UDK: 629.11-235-192
COSATI: 13-06

Determination of an Optimal Strategy for Maintaining Motor Vehicle Clutches Using Polycriterion Optimization

Božidar Krstić, PhD (Eng)[1)]
Vojislav Krstić. (Eng)[2)]
Ivan Krstić, (Eng)[3)]

With an appropriate design of maintenance models, it is possible to perform optimization, i.e. to select the best possible maintenance system. If all the important requests and limits are precisely given, then it is possible to solve this kind of problems. The basis of the presented methodology consists of reliability parameters of the analysed vehicles obtained from monitoring vehicle behavior, from the aspect of failure occurrence in real operational conditions as well as of the costs of their maintenance.

Key words: **motor vehicle, vehicle maintenance, frictional clutch, process optimization, reliability, cost.**

Introduction

THE task of maintenance system optimization is to find an optimal solution. The aim of this work is to find a solution to optimize the motor vehicle maintenance system, a solution which will be the most acceptable for the maintenance of used vehicles.

The optimization of the maintenance system with the application model of preventive maintenance is often completed by finding an answer whether it is useful to apply preventive maintenance, and if it is, how much work time is needed to apply it.

Only one solution of maintenance strategy, for a given motor vehicle and given operational conditions, is optimal. Only in that case the best values of availability, reliability, minimal costs of exploitation and maintenance are obtained and all life cycle costs are reduced.

The aim of this work is to determine optimal maintenance of the clutch of a particular vehicle, on the basis of the parameters of its reliability obtained from the exploitation data.

Determination of the parameters of the motor engine reliability

If it is possible to determine the regularity which also encompasses the function of reliability distribution, then it is possible to determine all previously mentioned reliability parameters. This regularity can be determined if there are the data about the vehicle failure occurrence during its exploitation. One of principal elements in predicting vehicle behaviour in the future and its maintenance system optimization is finding an adequate mathematical model which can present the vehicle behaviour regularity from the point of view of failure occurrence. The methodology of determining the most acceptable maintenance model will be presented on an example of a particular vehicle and its clutch. A GF310K clutch, intended for special purpose vehicles, is the object of this research.

The values of the time to failure of the previous clutch, obtained by monitoring the vehicle during exploitation, are given in Table 1.

The law of the reliability distribution is determined on the basis of the data from Table 1.

Numerous characteristics of the statistical set are calculated:

- Average value: T_0=14 965,4 km, T_0 =499 h
- Standard deviation: σ_T=4 692,7 km, σ_T=156 h
- Median: t_{50} =13972 km, t_{50} =466 h

The determined values of reliability indicators of the vehicle clutch, which follow from Table 1, are obtained using known methodology [1,2,3] and presented in Table 2 and Figures 1 and 2.

Table 1. Values of time to failure for the clutch of the motor vehicle

Number of failure	Path until failure (km)	Time to failure (h)	Number of failure	Path until failure (km)	Time to failure (h)	Number of failure	Path until failure (km)	Time to failure (h)
1	8243	275	18	12778	426	35	17384	579
2	8389	280	19	12935	431	36	17726	591
3	8756	292	20	12936	431	37	17752	592
4	8894	296	21	13186	440	38	17963	599
5	10128	338	22	13431	448	39	17981	599
6	10254	342	23	13757	459	40	19100	637
7	10280	343	24	13952	465	41	19196	640
8	10347	346	25	13972	466	42	19638	655
9	10387	347	26	14158	472	43	19882	663
10	10395	348	27	14373	479	44	20125	671
11	10656	355	28	14396	480	45	21492	716
12	10869	362	29	14563	485	46	23651	788
13	11496	383	30	14763	492	47	24697	823
14	11831	394	31	15938	531	48	26391	880
15	11863	395	32	16397	547	49	27391	913
16	11978	399	33	16967	566			
17	12382	413	34	17186	573			

1) Faculty of Mechanical Engineering, Sestre Janjić 6, 34000 Kragujevac, SERBIA
2) Faculty of Transport and Traffic Enginering, 11000 Belgrade, SERBIA
3) School of Electrical Engineering, 11000 Belgrade, SERBIA

Table 2. Estimated values of reliability indicators for the cluth of the motor vehicle

Number i	Time t_i	m(i)	Number of failures n_g(i)	$\bar{n}$ (i)	Frequency of failures $f(t_i)$	Reliability $R(t_i)$	Underli-ability $F(t_i)$	Fialure in-tensity $\lambda(t_i)$
1	300	10	49	44	2.04E-03	0.8980	0.1020	0.002273
2	400	12	39	33	2.44E-03	0.6735	0.3265	0.003636
3	500	10	27	22	2.04E-03	0.4490	0.5510	0.004545
4	600	9	17	12.5	1.84E-03	0.2551	0.7449	0.007200
5	700	4	8	6	8.16E-04	0.1224	0.8776	0.006670
6	800	2	4	3	4.08E-04	0.0612	0.9388	0.006670
7	900	2	2	1	4.08E-04	0.0204	0.9796	0.020000

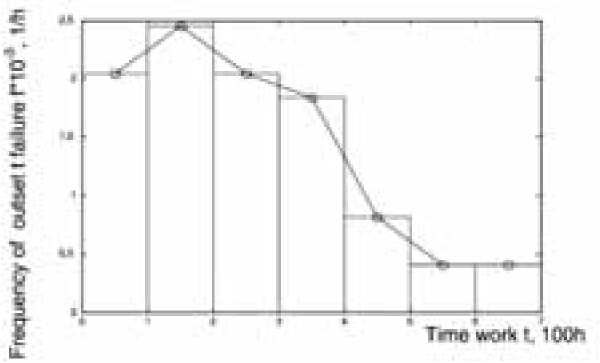

Figure1. Estimated values of the failure density $f(t_i)$ of the motor vehicle clutch

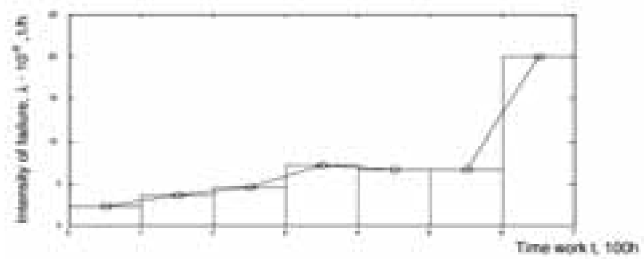

Figure 2. Estimated values of the failure intensity $\lambda(t_i)$ of the motor vehicle clutch

Test of Weibul distribution

Parameters of Weibul distribution: the parameter of measurement $\eta = 562,4$;

The parameter of form $\beta = 3,174$

Table 3. Deviation of the Weibull approximate distribution from the estimated function of the time to failure distribution

i	t(i)	$F_e(t_i)$	$F_t(t_i)$	Δ	Δ (%)
1	300	0.1020	0.1272	0.0252	19.8001
2	400	0.3265	0.2876	0.0389	13.5434
3	500	0.5510	0.4976	0.0534	10.7273
4	600	0.7449	0.7071	0.0378	5.3488
5	700	0.8776	0.8650	0.0125	1.4486
6	800	0.9388	0.9531	0.0143	1.5014
7	900	0.9796	0.9883	0.0087	0.8786

Unreliability function of the distribution is defined in the following way:

$$F_t(t_i) = 1 - R(t_i) = 1 - e^{-\left(\frac{t_i}{562,4}\right)^{3,174}} \quad (1)$$

The absolute differences of probability of failure which are estimated on the basis of the data of exploitation and the distribution:

$$\Delta = \left| F_e(t_i) - F_t(t_i) \right| \quad (2)$$

Test of Kolmogorov-Smirnov

For the accepted degree of significance $\alpha = 0,20 \Rightarrow \lambda = 1,07$. On the basis of experimental data, the biggest difference between the theoretical distribution $F_t(t)$ and the estimated values $F_e(t)$, is $D_{\max}$ = 0,0534 and it is on third place in Table 3. For the number of elements n = *49* and $\alpha = 0,20$ the allowed value of difference $D_{doz} = \lambda/\sqrt{n} =$ 0,15286. Since $D_{\max} < D_{doz}$, theoretical approximate distribution satisfies the test of Kolmogorov-Smirnov.

Test of Pirson

The parameter value χ^2 is determined from the following expression:

$$\chi^2 = \sum_{i=1}^{n} \frac{\left[F_e(t_i) - F_t(t_i)\right]^2}{F_t(t_i)} \quad (3)$$

Since the calculated value χ^2 = 0,018486 is lower than the table value $\chi^2_{0,99}$=0,297 for the number of degrees of freedom σ, the theoretical approximate distribution satisfies the test of Pirson.

Test of Romanovski

The criterion for this test is the following:

$$\frac{\left|\chi^2 - k\right|}{\sqrt{2k}} < 3 \quad (4)$$

Where the number of degrees of freedom is k = 6.

Since the calculated value for the Romanovski test is 1,7267<3, the theoretical approximate distribution satisfies this test.

Test of normal distribution

The values for $f(t_i)$ are presented in Table 3. The determination of parameter $f(t)$. for normal distribution is obtained in the following way:

$$f(t) = \frac{1}{\sigma\sqrt{2\pi}} \cdot e^{-\frac{(t-\mu)^2}{2\sigma^2}} \quad (5)$$

The parameter values of μ and σ can be determined directly by the use of functional search:

$$I = \sum_{i=1}^{k} \left[f(t_i) - \frac{1}{\sigma\sqrt{2\pi}} \cdot e^{-\frac{(t_i-\mu)^2}{2\sigma^2}} \right]^2 \quad (6)$$

(which is the measure of deviation of the theoretical distribution density function from the real one) with the method Nelder - Mead, implemented in the function "fminsearch" of the MATLAB programme [16]. The parameters such as mathematical expectation μ = 439,3854 and standard deviation σ = 170,9086 were determined.

Test of Kolmogorov-Smirnov

For the degree of significance $\alpha = 0,20 \Rightarrow \lambda = 1,07$. On the basis of experimental data, the biggest difference between the theoretical distribution $F_t(t)$ and estimated value $F_e(t)$ is the result in the first place in Table 4 and it is D_{max} = 0,1003. For the number of elements n = 49 and $\alpha = 0,20$ the allowed value of difference is $D_{doz} = \lambda / \sqrt{n}$ = 0,15286. Since $D_{max} < D_{doz}$ the theoretical approximate distribution satisfies the Kolmogorov-Smirnov test.

Table 4. Deviation of the normal approximate distribution from the estimated values of the time to failure distribution function

I	t_i	$F_e(t_i)$	$F_t(t_i)$	Δ	Δ (%)
1	300	0.1020	0.2023	0.1003	49.5610
2	400	0.3265	0.4038	0.0773	19.1356
3	500	0.5510	0.6335	0.0825	13.0205
4	600	0.7449	0.8213	0.0764	9.2981
5	700	0.8776	0.9128	0.0537	5.7697
6	800	0.9388	0.9775	0.0387	3.9614
7	900	0.9796	0.9914	0.0118	1.1920

Test of Pirson

Since the calculated value χ^2= 0,087093 is lower than the table value $\chi^2_{0,99} = 0,297$ for the number of degrees of freedom σ, the theoretical approximate distribution satisfies the test of Pirson.

Test of Romanovski

Since the calculated value for the Romanovski test 1,7069 < 3, the theoretical approximate distribution satisfies this test.

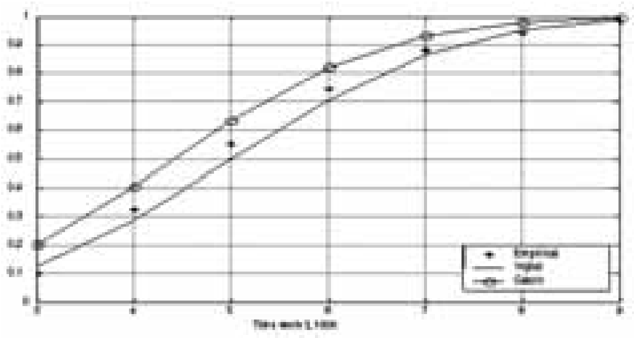

Figure 3. Deviations of the normal of Weibul distribution from the estimated values of the function of distribution of the time to failure of the motor vehicle clutch

From this test results, it is obvious that both distributions (Weibul's and normal) satisfy all tests. Since the Weibul distribution approximates empirical values with a lower relative error (Table 3 and 4), it is accepted for the theoretical approximate distribution. Accepting this law of distribution of reliability, it is possible to write the expressions for order reliability, frequency of failure, intensity of failure and average time of work without failure in the following forms:

$$R(t) = e^{-\left(\frac{t}{562,4}\right)^{3,174}} \tag{7}$$

$$f(t) = \frac{3,174}{562,4} \cdot \left(\frac{t}{562,4}\right)^{2,174} e^{-\left(\frac{t}{562,4}\right)^{3,174}} \tag{8}$$

$$\lambda(t) = \frac{3,174}{562,4} \cdot \left(\frac{t}{562,4}\right)^{2,174} \tag{9}$$

$$T_0 = \int_0^{\infty} t \cdot \frac{3,174}{562,4} \cdot \left(\frac{t}{562,4}\right)^{2,174} e^{-\left(\frac{t}{562,4}\right)^{3,174}} dt \tag{10}$$

On the basis of previous expressions, the optimal period of work time can be determined.

Determination of the optimal value of vehicle maintenance frequency by the criterion of minimal costs

Providing the required availability and reliability of the clutch, with minimal maintenance costs, it is possible to determine the periodicity interval of its maintenance [10]. The total clutch maintenance costs can be expressed in the form

$$C(t) = \frac{C_k - (C_k - C_p) \cdot R(t)}{\int_0^T R(t)dt} \tag{11}$$

where: $C(t)$ are the total specific maintenance costs; C_k are the corrective maintenance costs and C_p are the preventive maintenance costs. By the application of expression (11) for various periodicities of the clutch maintenance, the values for the maintenance costs are obtained shown in Table 5 and in Fig.4.

Table 5. Costs of clutch vehicle maintenance, for different frequency of its preventive maintenance

Frequency of maintenance (h)	7	100	150	200	250	300	350	400	450	500
Costs of corrective maintenance C_k	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
Costs of preventive maintenance C_p	600	600	600	600	600	600	600	600	600	600
Reliability $R(t)$	0.9995	0.995	0.9850	0.9631	0.9265	0.8728	0.8009	0.7124	0.6109	0.5024
$\int_0^T R(t)dt$	49.99	99.90	149.46	198.22	245.53	290.58	332.50	370.40	403.53	431.37
Total specific costs $C(t)$	12.024	6.105	4.2548	3.4736	3.1618	3.1157	3.2413	3.4833	3.8009	4.1596
$f_{i,2}$	50	100	150	200	250	300	350	400	450	500

Based on the results shown in Table 4 and Fig.4, it can be concluded that the lowest maintenance costs of the analyzed technical system clutch are obtained for the maintenance periodicity of 286 (C_{min}= 3,1083) working hours.

Determination of the optimal value of vehicle clutch maintenance frequency by the criterion of maximal availability

Since the most acceptable model of reliability distribution has been determined and since the time picture of the frictional clutch of the analyzed technical system is completely known (time in operation, time spent on waiting to operate while in order, time spent while out of order), it is possible to apply the maintenance model based on availability. By applying this model, the exploitational reliability of the technical system, from the aspect of the frictional clutch, can be determined using the expression:

$$G(t) = \frac{t_p + t_{cr}}{t_p + t_{cr} + t_o + \frac{F(t)}{R(t)} \cdot t_k} \tag{12}$$

where: t - is the periodicity of maintenance; t_{cr} - is the time spent to operate while in order; t_p - is the time of preventive maintenance; t_k - is the time of corrective maintenance.

By varying the periodicity of preventive maintenance, one obtains the functional dependence based on which the optimal value of the preventive maintenance periodicity can be determined, based on the maximal availability criterion. The results of the determination of availability, for various maintenance periodicities of the cutch of the considered technical system (12), are shown in Table 6 and in Fig.4.

Table 6. Tabular review of vehicle availability dependence from the clutch preventive maintenance frequency

Maintenance frequency (h)	50	100	150	200	250	300	350
Work time t_r (h)	50	100	150	200	250	300	350
Time of preventive maintenance t_p (h)	12	12	12	12	12	12	12
Unreliability F	0.0005	0.0042	0.0150	0.0369	0.0735	0.1272	0.1991
Reliability R	0.9995	0.9958	0.9850	0.9631	0.9265	0.8728	0.8009
Number of corrective maintenances between two preventive maintenances	0.0005	0.0042	0.0152	0.0383	0.0793	0.1458	0.2485
Time of corrective maintenance k_k(h)	0.0277	0.2505	0.9119	2.2979	4.7573	8.747	14.9114
Waiting time for work $t_{čr}$ (h), in accurate state	150	300	450	600	750	900	1050
Availability $G(t)$	0.9434	0.9709	0.9804	0.9851	0.9878	0.9891	0.9889
f_{i2}	50	100	150	200	250	300	350

Based on the results shown in Table 6 and in Fig.4 it can be concluded that the highest availability of the analyzed technical system, from the aspect of its clutch, is obtained for the maintenance periodicity of 286 working hours.

Determination of a compromising solution system of maintenance, on the basis of maximal availability and minimal costs of maintenance

It can be concluded from the above mentioned that the optimal interval of maintenance period of the main clutch, from the aspect of maximal availability and minimal maintenance costs, is found between 321 and 286 hours of work, and it is accepted on the basis of the given criteria (Fig.4).

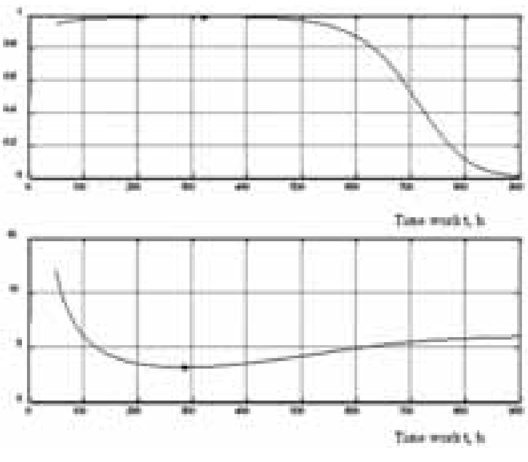

Figure 4. Dependence of availability from the clutch maintenance frequency costs

Determination of the optimal frequency of preventive maintenance of the vehicle clutch using polycriterion optimization

The value of the preventive maintenance periodicity of the analyzed technical system clutch lies between the times that correspond to maximal availability and to minimal costs. This period can be discretized. Each discrete value can be associated with a considered concept of the preventive maintenance. In that way, one obtains the corresponding number of preventive maintenance variations, which differ from each other only in working time lengths after which the procedures of preventive maintenance are being conducted. Since the values of optimal periodicities of the considered clutch preventive maintenance, obtained by the criterion of maximal availability and the criterion of minimal costs differ from each other, this part presents the results of determination of the periodicity by application of the optimization method, which is known in literature as the MCDM (Multi Criteria Decision making) problem. The basic characteristic of the MCDM problem, thus accordingly of the problem considered in this work, is that the best alternative is found in the sense of several attributes, simultaneously, or in the limited set of available alternatives.

Analytic hierarchy process - AHP

A great number of optimization methods can be found in the literature, eg. The Analytic Hierarchy Process (AHP). This method was developed at the end of XIX century [6]. The AHP method was developed on the principle of decision, human knowledge, as well as on data available to experts in the decision making process. The decision making process is a creative process, scientifically based on three fundamental principles [6]: Analytics, Hierarchy and Process.

The nature of the optimality criterion can be benefit-wise and cost-wise.4 When the benefits optimality criterion is used, the higher its value is, the better, and vice versa. When the costs optimality criterion is used, the lower their values are, the better, and vice versa.

The group of alternatives is presented as the group of alternative indexes, i= (1,…i,…K), $k \in K$, $i \in I$, where i is number of all considered alternatives. The problem is presented with the following matrix: $F = \left[f_{ik} \right]_{I \, x \, K}$ (13)

$f_{i,K}$ presents the value of optimization criterion k for alternative i. Optimization criteria are generally of different nature, different values and different measures. This means that the values of optimal criterion for alternative I are not parallel. It is thus necessary to do the normalization procedure when all values of f_{ik} are copied to the interval [0,1]. There is a great number of normalization types in the use [4]: simple, linear, vector, etc. Irrespective to which type of normalization is used, different analytic formulas for benefit and for cost criterion of optimization are used.

When the vector normalization is used, the decision making problem could be presented as matrix F=$[f_{i,k}]_{1xK}$ where $(f_{ik})_n$ is the normalized value of the optimal criterion k for the alternative i.

Each considered alternative is joined to the determined value [5]. The normalizing value of $f_{i,1}$ is done using the expression for vector normalization, and using the benefit optimality criterion.

The following expressions can be used in order to solve the task in case:

$$\left(f_{i\,j} \right)_n^b = \frac{f_{i\,j}}{\sqrt{\sum_{i=1}^{I} \left(f_{i\,j} \right)^2}} \qquad (14)$$

$$\left(f_{ij}\right)_n^t = \frac{\dfrac{1}{f_{ij}}}{\sqrt{\sum_{i=1}^{I}\left(\dfrac{1}{f_{ij}}\right)^2}} \tag{15}$$

The value of factors on the basis of which the best alternative of periodic maintenance a_I is determined, is determined using the supposition that importance of adopted optimization criteria (maximum availability, minimal maintenance costs) is equal, and they are given as normalized, as in this particular case, using expressions [4,5,6,7,8]:

$$a_i = \frac{\sum_{k=1}^{K} W_k \left(f_{ik}\right)_n}{\sum_{k=1}^{K} W_k} \tag{16}$$

$$a_i = \frac{1}{k}\sum_{k=1}^{K}\left(f_{ik}\right)_n \tag{17}$$

The elements of the matrix F are obtained in this way by equalizing the value of maximal availability from the point of view of its motor vehicle, for different periods of preventive maintenance which correspond to particular alternatives ($f_{i,1}$) and equalizing with the value of total costs of motor vehicle maintenance, for different periods of preventive maintenance which correspond to particular alternatives ($f_{i,2}$). On the basis of the data obtained by monitoring the analyzed vehicle from the point of view of its clutch, in real conditions of exploitation the values of elements $f_{i,1}$ (i.e. availability) were obtained using expressions (12) to determine availability, and the values of elements $f_{i,2}$ (i.e. costs of maintenance) were obtained using expressions (11) to determine costs of maintenance.

Determination of the optimal period of the main clutch preventive maintenance applying the method of polycriterion optimization

The time period of operation from 50 to 350 hours will be considered, because the availability and the maintenance costs of the given technical system within this period keep satisfactory values. In order to determine the optimal period of preventive maintenance, the interval from 50 to 350 hours, will be discretized with the increment Δ=1 Table 6, but Δ=50, MATLAB programme[12]).

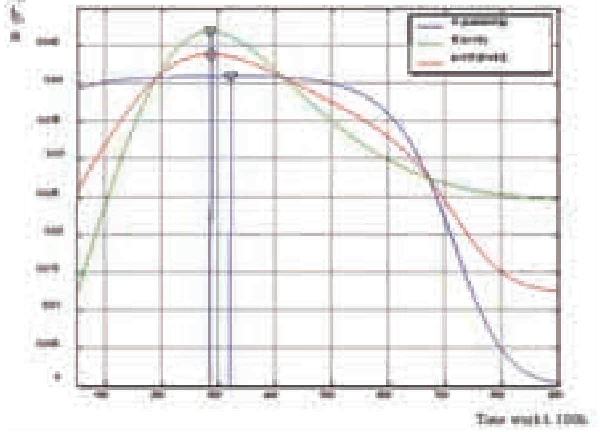

Figure 5. Determination of the best alternative of periodic maintenance

The elements of the matrix $F, f_{i,1}$ are obtained when they are equal to the values of availability for different time values at work, i.e. different periods of preventive maintenance which correspond to particular alternatives:

$$f_{i,1} = G(t_i) \tag{18}$$

The normalization of the values $f_{i,1}$ is done with the expression for vector normalization using the benefit criteria of optimization:

$$\left(f_{i,1}\right)_n = \frac{f_{i,1}}{\sqrt{\sum_{i=1}^{300}\left(f_{i,1}\right)^2}} \tag{19}$$

The elements of the matrix $F, f_{i,2}$ are obtained when they are equal with the values of all maintenance costs for different times at work (Table 5), i.e. different periods of preventive maintenance which correspond to particular alternatives:

$$f_{i,2} = C(t_i) \tag{20}$$

The normalization of the values $f_{i,2}$ is done with the expression for vector normalization using the cost criteria of optimization:

$$\left(f_{i,2}\right)_n = \frac{\dfrac{1}{f_{i,2}}}{\sqrt{\sum_{i=1}^{300}\left(\dfrac{1}{f_{i,2}}\right)^2}} \tag{21}$$

Each alternative is given the following value:

$$a_i = \frac{1}{2}\cdot\sum_{k=1}^{2}(f_{i,k})_n \tag{22}$$

Availability from the point of view of motor vehicle (the values of $f_{i,1}$ in the matrix F) and costs of maintenance (the values of $f_{i,2}$ in the matrix F) for different frequency of motor vehicle, preventive maintenance, normalized values of the elements of the matrix F $((f_{i,1})_n, f_{i,2})_n)$ and the values of the factors on the basis of which the best alternative of periodic maintenance a_i is determined (Fig.5).

The data obtained by formulas (19), (21), (22) using the MATLAB programme [12], are in Fig.5.

The best alternative is the one that has the highest value of the factor a_i. The values of this factor, determined by expression (22), are given in Fig.5. It can be concluded that the optimal periodicity of preventive maintenance of the motor vehicle clutch is after every 288 working hours.

Conclusions

The results of exhaustive investigations of the motor vehicle clutch reliability parameters, obtained by monitoring the behavior of the analyzed motor vehicle in real exploitation conditions, from the aspect of failure occurrence of its clutch, and with application of the corresponding scientific knowledge from the area of probability., mathematical statistics, systems theory and reliability theory, have served as a basis for finding the optimal periodicity of the clutch maintenance, taking into account the criteria of maximal availability and minimal costs of its maintenance.

Since the optimal periodicities of conducting the clutch preventive maintenance, determined by the criteria of maximal availability and minimal maintenance costs differ from each other, it was necessary to apply one of the multicriteria analysis methods and to determine the value of the required optimal periodicity of conducting the preventive maintenance procedures, taking into account both optimization criteria.

The value of optimal periodicity of conducting the preventive clutch maintenance procedures was determined according to maximal availability criterion to be 321 working hours, while according to criterion of minimal maintenance costs that value was 286 working hours.

By the application of the multicriteria analysis the value of the required optimal periodicity of conducting the preventive clutch maintenance procedures, with taking into account both optimization criteria, was 288 working hours.

The presented methodology of the multicriteria decision-making can be applied for obtaining reliable values of optimal periodicity of conducting the preventive maintenance procedures for other parts of the analyzed technical system. There one needs available data, which can be obtained by analysis and monitoring of the considered technical system, thus the reliability indicators of the system can be determined, as well as the characteristics of its maintenance.

References

[1] BRITISH STANDARD, BS5760, Part 2: *Guide to the assessment of reliability, Reliability of systems*, equipments and components, BSI, London, 1981.

[2] VUKADINOVIĆ,S.: Elements of the Probability Theory and Mathematical Statistics, Economy Review, Belgrade, 1981. (In Serbian)

[3] KRSTIĆ,B.: *Exploitation of Motor Vehicles, Faculty of Mechanical Engineering*, Kragujevac, 1997. (In Serbian)

[4] OPRICOVIĆ,S.: *Multicriteria Optimization*, Faculty of Civil Engineering, Belgrade, 1986. (In Serbian)

[5] YOON,K.P., HWANG,C.I.: *Multiple Attribute Decision Making, and Introduction, Series: Quantitative Applications in the Social Sciences 104*, Sage University Paper, Thousand Oaks, 1995.

[6] BASS,M.S., KWAKERNAK,H.: *Rating and Ranking of Multiple Aspect Alternatives Using Fuzzy Sets Automatics*, 1977,Vol.13, pp.47-58.

[7] MILANOVIĆ,D.,et al.: *Management Information Systems*, Megatrend University, Belgrade, 2003.

[8] PAVLIČIĆ,D.: *Normalization of Attribute Values in MADM the Conditions of Consistent Choice IV*, DI, EJOR, Belgrade, 2000, Vol.10, No.1.

[9] VINCKE,P.: *Multicriteria Decision – aid, John Wiley & Sons*, 1992.

[10] SATY,T.L.: *How to Make a Decision: The Analytic Hierarchy Process*, EJOR 48, 9, 1990.

[11] VARGAS,L.: *An Overview of the Analytic Hierarchy Process*, EJOR 48, 1990.

[12] Optimization Toolbox for Use with MATLAB, The Math Works, 1994.

Received: 22.11.2008.

Određivanje opitimalne periodičnosti održavanja spojnice motornog vozila

Pravilnim formiranjem modela održavanja moguće je izvršiti optimizaciju, odnosno izabrati najpovoljniji sistem održavanja. Ovakav problem moguće je rešiti ako su precizno određeni svi važni zahtevi i ograničenja. Osnovu izložene metodologije čine parametri pouzdanosti analiziranih vozila, dobijeni na osnovu praćenja ponašanja vozila, sa aspekta pojave otkazau realnim uslovima ekspoloatacije, kao i troškovi njihovog održavanja.

Ključne reči: **motorno vozilo, održavanje vozila, frikciona spojnica, optimizacija procesa, pouzdanost, troškovi.**

Предназначение оптимальной методологии обслуживания муфты включения моторного перевозочного средства

Правильным формированием модели обслуживания возможно провести оптимизацию, т.е. выбрать самую подходящую систему обслуживания. Такую проблему возможно решить только в случае уточнения и определения всех важных требований и ограничений. Основу приведённой методологии составляют параметры надёжности анализированных перевозочных средств, получены на основе проведения наблюдения над поведением перевозочного средства с аспекта явления неисправности (отказа) в реальных условиях эксплуатации, а в том числе и расходы обслуживания моторного перевозочного средства.

Ключевые слова: моторное перевозочное средство, обслуживание моторного перевозочного средства, фрикционная муфта, оптимизация процесса, надёжность, утраты (расходы).

Détermination de la périodicité optimale pour la maintenance de l'embrayage à friction des véhicules

Il est possible de faire l'optimisation, c'est-à-dire de choisir le plus favorable système d'entretien, à l'aide d'une formation appropriée du modèle de maintenance. Ce problème est facile à résoudre si tous les exigences et limites importants sont définis avec précision. La méthodologie exposée est basée sur les paramètres de fiabilité des véhicules analysés. Ces paramètres ont été obtenus en observant le comportement des véhicules de point de vue de l'apparition de la défaillance dans les conditions réelles de l'exploitation ainsi que le coût de leur maintenance.

Mots clés: **maintenance du véhicule, embrayage à friction, optimisation du procès, fiabilité, coût.**