VOJNOTEHNIČKI GLASNIK / MILITARY TECHNICAL COURIER, 2024, Vol. 72, Issue 4

Determination of a model of preventive maintenance of special purpose vehicles

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doi https://doi.org/10.5937/vojtehg72-50491

FIELD: mechanical engineering
ARTICLE TYPE: original scientific paper

Abstract:

Introduction/purpose: The aim of this paper is to obtain quantitative and qualitative indicators of vehicle condition and reliability based on operational data which can be used to determine the optimal periodicity of preventive maintenance for special purpose vehicles, and to more accurately manage the maintenance process and the operational readiness of these vehicles.

Methods: Based on operational failure data and statistical methods, a mathematical model of the reliability of special purpose vehicles was determined. Using this model and operational data, the periodicity of preventive maintenance for the vehicles was determined through multi-criteria optimization, considering both readiness and minimum maintenance costs. The same methodology was applied to determine the optimal preventive maintenance periodicity for 15 components of the mechanical system of special purpose vehicles. A group analysis was conducted using Minitab 15 statistical software, based on the theory of similarity in preventive maintenance periodicity for the 15 components, and a statistical analysis of the conducted research was performed using Minitab 16 statistical software.

Results: Models for preventive maintenance of special purpose vehicles were developed based on the recorded vehicle failures and the failures of *fifteen vital components. A group analysis grouped the fifteen components into optimal maintenance groups, similar in terms of working time between failures. The statistical analysis of the research determined a functional relationship for the optimal periodicity of preventive maintenance for special purpose vehicles.*

Conclusion: The maintenance periodicity obtained through multi-criteria analysis is optimal, as it achieves satisfactory vehicle readiness with optimal maintenance costs. The statistical analysis of the research concluded that the maintenance periodicities of the vehicle components are different. In both fleets, the engine and the transmission block have the longest maintenance intervals. The research results can be used to rationalize the existing preventive maintenance concept.

Key words: vehicle, reliability, availability, preventive maintenance, costs, optimal periodicity, multi-criteria analysis.

Introduction

Special purpose vehicles are the most common combat armored vehicles in the Serbian Armed Forces. They are used for general, special, and specific tasks, and are thus exposed to various workloads. Therefore, vehicles, their components, subassemblies, assemblies, and aggregates are exposed to constant environmental influences and disturbances that occur in processes of state changes, resulting in failures of various kinds. Such changes necessitate vehicle maintenance as a system, which should have a required relationship of permissible deviations from its prescribed technical and operational capabilities. The key question in maintaining special purpose vehicles is primarily to avoid the consequences of failures and to return the vehicle to a defined operational state. To achieve this, it is necessary to minimize failures to an acceptable level and, if possible, prevent their occurrence entirely by implementing preventive maintenance procedures at appropriate intervals.

Given all of the above, the aim of this study is to determine, based on vehicle operation data, the quantitative and qualitative indicators of vehicle condition and reliability. These indicators are used to establish the optimal periodicity for preventive maintenance of special purpose vehicles.

Methodology

The subject of this research refers to the vehicles from two technical parks, the A fleet/park and the B fleet/park. Each fleet has 20 special purpose vehicles (referred to as the vehicles in the following text). The vehicles from both fleets were used and stored under different operational and storage conditions. The data on operating times until failure were collected over a period of two years. During this period, the fleet of the A park had 269 failures, and the fleet of the B park had 279 failures. The mentioned failures, in both fleets of these vehicles, related to 29 vital components.

One of the basic prerequisites for optimizing the vehicle maintenance system and predicting its future behavior is finding a mathematical model that can represent the behavior of vehicles in terms of fault occurrence. If it is possible to determine the reliability distribution law, it is possible to determine all reliability parameters (reliability, unreliability, failure rate, failure density, time to failure). Therefore, based on the recorded failures, a reliability model of vehicles in the two fleets in question was determined.

After grouping failures by intervals of operating times until failure, an assessment was performed of the following reliability indicators: reliability function, unreliability function, failure density distribution function, and failure rate function (Ćatić, 2005, pp.157-232; Biočanin & Pavlović, 2011, pp.106-113; Biočanin & Timotijević, 2020, pp.1-6; Biočanin & Timotijević, 2021, pp.474-480; British Standards Institution, 2024). Based on the obtained data, theoretical distributions that best approximate empirical distributions were selected. The approximation of empirical distributions was done using the theoretical Weibull, exponential, Rayleigh, and normal distributions. The concordance of empirical and theoretical distributions was assessed using Kolmogorov-Smirnov, Pearson, and Romanovsky tests (Ćatić, 2005, pp.157-232; Biočanin & Pavlović, 2011, pp.106-113; Biočanin & Timotijević, 2020, pp.1-6; Biočanin & Timotijević, 2021, pp.474-480; British Standards Institution, 2024; Krstić et al, 2013). Based on the test results, for both vehicle fleets, the Weibull two-parameter distribution was adopted for the reliability model, confirming the universality of the Weibull two-parameter distribution in determining the reliability of complex technical systems.

The optimal maintenance interval for the vehicles was determined based on the criterion of maximum readiness and the criterion of minimum costs. The preventive maintenance interval obtained based on the criterion of maximum readiness, where the highest allowable costs are the constraint, is shorter than the interval obtained based on the criterion of minimum costs, where the minimum level of readiness is the constraint. This means that preventive maintenance according to the maximum readiness model needs to be performed more frequently, leading to higher maintenance costs. Preventive maintenance according to the minimum costs model is performed less frequently, but the vehicle readiness is unsatisfactory. Therefore, the preventive maintenance interval for the vehicles was determined by a compromise solution that considers both criteria. The maintenance interval obtained in this way is optimal because it achieves satisfactory vehicle availability with optimal maintenance costs.

Following this, the maintenance interval for the vehicle components was determined by a compromise solution, i.e., one of the methods of multi-criteria optimization.

A statistical analysis of the functional relationship of the maintenance periodicity of the vehicle components was performed.

In order to further optimize and manage preventive maintenance processes more precisely based on the determined optimal maintenance intervals for components, a group analysis of the obtained maintenance intervals was performed using Minitab 15 statistical software, which resulted in optimal grouping of local maintenance intervals for multiple components into a single common interval. This yielded another model for preventive maintenance of vehicles.

Results

The periodicity of preventive maintenance for specialized vehicles

According to the established methodology (Ćatić, 2005, pp.158-232; British Standards Institution, 2024; Biočanin & Timotijević, 2021; Biočanin Pavlović, 2011, pp.106-130), based on the systematized data on the vehicle failures from the A fleet and the B fleet, a reliability model of the vehicles from both fleets was determined. Then, the optimal maintenance periodicity for the vehicles was determined based on the criterion of maximum availability (Krstić, 2009, p.488), the criterion of minimum costs (Krstić, 2009, p.488), and a compromise solution (Bass & Kwakernaak, 1977, pp.47-58; Vincke, 1992.; Paul Yoon & Hwang, 1995; Pavličić, 2000, pp.109-122; Vargas, 1990; Biočanin & Timotijević, 2021; Biočanin & Pavlović, 2011, pp.106-130; Biočanin & Timotijević, 2023, pp.1084-1092), which provides satisfactory availability of the vehicles with the optimal maintenance costs.

a) The reliability model of the vehicles from the A fleet

In order to determine a theoretical distribution model that could be used to approximate the empirical distribution, an approximation of the empirical distribution was made using the theoretical Weibull, exponential, Rayleigh, and normal distributions. The agreement between the empirical and theoretical distributions was evaluated using the Kolmogorov-Smirnov test, Pearson's test, and the Romanovsky test. Statistical data processing was performed using the Statistics Toolbox for use with MATLAB.

Utilizing non-parametric testing of hypothetical distribution models, the quantitative indicators of deviation of theoretical models from the empirical distribution are obtained. The calculated deviations can be used not only to confirm whether the theoretical model satisfies a certain significance level test, but also to adopt the theoretical model for which all or the majority of deviations are the smallest (Ćatić, 2005, pp.158-232). The reliability function of the vehicles from the A fleet according to (Biočanin & Timotijević, 2021) is as follows:

$$R(t) = e^{-\left(\frac{t}{\eta_{wa}}\right)^{\beta_{wa}}} = e^{-\left(\frac{t}{331.3992}\right)^{2.4993}} \quad (1)$$

where:

- R is the reliability function,
- β_{wa} is the shape parameter for the A fleet,
- η_{wa} is the scale parameter for the A fleet, and
- t is time.

b) The reliability model of the vehicles from the B fleet

According to the same methodology, a reliability model for the vehicles in the B park was determined (Table 1).

Based on the obtained data, the Weibull two-parameter distribution has been adopted as the approximate reliability model with a scale parameter ηwb = 385.7522 and a shape parameter βwb = 2.8800. The reliability function for the special purpose vehicles from the B park is as follows:

$$R(t) = e^{-\left(\frac{t}{\eta_{wb}}\right)^{\beta_{wb}}} = e^{-\left(\frac{t}{385.7522}\right)^{2.8800}} \quad (2)$$

where:

- R is the reliability function,
- β_{wb} is the shape parameter for the B fleet,
- η_{wb} is the scale parameter for the B fleet, and
- t is time.

Table 1 – Distribution models for the B fleet

Distribution	Kolmogorov-Smirnov test			Pearson's test			Romanovsky test			Note
	PA	T	Z/N	PA	T	Z/N	PA	T	Z/N	
Weibull	0.0401	0.0641	Z	0.0103	12.592	Z	1.7291	3	Z	Adopted distribution
Exponential	0.3013	0.0641	N	0.5531	14.067	Z	1.7230	3	Z	
Rayleigh	0.1345	0.0641	N	0.1358	14.067	Z	1.8345	3	Z	
Normal	0.0538	0.0641	Z	0.0146	12.592	Z	1.7278	3	Z	
The reliability function for the vehicles in the B fleet			$R(t) = e^{-\left(\frac{t}{\eta_{wb}}\right)^{\beta_{wb}}} = e^{-\left(\frac{t}{385.9522}\right)^{2.8800}}$							

Determination of the periodicity of preventive maintenance of the vehicles using the maximum avialibility criterion

By varying the periodicity of the time between preventive maintenance, a functional dependence of availability on maintenance periodicity is obtained, based on which the maintenance periodicity that provides maximum readiness can be determined.

The value of operational readiness (Krstić, 2009, p.488) is as follows:

$$G(t) = \frac{t_r + t_{hr}}{t_r + t_{hr} + t_p + \frac{F(t)}{R(t)} \cdot t_k} \qquad (3)$$

where:

- *G(t)* is the operational readiness,
- t_r is the operating time,
- t_{hr} is the waiting time for operation availability,
- t_p is the preventive maintenance time,
- *F(t)* is the unreliability function, and
- t_k is the corrective maintenance time.

a) A fleet

The results of determining availability for different maintenance periodicities in the A fleet are given in Table 2.

In Figure 1, a graphical representation of the dependence of readiness on the periodicity of preventive maintenance of the vehicles in the A fleet is given (Krstić et al, 2013).

According to (Biočanin & Timotijević, 2021), based on Figure 5, it can be concluded that the maximum readiness of the vehicles from the A fleet (G_{max}=0.9940) is achieved for a maintenance periodicity of t_r =113 hours of work [h], because for this maintenance periodicity, the function $G(t_r)$ reaches its maximum.

Table 2 – Results of determining the availability for different maintenance periodicities in the A fleet

Maintenance periodicity [h]	50	100	150	200	250	300	350	400	450	500
t_r [h]	50	100	150	200	250	300	350	400	450	500
t_p [h]	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
t_k [h]	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
F(t)	0.0088	0.0488	0.1288	0.2465	0.3900	0.5415	0.6822	0.7982	0.8833	0.9389
R(t)	0.9912	0.9512	0.8712	0.7535	0.6100	0.4585	0.3178	0.2018	0.1167	0.0611
t_{hr} [h]	1.150	2.300	3.450	4.600	5.750	6.900	8.050	9.200	10.350	11.500
G(t)	0.9910	0.9939	0.9935	0.9918	0.9888	0.9841	0.9763	0.9632	0.93985	0.8959

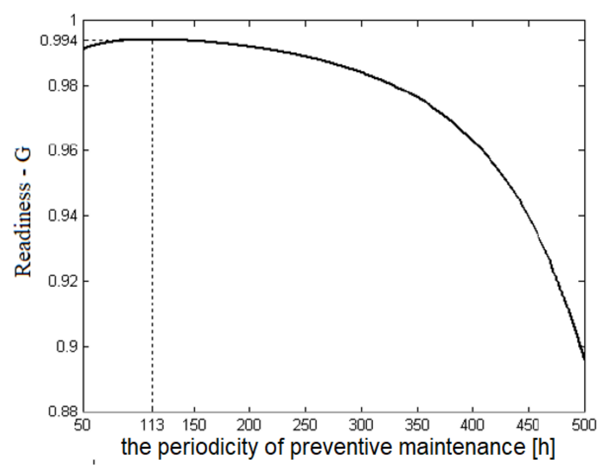

Figure 1 – Dependency of readiness on the periodicity of preventive maintenance of the special purpose vehicles in the A fleet

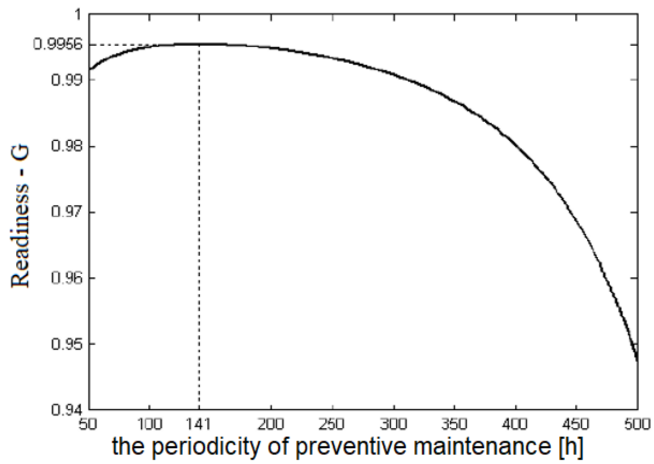

Figure 2 – Dependency of readiness on the periodicity of preventive maintenance of the special purpose vehicles in the B fleet

b) B fleet

Using the same methodology as for the A fleet, the optimal maintenance periodicity for the vehicles in the B fleet has been determined. Table 3 shows the results of the availability determination for different maintenance frequencies in the B fleet.

Table 3 – Results of determining the availability for different maintenance periodicities in the B fleet

Maintenance periodicity [h]	50	100	150	200	250	300	350	400	450	500
t_r [h]	50	100	150	200	250	300	350	400	450	500
t_p [h]	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
t_k [h]	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
F(t)	0.0028	0.0203	0.0637	0.1400	0.2493	0.3842	0.5303	0.6705	0.7895	0.8789
R(t)	0.9972	0.9797	0.9363	0.8600	0.7507	0.6158	0.4697	0.3295	0.2105	0.1211
t_{hr} [h]	1.150	2.300	3.450	4.600	5.750	6.900	8.050	9.200	10.350	11.500
G(t)	0.9915	0.9950	0.99554	0.9948	0.9934	0.9909	0.9868	0.9802	0.9688	0.9476

Based on Figure 2, it can be concluded that the maximum readiness of the vehicles from the B fleet (G_{max} = 0.9956) is achieved for a maintenance periodicity of t_r = 141 h.

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Determination of the periodicity of preventive maintenance of vehicles using the minimum cost criterion

This model determines the optimal interval for the periodic implementation of preventive maintenance procedures for vehicles, which minimizes costs while ensuring the required availability and readiness.

Maintenance costs can be expressed as (Krstić, 2009, p.488; Krstić et al, 2013):

$$C(t) = \frac{C_k - (C_k - C_p) \cdot R(t)}{R(t)dt} \quad (4)$$

where:

- $C(t)$ is maintenance costs,
- C_k is corrective maintenance costs, and
- C_p is preventive maintenance costs.

a) A fleet

By applying the given expression for maintenance costs, for different periodicities of preventive maintenance of special purpose vehicles, the maintenance cost values for the vehicles in the A fleet were obtained, as shown in Table 4.

Table 4 – Maintenance costs for different maintenance periodicities of the vehicles in the A fleet

Maintenance periodicity [h]	50	100	150	200	250	300	350	400	450	500
C_k [mu]	35000	35000	35000	35000	35000	35000	35000	35000	35000	35000
C_p [mu]	7000	7000	7000	7000	7000	7000	7000	7000	7000	7000
$R(t)$	0.9912	0.9512	0.8712	0.7535	0.6100	0.4585	0.3178	0.2018	0.1167	0.0611
$\int_0^t R(t)dt$	49.87	98.590	144.31	185.07	219.23	245.93	265.26	278.13	285.96	290.30
$C(t)$ [mu]	145.30	84.86	73.49	75.11	81.74	90.11	98.39	105.52	110.,96	114.67

Note: The abbreviation "mu" in Table 4 reffers to a "monetary unit".

The data on preventive maintenance costs (C_p) and corrective maintenance costs (C_k) are taken from the accounting documentation of the authorized maintenance workshop.

Table 2 shows that the minimum maintenance costs for the vehicles in the A fleet are achieved for a preventive maintenance periodicity of 100 to 200 h. By discretizing the maintenance periodicity interval from 50 to 500 with a step of 1, the minimum total specific costs and the maintenance periodicity for minimum total specific costs are calculated.

Figure 3 provides a graphical representation of the dependence of total specific costs on the periodicity of preventive maintenance of vehicles.

According to (Krstić et al, 2013) and Figure 3, the optimal maintenance periodicity is 163 h.

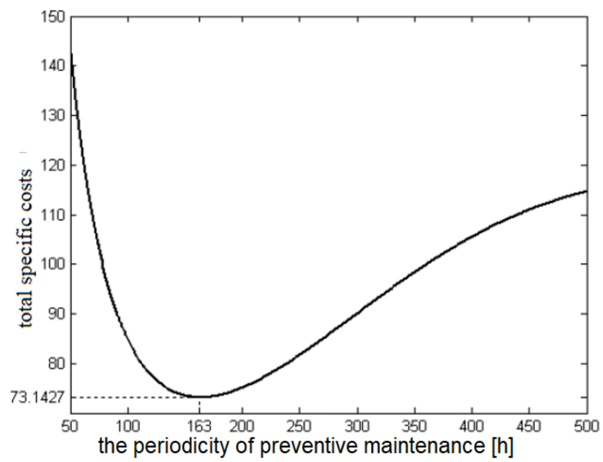

Figure 3 – Dependency of total specific costs on the periodicity of preventive maintenance of the special purpose vehicles in the A fleet

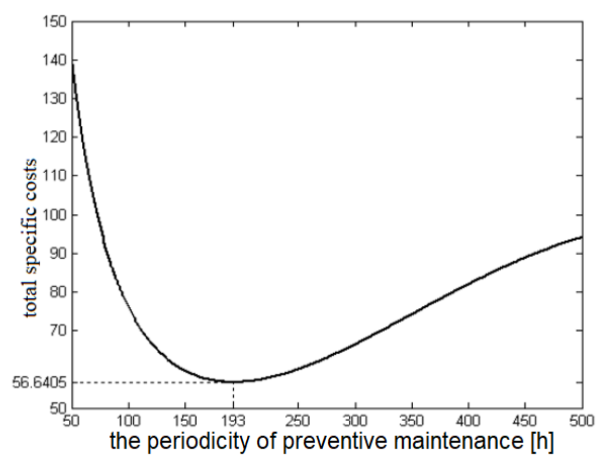

Figure 4 – Dependency of total specific costs on the periodicity of preventive maintenance of the special purpose vehicles in the B fleet

b) B fleet

Using the same methodology as for the A fleet, the maintenance costs (Table 5) and the optimal maintenance periodicity for the vehicles in the B fleet were determined (Figure 4). Based on Figure 4, it can be concluded that the minimum costs (C_{min}=56.6405 [mu]) are achieved for a maintenance periodicity of the vehicles from the B fleet of t_r = 193 h.

Table 5 – Maintenance costs for different maintenance periodicities of the vehicles in the B fleet

Maintenance periodicity [h]	50	100	150	200	250	300	350	400	450	500
C_k [mu]	35000	35000	35000	35000	35000	35000	35000	35000	35000	35000
C_p [mu]	7000	7000	7000	7000	7000	7000	7000	7000	7000	7000
$R(t)$	0.9972	0.9797	0.9363	0.8600	0.7507	0.6158	0.4697	0.3295	0.2105	0.1211
$\int_0^t R(t)dt$	49.964	99.475	147.50	192.55	232.94	267.19	294.34	314.26	327.64	335.80
C_t [mu]	141.658	76.077	59.555	56.709	60.015	66.456	74.230	82.012	88.835	94.126

Determination of the optimal periodicity of preventive maintenance of vehicles using multi-criteria optimization

For solving this task, a multi-criteria optimization method known in the literature as MCDM (Multi Criteria Decision Making) was applied. One of the methods of multi-criteria optimization used in the paper is the Analytic Hierarchy Process (AHP). This method is based on the principle of decision making based on the knowledge and data available at the time of decision making. The creative decision-making process is scientifically based on the concept of analytics, hierarchy, and process, as well as on the benefit and the cost criteria of optimality.

a) A fleet

The optimal periodicity of preventive maintenance has been determined and amounts to 162 h (Biočanin & Timotijević, 2021).

b) B fleet

Using the same methodology, the optimal periodicity of preventive maintenance for the special purpose vehicles in the B fleet was adopted and amounts to 192 h. Figure 6 provides a graphical representation of finding the best alternative.

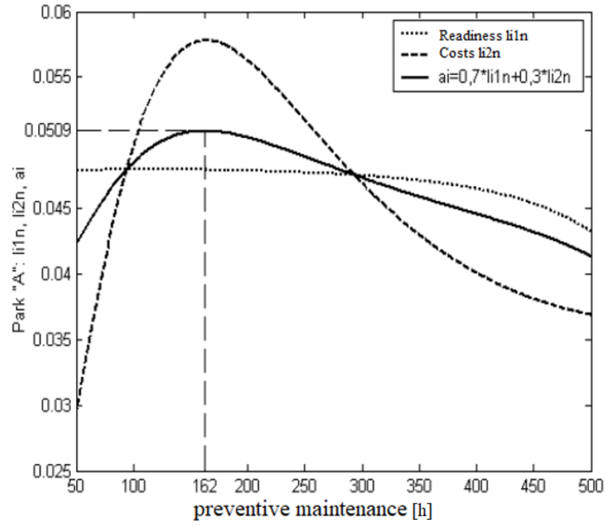

Figure 5 – Graphic representation of finding a compromise solution for the A fleet

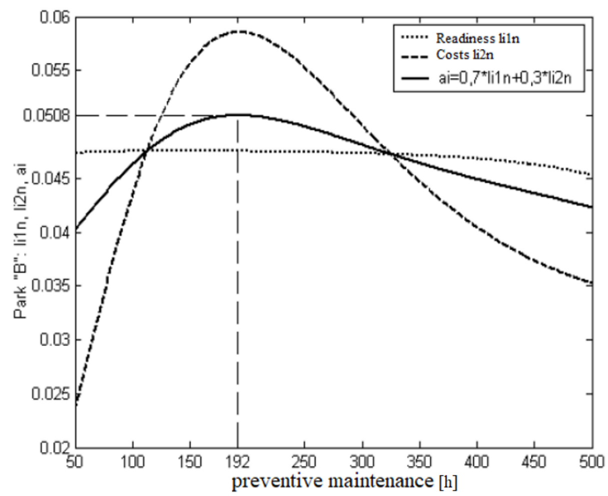

Figure 6 – Graphic representation of alternatives for determining the maintenance periodicity by a compromise solution in the B fleet

The value of the optimal periodicity for conducting preventive maintenance procedures for special purpose vehicles is determined according to the criterion of the maximum vehicle readiness to be 113 h for the vehicles from the A fleet and 141 h for the vehicles from the B fleet, and according to the criterion of the minimum maintenance costs to be 163 h for the vehicles from the A fleet and 193 h for the vehicles from the B fleet. By compromising, the value of the sought optimal periodicity for conducting preventive maintenance procedures was determined, taking into account both optimization criteria, and it amounts to 162 h for the vehicles from the A fleet and 192 h for the vehicles from the B fleet. A graphical representation of the periodicity of preventive maintenance for special purpose vehicles, determined according to the three mentioned criteria, is given in Figure 7 for the vehicles from the A fleet and in Figure 8 for the vehicles from the B fleet.

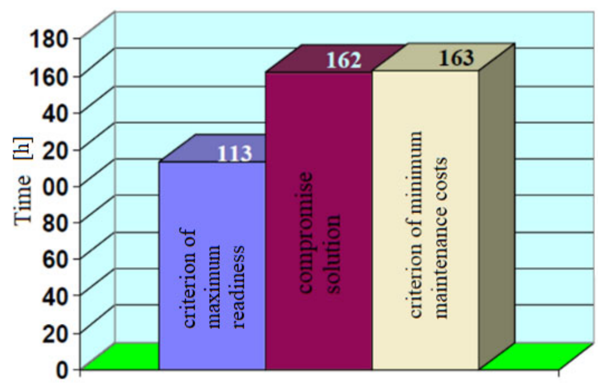

Figure 7 – Graphic representation of the preventive maintenance period for the specialized vehicles in the A park

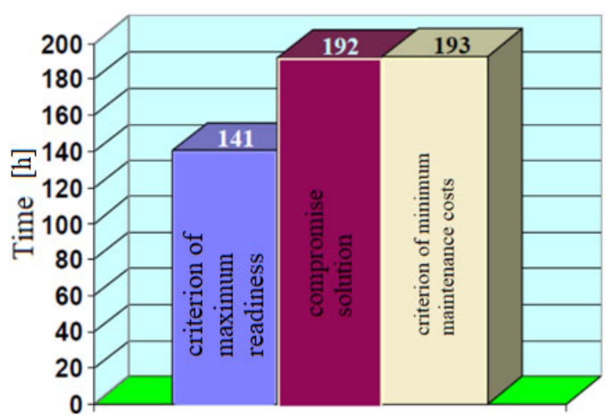

Figure 8 – Graphic representation of the preventive maintenance period for the specialized vehicles in the B park

The calculated periodicities of preventive maintenance for the special purpose vehicles in the A fleet and the B fleet are different. The maintenance periodicity for the vehicles in the B fleet is longer than that for the vehicles in the A fleet.

The vehicles from B fleet were used under harsher operational conditions in a geographic area with notably hilly terrain. The driving crews and maintenance personnel are less trained, and the workshop capacities are inadequate for work, especially during the winter period, with workshop equipment being of an older generation. The storage and preservation conditions for the vehicles are also worse since vehicles in the A fleet are stored under a canopy, while those in the B fleet are stored in an open area.

Determination of the optimal periodicity of preventive maintenance of vehicles by analyzing the maintenance periodicity of vehicle components

Most models optimize preventive maintenance of technical systems at the component level. Therefore, it is a major challenge to optimize the preventive maintenance process of a complex technical system such as a motor vehicle, which consists of several tens of thousands of components, 50-60% of which lose their initial properties during operation, 30-40% have a shorter lifespan than the vehicle, and an average of 200-300 components are critical in terms of reliability and require more frequent preventive inspections and corrective actions. The solution lies in finding an optimization model for preventive maintenance of vehicles based on the combined application of the results of several maintenance mathematical models for vehicle components, and then grouping the preventive maintenance periods for multiple components into a common periodicity. To avoid frequent vehicle downtimes for preventive maintenance, optimal grouping of local periodicities for multiple components into a common periodicity was performed through a group analysis. This approach enables more precise management of vehicle maintenance processes and their operational readiness, which was the goal of this study.

Using the same methodology as in the previous section of this study, a reliability model and optimal periodicity of preventive maintenance were determined for fifteen vital components of the vehicles.

The optimal periodicity of preventive maintenance for the vital components of the vehicles in the A fleet

The results of the research on the optimal periodicity of preventive maintenance for vital components of vehicles according to the three models are presented in the following Table 7.

Table 7 – Optimal maintenance periodicities for the components of the specialized vehicles in the A fleet

No.	Component name	Criterion	Maintenance Periodicity Time (h)
1	*2*	*3*	*4*
1.	Transmission Unit Block (TUB)	Maximum Availability	115
		Minimum Costs	341
		Compromise Solution	332
2.	Hydraulic System for Fan Drive (HCPF)	Maximum Availability	105
		Minimum Costs	183
		Compromise Solution	172
3.	Coolant Heating Device for Engine and Transmission	Maximum Availability	109
		Minimum Costs	169
		Compromise Solution	181
4.	Control Block	Maximum Availability	144
		Minimum Costs	199
		Compromise Solution	162
5.	Side Transmission with Disk Brakes	Maximum Availability	127
		Minimum Costs	161
		Compromise Solution	157
6.	Hand Brake with Command	Maximum Availability	174
		Minimum Costs	113
		Compromise Solution	164
7.	Water Ingress Protection Mechanism for the Engine	Maximum Availability	123
		Minimum Costs	194
		Compromise Solution	181
8.	Engine Throttle Controls	Maximum Availability	117
		Minimum Costs	201
		Compromise Solution	173
9.	Armored Body (connecting parts)	Maximum Availability	139
		Minimum Costs	175
		Compromise Solution	194
10.	Commander's Turret with links to the Armored Body	Maximum Availability	129
		Minimum Costs	187
		Compromise Solution	169

No.	Component name	Criterion	Maintenance Periodicity Time (h)
1	*2*	*3*	*4*
11.	Cooler Louver and Fan Controls	Maximum Availability	117
		Minimum Costs	176
		Compromise Solution	171
12.	Windbreak with Movement Mechanism	Maximum Availability	147
		Minimum Costs	184
		Compromise Solution	173
13.	Fire Prevention Device	Maximum Availability	154
		Minimum Costs	191
		Compromise Solution	181
14.	Barrel Gas Vent Device	Maximum Availability	112
		Minimum Costs	184
		Compromise Solution	163
15.	Engine OM-403	Maximum Availability	142
		Minimum Costs	372
		Compromise Solution	362

The optimal periodicity of preventive maintenance for the vital components of the vehicles in the B fleet

Using the same methodology as for the vital components of the vehicles in the A fleet, the periodicities of preventive maintenance for the components in the B fleet were calculated and provided in Table 8.

Table 8 – Optimal maintenance periodicities for the components of the specialized vehicles in the B fleet

No.	Component name	Criterion	Maintenance Periodicity Time (h)
1	*2*	*3*	*4*
1.	Transmission Unit Block (TUB)	Maximum Availability	140
		Minimum Costs	352
		Compromise Solution	348
2.	Hydraulic System for Fan Drive (HCPF)	Maximum Availability	112
		Minimum Costs	194
		Compromise Solution	186
3.	Coolant Heating Device for Engine and Transmission	Maximum Availability	116
		Minimum Costs	187
		Compromise Solution	182

No.	Component name	Criterion	Maintenance Periodicity Time (h)
1	*2*	*3*	*4*
4.	Control Block	Maximum Availability	152
		Minimum Costs	204
		Compromise Solution	195
5.	Side Transmission with Disk Brakes	Maximum Availability	141
		Minimum Costs	192
		Compromise Solution	184
6.	Hand Brake with Command	Maximum Availability	133
		Minimum Costs	188
		Compromise Solution	186
7.	Water Ingress Protection Mechanism for the Engine	Maximum Availability	136
		Minimum Costs	215
		Compromise Solution	203
8.	Engine Throttle Controls	Maximum Availability	121
		Minimum Costs	204
		Compromise Solution	198
9.	Armored Body (connecting parts)	Maximum Availability	140
		Minimum Costs	202
		Compromise Solution	194
10.	Commander's Turret with links to the Armored Body	Maximum Availability	161
		Minimum Costs	193
		Compromise Solution	183
11.	Cooler Louver and Fan Controls	Maximum Availability	137
		Minimum Costs	199
		Compromise Solution	187
12.	Windbreak with Movement Mechanism	Maximum Availability	162
		Minimum Costs	201
		Compromise Solution	190
13.	Fire Prevention Device	Maximum Availability	157
		Minimum Costs	218
		Compromise Solution	212
14.	Barrel Gas Vent Device	Maximum Availability	141
		Minimum Costs	201
		Compromise Solution	191
15.	Engine OM-403	Maximum Availability	152
		Minimum Costs	369
		Compromise Solution	361

Based on the obtained results, it can be concluded that there are different maintenance periodicities for the components, and that in both fleets, the transmission unit and the OM 403 engine of special purpose vehicles have the longest maintenance periodicity.

Cluster/group analysis

A cluster analysis was performed based on the theory of similarity of the adopted compromise solution for the optimal maintenance periodicity of 15 vehicle components.

The analysis was carried out using Minitab 15statistical software, based on Jaccard similarity coefficients:

$$\text{similarity coefficient} = \frac{A \cap B}{A \cup B} \qquad (5)$$

where:

- A and B are the lengths of the optimal maintenance periodicity for two consecutive components/assemblies compared.

The similarity coefficient matrix for the A fleet is shown in Table 9, and that for the B fleet in Table 10.

Table 11 displays the results of grouping the optimal maintenance periodicities of components into two, three, four, five, and six groups for the A fleet and the B fleet.

Within each group, the components are simultaneously subjected to preventive maintenance with adopted optimal maintenance periodicities.

Depending on the number of optimal maintenance periodicities, a vehicle will enter the workshop many times for the purpose of preventive maintenance.

For the second group, the vehicle will enter the workshop twice, and for the sixth group, six times.

Table 9 – Jaccard similarity coefficients for the A fleet

ASSEMBLY GROUP/AGGREGATE		ASSEMBLY GROUP/AGGREGATE														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	1	1.000	0.518	0.545	0.488	0.473	0.494	0.545	0.521	0.527	0.509	0.515	0.521	0.545	0.491	0.917
	2	0.518	1.000	0.951	0.942	0.913	0.953	0.950	0.994	0.983	0.983	0.994	0.994	0.950	0.948	0.475
	3	0.545	0.951	1.000	0.895	0.867	0.906	1.000	0.956	0.967	0.340	0.945	0.956	1.000	0.901	0.500
	4	0.488	0.913	0.895	1.000	0.969	0.988	0.895	0.936	0.926	0.959	0.947	0.936	0.895	0.994	0.448
	5	0.473	0.957	0.867	0.969	1.000	0.957	0.867	0.908	0.897	0.929	0.918	0.908	0.867	0.963	0.434
	6	0.494	0.953	0.906	0.989	0.957	1.000	0.906	0.948	0.937	0.970	0.950	0.948	0.906	0.984	0.453
	7	0.545	0.950	1.000	0.895	0.867	0.906	1.000	0.956	0.967	0.934	0.945	0.956	1.000	0.901	0.500
	8	0.521	0.994	0.956	0.936	0.908	0.948	0.956	1.000	0.989	0.977	0.988	1.000	0.956	0.942	0.478
	9	0.527	0.983	0.969	0.926	0.897	0.937	0.967	0.989	1.000	0.966	0.977	0.989	0.967	0.931	0.483
	10	0.509	0.983	0.934	0.950	0.924	0.970	0.934	0.977	0.956	1.000	0.988	0.977	0.934	0.964	0.467
	11	0.515	0.994	0.945	0.947	0.918	0.959	0.945	0.988	0.977	0.988	1.000	0.988	0.945	0.953	0.472
	12	0.521	0.994	0.956	0.936	0.908	0.948	0.956	1.000	0.989	0.977	0.988	1.000	0.956	0.942	0.478
	13	0.545	0.950	1.000	0.895	0.867	0.906	1.000	0.956	0.967	0.934	0.945	0.956	1.000	0.901	0.500
	14	0.491	0.948	0.901	0.994	0.963	0.994	0.901	0.942	0.931	0.964	0.953	0.942	0.901	1.000	0.450
	15	0.917	0.475	0.500	0.448	0.434	0.453	0.500	0.478	0.483	0.467	0.472	0.478	0.500	0.450	1.000

Table 10 – Jaccard similarity coefficients for the B fleet

ASSEMBLY GROUP/AGGREGATE		ASSEMBLY GROUP/AGGREGATE														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	1	1.000	0.534	0.523	0.560	0.529	0.534	0.583	0.583	0.557	0.053	0.537	0.546	0.609	0.545	0.991
	2	0.534	1.000	0.978	0.954	0.989	1.000	0.916	0.939	0.959	0.984	0.995	0.979	0.877	0.974	0.530
	3	0.523	0.978	1.000	0.933	0.989	0.978	0.897	0.919	0.938	0.995	0.973	0.958	0.858	0.953	0.519
	4	0.560	0.954	0.933	1.000	0.933	0.954	0.961	0.985	0.995	0.938	0.959	0.974	0.920	0.979	0.556
	5	0.529	0.989	0.989	0.943	1.000	0.989	0.906	0.929	0.948	0.995	0.984	0.968	0.868	0.963	0.524
	6	0.534	1.000	0.978	0.954	0.989	1.000	0.916	0.939	0.959	0.984	0.995	0.979	0.877	0.974	0.530
	7	0.583	0.916	0.897	0.961	0.906	0.916	1.000	0.975	0.956	0.901	0.921	0.936	0.958	0.941	0.578
	8	0.583	0.939	0.919	0.985	0.929	0.939	0.975	1.000	0.980	0.924	0.944	0.960	0.934	0.965	0.564
	9	0.557	0.959	0.938	0.995	0.948	0.959	0.956	0.980	1.000	0.943	0.964	0.979	0.915	0.985	0.553
	10	0.053	0.984	0.995	0.938	0.995	0.984	0.901	0.924	0.943	1.000	0.979	0.963	0.863	0.958	0.521
	11	0.537	0.995	0.973	0.959	0.984	0.995	0.921	0.944	0.964	0.979	1.000	0.984	0.984	0.995	0.533
	12	0.546	0.979	0.958	0.974	0.968	0.979	0.936	0.960	0.979	0.963	0.984	1.000	0.896	0.995	0.541
	13	0.609	0.877	0.858	0.920	0.868	0.877	0.958	0.934	0.915	0.863	0.984	0.896	1.000	0.901	0.604
	14	0.545	0.974	0.953	0.979	0.963	0.974	0.941	0.965	0.985	0.958	0.995	0.995	0.901	1.000	5.440
	15	0.991	0.530	0.519	0.556	0.524	0.530	0.578	0.564	0.553	0.521	0.533	0.541	0.604	5.440	1.000

Table 11 –- Grouping of components/aggregates for simultaneous preventive maintenance

Group	A fleet		B fleet	
	Agregate X_i; i=1,2,3,...,15	Opt. period. Min X_i /hour/	Agregate X_i; i=1,2,3,...,15	Opt. period. Min X_i /hour/
II group	1, 15	332	1, 14,15	191
	2,3,4,5,6,7,8,9,10,11,12,13,14	157	2,3,4,5,6,7,8,9,10,11,12,13	182
III group	1,15	332	1,15	348
	3,7,13	181	4,7,8,13	195
	2, 4, 5, 6, 8, 9,10,11,12,14	157	2,3, 5,6, 9,10,11,12,14	182
IV group	1,15	332	1	348
	2,3,7,8,9,11,12,13	171	2,3,4,5,6,7,8,9,10,11,12,13	182
	4,5,6,14	157	14	191
	10	169	15	351
V group	1,15	332	1	348
	2,8,9,11,12	171	2,3,4,5,6,7,8,9,10,11,12	182
	3,7,13	181	13	212
	4,5,6	157	14	191
	10	169	15	351
VI group	1	332	1	348
	2,8,9,11,12	171	2,3,4,5,6,7,8,9,11,12	182
	3,7,13	181	10	183
	4,5,6,14	157	13	212
	10	169	14	191
	15	362	15	351

An example dendrogram for grouping parts into three groups is shown in Figure 9.

An example dendrogram for grouping parts into five groups is shown in Figure 10.

Based on the obtained results, the following preventive maintenance model for components has been selected:

A fleet: The optimal periodicity for preventive maintenance for the engine and transmission in the specialized vehicle unit block is 332 h, while it is 157 h for all other components. In order to reduce maintenance costs, the engine and transmission in the unit block should undergo preventive maintenance every other time the vehicle enters the workshop.

B fleet: The optimal periodicity for preventive maintenance for the engine and transmission in the specialized vehicle unit block is 348 h, while it is 182 h for all other components.

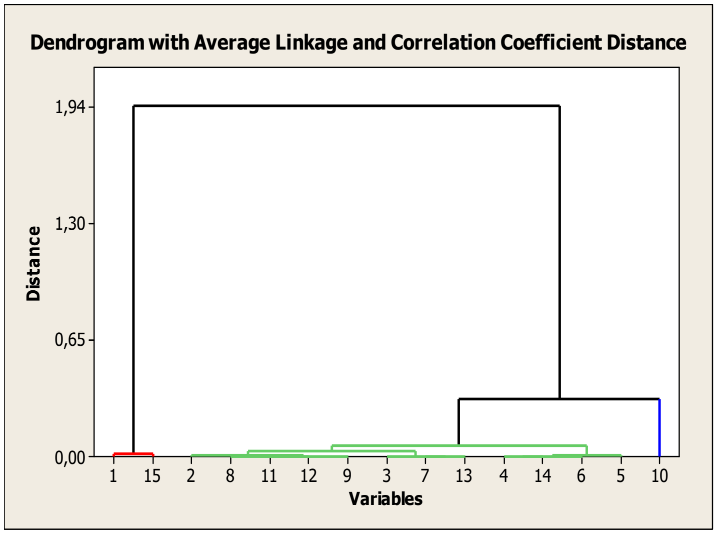

Figure 9 – Example of software grouping of components/aggregates into three groups
`Cluster 1: 1 15; Cluster 2: 2 3 4 5 6 7 8 9 11 12 13 14; Cluster 3: 10`

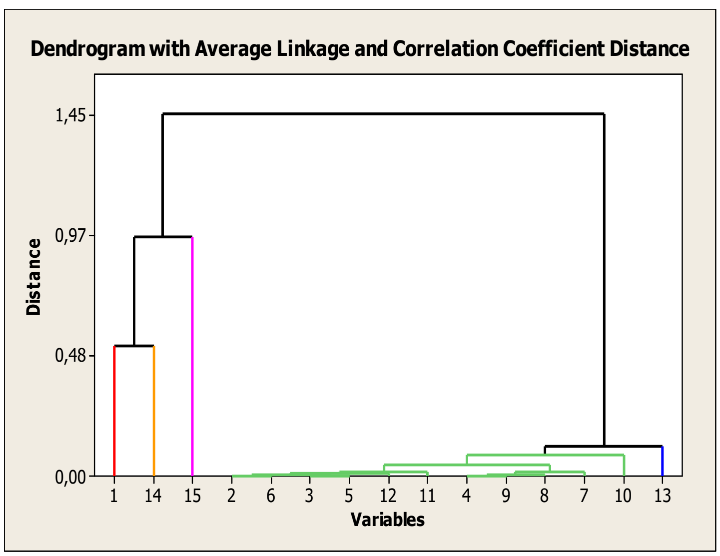

Figure 10 – Example of software grouping of components/aggregates into five groups
`Cluster 1: 1 15; Cluster 2: 2 8 9 11 12; Cluster 3: 3 7 13; Cluster 4: 4 5 6 14; Cluster 5: 10`

Statistical analysis of the research

Based on the analysis of the periodicity of preventive maintenance of vital vehicle components, using the same methodology, it was concluded that the maintenance periodicities of these components are different. In order to investigate the functional relationship of optimal periodicities of preventive maintenance of vehicles, an experiment was conducted in Minitab 16 statistical software based on 5 measurements of time between two failures for the observed 15 groups of components, in the A fleet and the B fleet.

The *General full factorial design* with two factors was applied:

1. Factor A: Relating to the specialized vehicle fleet, with two levels (A fleet and B fleet).
2. Factor B: Relating to the components/aggregates of the specialized vehicles, with 15 levels (components from 1, 2, 3, ..., 14, 15).

The X_0 hypothesis was set, assuming that the mean times between failures in the A fleet and the B fleet are equal, i.e., $\mu_1 = \mu_2$ with an alternative hypothesis X_1: $\mu_1 \neq \mu_2$.

Similarly, for the component groups "system/aggregate groups," the mean times between failures were observed, with X_0 ($\mu_1 = \mu_2$) and X_1($\mu_1 \neq \mu_2$) hypotheses.

After entering the data, certain statistical characteristics of the failure times behavior were obtained depending on the FLEET and the observed COMPONENT.

Multilevel Factorial Design

```
Factors:       2     Replicates:      5
Base runs:    30     Total runs:    150
Base blocks:   1     Total blocks:    1
Number of levels: 2. 15
```

General Linear Model: TIME BETW. FAILURE versus FLEET. SYSTEM GRUPS/AG

```
Factor                  Type   Levels  Values
FLEET                    fixed       2  1. 2
SYSTEM GRUPS/AGREGATES   fixed      15  1. 2. 3. 4. 5. 6. 7. 8. 9.
10. 11. 12.
                                      13. 14. 15

Analysis of Variance for TIME BETW. FAILURE, using Adjusted SS for
Tests
Source                          DF   Seq SS   Adj SS  Adj MS     F
P
FLEET                            1   100259   100259  100259  6,16
0,014
```

SYSTEM GRUPS/AGREGATES	14	360803	360803	25772	2,58	0,044
FLEET*SYSTEM GRUPS/AGREGATES	14	72137	72137	5153	0,32	0,991
Error	120	1954597	1954597	16288		
Total	149	2487795				

Based on the given analysis of variance and based on the F-statistic and p-value for factor A, it can be concluded that $F_{kr} > F_{tabl.}$ (6.16 > 2.76) and $p < \alpha$ (0.014 < 0.05), which means that the fleet, as a factor of observation, has a different effect on failures, thus rejecting the null hypothesis and accepting the alternative hypothesis.

Based on the given analysis of variance and based on the F-statistic and p-value for factor B, it was concluded that $F_{kr} > F_{tabl.}$ (2.58 > 1.80) and $p < \alpha$ (0.044 < 0.05), which means that the fleet, as a factor of observation, has a different effect on failures, thus rejecting the null hypothesis and accepting the alternative hypothesis.

In addition, the coefficients $R\text{-}C_q$ = 21.43%, $R\text{-}C_{q(adj)}$ = 2.45% indicate that there is no strong correlation between the observed levels of this factor. The regression equation of the time between failures depending on the fleet is:

$$TIME\ BETWEEN\ FAILURES = 227.3 + 51.71\ FLEET \tag{6}$$

and there is no polynomial relationship.

The functional relationships between the failure times of the vehicles in the A and B fleets is given in Figure 11, and the groups of components are shown in Figures 12 and 13.

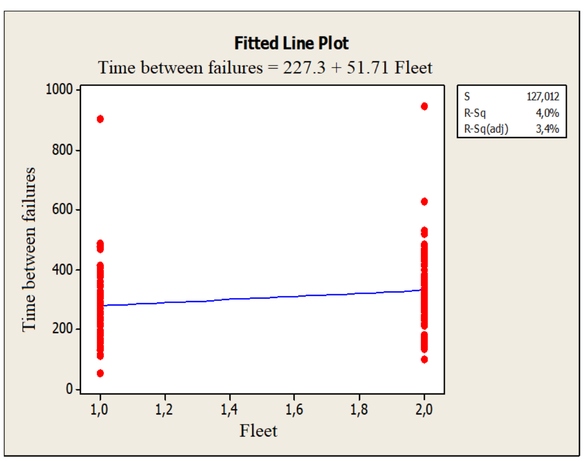

Figure 11 – Functional relationship Time between failure – Park/fleet

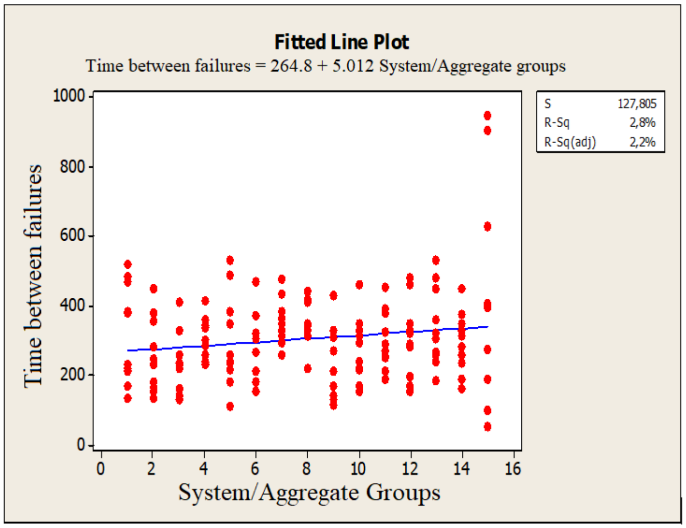

Figure 12 – Functional relationship Time between failure – System/Aggregate groups

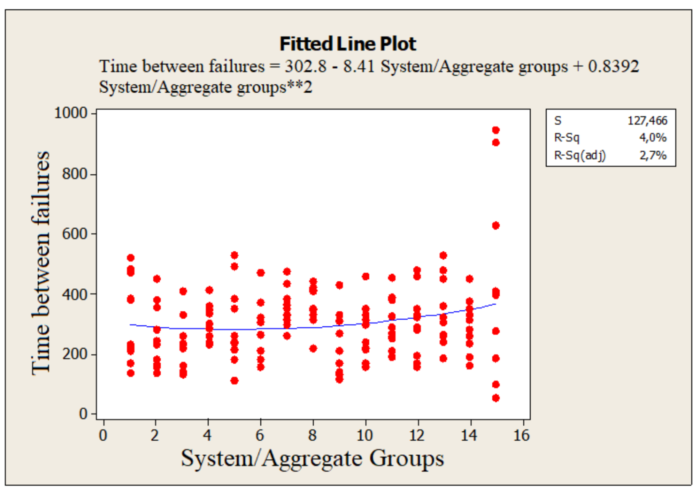

Figure 13 – Functional relationship Time between failure – System/Aggregate groups in the polynomial relationship

A spatial view of the functional relationship of time between failures for fleets and system/aggregate groups is provided in Figure 14, a contour view in Figure 15, and the main effects in relationships and time between failures in Figures 16 and 17.

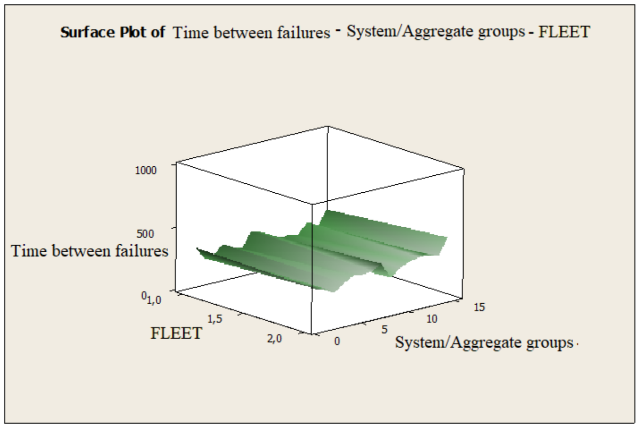

Figure 14 – Spatial view of the functional relationship Time between failure – Fleet - System/Aggregate groups

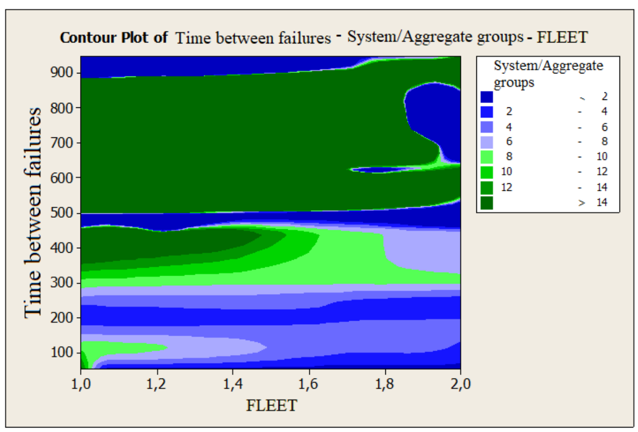

Figure 15 – Contour view of the functional relationship Time between failure – Fleet - System/Aggregate groups

The regression equation for the function of time between failures depending on a system/aggregate group is:

$$TIME\ BETWEEN\ FAILURES = 264.8 + 5.012\frac{SYSTEM\ OR}{AGGREGATE}GROUP \quad (7)$$

and the polynomial relationship is:

$$TIME\ BETWEEN\ FAILURES = 302.8 - 8.41\frac{SYSTEM\ OR}{AGGREGATE}GROUP + 0.8392\frac{SYSTEM\ OR}{AGGREGATE}GROUP ** 2 \quad (8)$$

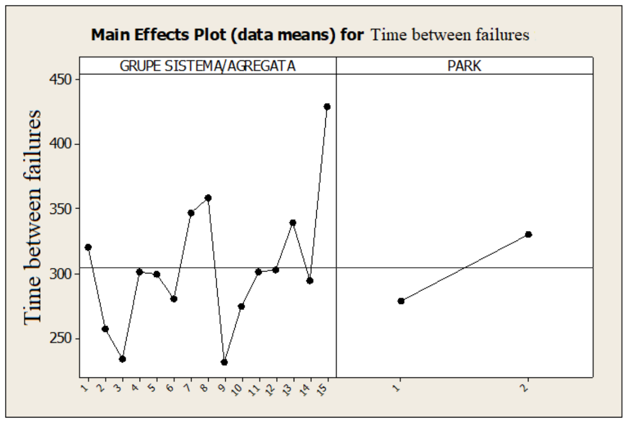

Figure 16 – Main effects in relations Time between failures - Fleet - System/Aggregate groups

Figure 16 clearly shows that there is a polynomial relationship between the maintenance periodicity of fifteen vital components. There is no polynomial relationship between the maintenance periodicity of the vital components in the two specialized vehicle parks.

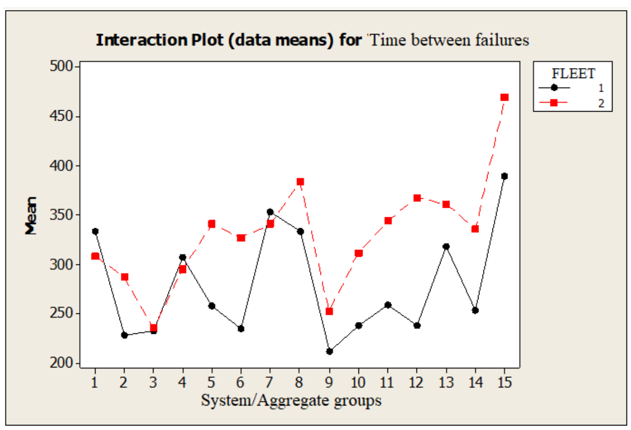

Figure 17 – Main interactions in relations Time between failures - Fleet - System/Aggregate groups

From Figure 17, it can be seen that, by analyzing five times between failures in Minitab 16 statistical software, different maintenance periodicities for vehicles were obtained in fleet 1 (A fleet) and fleet 2 (B fleet). Approximately the same maintenance periodicity in both fleets is observed for the Coolant Heating Device for the Engine and Transmission (Component 3), the Control Block (Component 4), and the Water Ingress Protection Mechanism for the Engine (Component 7).

Discussion

Stemming from the data from vehicle operation, the quantitative and qualitative indicators of the system condition and reliability of the special purpose vehicles were obtained. Based on it, the optimal maintenance periodicity of these vehicles was determined.

The periodicity of preventive maintenance of the special purpose vehicles was determined by a compromise solution. The maintenance periodicity obtained in this way is optimal because it provides satisfactory vehicle readiness and availability with optimal maintenance costs.

According to the research results, the maintenance periodicity of the vehicles from the B fleet is higher compared to the maintenance periodicity of the vehicles from the A fleet.

Compared to the existing maintenance concept, the calculated periodicity of preventive maintenance for the entire vehicle falls between the first and second technical inspections of the special purpose vehicle. It is concluded that it is unnecessary to implement preventive maintenance with two technical inspections in a relatively short time interval (first and second technical inspection); nevertheless, only one preventive inspection at the calculated time of preventive maintenance is sufficient. This approach would rationalize the existing concept of preventive maintenance, reduce maintenance costs, and increase the availability of special purpose vehicles.

Based on the analysis of the periodicity of preventive maintenance of vital components of special purpose vehicles, it was concluded, using the same methodology, that the maintenance periodicities of these components are different. The analysis and calculations showed that the engine of the vehicle and the transmission, in both fleets, have the highest reliability, which is why their maintenance periodicity is significantly higher than the maintenance periodicity of other components. If preventive maintenance of special purpose vehicles is performed through maintenance of components, in the calculated periods, then the special purpose vehicle would be very often undergoing preventive maintenance, the same operations would be repeated several times (opening documentation, vehicle washing, component construction and installation, testing, etc.), which would increase costs and decrease readiness due to the long time spent on maintenance. In order to avoid this, optimal grouping of local maintenance periodicities for multiple components into a single common periodicity was achieved through the group analysis. This way, the optimal availability and maintenance costs are achieved. Additionally, the group analysis showed that in the processes of vehicle management and maintenance, operational readiness can be more precisely managed based on the determined optimal periods of preventive maintenance.

Through the statistical analysis in Minitab 15 and Minitab 16 statistical software, it was concluded that there is no polynomial relationship between the time of operation until failure for the A fleet and the B fleet. It was concluded that there is a polynomial relationship between operating time and failure in the analysis of the groups of vital components. By analyzing the five times between two failures in Minitab 16 statistical software, different maintenance periodicities for the vehicles in park 1 (A fleet) and park 2 (B fleet) were obtained. The Coolant System Heating Device (Component 3), the Control Block (Component 4), and the Water Ingress Protection Mechanism for the Engine (Component 7) have approximately the same maintenance periodicity in both fleets. Other components have different maintenance periodicities, indicating that the maintenance periodicity depends on the terrain configuration and other vehicle operation conditions and that if the same vehicle changes its location and maintenance place, optimal maintenance periodicity calculations must be re-performed.

By grouping certain components and assemblies based on similar operating times between two failures, a kind of analysis of the condition of these elements was performed at a qualitative and quantitative level. The group analysis has contributed to more precise management of operational readiness and optimal maintenance costs of vehicles in the processes of vehicle management and maintenance based on the determined optimal periods of preventive maintenance of components. Another preventive maintenance model for vehicles was set up through the group analysis.

The research conducted in the A fleet and the B fleet shows that the condition and the maintenance periodicity of special purpose vehicles depend on the terrain where the vehicle is used, the drivers who operate the vehicle, the crew in the vehicle, and the workshop conditions for maintenance (technical equipment and quality of personnel). The study has proven that the vehicles from the B fleet have longer maintenance intervals, indicating that the operating conditions are different. The conclusion is that if the same vehicle changes its location and maintenance place, then optimal maintenance periodicity calculations must be re-performed. The analysis also showed that the engine and the transmission in the block have high reliability and are not affected by changes in operating conditions.

Conclusion

Based on the overall results obtained in this study, it can be concluded that the most suitable preventive maintenance concept for special purpose vehicles is maintenance based on time intervals derived from reliability with preventive inspections and preventive replacements according to the periodicities obtained from the calculations in this study, with the application of functional diagnostics and the lean maintenance concept. It is necessary to continuously monitor the behavior of vehicles and the occurrence of failures in operation, which can best be done by introducing a designed information system. By analyzing failure occurrence data, it is possible to predict future reliability, which in turn allows for informed decisions on preventive inspection procedures and the replacement of parts before they fail, ultimately enhancing vehicle reliability and minimizing the impact of potential failures.

The scientific contribution of the conducted research includes:

1. Optimization of Maintenance Periodicity:
   - Quantitative and qualitative indicators of the system condition and vehicle reliability were obtained based on operational data, which led to the determination of the optimal maintenance periodicity for special purpose vehicles.
   - This periodicity, derived as a compromise solution, ensures satisfactory vehicle readiness with optimal maintenance costs.
2. Improvement in Maintenance Strategies:
   - The calculated periodicity for preventive maintenance falls between the first and second technical inspections, suggesting the redundancy of two closely timed technical inspections. Instead, a single preventive inspection at the calculated time would suffice, rationalizing the existing maintenance concept, reducing costs, and enhancing vehicle readiness.
3. Analysis of Vital Assemblies:
   - The analysis revealed different maintenance periodicities for vital assemblies. Engines and transmissions in both parks showed the highest reliability, resulting in significantly longer maintenance intervals compared to other assemblies.
   - Optimal grouping of local periodicities for multiple assemblies into a common periodicity was performed through group analysis, achieving optimal readiness and maintenance costs.

4. Statistical Analysis Findings:
- Statistical analysis using Minitab 15 and 16 concluded that there is no polynomial relationship between operation time until failure for the A and B parks, but such a relationship exists for the group of fifteen vital assemblies.
- Different maintenance periodicities were determined for the vehicles in the A and B parks. Some assemblies, such as the engine cooling system and transmission (assembly 3), the steering block (assembly 4), and the water protection mechanism (assembly 7), had similar maintenance periodicities in both parks.
5. Influence of Operational Conditions:
- The research showed that the condition and the maintenance periodicity of special purpose vehicles depend on the terrain, drivers, crew, and workshop conditions.
- The vehicles in the B park had longer times between maintenance, indicating different operational conditions. If a vehicle changes location and a maintenance site, new calculations for optimal maintenance periodicity must be performed.
6. Development of a New Preventive Maintenance Model:
- Grouping certain assemblies and aggregates based on similar time between failures allowed for a comprehensive analysis of their condition on a qualitative and quantitative level.
- The group analysis contributed to more precise management of vehicle operational readiness with optimal maintenance costs based on determined optimal preventive maintenance periods.
7. Adaptation to Different Operational Conditions:
- The analysis indicated that maintenance periodicity depends on terrain configuration and other operational conditions. If the same vehicle changes the location, optimal maintenance periodicity calculations need to be recalculated.
- The study also found that the engine and the transmission block have high reliability and are not significantly affected by changes in operational conditions.

The results in this paper represent a research contribution to determining the optimal periodicity of preventive maintenance for special purpose vehicles and can serve as a basis for further research. The continuation of the research could proceed in the following directions:

- Using the presented methodology, or a similar one, to investigate the periodicity of preventive maintenance for other assemblies of

special purpose vehicles (such as armaments and communication equipment);
- Conduct research on the optimal periodicity of preventive maintenance for all other fleets of special-purpose equipment using the presented methodology, with the aim of making final and precise conclusions on the optimal periodicity of maintenance for special purpose vehicles;
- Investigate the maintenance periodicity of vehicles in passive operation that are exposed to various degradative factors under such conditions; and
- Explore the possibility of installing an automated diagnostic system for functional diagnostics to ensure objective, highly precise, and continuous monitoring of the vehicle's operation and its vital systems (e.g., oil pressure drop in the engine, insufficient brake fluid level, excessive wear of brake pads, excessive wear of clutch disc linings, clogged fuel filters, failure of missile launch and guidance systems, wear of the drive wheel gear, wear of the support wheel, etc.).

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Determinación de un modelo de mantenimiento preventivo de vehículos de propósito especial

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CAMPO: ingeniería mecánica
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: El objetivo de este documento es obtener indicadores cuantitativos y cualitativos del estado y la confiabilidad del vehículo basados en datos operativos que puedan usarse para determinar la periodicidad óptima del mantenimiento preventivo para vehículos de *propósito especial y para gestionar con mayor precisión el proceso de mantenimiento y la disponibilidad operativa de estos vehículos.*

Métodos: A partir de datos de fallas operativas y métodos estadísticos, se determinó un modelo matemático de confiabilidad de vehículos para fines especiales. Utilizando este modelo y datos operativos, se determinó la periodicidad del mantenimiento preventivo de los vehículos mediante optimización multicriterio, considerando tanto la disponibilidad como los costos mínimos de mantenimiento. La misma metodología se aplicó para determinar la periodicidad óptima de mantenimiento preventivo de 15 componentes del sistema mecánico de vehículos de propósito especial. Se realizó un análisis grupal mediante el software estadístico Minitab 15, basado en la teoría de la similitud en la periodicidad del mantenimiento preventivo para los 15 componentes, y un análisis estadístico de la investigación realizada mediante el software estadístico Minitab 16.

Resultados: Se desarrollaron modelos para el mantenimiento preventivo de vehículos de propósito especial con base en las fallas registradas de los vehículos y las fallas de quince componentes vitales. Un análisis de grupo reunió los quince componentes en grupos de mantenimiento óptimos, similares en términos de tiempo de trabajo entre fallas. El análisis estadístico de la investigación determinó una relación funcional para la periodicidad óptima del mantenimiento preventivo para vehículos de propósito especial.

Conclusión: La periodicidad de mantenimiento obtenida a través del análisis multicriterio es óptima, ya que logra una disponibilidad satisfactoria del vehículo con costos de mantenimiento óptimos. El análisis estadístico de la investigación concluyó que las periodicidades de mantenimiento de los componentes del vehículo son diferentes. En ambas flotas, el motor y el bloque de transmisión tienen los intervalos de mantenimiento más largos. Los resultados de la investigación pueden utilizarse para racionalizar el concepto de mantenimiento preventivo existente.

Palabras claves: vehículo, confiabilidad, disponibilidad, mantenimiento preventivo, costos, periodicidad óptima, análisis multicriterio.

Определение модели профилактического обслуживания автомобиля специального назначения

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РУБРИКА ГРНТИ: 78.25.09 Военная автомобильная техника,
73.31.41 Техническая эксплуатация и ремонт средств автомобильного транспорта. Автосервис
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Целью данной статьи является получение количественных и качественных показателей состояния и надежности транспортных средств на основании эксплуатационных данных, которые могут быть использованы для определения оптимальной периодичности профилактического обслуживания транспортных средств специального назначения и для более точного управления процессом технического обслуживания и эксплуатационной готовности.

Методы: На основании данных об эксплуатационных отказах и статистических методов была разработана математическая модель надежности транспортных средств специального назначения. Используя эту модель и эксплуатационные данные, путем многокритериальной оптимизации была определена периодичность профилактического обслуживания транспортных средств с учетом как готовности, так и минимальных затрат на техническое обслуживание. Аналогичный метод был применен для определения оптимальной периодичности профилактического обслуживания 15 компонентов механической системы транспортных средств специального назначения. Групповой анализ был проведен с использованием статистического программного обеспечения Minitab 15, основанного на теории подобия периодичности профилактического обслуживания 15 компонентов, а статистический анализ проведенного исследования был выполнен с помощью статистического программного обеспечения Minitab 16.

Результаты: На основании выявленных отказов транспортных средств и их пятнадцати ключевых компонентов были разработаны модели профилактического обслуживания транспортных средств специального назначения. Групповой анализ позволил оптимально сгруппировать пятнадцать компонентов для технического обслуживания, близких по продолжительности эксплуатации между двумя отказами. Благодаря статистическому анализу результатов исследования выявлена функциональную связь оптимальной периодичности профилактического обслуживания транспортных средств специального назначения.

Выводы: Периодичность технического обслуживания, полученная в результате многокритериального анализа, является оптимальной, поскольку обеспечивает удовлетворительную готовность автомобиля при оптимальных затратах на техническое обслуживание. Статистический анализ исследования показал, что периодичность технического обслуживания различных компонентов автомобиля различается. В обоих автопарках наиболее длительной периодичностью технического обслуживания оказалось периодичность обслуживания двигателя и трансмиссии. Результаты исследований могут быть использованы для рационализации существующей концепции профилактического обслуживания.

Ключевые слова: транспортное средство, надежность, готовность, профилактическое обслуживание, затраты, оптимальная периодичность, многокритериальный анализ.

Одређивање модела превентивног одржавања возила посебне намене

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ОБЛАСТ: машинство
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Циљ рада јесте да се, на основу података из експлоатације возила, добију квантитативни и квалитативни показатељи стања возила и поузданости, на основу којих се може одредити оптимална периодичност превентивног одржавања возила посебне намене и прецизније управљати токовима процеса одржавања возила и њиховом оперативном готовошћу.

Методе: На основу података о отказима из експлоатације, добијених статистичким методама, одређен је математички модел поузданости возила посебне намене. На основу овог модела и података из експлоатације одређена је периодичност превентивног одржавања возила применом вишекритеријумске оптимизације, уважавајући критеријум готовости и критеријум *минималних трошкова одржавања. По истој методологији одређена је оптимална периодичност превентивног одржавања петнаест склопова моторно-техничког дела возила посебне намене. Извршена је групна анализа, у статистичком софтверу Minitab 15, на основу теорије сличности периодичности превентивног одржавања ових склопова, и статистичка анализа спроведених истраживања у статистичком софтверу Minitab 16.*

Резултати: Добијени су модели превентивног одржавања возила посебне намене на основу евидентираних отказа возила и отказа петнаест виталних склопова возила посебне намене. Петнаест склопова је групном анализом груписано у оптималне групе за одржавање, које су сличне по дужини рада између два отказа. Статистичком анализом спроведених истраживања одређена је функционална веза оптималних периодичности превентивног одржавања возила посебне намене.

Закључак: Периодичност одржавања, добијена вишекритеријумском анализом, оптимална је јер се добија задовољавајућа готовост возила уз оптималне трошкове одржавања. Статистичком анализом истраживања дошло се до закључка да су периодичности одржавања склопова возила различите. У обе флоте мотор и трансмисија у блоку имају најдужу периодичност одржавања. Резултати истраживања могу се користити у рационализацији постојећег концепта превентивног одржавања.

Кључне речи: возило, поузданост, готовост, превентивно одржавање, трошкови, оптимална периодичност, вишекритеријумска анализа.

Paper received on: 16.04.2024.
Manuscript corrections submitted on: 16.11.2024.
Paper accepted for publishing on: 18.11.2024.

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