Planning Method for the Maintenance and Repair of the Vehicle Fleet Based on the Life Cycle Contract

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Abstract. Solving the problem to improve the motor vehicles reliability is provided by the automotive industry, on the one hand, through the production of more reliable vehicles and their components and, on the other hand, by improving the methods of vehicles' technical operation. Reliability indicators arise themselves in the vehicle's operation process and depend on methods and conditions of its operation, accepted system and methods of maintenance and repair (M&R), operating modes, etc. Authors describe a long-term planning method of vehicles' M&R when concluding the life cycle contract. Data sources for such long-term planning of M&R were identified. It is proposed to use the extrapolation method based on current values of technical condition indicators for future periods, taking into account conditions and product operation modes. Constructor and manufacturer get an opportunity to analyze statistics on vehicles' faults and failures for organizational, design or technological decision-making. Proposed method helps to improve the vehicle fleet's technical state and to manage its operation.

Keywords: Maintenance and repair · Life cycle contract · Vehicle fleet

1 Introduction

With the transition to Industry 4.0, the efficiency of the system to maintain vehicles in good operating condition starts to be more and more important. At the same time, there is a certain complexity to organize such a system, because the concept of Industry 4.0 implies the manufacture of a product for an individual customer according to its specific demands, which increases an amount of product modifications. Classical approaches when the vehicles manufacturer is responsible for the entire life cycle of a product are often not enough effective due to the fact that an owner does not take responsibility for the technical state of vehicle and, thus, can break the operating conditions as well as maintenance regulations. From year to year products of automobile factories becomes more complicated both technically and programmatically,

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requires the thorough preparation at manufacturing site and in service network. Furthermore, manufacturer will be interested to create a corporate service network, which should allow to realize the principle of the responsibility for an own product during the whole life cycle [1]. That is particularly relevant for modern lorries, because in comparison to passenger cars it is practically impossible to maintain such vehicles in small vehicle repair shops. Also thanks to an own service system the full information about the operation specifications as well as maintain and repair of both a particular truck and the whole vehicle fleet is collected (Fig. 1).

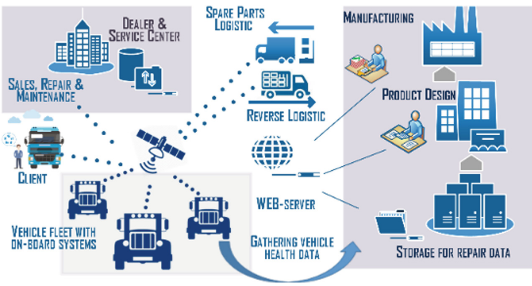

Fig. 1. Unified information environment to support a vehicle's life cycle.

One of the tools to organize an interaction between manufacturer and vehicle's owner can be a life cycle contract (LCC), which considered as an option of public-private partnership (PPP). It is a long-term agreement, under which the contractor undertakes to carry out the purchase of product and maintenance of purchase object, and the state pays for it. As a rule, such cases are related to infrastructure facilities, namely, to roads, bridges, tunnels, etc., but also such regulations are applied when purchasing vehicles for public use (subway cars, buses, etc.) or air, sea and river vessels. In our opinion, a similar partnership option can also be used for an interaction between owners of large logistics companies and vehicle manufacturer. In this situation, the contract will be concluded between two parties: owner, who buys a vehicle, and manufacturer, whose responsibilities include to keep a vehicle in a technically sound condition during its life cycle. LCC will allow to transfer the part of risks to the owner, who will be interested to implement the operating regulations and standards in order to reduce the probability of some risks.

2 Current Status of the Problem

LCC in the world practice has proven itself as a good solution in different industries types. In the Russia, a successful example of LCC is the operation of railway trains. This allows the owner to concentrate only on the monitoring of object operation parameters and on the control of specified target indicators. Thus, article authors [2] presented a life cycle model to estimate the life cycle cost of rail vehicle. The proposed model is focused on the calculation of service strategies. The scheme of LCC is widely used in the field of transport infrastructure. LCC is often realized within the scope of PPP. The development issues of PPP are analyzed in articles [2–4]. The author of the research paper [3] considers the strengths and weaknesses of PPP as well as its development prospects. In the article [4] author concludes that partnership relations could not be the most appropriate means for some types of public goods and services. Therefore, they should be applied mainly to those social problems, which require special advantages of partnership. In the article [5] the importance of interaction between partners was emphasized, without which public and private parties cannot come to a common understanding, cannot contribute to enrich the project content as well as cannot develop mutual trust. The research work [6] provides rationale reasons to attract the participation of private business in developing countries. The author identifies critical success factors and policy requirements for the successful implementation of PPP. The research results presented in the article [7] can serve as an information source on the private sector's motivation formation to participate in PPP.

The article [8] analyses a role of PPP in the transport management by using the example of car sharing. Authors of the research [9] consider pricing issues based on marginal social cost and analyse disadvantages and advantages of different PPP options. In the book [10] it is indicated that although the PPP was used to provide transport projects and services, but studies on this issue have a fragmentary nature. PPPs are complex mechanisms, which require an interdisciplinary approach to ensure their success. The article [11] analyses the success and failure factors of three large PPP projects in the transport field, namely: the concession project of toll road in Lekki (Nigeria), the toll road N4 (South Africa/Mozambique) and the port of Maputo (Mozambique). The aim of this study was to develop policy measures for the future effective implementation.

The information set out in the article [12] shows that the use of a LCC model in the framework of supply and maintenance contracts for public transport fleet allows to provide the city with vehicle of new generation with increased comfort and safety, to obtain additional reliability guarantees and travel schedule adherence, to keep consumer performance of vehicle during the whole operation period. The project success will depend on how well the risks are understood and to what extent the problem of sharing responsibility for them is solved. The works [13–15] considered the nature of risk transfer in PPP, since it is associated with large financial resources and long contract duration. The article [16] defines management approaches, which help or hinder the harmonization of private sector participation in urban infrastructure projects to increase the urban environment sustainability. The possibility to implement LCC in the automotive industry, when planning of motor vehicles' M&R, should be studied based on the experience in other areas: in rail transportation, in road construction and other infrastructure projects.

3 Hypotheses and Methods

3.1 Risk Classification

The operation stage includes two components: commercial operation (the transportation processes realization) and technical operation (operating capacity maintenance). These two directions are inextricably linked: commercial operation is provided by high-quality technical operation. In the LCC context, this approach shares risk management responsibility between owner, which is responsible for commercial operation, and manufacturer, which will be responsible for technical operation. Thus, each of the parties controls the respective risks types (Fig. 2). At the same time, it is necessary to take into account the possible risks associated with functioning the vehicle service system. The reason is so that manufacturer invests funds to create such a system and main goal is to reach its optimal functioning mode. On the other hand, the vehicle's branded service system is characterized by unsteady demand. Therefore, parameters of technological process are stochastic, which causes additional risks generated by the unsteadiness of demand, and results unbalanced load equipment and personnel loading [17–19].

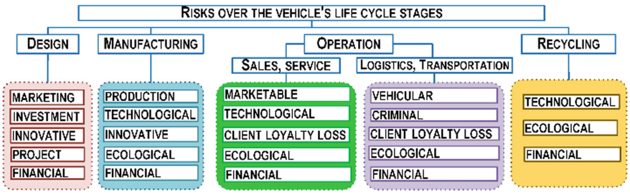

Fig. 2. Risk classification in the automotive industry.

It is important to understand that all risks types are related in a varying degree to each other and the appearance of one risk type can have a negative impact on the work of all subsystems associated with it. Technical risks can be defined as probability of loss due to: (1) negative research results; (2) failure to achieve the planned technical parameters during design and technological development; (3) low production technological capabilities, which does not allow to apply the results of new developments; (4) side effects or delayed problems when using new technologies and products; (5) failures and equipment breakdown, etc. Technical risk is attributed to the group of internal risks, because these risks can be directly influenced by enterprise as well as their occurrence, as a rule, depends on the production activity of enterprise.

3.2 Hypotheses and Approaches in the Development of Methods

The long-term planning methods of vehicles' M&R is necessary to make possible to form a plan-schedule of vehicles' M&R for the specified period. It gives an opportunity to predict and to estimate the possible volumes of work associated with types of services based on the predicted technical condition of fleet and possible risks. From the methodological point of view, the long-term planning for the vehicles' M&R is similar to the prediction of vehicles' technical condition. That is why the list of data sources is in many ways similar: (1) long-term fleet operation plans to determine the fleet's type and age structure as well as to cluster it into groups, taking into account future expansion and renewal; (2) current values of indicators concerning operating time of vehicles' samples and their component parts; (3) resource associated with operating time till a certain technical impact; (4) planned operating time for a certain period, established by the vehicles manufacturer based on the reference operation group; (5) coefficient presenting the intensity of the operating time when used in other of operation groups; (6) seasonal factors affecting the operation intensity; (7) probability to provide unplanned technical impacts on vehicles; (8) data from on-board diagnostic systems (if available).

The current values of operating time for vehicles and their components will be entered into the system, providing information support for M&R processes. Data input will be done by using specialized tools either manually, taking into account the readings from the on-board diagnostic systems, or automatically, on the basis of integration with the objective control system. Planned operating time for a certain period is determined by the vehicles manufacturer based on the statistical data for each reference operation group and is indicated in the corresponding design and technological documentation. The coefficients presenting the growth intensity of operating time when using vehicles of other operation groups, seasonal coefficients as well as probability values of the unplanned technical impacts implementation are normative-reference information with an economic nature. The legal framework and regulations to conduct these data sources must be developed and approved by contractor and customer, who sign agreement to support the vehicles life cycle maintenance, in accordance with the state laws.

4 Results and Discussion

4.1 Method for the Long-Term Planning of Motor Vehicles' M&R

To carry out the long-term planning of motor vehicles' M&R, it is proposed to use the method to extrapolate current values of the technical condition indicators for future periods, taking into account influential factors, such as conditions and modes of vehicle operation. To improve the efficiency of such planning, it is necessary to remember that different units, components and systems of a motor vehicle have different resources and different degrees of reliability, which depend usually on many factors with stochastic nature. The prediction of failures allows to predetermine possible problems and to make the well-timed replacement of unreliable elements.

A failure of motor vehicle occurs at the point of time T, which can be predicted with a certain probability. As the performance analysis shows, the failure rate of vehicle $\lambda(t)$ is divided into three operational phases: (1) the first phase is connected with a decrease of failure rate and known as early failures; (2) the second stage is characterized by a constant failure rate, known as random failures; (3) the third phase, also known as wear-out failures, is an increase of failure rate. During the period of running-in, an enhanced intensity of failures is observed. It is connected directly with the process of components running-in and caused usually by manufacturing defects. During the regular operation, failures have a random nature and appear unexpectedly. In the first instance, it is connected with the noncompliance with operating conditions, load changes, impacts of negative external factors, etc. The third period is characterized by a failure rate increase, which is caused by aging and other reasons related to long-term operation. Depending on the mileage from when the vehicle's operation starts, not only the number of failures goes up, but also both the labor costs to eliminate them and the costs associated with keeping vehicles in working condition increase. At the same time, there is a decrease in the technical availability as well as annual runs and performance of vehicles are reduced. The long-term forecasts should be carried out taking into account the type and age structure of vehicle fleet as well as statistical information about failures. Therefore, service and spare parts planning mechanisms will vary.

For parts, units, components and their elements there are three main types of failure reasons, which are corresponding to a specific period of operation: (1) latent manufacturing defects; (2) overload, external effects; (3) wear, aging, consumption. The long-term planning method on M&R of vehicles as well as their components can be divided into stages corresponding to the reliability curve. For the initial stage of vehicle operation, it is necessary to create a reserve of spare parts. Such reserve should include components, which are most susceptible to failures during the running-in period. In this regard the automotive company establishes a warranty period. For the second stage (regular operation), failures depend strongly on the operating conditions, they have a stochastic nature and, therefore, the forecast of the demand for spare parts is based on the dependencies established by using the analyze of statistical information. At the third stage, the service strategy is realized taking into account the type and age structure of vehicle fleet as well as reliability indicators. This strategy must consider the resource for a specific group of vehicles operated in specific conditions. It is necessary to pay attention on the expediency to continue a vehicle operation keeping in mind the cost of its repairs (both the labour intensity and the cost of spare parts). The most effective method to increase the vehicles operational reliability is the prediction of its technical state, i.e. failures for a certain time as well as their prevention through planning service time, spare parts supply according to the required specification and quantity taking into account operating conditions, climatic conditions in a particular region; year time; type, model and vehicle configuration.

The failure rate indicator is used in the problems of vehicle failure prediction. This indicator is connected with the reliability function *P(T)* by the following formula:

$$\lambda(t) = -P'(t)/P(t). \tag{1}$$

The statistical estimate $\breve{\lambda}(t)$ for failure rates can be calculated in the following way:

$$\breve{\lambda}(t) = \frac{n(t + \Delta t/2) - n(t - \Delta t/2)}{[N - n(t)\Delta t]}. \tag{2}$$

The time interval Δt is chosen so that it contains a sufficient number of values t_k and is sufficiently small in comparison with the total duration of tests or observations. To meet these conflicting requirements, it is necessary to have large-scale samples. If the end of a running-in is taken as the start of objects operation and the limit state is the point of time when the period of regular operation ends, then during the operation time, it can be considered $\lambda = const$, which corresponds to the direct part of the reliability curve. The following formula is got as a result:

$$P(t) = \exp[-\lambda t]. \quad (3)$$

The mathematical expectation of the service life (resource) is equal to $1/\lambda$, so the formula can be written as:

$$P(t) = \exp(-t/t_c), \quad (4)$$

where $t_c = E[T]$ – mathematical expectation of the service life.

An example of the operation process will be considered: vehicle unit is operated before failure, then it replaces with new one from the same reserve lot, then the replaced unit is being brought to failure and is changed by the third one, and so on. It is assumed that the length of time to replace one object with another one is small compared to the duration between consecutive failures. The process is described by using the sequence of t_1, t_2, … moments of failure. Since a time between failures is a random value, this sequence is a stream of random events. Addition to the unit of the time distribution function between neighboring events coincides with the probability of failure-free operation *P(t)*. If this probability does not depend on the number of events in the stream, it means that this stream is stationary, recurrent, and Markov one. If the reliability function *P(t)* has the form (3), then the stream of random events is Poisson one. The probability of occurrence to failure *k* on the interval [0, t] follows the Poisson law:

$$Q_k(t) = \frac{(\lambda t)^k}{k!} \exp[1 - \lambda t], \quad (5)$$

where $k = (0, 1, \ldots)$.

Having a data on residual resources t_{res} calculated on the basis of the probability of failures *P(t)*, it is possible to determine the probable failure date for any unit:

$$T_{failure} = T_b + t_{res} \quad (6)$$

where T_b – date when starting the prevention of the predicted failure.

The long-term planning method of M&R, which is proposed to implement in the system, suggests few options: more rigorous approach to planning, when technical impacts on a vehicle and its component parts are planned within certain periods, but has an advisory nature, or softer approach, when technical impacts on vehicle and its components are planned only if it is necessary, i.e. work on the technical condition is carried out. The current value of operating time indicator (amount of km run) is transmitted from the vehicle's on-board system or its remote control system. This value is calculated as follows:

$$B'_{ijk} = R_{ik} - \Delta A_{ij} * C_j, \quad if\, A_{ij} = 0, \quad (7)$$

or:

$$B'_{ijk} = B_{ijk} - \Delta A_{ij} * C_j, \quad if\, A_{ij} \neq 0. \tag{8}$$

where: B'_{ijk} – current value of the operating time indicator i by item j, remaining (without taking into account correction coefficients) until a certain type of regulatory technical impacts k; R_{ik} – manufacturer's regulated value of the operating time indicator i for a certain type of regulatory technical impacts k; $\Delta A_{ij} = A'_{ij} - A_{ij}$ – difference between current and previous values of the operating time indicator i by item j; A'_{ij} – current (actual) value of the operating time indicator i by item j; A_{ij} – previous value of operating time indicator i by item j; C_j – cumulative correction coefficient by item j, showing the intensity of operation; B_{ijk} – calculated value of the operating time indicator i by item j, till a certain type of regulatory technical impacts k.

Calculation of the predicted value of the operating time indicator i by item j until a certain type of regulatory technical impacts k during the planned period l:

$$D_{ijkl} = B'_{ijk} - P_{ijl} * C_j. \tag{9}$$

The obtained value D_{ijkl} is analyzed if

$$D_{ijkl} \leq F_{ijk}, \tag{10}$$

where P_{ijl} – planned increase in the operating time indicator i by item j in period l; F_{ijk} – threshold value of the operating time indicator i by item j for a certain type of regulatory technical impacts k.

The threshold value of the operating time shows the allowable service interval, which is set by the manufacturer in the service book. For example, for KAMAZ vehicles of environmental level EURO-2 for *TO-15000* (by km run) this value is 15,000 km, i.e., it is allowed to perform maintenance in the interval from 13,500 to 16,500 km.

As a result, the following will be determined: period l, for which maintenance is planned; forecast indicator of operating time in a certain period D_{ijkl}.

$$D_{ijkl+1} = D_{ijkl} - P_{ijl+1} * C_j. \tag{11}$$

Proposed method works separately and simultaneously: for each sample of vehicle or its component; for each operating time indicator; for each group of types of technical impacts (i.e., if the conduction of one impact excludes another one, it becomes possible only after reaching the next milestone of operating time).

4.2 Exemplary Calculation of Warranty Costs

To guarantee risk's operational assessment, the functional dependence of the risk value on the warranty time and the amount of deductions to the guarantee fund of the enterprise in % of the vehicle value are determined. Data on faults of KAMAZ vehicles operated in 28 countries are used. Since in each country vehicles are purchased in lots for a certain type of work (construction, agriculture, utilities, etc.), and the organization and quality of services are homogeneous throughout the country as a whole, these values were used as the warranty service's cost.

$$P = 7{,}4 \cdot 10^{-12} \cdot t^2 + 0{,}76 \cdot C_{\%}^2 - 4{,}6 \cdot 10^{-7} \cdot C_{\%} \cdot t - 1{,}78 \cdot C_{\%} + 3{,}8 \cdot 10^{-7} \cdot t + 1, \quad (12)$$

where t – operating time indicator, km; $C_{\%}$ – deductions to the enterprise's guarantee fund.

The analysis of statistical data in the STATICTICA package allowed to identify units and components of motor vehicles, which have the largest number of failures (Table 1). The relative number of failures is presented in Table 2. To determine the cost of replacing a part, its price was taken into account, the complexity of eliminating the failure and the mileage, at which the failure occurred (Table 3). The electrical equipment system was chosen as the object of study (Figs. 3 and 4).

Table 1. Statistics of the most common failures.

Units and components of vehicles	*Absolute value **Reduced value	RUN, 1,000 km							
		0–10	10–20	20–30	30–40	40–50	50–60	60–70	70–85
		Number of failures							
Engine	*	132	115	112	86	75	52	26	22
	**	0.22	0.17	0.16	0.15	0.10	0.20	0.09	0.07
Transmission	*	90	58	42	37	21	19	14	9
	**	0.31	0.18	0.15	0.14	0.13	0.12	0.10	0.07
Electrical equipment and appliances	*	116	102	95	83	57	38	24	15
	**	0.22	0.21	0.20	0.17	0.14	0.13	0.10	0.06
Engine clutch	*	52	34	29	25	19	15	12	9
	**	0.27	0.20	0.19	0.17	0.14	0.13	0.12	0.07

Table 2. The relative number of failures by units and components in 2014.

Name of unit/component	Total number of failures	% failures on sold vehicles number
Electrical equipment	530	35.3
Engine	610	40.6
Transmission	290	19.3
Engine clutch	195	13

Table 3. Distribution of costs and labour intensity referring to the run of the electrical system.

Run, km	Costs of spare parts, %	Labour intensity to eliminate a fault, %
0–1,500	42.2	37.7
1,500–2,500	39.3	35
2,500–5,500	35	24.6
5,500–9,500	27	21.1
9,500–12,500	24.7	19
12,500–14,500	17	17
14,500–20,500	19	15.9
20,500–26,500	15.9	14.3
26,500–35,500	14.1	12.8
35,500–48,000	12.5	11.6
48,000–68,000	11	10.7
68,000–72,500	9.8	10.5
72,500–75,500	6.5	9.6
80,000	3.2	5.4

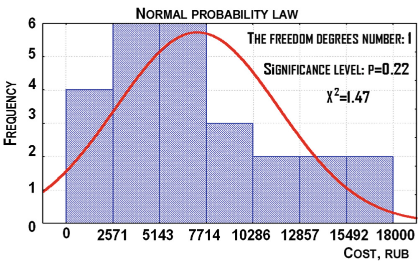

Fig. 3. Distribution frequency of the cost of warranty repairs with an operating time indicator of 70 thousand km.

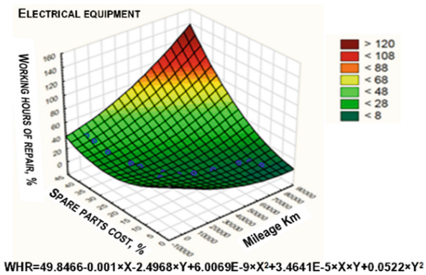

Fig. 4. Surface costs for replacing faulty electrical equipment during the break-in period.

5 Conclusion

The proposed method of long-term planning of M&R will prevent the failures occurrence in the period before the scheduled maintenance. According to the developed methodology, the maintenance is shifted to the failure limit. Each of the service process participants will promptly receive the required information. The operating organization will be able to assess condition and resource of each vehicle, the service center will have access to the repair documentation during M&R, the manufacturer will be able to collect repair statistics, to make an organizational, design or technological solution, namely: a design change, or claims to the supplier of the purchased component. This mechanism makes possible to identify the factors contributing to a decrease in the value of the technical readiness coefficient as well as to influence on these factors with the aim to achieve an increase in the coefficient to the required level.

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