tire; truck; control wear of tire; technical service; term of service; tread depth

Alexander KRAVCHENKO*, Olga SAKNO
Volodymyr Dahl East-Ukraine National University
Molodyozhny block, 20a, Lugansk, 91034, Ukraine
Alexander LUKICHOV
Donetsk Academy of Motor Transport
Dzherzhinskogo st. 7, Donetsk, 83086, Ukraine
**Corresponding author*. E-mail: avtoap@ukr.net

TRUCKS TIRES RESOURCE CONTROLLING BY CONTROL OF PROCESS OF THEIR WEARING-OUT

Summary. Intensity and form of wear of tire′s tread depends on the technical state of assemblies of car suspension. The database according to the information of control of the height of the protector picture is forming. On its basis on the developed system of maintenance of tires setting of norms, prognostication and optimization of resource of tires is made, necessary repair influences of tires and assemblies of suspension are appointed.

УПРАВЛЕНИЕ РЕСУРСОМ ШИН ГРУЗОВЫХ АВТОМОБИЛЕЙ НА ОСНОВЕ КОНТРОЛЯ ПРОЦЕССА ИХ ИЗНАШИВАНИЯ

Аннотация. Интенсивность и форма износа протектора шин зависит от технического состояния функциональных узлов подвески автомобиля. По данным контроля высоты рисунка протектора формируется база данных. На ее основе по разработанной системе обслуживания шин производится нормирование, прогнозирование и оптимизация ресурса шин, назначаются необходимые ремонтные воздействия для шин и узлов подвески.

1. INTRODUCTION

An increase of requirements to safety of motion at the increase of efficiency of the use of facilities of transport is strategy of development of automobile industry. To a full degree it belongs to the tires of trucks. Realization of requirements during exploitation of trucks is predefined a necessity to service them on the technical state which can be certain on intensity and form of treadwear. It is thus important objectively to ration and forecast the resource of tires, optimize an actual resource due to the timely repair affecting assemblies of car suspension which treadwear tires depends on. Thus the decision of general problem of the effective use of tires of trucks resource requires to form single approach of the systems to their service on the actual technical state. Control of treadwear, its dynamics, which is carrying out during the leadthrough of all of types of technical service, is the basis (TS). On the basis of assignment of dependence of intensity and form of treadwear from the technical state of assemblies of car suspension it is necessary to develop the new way for the resource of tires by control of their wear process in an order to increase the daily allowance runs of trucks, provide safety of their motion, reduce outages and cost of transportations.

2. PUBISHED WORK ANALYSIS AND THE RESEARCH GOAL

As shown in the papers of V.L Biderman, G. Paseyka, He JF, Jin XX, S.M. Zuckerberg, N.Y. Govorushchenko, V.P. Volkov, V.I. Knoroz, A.N. Yurchenko, N.E. Zhukovsky, M.V. Keldish, E. Robecca, R. Smiley, R. Hadekel, I.V. Balabin [1-7], the study of the process of tire′s wear is causing big problems, because when they contact with the road a powerful force interaction of the vehicle with the road surface is formed, that is influenced by operational factors which are impossible to be fully taken into account in practice, and the wear intensity and technical condition of the tires in 80-90% depend just on them.

The problem of monitoring of the technical condition of truck′s tires, residual height of the tread remains relevant in practical use. In [4, 8, 9, 10] it is shown that the control of the residual height of the tread pattern of the truck tire, the creation of appropriate databases in comparison with the previous measurement values is the most expedient method of treading wear dynamics in the operation conditions . This method does not require sophisticated equipment, previous exposure to the tire, the destructive action on it and dismounting. In so doing the analytical and statistical methods for calculating the tread wear intensity both on the basis of solution of the contact problem of friction, and assessing of the impact of operational factors compared to the actual resource give an error of 10-90% [11-14].

In addition the method of the direct measurement of the height of the tread pattern can detect unevenness of the tire wear, such to the width of the toe cam and as to the length of the circumference, which is virtually impossible with volumetric and gravimetric assessment methods. The aim of this study is to develop the system of the tire resource controling, technical inspection of trucks on the basis of information on the intensity and shape of the tread wear of the tires [15, 16]. Tire life prediction and control of their technical condition allow solving the problem of increasing efficiency of cars usage.

3. CONTROLLING OF REPAIR ACTIONS ACCORDING TO THE DATA OF INTENSITY AND TREAD WEAR FORM CONTROL

The main objective of control of the technical condition of the vehicles is to ensure its reliability and performance of the set with minimum labor and material costs. That is, the objective function of the efficiency of road transport enterprises (RTE) is based on the productivity of transportations $\mathrm{W_i}$ [17]. It is the generalized index of efficiency, and is suitable for use on any RTE. This objective function is the minimum total cost C per unit of transportation process capacity at the optimum technical availability (the total efficiency is divided into economic and technical components):

$$C = \sum_{i=1}^{n} C_{i_{total}} / \mathrm{W_i} \rightarrow \min \text{ при } \alpha_{TT} \rightarrow \text{opt}, \quad (1)$$

where $\sum_{i=1}^{n} C_{i_{\,total}}$ – is the total overall operating costs, in which the cost is 15-20% for the truck tires, which corresponds to the same share of the objective function. Reducing the cost complex for the vehicle operation can be mainly achieved by reducing the cost of tires, fuel and maintenance.

The second condition of the objective function, namely the optimization of the efficiency of technical operation, can be characterized by the degree of technical readiness of the vehicles to the implementation of the transport operation α_T. A mathematical model of the α_T forming is presented in the expanded form [17]:

$$\alpha_T = \mathrm{f}(\mathrm{X_L}, \mathrm{X_t}, \mathrm{Z_L}, Z_t, W_L, W_t, W_\lambda) \rightarrow 1, \quad (2)$$

where X_L, X_t – are the controlled variable factors that are associated with the mileage and time, respectively; Z_L, Z_t – are uncontrolled variable factors that are associated with the mileage and time, respectively; W_L, W_t, W_λ – are uncontrolled uncontrollable variable factors that are associated with mileage, time and operation intensity respectively.

Analysis of different types of RTE gives considerable variation α_T, such as for trucks $\alpha_{T\min} = 0.6$, $\alpha_{T\max} = 0.9$, $\alpha_T^* = 0.8$ is the average one according to the Donetsk Region's data. There is a considerable scope to improve by taking into account the existing operational factors and the controlling of the process of their forming. This fully applies to the factors that affects vehicle downtime due to the tire failure and lack of their spare kits. To achieve the objective function of improving the overall efficiency of the transport operation α_T – the technical component must be increased, and C – the economic component- must be reduced. The solution to this problem is largely associated with the operation of the tires. This factor has become the focus of research in the paper.

To implement this task the control system requires rapid, accurate and reliable information about the technical condition of the car as it is the basis of the formation of the technical interference complex during its maintenance and repair. A perspective direction of informatization of the service processes is improving of the diagnostic support of this system. Diagnosis is the process of determining the technical state of the object without disassembly, by its appearance, by measuring the parameters that characterize its condition, and comparing them with normative values. Therefore, control of the height of the tire tread is covered by this definition, and the information obtained in this way is an essential complement of the standard diagnostic information. In [18] it is suggested to consider the height of the tread pattern as an indicator that provides the controlling information on the state of elements of the vehicle and processes.

In the proposed system of the tire resource control the diagnosis based on the tread pattern residual height, wear intensity and shape is a subsystem of the information for the manufacturing controlling. But at the same time it is an element of the complex of technical actions carried out in the course of maintenance, quality assurance and technical actions carried out to ensure the specified technical condition of vehicles. The main function of diagnosis in the control of the complex of the technical influences is providing of the closed-loop control system with feedback, which is also an element of the diagnosis. The criterion of effectiveness, which is controlled by the diagnosis, including the control of the intensity and shape of the tread wear, should be considered an approximation of the measurements to the standard. The feedback acts as a regulation, creates a given (optimal) mode, and is a stabilizing factor in the system.

In the process of wear of the tread pattern the shape is the function of the technical condition of the car, which is one of the key operating factors. But if such a functional dependence is common, the use of inverse functional dependence is rare. Let us consider the main types of technical faults of the steering components, chassis and brake systems of trucks and their corresponding forms of the worn tread surface (Fig. 1), as well as the ability to use these relationships to build a system of tire resource control.

The concept of "resource control system" provides for the hierarchical structure of the control system. That is it is necessary to determine the composition and the relationship between the elements of the system. The elements of the system are the nodes of the system control and the elements of the component software. This problem is most convenient to introduce by the method of graphs. In the process of building the system of control of the technical state the tasks on formation of the complex of technical influences, its optimization and performance evaluation arises. The accomplishment of these tasks is only possible at the construction of the appropriate mathematical and graphical models. Optimization criterion, as in the objective function, is the cost of maintenance, while providing the parallel necessary technical level of the vehicle.

Let us present the simulated object in the form of a mark-up graph of the states. Nodes of the graph are the operations of technical actions to identify and localize the malfunctions, and troubleshoot.

Truck tire tread patter ware form	Even wear	The effectiveness of the suspension			The characteristic malfunctions of the elements of steering, chassis and brake systems of trucks
		The effectiveness of shock absorbers			
		The value of brake force			
	Uneven wear	Trailing wear	Centre wear	Tire pressure which is above normal	
			Bothe edge wear	The air pressure in the tire which is below normal	
		One-sided wear	Smooth	Camber	
				Inconsistency of load behind the axles and wheels	
				The pin transverse angle	
			Saw tooth	Misalignment of the wheel axis	
				Pivot trim	
				Toe-in	
		Wear at the tread	The ratio of the steering wheel turning angles		
		Spotted wear	Shock absorber malfunction		
			Violation of the base (the time of tightening of the nuts of the rear spring U-bolts)		
			Chequered	Dynamic misbalance	
				Disc beat	
				Inconsistency to the specifications of the wheel strengthening	
			Areal	Static misbalance	
				Braking force unevenness	
				Brake ovality	
		Wavy saw tooth wear	Steering mechanism play		
			Wheel boss bearing play		
			Pivot connection play		
		The eccentric wear	Deformation of the rim		
			Inconsistency to the specifications of the side fix		

Fig. 1. Chart of interconnection of the tread pattern wear shape with the technical state of assemblies of steering, running and brake systems of the trucks
Рис. 1. Схема взаимосвязи формы износа рисунка протектора с техническим состоянием элементов рулевого управления, ходовой и тормозной систем грузовых автомобилей

The list of graph elements is determined on the basis of analysis of elements that affect the intensity and nature of the tread wear of tires for trucks (Table 1). The parameters listed in the table can be divided into two categories: the direct impact on traffic safety (d_0, $d_1 - d_3$), and others, the technical condition of which has no direct impact on the traffic safety, or check of which is not foreseen by the system of maintenance. This list is not exhaustive and may be expanded gradually, perfected according to the vehicle suspension design changes and re-established relationships. But the general approach of using of functional relationships is preserved.

Technical steps to resume the nominal values of the parameters of the first category are made: for d_0 – mandatory for $d_1 - d_3$ (components d_0) – on the basis of the information on tire wear (i.e. state). Status parameters $d_1 - d_3$ are the components of d_0. Using this relationship, there is no need for periodic verification of the totality of the parameters; consequently, the average value may be reduced.

Definition of the technical condition of the remaining parameters is carried out on the results of monitoring of the state of the tires. Each element of the complex of technical actions is considered as one of the states of the control system. According to the reflected in Table 1 notations, the structure of the technical effects on the components and systems that determine the intensity and the nature of the tire wear the generalized graph shown in Fig. 2 is constructed. The graph [19] can vary for each type of the rolling stock.

Table 1

Designation of the elements of the graph of the complex technical actions

№	Parameter name	Symbol: Monitored parameter d_i	Symbol: Localization and troubleshooting of malfunctions r_i
1	Steering wheel play	d_0	-
2	Steering mechanism play, traction	d_1	r_1
3	Wheel boss bearing play	d_2	r_2
4	Pivot connection play	d_3	r_3
5	Tire technical condition	d_4	r_4
6	Air pressure in the tire	d_5	r_5
7	Axle defect	d_6	r_6
8	Wheel camber	d_7	r_8
9	Toe-in	d_8	r_8
10	Wheel disc beat	d_9	r_9
11	Dynamic misbalance	$d_{10.1}$	r_{10}
	Static misbalance	$d_{10.2}$	r_{10}
12	Brake mechanism ovality	$d_{11.1}$	r_{11}
	Brake mechanism technical state	$d_{11.2}$	r_{11}
13	Steering wheel angle turning ratio	d_{12}	r_{12}
14	Braking force value	d_{13}	r_{13}
15	Suspension efficiency	$d_{14.1}$	r_{14}
	Shock absorber efficiency	$d_{14.2}$	r_{14}
16	Rim deformation	d_{15}	r_{15}
17	Inconsistency to the specifications of the side fix conditions	d_{16}	r_{16}
18	Inconsistency to the specifications of the wheel fix	d_{17}	r_{17}
19	Shock absorber malfunction	d_{18}	r_{18}
20	Violation of the base (the time of tightening of the nuts of the rear spring U-bolts)	d_{19}	r_{19}
21	Pivot inclination	d_{20}	r_{20}
22	Inconsistency to the given spread of load on the axels	$d_{21.1}$	r_{21}
	Inconsistency to the given spread of load on the wheels (near-side and off-side)	$d_{21.1}$	r_{21}

On the whole, the information about intensity and shape of treadwear of tires diminishes the cost of maintenance. The basic object of control is the technical state of the car on the base of the information about the wear of tires (Fig. 3).

The considered functions are executed by the personnel of the zone of technical actions with the use of necessary tools, equipment, spare parts and materials. During the implementation of obligatory technical actions it is suggested to use an additional level which is the control of the technical state of tires, namely measuring of the height of the tread and external examination.

In the process of the general diagnosis three types of disrepairs can be found out:

- disrepairs the removal of which are of regulation character; it requires the complex of diagnostics and have small labour intensiveness;
- disrepairs that require localization that is clarification of the list of defective or failed assemblies and details;
- disrepairs, that do not require localization, and the removal of which requires replacement of assemblies and details or considerable labour intensiveness of work.

Thus, the complex of repair-regulation actions is formed.

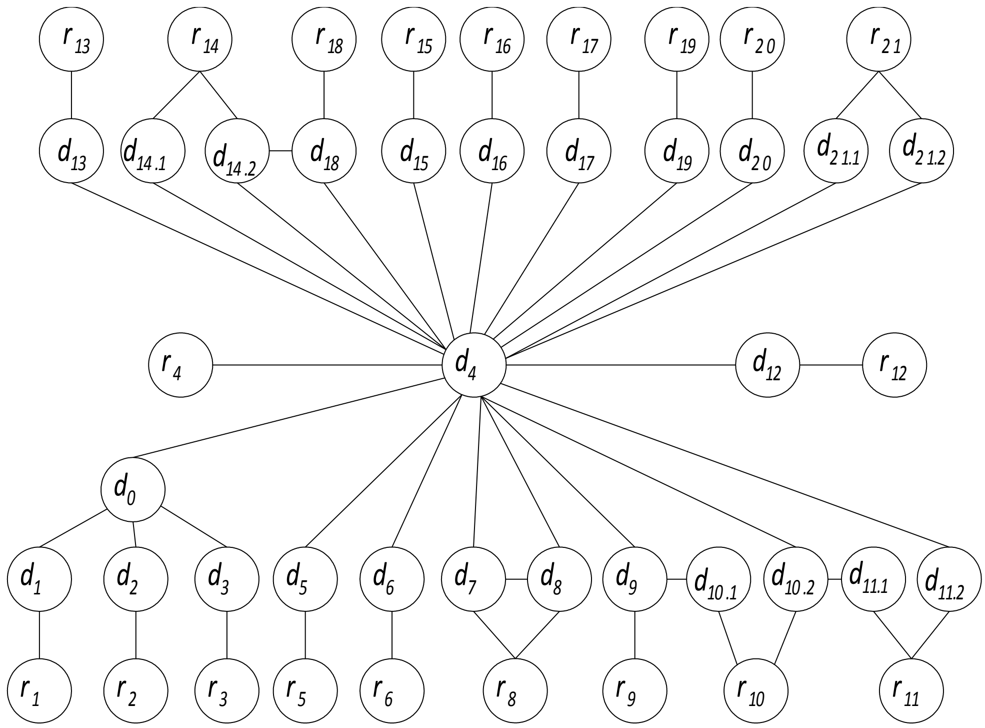


Fig. 2. Graph of the complex of technical influences of the system checking the technical state of the steering elements , working and brake systems of trucks by the basis of estimation of treadwear

Рис. 2. Граф комплекса технических воздействий системы контроля за техническим состоянием элементов рулевого управления, ходовой и тормозной систем грузовых автомобилей на основе оценки износа протектора

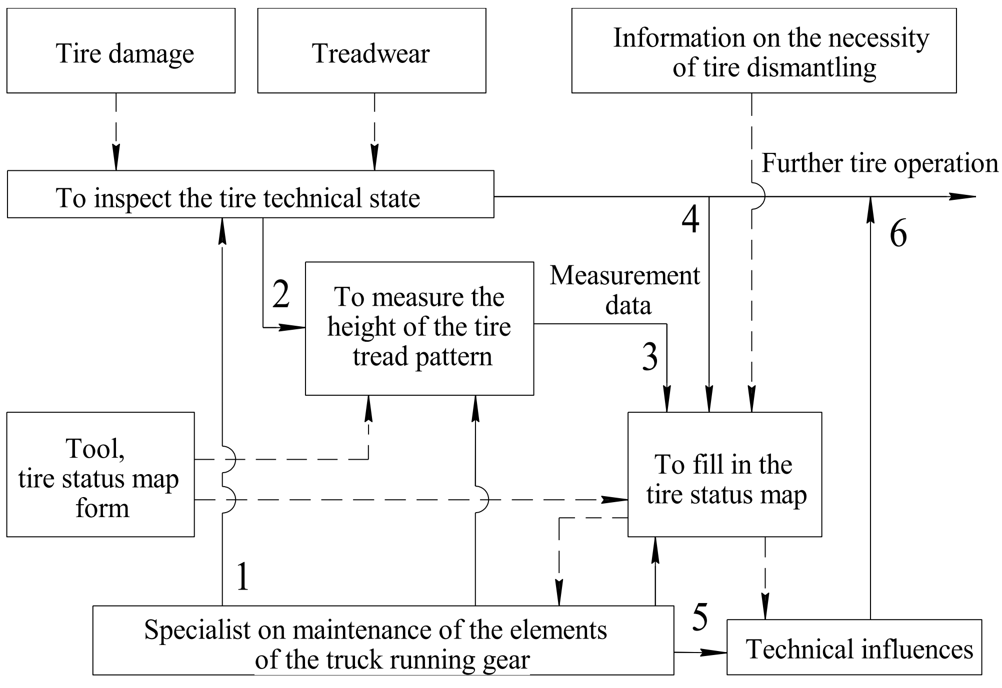


Fig. 3. Control of the technical state of the car on the basis of the information about intensity and shape of treadwear of tires

Рис. 3. Управление техническим состоянием автомобиля на основе информации об интенсивности и форме износа протектора шин

4. TIRE RESOURCE CONTROL SYSTEM

Tire resource prediction methods are discussed earlier [20] (Fig. 4) and implemented in the resource control formulated system [21] (Fig. 5, 6).

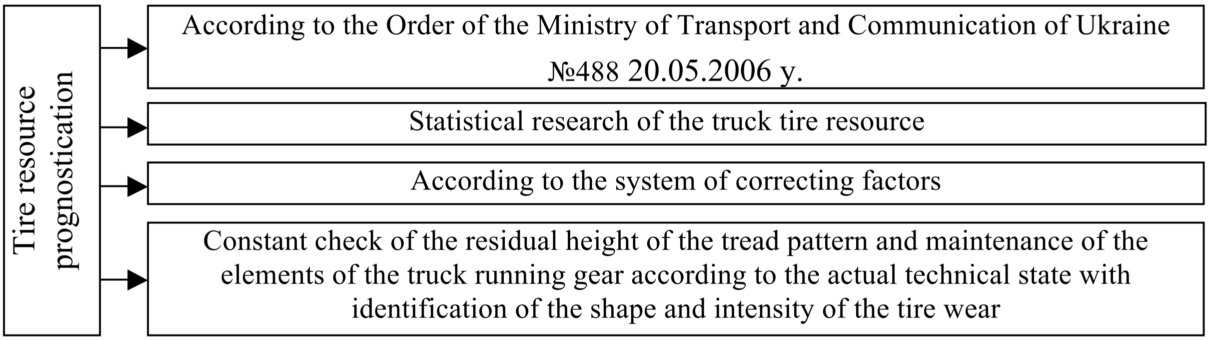


Fig. 4. Prognostication of the resource of tires of trucks
Рис. 4. Прогнозирование ресурса шин грузовых автомобилей

Forecasting and tire resource setting are interrelated tasks. The ratio of the tire resource is essentially the forecast approved by an authorized person for the specified period of time with the given probability of failure-free operation. Therefore, the principles of forecasting are in-depth and focused principles of setting [14, 20, 21], mostly based on the same performance factors for the specific car or tire. Let us consider the prediction of actual resource, as a change in the designated regulatory resource L_{norm} that is functionally determined by a number of variables that were not included in the table of the estimated coefficients, but were apparent and registered during the monitoring of the residual height of the tread pattern:

$$L = L_{norm} \cdot f(X_{qual}, X_{TSC}, X_{ts}, X_{sub}, X_{SOF}, X_{IW}, X_{CF}), \quad (3)$$

where the variable parameters take into account: X_{qual} – tire variable quality depending on the production lot, delivery terms and storage; X_{TSC} – technical state of the truck suspension as a whole; X_{ts} – quality of maintenance of the steering elements, running gear and brake system of the truck; X_{sub} – influence of the driver's subjective characteristics and maintenance personnel and transportation planning; X_{SOF} – specific operation factors; X_{IW} – change of wear intensity during the operation; X_{CF} – accidental factors.

Optimal prediction is possible with the constant monitoring of residual height of the tire tread pattern, which numerically displays all of the above factors in a complex, rather than their individual effects.

Consequently, the vehicle tire resource control provides:

a) the definition of the standard tire resource on the basis of experimental data on monitoring of the residual height of the tire tread pattern;

b) prediction of the gamma-percent tire resource on the data of the grounded selection and continuous monitoring of the process of the wear with the definition of intensity;

c) increase of tire resource by improving the system of maintenance of the running gear components according to the actual technical condition;

d) reduction in the percentage of early tire failure according to the criterion of the "damage" by excluding them from service upon reaching the critical wear area;

e) the efficient use of the tire resource due to the constant control of the residual height of the tread pattern.

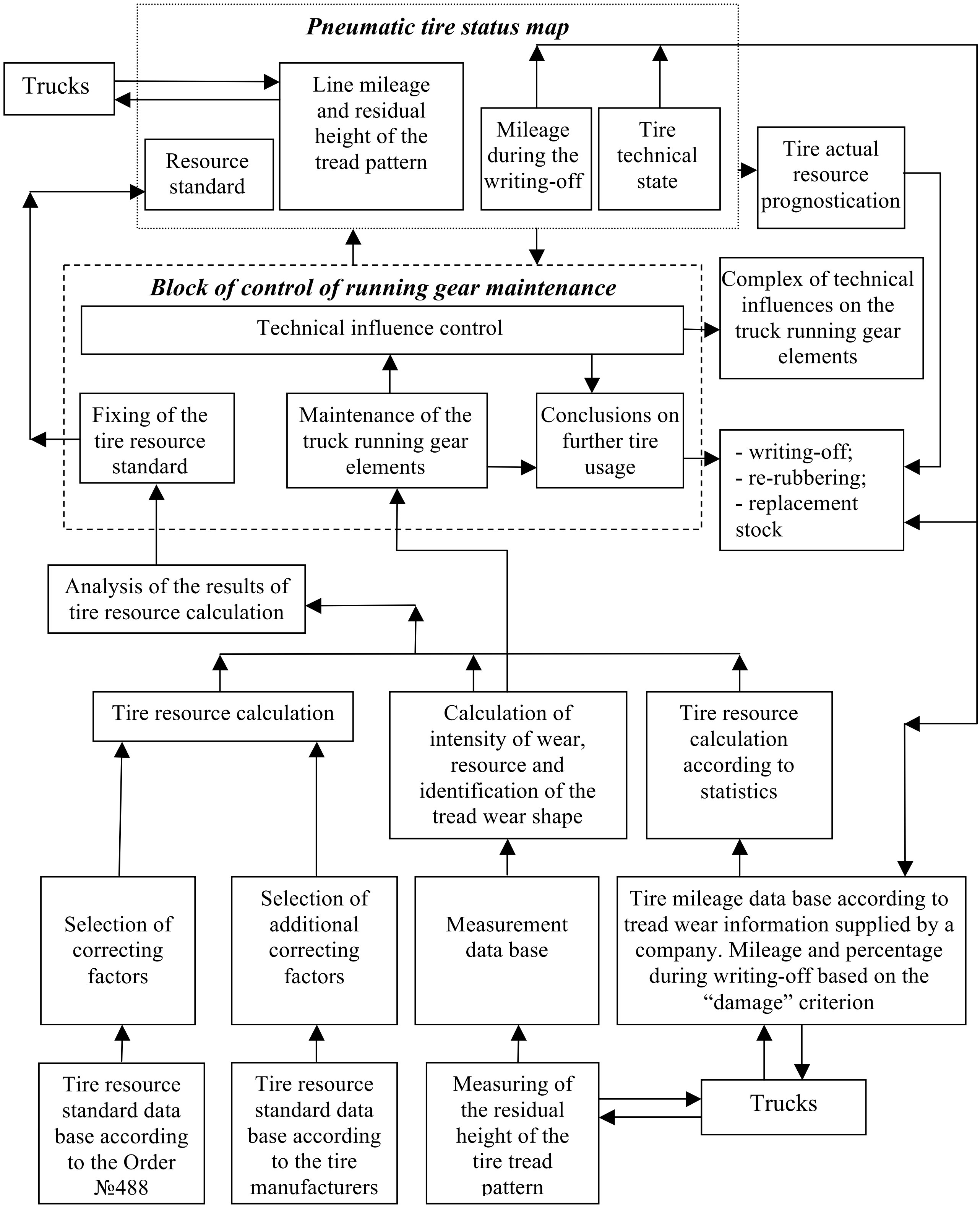
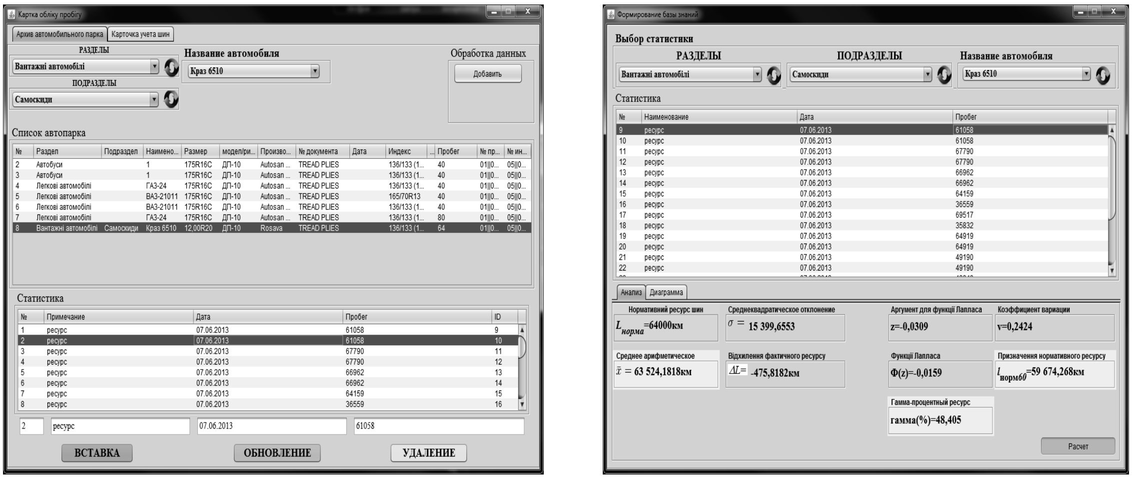


Fig. 5. Truck tire resource control system
Рис. 5. Система управления ресурсом шин грузовых автомобилей



a) b)

Fig. 6. Calculation of normative resource of tires: a – forming of statistical database resource of tires; b – with setting of g-percentile resource

Рис. 6. Расчет нормативного ресурса шин: а – формирование статистической базы данных ресурса шин; б – с назначением гамма-процентного ресурса

5. CONCLUSIONS

Developed measures of control of technical condition of tires can improve the performance of the technical operation of trucks through the optimization $\alpha_{\mathrm{T}} \rightarrow \mathrm{opt}$ due to the expected growth rate of the coefficient of technical readiness, which provides cost-effectiveness:

$$\Delta\alpha_T^{\exp} = \Delta\alpha_h^{\exp} + \Delta\alpha_{TE}^{\exp} + \Delta\alpha_t^{\exp} + \Delta\alpha_R^{\exp}, \quad (4)$$

where $\Delta\alpha_h^{\exp}$ – growth at the expense of the efficient use of the tire resource with taking into account the constant monitoring of residual height of the tread pattern ($\bar{h}$); $\Delta\alpha_{TE}^{\exp}$ – growth due to controlling of the amount of technical effects, which are determined by the proposed control for the technical condition of steering components, chassis and brake systems of trucks; $\Delta\alpha_t^{\exp}$ – an increase due to controlling of the inventory of tires by predicting their resources $\Delta\alpha_R^{\exp}$ – increase due to the tire resource control.

The developed system contributes to the solution of the objective function of the research. Tire resource control provides improved safety of the vehicles based on its rate setting and forecasting and allows planning of: a) specific consumption for their operation, and b) the norms of expenditure of spare parts and c) the cost of transportation.

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