amplitude of oscillations of the traction force in the case of using a combined electromechanical drive

$$A_p = \frac{k_1}{2r_d}\cdot\left(\bar{M}_i \cdot u_{tr}\cdot\eta_{me}\cdot\eta_{tr} - M_{em}\cdot n_1\right) = \frac{k_1}{2}\cdot\Sigma P_r\cdot\left(1-k_{em}\right) = \left(0.04+\frac{7.22}{i_c}\right)\cdot\left(1-k_{em}\right)\cdot\Sigma P_r\,. \quad (41)$$

After substituting the expression (41) into the equation (28), we get

$$\Delta W_S' = \frac{\left(0.04+\dfrac{7.22}{i_c}\right)\cdot S\cdot\Sigma P_r\cdot\left(1-k_{em}\right)\cdot\Omega_M^2}{\pi\cdot\sqrt{\left(k^2-\Omega_M^2\right)^2+4n^2\cdot\Omega_M^2}}\,. \quad (42)$$

Transforming the equation (42), we obtain the relative additional energy loss transforming the equation (42), we obtain the relative additional energy loss

$$\frac{\Delta W_S'}{S\cdot\Sigma P_r} = \frac{\Delta W_S'}{A_r} = \frac{\Delta W_S'}{W_{por}} = \frac{\left(0.04+\dfrac{7.22}{i_c}\right)\cdot\left(1-k_{em}\right)}{\pi\cdot\sqrt{\left(\dfrac{k^2}{\Omega_M^2}-1\right)^2+\dfrac{4\cdot n^2}{\Omega_M^2}}}\,. \quad (43)$$

Assuming the assumption that there is no damping (n = 0), we transform (43) to

$$\frac{\Delta W_S'}{W_{por}} = \frac{\left(0.04+\dfrac{7.22}{i_c}\right)\cdot\left(1-k_{em}\right)}{\pi\cdot\left|\dfrac{k^2}{\Omega_M^2}-1\right|}\,. \quad (44)$$

Comparing the expressions (40) and (44) with each other, we can conclude that the use of a combined electromechanical drive allows one to reduce (compared with a mechanical drive) additional energy losses. When k_{em} = 1 (with all-electric drive), the indicated losses are equal to zero.

Authors should discuss the results and how they can be interpreted in perspective of previous studies and of the working hypotheses. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted.

5. Conclusions

Longitudinal flexibility of the running gear of the car when the traction force on the wheels fluctuates leads to an increase in additional energy losses. These losses increase as the frequency of oscillations of the torque of the internal combustion engine approaches the frequency of free (natural oscillations) of the running gear of the car in the longitudinal direction.

When designing cars, it is necessary to strive to ensure that the ratio $\frac{k}{\Omega_M}$ is significantly greater than one. With $\frac{k}{\Omega_M} > 4$ relative additional energy losses $\frac{\Delta W_S}{W_{por}}$ does not exceed the value of 0.2, and when $\frac{k}{\Omega_M} > 6$ - does not exceed the value of 0.1.

When using a combined electromechanical drive of the drive wheels as well as in the case of a mechanical transmission of a car, resonance is dangerous, i.e. equality $k = \Omega M$. But with the increase in the share of torque k_{em} on the wheel generated by the electric motor, the relative additional energy losses for the movement of the car are reduced. When $k_{em} = 1$, these losses are equal to zero.

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Diagnostics of car wheel bearings with the use of noise-acoustic control methods

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Abstract: This paper presents a method of noise-acoustic non-destructive control during carrying out of diagnostics of bearings of mats rolling in car wheels. The proposed non-destructive method of control provides an opportunity to check the efficiency of the selected lubricant, thereby increasing the life and performance of the bearings. A laboratory installation for the diagnosis of roller bearings has been created, which allows to obtain their acoustic parameters depending on the load of the bearing unit, the time of application, and application of different types of lubricants in bearings. The theoretical and practical contribution of this proposition is that the mathematical model developed by the authors is aimed at determining the degree of wear of bearing shafts, which allows to predict their possible work life based on the received noise-acoustic parameters.

Keywords: bearing, non-destructive control, diagnostics, acoustic parameters, lubricants, laboratory setting.

1. Introduction

The resource of cars is determined, basically, by the rolling bearings resource. Defects in the manufacture and operation of bearings in different ways affect the signal of vibration and have different diagnostic features. This allows detecting defects at the stage of their occurrence and predict further development. The manufacturing defects include: deflection of the form in the fabrication of rolling bodies, unbalanced rings, eccentricity of the wraps, radial gaps; violation of roughness of rolling surface. The defects of installation include: defects of planting bearings in the nest; strong drag; wrong centering.

The main reasons for the release of the bearing are: failure of lubrication (40%); violation of the montage (30%); other causes (20%); natural wear (10%) [1].

The acoustic method of non-destructive control is based on the use of waves and elastic oscillations. When acoustic control is usually used oscillations with a frequency of 0.5...25 MHz (ultrasound) [2]. Therefore, most acoustic techniques are ultrasound, although there are known cases of use and oscillation of the sound frequency. Currently, four methods of ultrasound evaluation of the technical condition of rolling bearings are used in practice: the Peak-factor, the direct spectrum, the spectrographs and shock impulses.

The purpose of the work is to develop a method for carrying out research on the performance of rolling bearings by the method of acoustic non-destructive testing and obtaining the dependencies of acoustic performance of bearings on their development, as well as the use of lubricants in them. Development of a mathematical model, which involves evaluating the bearing of the rolling bearing, depending on its acoustic parameters.

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2. Analysis of literature

Many scientists are involved in the diagnostics of parts and units of automobiles using non-destructive methods of control. Much attention is paid to the diagnosis of roller bearings.

So in [3] the authors proposed a method for diagnosing bearings, which involves the use of deformation measurements obtained with the help of fiber optic sensors, which allows to estimate damage by measuring the size of small chips in the bearings of bearings. Using this method it is not possible to determine the degree of bearing of the bearing, but only to assess the degree of damage to its internal and external cartridges.

Work [4] is devoted to the method of evaluation of the quality of lubricants, namely the determination of contamination in the lubrication of rolling bearings using acoustic emission signals. The authors of the article argue that the signature of the contaminated lubricant is much stronger than the effect on conventional state indicators, such as RMS. However, a comprehensive evaluation of the application of one or another lubricant in the roller bearing does not provide for the proposed method.

Proposed in [5], the methodology for the diagnosis of rolling bearings uses packet wavelet transformation, tracking the order and the approach to modeling the features for generating the diagnostic metric as a measure of difference. The disadvantages of this method of diagnostics include its great complexity (it is necessary to carry out the assessment of the distribution of the probability of the diagnostic metric, which is statistically determined in the relevant conditions of use), as well as some inaccuracy in the evaluation of bearing applications with or without lubricants.

The proposed method for the diagnosis of bearings [6] involves obtaining parameters using the method of vibration. This method of variable structure was used to improve the reliability of the malfunctioning while simultaneously reducing the uncertainty in the feedback linearization observer. The main disadvantage of diagnosing with the linearization method is that the equivalence of the initial nonlinear system and its linear approximation is preserved only for certain processes, and if the system moves from one mode to another, it is necessary to change its linearized model, that is, it makes it impossible to take into account the change in the load on bearing unit.

The method of diagnosing roller bearings in labor [7] involves identifying and eliminating defects in bearings at the stage of harvesting them in the bearings of the assembly. The authors investigate the geometry and vibration signals generated by the acting bearings. The proposed method does not make it possible to evaluate the bearing life after a certain period of working time, as well as evaluate the efficiency of the lubricant used in it.

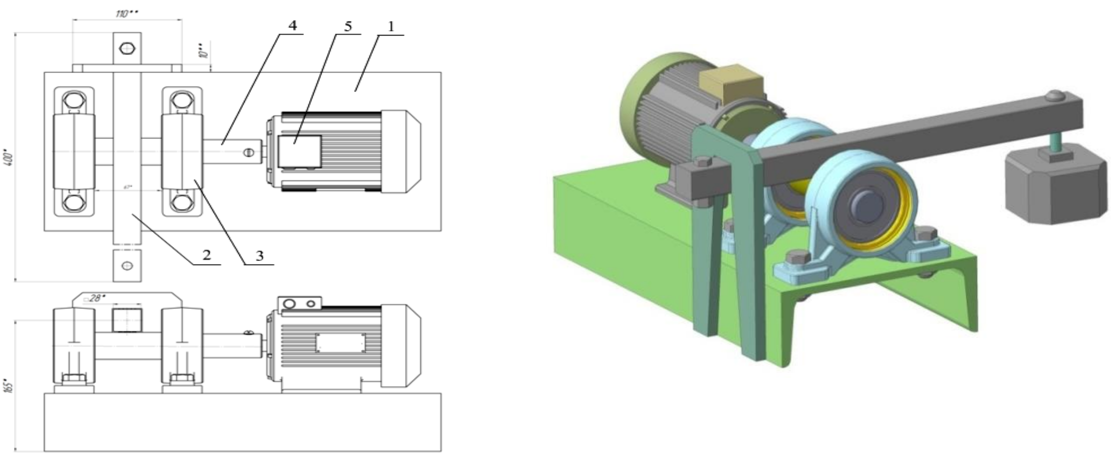
3. Methodology and results of research

Experimental studies were carried out on a laboratory installation (Fig. 1) for the diagnosis of roller bearings, using a sound-acoustic method using the software Gold Wawe and Spectrogram. For research, the bearings of the front hub of the Mercedes Vito are selected.

Experiment on research of noise-acoustic indices of rolling bearings was carried out in several stages. The first stage was carried out as follows: the bearing of the wheel hub was lubricated with lubricant number 158, and installed on a laboratory installation (Fig. 1), that is, the case with a bearing was installed with a tension on the shaft and connected to the electric motor; the system of the levers changed the load on the shaft on which the post - The bearings are rolling, thus changing the load on the bearing itself.

With acoustic sensors and computer technology, audio files were recorded with the corresponding software; after switching off the plant, it was partially disassembled to replace the bearings with another lubricant. Next, the next launch of the installation with bearings was used in which the lubricant LITOL-24 and CIATIM-201 was used and the audio files were recorded. The load shift on the bearing also occurred with the use of counter-loads.

Several cycles of filing the bearings with different lubricants and different loadings on the bearing unit were carried out, and then analysis of these files was performed using Gold Wave and Spectrogram programs.

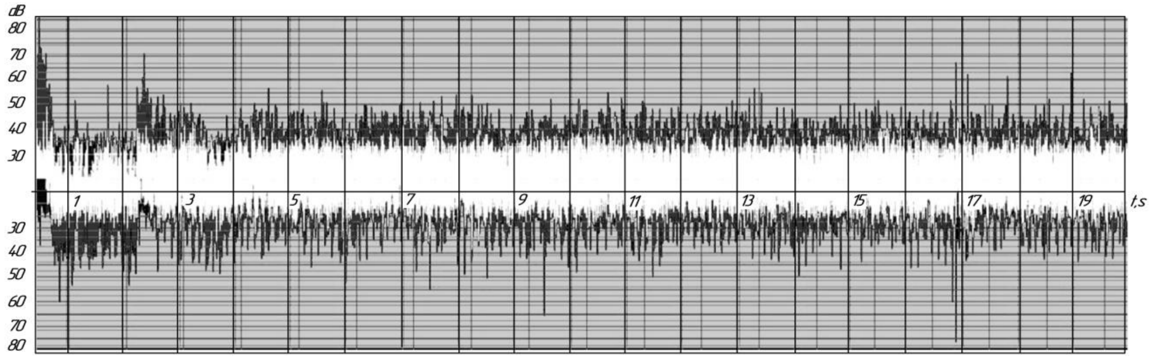


(**a**) (**b**)

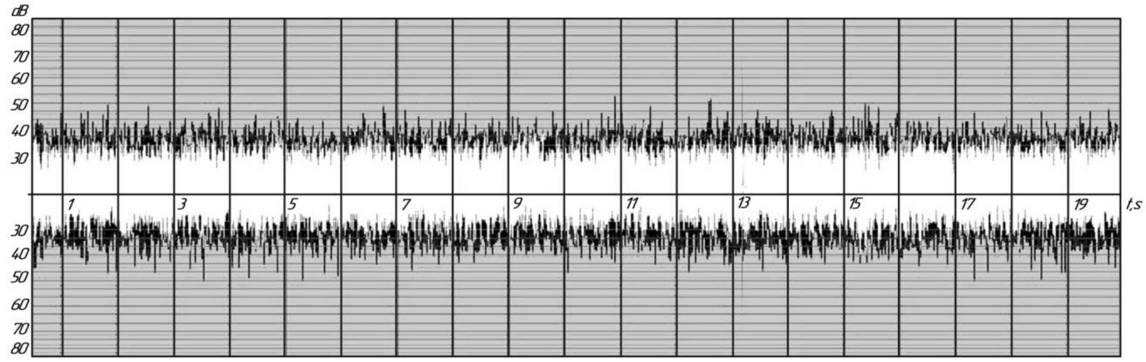
Figure 1. Installation for the diagnosis of roller bearings: (**a**) installation scheme; (**b**) three-dimensional model of installation; 1 – frame; 2 – loading mechanism; 3 – bearing; 4 – intermediate shaft; 5 – an electric motor.

The obtained data (spectrographs, diagrams and noise indicators) allow visually seeing and analyzing the wear condition of the bearing and the development of the defect in it, as well as the influence of the lubricant on the behavior of the noise-acoustic indicators.

An analysis of audio files (Fig. 2) made it possible to see how the behavior of the vibration acoustic indices of the bearing changes with the use of different lubricants.



(**a**)



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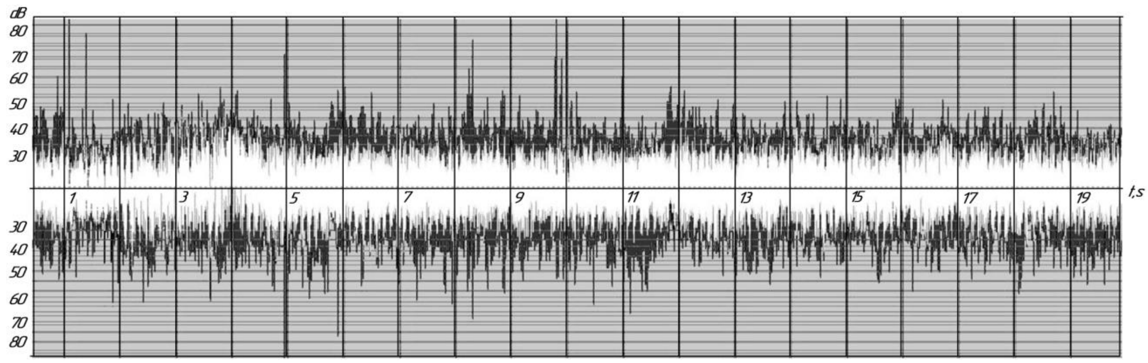

(**c**)

Figure 2. Diagrams of noise-acoustic indicators of bearings with the use of different lubricants: (a) lubricant №158; (b) lubricant LITOL-24; (c) lubricant CIATIM-201.

Diagrams allow you to clearly see the development of the defect and the overall picture of the state of the experimental under-spike and the dependence of the condition on the lubricant. The white color in the diagram shows the initial state of the test bearing, and the black is the limiting state.

The experiment used an electret microphone, microphone with the principle of action similar to the micro-phonons of the condenser type, which uses as a stationary plate of the condenser and the source of the post-voltage voltage plate from the electret.

Table 1 provides data on the magnitude of the noise band that was recorded during each cycle of the experiment with different lubricants.

Figure 3 shows the dependence of the magnitude of sound vibrations on the development of bearings and mastic materials.

Table 1. Results of measurement of noise level

Working hours, hours		100	200	300	400	500	600	800	1000
Number of revolutions of a bearing, 10^6 rev		6	12	18	24	30	36	48	60
The size of the sound oscillations, dB	Lubricant №158	47.2	47.2	48.1	50.5	56.4	61.3	70.4	75.1
		47.5	47.3	48.3	50.4	56.6	61.7	70.5	75.2
		47.3	47.5	48.6	50.9	56.4	61.2	70.3	75.5
	LITOL-24	45.3	46.4	49.4	55.3	61.1	69.6	77.7	78.3
		45.5	46.1	49.7	55.7	61.2	69.2	77.4	78.6
		45.4	46.3	49.5	55.8	61.5	69.4	77.9	78.4
	CIATIM-201	42.3	50.4	56.2	64.6	68.3	74.3	78.4	80.3
		42.5	49.5	56.7	64.5	68.6	74.4	78.8	80.4
		42.6	49.8	56.3	64.2	68.4	74.5	78.4	80.5

In the second stage, the dependence of the radial beating of the bearings of the hub of the wheel on their overall performance was measured and the corresponding value of sound oscillations was measured. To determine the indications of radial beating of rolling bearings, a clock-type indicator mounted on a magnetic rack was used. The values of radial beating of bearings from their total output are given in Table 2.

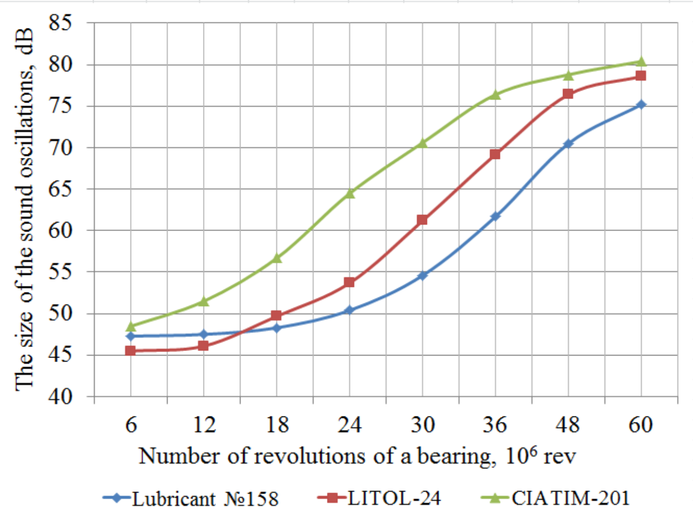

Figure 3. The dependence of the magnitude of sound vibrations on the development of bearings and lubricants

Table 2. Radial beating of bearings from their overall work

Number of revolutions of a bearing, 10^6 rev	6	12	18	24	30	36	48	60
Radial beating of bearings, μm	9.5	11.2	12.1	15.4	18.2	25.4	32.6	41.3
The size of the sound oscillations, dB	42.3	49.4	56.2	64.6	68.3	74.3	78.4	85.3

Figure 4 shows the dependence of the radial beat of bearings on the value of sound vibrations. For the bearing of the hub of the wheel, which was investigated, the permissible values of radial beats were set, which make up for the lower limit of 10 μm, and for the upper one – 35 μm. Depending on the value of the sound vibrations, we determine the degree of bearing operation and its possible work life.

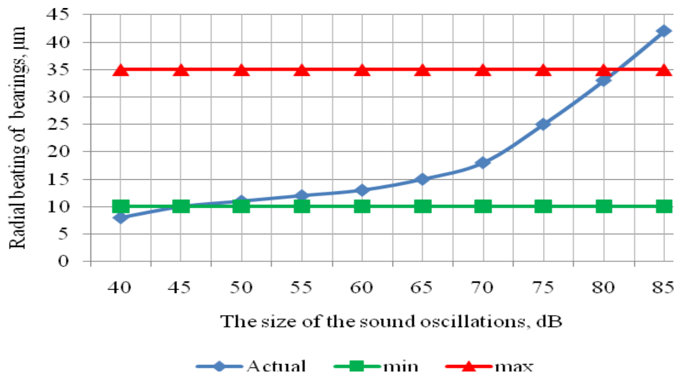

Figure 4. Dependence of radial beating of bearings on the value of sound oscillations

In the third stage a mathematical model was obtained for determining the dependence of acoustic parameters of bearings on their wear. This model takes into account the following parameters: the number of revolutions of the bearing; Load bearing perceived by the bearer; type of grease (number of penetration). Levels of variation above the above parameters are presented in Table 3.

Table 3. Levels of variation of factors

Factors	Marking factors	x_i*= –1.68	x_i= –1	x_i= 0	x_i= 1	x_i*=1.68
Number of revolutions of a bearing *N*, 10^6 rev	x_1	5	15	30	45	55
Load bearing perceived by the bearer *G*, 10^3 H	x_2	4.5	5.5	7	8.5	9.5
Number of lubrication penetration *ρ*, mm^{-1}	x_3	235	250	270	290	305

Encoding of factors by means of transformation:

$$x_j = \frac{\tilde{x}_j - \tilde{x}_{j0}}{I_j}, \quad (1)$$

where $\tilde{o}_j$ – coded value of the factor; $\tilde{x}_j$ – the natural value of the factor; $\tilde{x}_{j0}$ – the natural value of the main level; I_j – variation interval; *j* – factor number.

We show the matrix of the plan calculated according to the formula and the corresponding results of the experiment obtained (Table 4).

Table 4. The matrix of planning and research results

Experiment No.	x_0	x_1	x_2	x_3	x_1x_2	x_1x_3	x_2x_3	x^2_1	x^2_2	x^2_3	*y*	y_p	Deviation, %
1	1	1	1	1	1	1	1	1	1	1	78.2	77.3	1.15
2	1	1	1	–1	1	–1	–1	1	1	1	76.6	75.3	1.7
3	1	1	–1	1	–1	1	–1	1	1	1	65.8	66.5	-1.1
4	1	1	–1	–1	–1	–1	1	1	1	1	67.3	66.5	1.19
5	1	–1	1	1	–1	–1	1	1	1	1	52.4	53.3	-1.7
6	1	–1	1	–1	–1	1	–1	1	1	1	53.8	53.3	0.93
7	1	–1	–1	1	1	–1	–1	1	1	1	45.1	45.5	-0.9
8	1	–1	–1	–1	1	1	1	1	1	1	46.4	45,5	1,94
9	1	1.68	0	0	0	0	0	2.83	0	0	80.0	81.1	-1.4
10	1	–1.68	0	0	0	0	0	2.83	0	0	45.2	44.5	1.55
11	1	0	1.68	0	0	0	0	0	2.83	0	64.6	65.6	-1.5
12	1	0	–1.68	0	0	0	0	0	2.83	0	52.7	51.6	2.09
13	1	0	0	1.68	0	0	0	0	0	2.83	57.2	58.4	-2.1
14	1	0	0	–1.68	0	0	0	0	0	2.83	58.8	58.4	0.68
15	1	0	0	0	0	0	0	0	0	0	57.6	58.4	-1.4
16	1	0	0	0	0	0	0	0	0	0	57.1	58.4	-2.3
17	1	0	0	0	0	0	0	0	0	0	58.8	58.4	0.68
18	1	0	0	0	0	0	0	0	0	0	59.3	58.4	1.52
19	1	0	0	0	0	0	0	0	0	0	59.1	58.4	1.18
20	1	0	0	0	0	0	0	0	0	0	59.6	58.4	2.01

In this case, the mathematical model for a complete four factor experiment with the interaction of the mode has the form:

$$y_p = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2. \quad (2)$$

The coefficients of the model are calculated by the formula:

$$b_j = \frac{\sum_{i=1}^{N} x_{ji} \cdot y_i}{N}, \tag{3}$$

where j = 0, 1, 2, ..., k; N – number of performed experiments (N = 20).

The coefficients of the model (2), which are calculated by the formula (3), make up:

$$b_0 = 58.5;\ b_1 = 10.9;\ b_2 = 4.1;\ b_3 = -0.83;\ b_{12} = 1.5;\ b_{13} = 0.25;\ b_{23} = 0.75;$$
$$b_{11} = 1.55;\ b_{22} = 0.14;\ b_{33} = -0.4.$$

The dispersion S_y^2 of reproducibility is determined by the results of research in the center of the plan. Dispersions that characterize the errors in determining the coefficients of the regression equation according to [8] for k = 4 are:

$$S^2\{b_0\} = 0.5833;\ S^2\{b_i\} = 0.2563;\ S^2\{b_{il}\} = 0.1375;\ S^2\{b_{ii}\} = 0.0433.$$

When checking the coefficients by the criterion of the Investigator (with a 5% level of significance and a degree of free-body f = 4) found that all the coefficients are significant and exceptionally to the model (2).

Substituting the found coefficients into equation (2), we obtain the following relation:

$$y = 58.5 + 10.9 \cdot \tilde{x}_1 + 4.1 \cdot \tilde{x}_2 - 0.83 \cdot \tilde{x}_3 + 1.5 \cdot \tilde{x}_1 \cdot \tilde{x}_2 + 0.25 \cdot \tilde{x}_1 \cdot \tilde{x}_3 + 0.75 \cdot \tilde{x}_2 \cdot \tilde{x}_3 +$$
$$+ 1.55 \cdot \tilde{x}_1^2 + 0.14 \cdot \tilde{x}_2^2 - 0.4 \cdot \tilde{x}_3^2. \tag{4}$$

The verification of the hypothesis of the adequacy of the model (4) according to Fisher's criterion at the 5% level of significance and the degrees of freedom of dispersion of adequacy $f_{ad} = N - k - (n_0 - 1) = 20 - 4 - (6 - 1) = 11$ and dispersion of reproducibility $f_y = n_0 - 1 = 6 - 1 = 5$ showed that the obtained models are adequate, since the calculated value of the criterion is less tabular $F_{cal} = 1{,}54 < F_T\,(0{,}05;\ 11;\ 5) = 3.2$.

In the equation (4), the variables $\tilde{x}_1$, $\tilde{x}_2$, $\tilde{x}_3$ are coded values:

$$\tilde{x}_1 = \frac{N - 30}{15} = 0.067 \cdot N - 2;$$
$$\tilde{x}_2 = \frac{G - 7}{1{,}5} = 0.67 \cdot G - 4{,}67; \tag{5}$$
$$\tilde{x}_3 = \frac{\rho - 270}{20} = 0.05 \cdot \rho - 13{,}5.$$

where N – number of revolutions of a bearing, 10^6 rev; G – load bearing perceived by the bearer, 10^3 H; ρ – number of lubrication penetration, mm^{-1}.

For ease of computation, we convert the mathematical model (4) to a natural value:

$$\partial B = 33.15 - 0.381 \cdot N - 6.92 \cdot G + 0.3 \cdot \rho + 0.067 \cdot N \cdot G + 0.00084 \cdot N \cdot \rho + 0.025 \cdot G \cdot \rho +$$
$$+ 0.007 \cdot N^2 + 0.063 \cdot G^2 - 0.001 \cdot \rho^2. \tag{6}$$

4. Conclusions

On the basis of the conducted experiment and the analysis of the data obtained, it can be concluded that the method of non-destructive noise-acoustic control of roller bearings with the use of various lubricants is used to obtain the most reliable data on the degree of wear of rolling bearings, their operation and to prevent the destruction of the entire site as a whole.

The considered noise-acoustic method allows us to develop recommendations for the application of certain types of lubricants in roller bearings.

The developed mathematical model allows, based on the acoustic parameters of the bearings, which were obtained during experimental studies, to determine the degree of wear and to predict the potential life of the bearing roller.

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Improvement of the method for assessing the energy load of vehicle

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Abstract: The aim of the research is to improve the indicators assessment accuracy of the vehicle energy load by improving the method of experimentally - theoretical determination of the aerodynamic drag parameters of vehicle in motion. To achieve this goal, it is necessary to solve the problem of determining the dependence of the energy load level on vehicle speed with varying frontal aerodynamic drag coefficient. Studies carried out to clarify the calculation of the parameters of vehicle aerodynamic drag in motion made it possible to determine the correlation between the actual effective engine capacity and the maximum kinetic energy of vehicle at translational motion. When determining the vehicle aerodynamic drag, the constant coefficient of aerodynamic drag is used depending on the speed in all range of vehicle speeds. This leads to significant mistakes in determining the necessary engine capacity expendable to overcome the aerodynamic drag, and vehicle fuel consumption. As a result of the research, analytical expressions, allowing to take into account additional energy losses and correlation between the kinetic energy of the vehicle steady motion and the effective engine capacity have been obtained. The theoretical contribution of the research is that the correlation coefficient between the kinetic energy of vehicle in motion and the effective engine capacity – K_w have been proposed. Studies have shown that if speed of vehicle increases the indicator K_w will monotonously decrease in the range of actual speeds.

Keywords: aerodynamic drag, energy load, vehicle, accuracy of estimation, energy losses, effectiveness of the car

1. Introduction

Energy load characterizes both dynamic and economic properties of vehicle. The most important factor determining the energy load and energy efficiency of vehicles is aerodynamic drag to vehicle movement.

One of the most important areas is the vehicle aerodynamic design, based on the system optimization of its aerodynamic properties, which allows significantly increase fuel efficiency, dynamic properties, vehicle productivity, reduce pollution and noise. At the same time, achieving the minimum value of the aerodynamic drag coefficient is not the only objective of the vehicle aerodynamic design. In this case a number of important tasks are solving, affecting the technical, economic, consumer and environmental qualities of vehicle. New methods are developing for determining and refining the aerodynamic characteristics of vehicles on the road, when complete geometric and kinematic aerodynamic similarity is ensured [1-3].

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In the study, using the refined method of calculating the parameters of aerodynamic drag, the calculation of indicators of energy load and energy efficiency of vehicle was improved. An improved method for estimating energy load is based on the results of experimental studies of vehicle aerodynamics.

2. Methodology

Energy load characterizes the necessary consumption of engine capacity for the translational motion of vehicle with a given level of kinetic energy [4-7]. In case for vehicle with laden mass moving at maximum speed, in paper [4], there was proposed an indicator called the energy load level.

$$Y_W = \frac{2N_{e_{max}}}{m_{полн} V_{max}^2}, \quad (1)$$

where $N_{e_{max}}$ is the maximum effective engine capacity; $m_{полн}$ Is laden mass of vehicle; V_{max} is vehicle maximum speed.

The smaller the value of Y_W, the lower the energy load of vehicle [1]. The inverse of value Y_W is an indicator of energy efficiency

$$Э_W = \frac{1}{Y_W} = \frac{m_{полн} V_{max}^2}{2N_{e_{max}}}, \quad (2)$$

because it characterizes the amount of kinetic energy of vehicle per unit of maximum effective engine capacity.

From the point of view of the physical meaning, the value $Э_W$ (has the dimension of time) it is a vehicle acceleration time, if $N_e = N_{e_{max}} = const$ it provides that all the productive and non-productive expenditures of capacity (energy) are zero.

The calculations given in [4] showed that for a number of passenger car models produced from 1959 to 2004, the value Y_W of the indicator Y_W varies in the range of [0.037; 0.055], which is significantly below the limits [27.63; 115.37] of the power density $N_{уд}$ for the same cars [4]. It is because of the known power density indicator

$$N_{уд} = \frac{N_{e_{max}}}{m_{полн}}. \quad (3)$$

does not take into account the vehicle's maximum design speed V_{max}

The authors [8, 9] convincingly showed that aerodynamic drag plays a major role in consumption of engine capacity, especially at high speeds (the total road resistance on paved roads is relatively small). Therefore, a correct calculation of the aerodynamic drag forces increases the accuracy of estimating the energy load of vehicle.

The current method of calculating the force of aerodynamic drag was proposed at the beginning of the last century in the well-known work [10]. According to [10], the force of aerodynamic drag can be defined as

$$P_W = \frac{C_x}{2} \rho F V_a^2. \quad (4)$$

where C_x is the coefficient of aerodynamic drag; ρ is air density; F is midsection of vehicle (the largest cross-sectional area of the body, perpendicular to the direction of movement) or any other measurement of the area characterizing the size of the body; V_a is vehicle speed, m/s.

The coefficient C_x depends on the shape of the body [10]. If we consider it independent of speed, then, as shown the results of theoretical and experimental studies, expression (4) is not valid for the entire range of speeds [10]. At low speeds (up to 1 m/s), the law of the first speed degree is justified; at high speeds, close to the speed of sound, the law of cubes seems to take place; at speeds above the speed of sound, the law of squares is observed [10]. In this work [10] it is noted that taking the square law everywhere, one should set the coefficient C_x depending on speed V_a [10]. Fig. 1 shows dependence graph of the coefficient C_x on the ratio of the body velocity to the speed of sound

However, in the range of speeds when it is necessary to use aeroplane details (from 20 to 80 m/s), the square law of speeds is quite well justified [11].

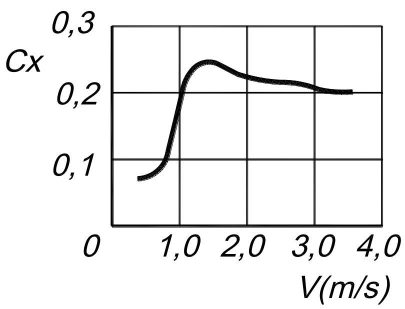
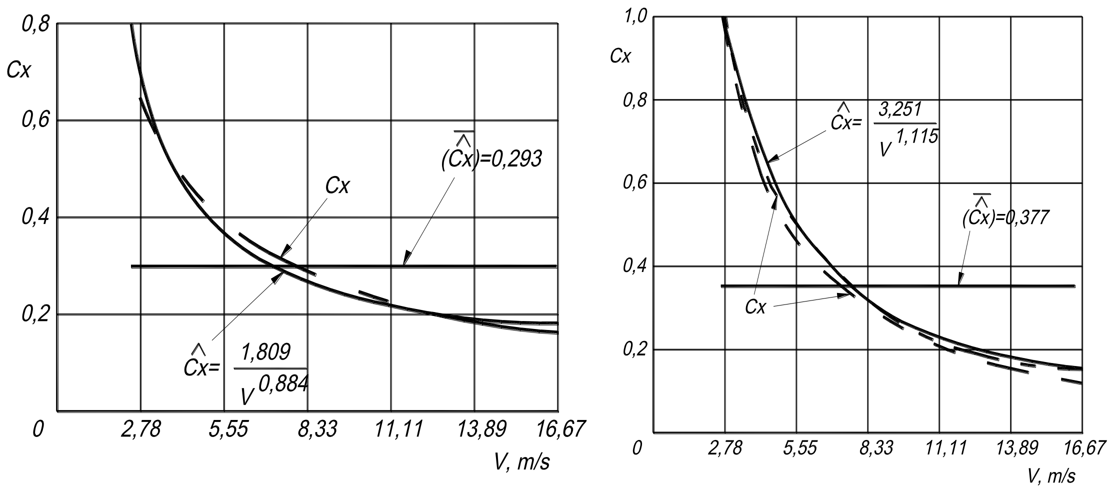


Figure 1. The dependence of the aerodynamic drag coefficient $C_x(V_a)$ on the vehicle speed [10]



(**a**) (**b**)

Figure 2. Dependence of the vehicle aerodynamic drag coefficient C_x on speed: C_x - approximating dependencies, (a) – passenger car VAZ-2107, (b) - passenger car ZAZ-1103 «Slavuta».

In work [11], using the method of partial accelerations, the dependencies of the coefficient C_x on speed are experimentally determined for passenger cars ZAZ-1102 “Slavuta” and VAZ-2107 (Fig.2). For approximation of experimental curves $C_x(V_a)$, an approximating hyperbolic dependence [11] is proposed like

$$\hat{C}_x = \frac{C_x}{V_a^n} \quad , \tag{5}$$

where C_{xo} is the coefficient of aerodynamic drag at V_a = 1 m/s; n is exponent at V_a.

However, a methodological mistake was made in work [11], because the value C_{xo} in equation (5), in contrast to the dimensionless value, C_x should have the dimension (m/s)^n. Therefore, the equation (5) must be represented in the form:

$$\hat{C}_x = \frac{A_W}{V_a^n} \, , \tag{6}$$

where A_W is the coefficient numerically equal C_x at = 1 m/s.

Therefore, it is necessary to clarify the indicator of the vehicle energy load level by more correctly determining the forces of aerodynamic drag.

3. Research results

Equation of the capacity balance at translational motion of vehicle

$$N_e \eta_{mp} = V_a (P_\psi + P_w) , \qquad (7)$$

where P_φ is the strength of the total road resistance;

$$P_\varphi = m_a g \psi , \qquad (8)$$

N_e is current value of the effective engine capacity; g is acceleration of gravity, g = 9.81 m/s^2; ψ is the coefficient of total road resistance;

$$\psi = f \pm i , \qquad (9)$$

f is rolling resistance coefficient; i is the longitudinal slope of the road; η_{mp} is transmission efficiency.

Equation (4) with the expression (6) takes the form:

$$P_w = \frac{A_w}{V_a^n} \cdot \frac{\rho F}{2} V_a^2 = \frac{A_w}{2} \rho F V_a^{2-n} \quad . \qquad (10)$$

After substituting expressions (8) and (10) into the power balance equation (7) we get:

$$N_e \eta_{mp} = V_a (m_a \; g \psi \frac{A_w}{2} \rho F V_a^{2-n}) \quad . \qquad (11)$$

By analogy with the work [4], we take out the value from the brackets $\frac{m_a V_a}{2}$. As a result, we get

$$N_e \eta_{mp} = \frac{m_a V_a^2}{2} \left(\frac{2 g \psi}{V_a} + \frac{A_W}{m_a} \rho F V_a^{1-n} \right), \qquad (12)$$

Dividing the left and right parts η_{mp} we get:

$$N_e = \frac{m_a V_a^2}{2 \eta_{mp}} \left(\frac{2 g \psi}{V_a} + \frac{A_w \rho F}{m_a} V_a^{1-n} \right) = \frac{m_a V_a^2}{2} K_w = W_{кин} K_w \quad , \qquad (13)$$

where K_w is the coefficient of the correlation between the kinetic energy of the vehicle translational motion and effective actual engine capacity [4]

$$K_w = \frac{1}{\eta_{mp}} \left(\frac{2 g \psi}{V_a} + \frac{A_w \rho F}{m_a} V_a^{1-n} \right) \quad . \qquad (14)$$

With $m_a = m_{полн}$; $V_a = V_{max}$ the value K_w = Y_W (see the equation (1)).

To ensure high energy efficiency (low energy load) it is necessary to strive to obtain the lowest values K_w. The dependency graph $K_w(V_a)$ has the form shown in fig. 3

speed: 1 - $\frac{A_W \rho F}{\eta_{mp} m_a} V_a^{1-n}$, 2 - $\frac{2 g \psi}{\eta_{mp} V_a^2}$

The condition for finding the point of minimum $V_a = V_{opt}$ and minimum of functions $(K_w)(V_{opt})$

$$\begin{cases} \partial K_W / \partial V_a = 0 \\ \partial^2 K_W / \partial V_a^2 \Big|_{npu V_a = V_{opt}} > 0 \end{cases} . \qquad (15)$$

In this way

$$\frac{\partial K_W}{\partial V_a} = -\frac{2g\psi}{\eta_{mp} V_a^2} + (1-n)\frac{A_W \rho F}{\eta_{mp} m_a} V_a^{-n} = 0, \tag{16}$$

Then we find

$$V_a = V_{opt} = \sqrt[2-n]{\frac{2m_a g\psi}{(1-n)A_W \rho F}}. \tag{17}$$

Solving logarithm equation (16) with following potentiation, we can obtain an invariant formula of expression (17), which allows to simplify arithmetic calculations

$$V_a = V_{opt} = exp\left[\frac{ln\left|\frac{2m_a g\psi}{(1-n)A_W \rho F}\right|}{2-n}\right]. \tag{18}$$

Equation (14) if $V_a = V_{opt}$ will take the form

$$K_w = (K_W)_{min} = \frac{2g\psi}{\eta_{mp}}\frac{2-n}{1-n}\sqrt[2-n]{(1-n)\frac{A_w \rho F}{2m_a g\psi}} = \frac{2g\psi}{\eta_{mp}}\frac{2-n}{1-n} exp\left[-\frac{ln\left|\frac{2m_a g\psi}{(1-n)A_w \rho F}\right|}{2-n}\right]. \tag{19}$$

Let us check the equation to obtain a minimum (equation (15))

$$\frac{\partial^2 K_w}{\partial V_a^2} = +\frac{4g\psi}{\eta_{mp} V_a^3} - n(1-n)\frac{A_W \rho F}{\eta_{mp} m_a} V_a^{-(n+1)}. \tag{20}$$

From the equation (16) we get

$$(1-n)C_x \rho F V_2^{2-n} = 2gm_a \psi. \tag{21}$$

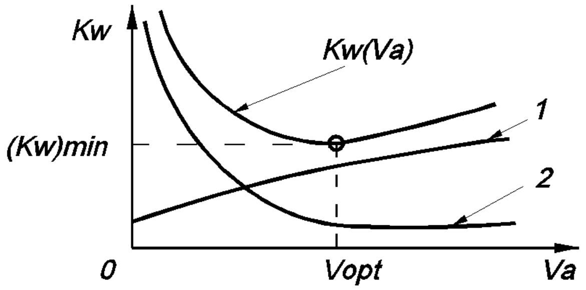


Figure 3. Dependency of the correlation coefficient between the kinetic energy of the vehicle steady motion and the effective engine capacity power $K_w(V_a)$ from the optimal

Substituting the equation (21) into the equation (20), we get if $V_a = V_{opt}$

$$\frac{\partial^2 K_w}{\partial V_a^2} = \frac{A_W \rho F}{\eta_{mp} m_a} V_{opt}^{2-n}\left[2(1-n) - n(1-n)\right] = \frac{A_W \rho F}{\eta_{mp} m_a} V_{opt}^{2-n}(2 - 3n + n^2). \tag{22}$$

The value $\frac{\partial^2 K_w}{\partial V_a^2} > 0$ if the condition

$$n^2 - 3n + 2 > 0. \tag{23}$$

We solve the quadratic inequality in the form

$$n_1 < 1; \quad (24)$$

$$n_2 > 2 \quad (25)$$

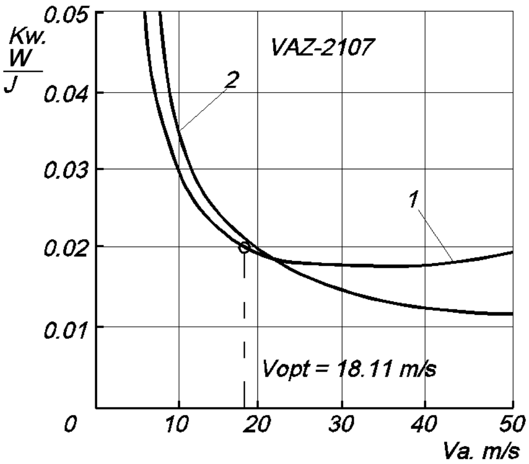
Thus, for n_1 <1 and n_2> 2, we have $K_w = (K_W)_{min}$ for $V_a = V_{opt}$. For values of n falling in the interval [1, 2], $K_w = (K_W)_{max}$ ($V_a = V_{opt}$). It means that the curve $K_w(V_a)$ in this case has a bulge in the opposite direction.

Figure 4 shows dependency graphs $K_w(V_a)$ for VAZ-2107 and ZAZ-1103 «Slavuta» cars if $C_x = const$ and $\widehat{C}_x$ changing according to the law (5). Analysis of these graphs shows that if $C_x = const$ the curves $K_w(V_a)$ have a minimum. The minimum point is equal V_{opt} = 18.11 m/s (65.2 km/h) for the passenger car VAZ-2107 and V_{opt} = 22.06 m/s (79.4 k /h) for the passenger car ZAZ-1103 «Slavuta».

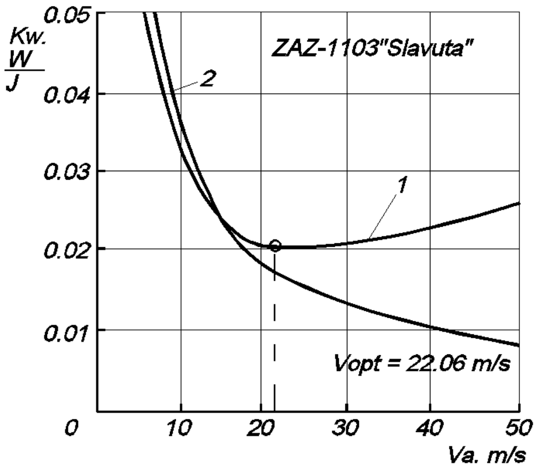
If $\widehat{C}_x$ changing according to the law (5), the extremum points (curves 2 in Fig. 4) are absent in the interval of actual vehicle speeds V_a.

Table 1 shows the results of assessments of the energy load level Y_W and energy efficiency indicator $Э_W$ for the considered models of passenger cars.

Analysis of the results of the calculations given in the table shows that the energy load of the VAZ-2107 is higher than the ZAZ-1103, and the energy efficiency indicator, on the contrary, is lower.



(a)



(b)

Figure 4. Dependencies of the correlation coefficient between the kinetic energy of the vehicle steady motion and the effective engine capacity power $K_w(V_a)$ from speed: 1– at $C_x = const$,

2– at $C_x = A_w V_a^{-n}$

Table 1. Calculation of indicators Y_W and $Э_W$

Automobile model	$N_{e_{max}}$**, kW**	$m_{полн}$**, kg**	V_{max}**, m/s**	$\frac{m_{полн}V^2_{max}}{2}$**, J**	Y_W**, Vt/J**	$Э_W$**, J/Vt**
VAZ -2107	56,6	1430	42	1261	0,0566	17,67
ZAZ -1103 «Slavuta»	48,53	1190	41	1000	0,0485	20,61

4. Conclusions

Resulting analytic expressions can serve as a basis for evaluating the energy efficiency of cars during steady. Refinement of the aerodynamic drag calculation parameters to motion made it possible to clarify the correlation between the actual effective engine capacity and the maximum kinetic energy of the steady translational motion of the vehicle. With an increase of vehicle speed, the indicator K_w characterizing the link between the actual effective engine capacity and the kinetic energy of vehicle monotonously decreases in the range of actual speeds. Refinement of the calculation of the aerodynamic drag to the movement of the vehicle using the equation (10) made it possible to determine that at high speeds the value of the indicator K_w significantly lower than with the traditional method of calculation (equation (4)). This reduction is up to 33% (at speed $V_a = 40$ m/s) for the VAZ-2107 and at the same speed - 46%.

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