Serbian Tribology Society

SERBIATRIB '19

16th International Conference on Tribology

Faculty of Engineering University of Kragujevac

Kragujevac, Serbia, 15 – 17 May 2019

THE POSSIBILITY OF IMPROVING THE SAFETY OF TRAFFIC USING AN ADEQUATE SYSTEM FOR MAINTAINING THE VEHICLE'S CONTROL SYSTEM

Vojislav Krstić [1], Boris Antić[2]

[1,2)] Faculty of transport and traffic engineering, University of Belgrade, Beograd, Serbia,
vojislavkrstic33@gmail.com, mpeeric@gmail.com

Abstract: *Results of voluminous investigations of the control system reliability parameters, which were obtained by monitoring the behavior of the analyzed motor vehicle in the real exploitation conditions, from the aspect of failure occurrence of its motor engine, 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 control system maintenance, taking into account the criteria of maximal availability and minimal costs of its maintenance.*

Since the optimal periodicities of conducting the control system preventive maintenance, determined by criteria of maximal availability and minimal maintenance costs differ from each other, it was necessary to apply one of the multicriteria analysis methods.

The presented methodology of the multicriteria decision-making can be applied for obtaining the reliable value of optimal periodicity of conducting the preventive maintenance procedures also of other parts of the analyzed control system.

Keywords: *Safety of traffic using, Motor vehicle, Control system, Maintenance, Reliability, Availability, Costs*

1. INTRODUCTION

This work presents a possibility to find the optimal solution in the maintenance of the control system when the criteria functions are maximal availability and minimal maintenance costs. These two criteria lead to several solutions of the motor engine assembly maintenance; therefore, it was necessary to apply the multicriteria optimization.

By correct forming of the maintenance model it is possible to perform the optimization, namely to select the most favorable maintenance system. Such a problem can be solved if all the important requirements and restrictions are precisely determined. As the optimal periodicity of the preventive maintenance procedure of the analyzed control system, determined according to the criterion of the maximal availability differs from the optimal periodicity determined according to the criterion of the minimal costs, it is necessary to apply the multicriteria analysis methods and to determine the value of the required optimal periodicity, taking into account both mentioned optimization criteria. This actually is the basic goal of this work.

By the method of the compromise selection, the limits are determined of the optimal periodicity for the preventive maintenance procedure conducting, which correspond to extreme values of the adopted criterion functions. By applying the method of the multicriteria analysis, one determines the discrete value of this periodicity, whose exactness depends on selection of the discretization step of the analyzed time interval. Generally considering, the presented methodology of the multicriteria decision-making can be applied for obtaining the reliable value of the preventive maintenance procedure conducting periodicity of the technical systems. There one needs to know the availability of data, which are acquired by analysis of the control system during their operation and maintenance, based on which one can determine the indicators of their reliability, as well as the characteristics of their maintenance.

2. DETERMINATION OF PARAMETERS OF THE CONTROL SYSTEM RELIABILITY

Determination of the control system reliability distribution law represents the Basis for evaluation of its state, as well as for decision-making on when, i.e., after how many working hours, one should conduct procedures of the preventive maintenance. Determination of the most acceptable model of the reliability distribution, based on data on its behavior, from the aspect of irregularities appearance, is a complex task and it is solved by application of the corresponding algorithm [1], with application of the probability theory, mathematical statistics and the reliability theory [2].

Based on voluminous research of the control system behavior, in the real exploitation conditions, for a longer period of operation, in Table 1 are presented the working times until occurrence of failure and between the two consecutive failures.

Estimated values of the control system reliability indicators, based on data from Table 1, are determined using the known methodology [1] and presented in the table 2. Based values of deviation of the reliability theoretical values, obtained by testing the corresponding hypotheses by application of the known methodology [2], from results of the estimated values, obtained from the exploitation data (Table 1), one came up to the conclusion that the Weibull's two-parameter distribution, with the shape parameter 2.68 and scale parameter 450, was the most acceptable for the analyzed vehicle sample.

Table 1. The working times until occurrence of failure

Failure number (i)	Working time till failure (h)	Number of km passed till failure (km)	Failure number (i)	Working time till failure (h)	Number of km passed till failure (km)	Failure number (i)	Working time till failure (h)	Number of km passed till failure (km)
1	383	11496	13	472	14158	25	599	17963
2	394	11831	14	479	14373	26	637	17981
3	395	11863	15	480	14396	27	640	19100
4	399	11878	16	485	14563	28	655	19196
5	413	12382	17	492	14763	29	663	19638
6	426	12778	18	531	15938	30	671	19882
7	431	12935	19	547	16397	31	716	20125
8	440	13186	20	566	16967	32	788	21492
9	448	13431	21	573	17186	33	823	23651
10	459	13757	22	579	17384	34	880	24697
11	465	13952	23	591	17726	35	913	26391
12	466	13972	24	592	17752	36	913	27391

Table 2. Estimated values of the control system reliability indicators

Number, (i)	Time, (t_i)	Number of failures, n(t_i)	Frequency of failure occurrence, f (t_i)	Reliability, R (t_i)	Unreliability, F (t_i)	Failure intensity λ (t_i)
1	400	12	0,00245	0,5520	0,4480	0,00318
2	500	10	0,00204	0,3478	0,6522	0,00360
3	600	9	0,00184	0,1643	0,8357	0,00519
4	700	4	0,000816	0,0824	0,9176	0,00520
5	800	2	0,000408	0,0426	0,9574	0,00530
6	900	2	0,000408	0,0212	0,9788	0,01020

Table 3. Control system maintenance costs for various periodicities of its preventive maintenance

Maintenance frequency (h)	120	140	180	1120	1160	1200	1250	1300	1350	1400	1450
Costs of corrective maintenance (Ck)	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
Costs of preventive maintenance (Cp)	600	600	600	600	600	600	600	600	600	600	600
Reliability R(t)	0,997	0,988	0,9831	0,9536	0,906	0,841	0,7599	0,6666	0,5663	0,4649	0,3679
$\int_0^T R(t)dt$	50	99,84	99,80	148,78	195,43	239,15	279,09	314,75	345,65	371,36	392,10
Total specific costs C(t)	14,11	7,40	6,50	5,86	5,11	4,01	4,32	4,41	4,63	5,25	5,55
$f_{i,,2}$	12,11	6,40	5,48	4,76	4,21	4,11	4,22	4,44	4,73	5,05	5,41

Adopting this reliability distribution law for the control system of the analyzed technical system, expressions for determination of the reliability function *R(t)*, the density function *f(t)* and failure intensity $\lambda(t)$, can be written in the following forms:

$$R(t) = e^{-(\frac{t}{450})^{2,68}} \quad (1)$$

$$f(t) = \frac{2,68}{450} \cdot (\frac{t}{450})^{1,68} \cdot e^{-(\frac{t}{4450})^{2,68}} \quad (2)$$

$$\lambda(t) = \frac{2,68}{450} \cdot (\frac{t}{450})^{1,68} \quad (3)$$

Based on the previous expressions, the optimal periodicity of the working time can be determined, after which either of the following should be performed: preventive inspections, preventive substitutions, repairs or general revisions, as well as providing the optimal values of spare parts stocks [3].

3. DETERMINATION OF THE CONTROL SYSTEM PREVENTIVE MAINTENANCE PERIODICITY BASED ON CRITERION OF THE MINIMAL MAINTENANCE COSTS

Providing for the required availability and reliability of the control system, with minimal maintenance costs, is possible if one correctly determines the periodicity interval of that maintenance [3].

The total control system maintenance costs can be expressed in the form [3]:

$$C(t) = \frac{C_k - (C_k - C_p) \cdot R(t)}{\int_0^T R(t)dt} \quad (4)$$

where: *C(t)* are the total specific maintenance costs; $C_k$are the corrective maintenance costs and C_p re the preventive maintenance costs.

By application of expression (4) for various periodicities of the control system maintenance, the values for the maintenance costs are obtained shown in Table 3.

Based on results shown in Table 3, one can conclude that the lowest maintenance costs of the analyzed technical system clutch are obtained for the maintenance periodicity of 1200 working hours.

4. DETERMINATION OF THE CONTROL SYSTEM PREVENTIVE MAINTENANCE PERIODICITY BASED ON CRITERION OF MAXIMAL AVAILABILITY

Since the most acceptable model of reliability, distribution is determined and since the time picture of the control system of the analyzed control 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 [3]. By application of this model, the exploitational reliability of the control system, from the aspect of the frictional control system, can be determined by using the expression:

$$G(t)=\frac{t_p+t_{cr}}{t_p+t_{cr}+t_o+\frac{F(t)}{R(t)}\cdot t_k} \quad (5)$$

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. Results of determination of availability, for various maintenance periodicities of the control system of the considered control system, are shown in Table 4.

Based on results shown in Table 4 and in Figure 2 it can be concluded that the highest availability of the analyzed control system, from the aspect of its clutch, is obtained for the maintenance periodicity of 1300 working hours.

5. DETERMINATION OF THE OPTIMAL PERIODICITY OF THE PREVENTIVE MAINTENANCE OF THE CONTROL SYSTEM BY APPLICATION OF THE MULTICRITERIA OPTIMIZATION

The value of the preventive maintenance periodicity of the analyzed control system 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 considered concept of the preventive maintenance. In that way, one obtains the corresponding number of

Table 4. Motor vehicle availability as a function of its control system preventive maintenance periodicity

Maintenance periodicity (h)	1160	1200	1250	1300	1350	1400	1450
Working time t_r (h)	1160	1200	1250	1300	1350	1400	1450
Preventive maintenance time t_p (h)	20	20	20	20	20	20	20
Unreliability F	0,016	0,046	0,093	0,159	0,240	0,333	0,433
Reliability R	0,906	0,841	0,7599	0,6666	0,5663	0,4649	0,3679
Number of corrective maintenances between the two preventive ones	0,017	0,048	0,103	0,189	0,316	0,500	0,765
Time of corrective maintenance k_k (h)	1,03	2,92	6,21	11,35	18,96	30,01	45,95
Time spent on waiting while in order $t_{čr}$ (h)	30	45	60	75	90	105	120
Availability G(t)	0,983	0,984	0,985	0,986	0,981	0,978	0,977
$f_{I,,2}$	0,983	0,985	0,984	0,983	0,981	0,978	0,977

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 criterion of maximal availability and criterion of minimal costs differ from each other (parts 3 and 4 of this paper), in this part are presented results of determination of the periodicity by application of the multicriteria optimization method, which is known in literature as the MCDM (Multi Criteria Decision making) problem [5]. 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.

In literature can be found a large number of multicriteria optimization methods [5]. One of the most frequently used methods is the Analytical Hierarchy Process [7]. The AHP method was developed based on the principle of decision making, human knowledge, as well as on data that are available to experts in the process of decision making. That process is a creative one, which is based on three main concepts: analytics, hierarchy and process [3].

The nature of the optimality criterion can be benefit wise and coastwise [6]. 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 less their values are the better and vice versa.

The set of alternatives i is being represented by the set of alternative indices i = (1, … i, … I) where I is the total number of the considered alternatives. The problem is represented by matrix F = $[f_{ik}]_{,1\times K}$. Here f_{ik} denotes the optimality criterion k for alternative i. In the general case, the optimality criteria are of various natures; they have different values and different units. This means that the optimality criteria values, for alternative are not comparable. From that reason it is necessary to perform the normalization procedure by which all the values of f_{ik} are being mapped within interval [0, 1]. At present, a large number of the normalization types are being used[7]: simple, linear, vectorial, etc. regardless of which type of normalization is being used, different expressions are used for benefit wise and coastwise optimality criteria. When the vectorial normalization is applied, the decision making process can be represented by matrix F = $[f_{ik}]_{,1\times K}$, where $(f_{ik})_{,n}$ is the normalized value of the optimality criterion k for alternative i. To each considered alternative, certain value is being associated [7].

Normalization of values $f_{i,1}$ is being done by application of the expression for vectorial normalization and by application of the benefit wise optimality criterion. For solving the concrete task the following expressions can be used:

$$(f_{i,1})_n = f_{i,1} \Big/ \Big(\sum_{i=1}^{7}(f_{i,1})^2\Big)^{1/2} \qquad (6)$$

$$(f_{i,2})_n = (1/f_{i,2}) \Big/ \Big(\sum_{i=1}^{7}(1/f_{i,2})^2\Big)^{1/2}. \qquad (7)$$

The value of the factor based on which the best alternative of the maintenance periodicity a_i is being determined by application of the assumption that validities of the adopted optimization criteria (maximal availability and minimal maintenance costs) are equal and that they are set as normalized, what is the case in this concrete task, by application of the following expression [7]:

$$a_i = \frac{1}{k}\sum_{k=1}^{K}(f_{ik})_n = \frac{1}{2}\cdot\left[(f_{i,1})_n + (f_{i,2})_n\right]. \qquad (8)$$

The optimal value of the periodicity of conducting the preventive maintenance of the motor vehicle's control system is within interval of 1200 to 1300 working hours, because the limits of that interval were obtained based on criterion of the control system maintenance minimal costs and criterion of the maximal availability in that interval.

Table 5. Availability of the motor vehicle from the aspect of its control system

Alternative number (i)	Control system maintenance periodicity (h)	Vehicle's availability (G) from the control system aspect	$f_{i,1}$	$(f_{i,,1})_n$	Total specific maintenance costs (C)	$f_{i,,2}$	$(f_{i,,2})_n$	a_i
1	1200	0,9841	0,9841	0,369	4,11	4,11	1,54	1,012
2	1210	0,9842	0,9842	0,364	4,19	4,19	2,80	1,554
3	1220	0,9843	0,9843	0,369	4,20	4,20	3,43	1,995
4	1230	0,9844	0,9844	0,369	4,24	4,24	3,43	2,096
5	1240	0,9845	0,9845	0,361	4,30	4,30	3,44	2,097
6	1250	0,9846	0,9846	0,362	4,32	4,32	3,45	2,098
7	1260	0,9847	0,9847	0,351	4,33	4,33	3,45	2,099
8	1270	0,9853	0,9853	0,353	4,35	4,35	3,45	2,026
9	1280	0,9854	0,9854	0,351	4,36	4,36	3,57	1,967
10	1290	0,9860	0,9860	0,346	4,39	4,39	3,27	1,896
11	1300	0,9863	0,9863	0,335	4,44	4,44	3,15	1,879

The interval is being divided into 11 equal parts (Table 5).

Elements of matrix F are being obtained in such a way that they are being made equal to values of the analyzed motor vehicle availability, from the aspect of its control system, for various periods of the preventive maintenance that correspond to individual alternatives ($f_{i,1}$) and by making them equal to values of the total control system maintenance costs for different periods of preventive maintenance that correspond to individual alternatives ($f_{i,2}$).

Based on data obtained by monitoring the analyzed control system, from the aspect of its control system, in real exploitation conditions, by application of expression (5) for determination of availability, obtained were the values of elements $f_{i,\ 1}$ (namely the availabilities) of matrix F, while by application of expression (4) for determination of the maintenance costs obtained were the values of elements $f_{i,2}$ (namely the maintenance costs) of matrix F (Table 5).

The best alternative is one for which the value of factor a_i has the highest value. The values of this factor, calculated by application of expression (8) are given in table 5 based on those values and by recognizing the aforementioned, it can be concluded that the optimal value of periodicity of conducting the preventive maintenance procedures of the analyzed control system, from the aspect of its control system, is after every 1260 working hours.

6. CONCLUSIONS

Results of voluminous investigations of the motor vehicle’s control system reliability parameters, which were obtained by monitoring the behavior of the analyzed control system the real exploitation conditions, from the aspect of failure occurrence of its control system, 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 control system maintenance, taking into account the criteria of maximal availability and minimal costs of its maintenance.

Since the optimal periodicities of conducting the control system preventive maintenance, determined by 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 maintenance procedures of a control system was determined according to maximal availability criterion to be 1200 working hours, while according to criterion of minimal maintenance costs that value was 1300 working hours.

By application of the multicriteria analysis the value of the required optimal periodicity of conducting the preventive maintenance procedures of a control system, with taking into account both optimization criteria, was 1260 working hours.

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

REFERENCES

[1] BS5760 *British Standard - Part 2, Guide to the assessment of reliability, Reliability of systems, equipments and components*, 1981.

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

[3] T.L. Saaty: How to Make a Decision: The Analytic Hierarchy Process, European Journal of Operational Research, Vol. 48, pp. 9-26, 1990.

[4] P. Kaur, S. Chakrabortyb: A New Approach to Vendor Selection Problem with Impact Factor as an Indirect Measure of Quality, Journal of Modern mathematics and Statistics, Vol. 1, No. 1, pp. 8-14, 2007.

[5] J. Puente, P. de la Fuente, R.P. Priore: ABC classification with uncertain data: a fuzzy model vs. A probabilistic model.*Applied* Artifical Intelligence, Vol. 16, No. 6, pp. 443-456, 2002.

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

[7] R. Ramanathan: ABC inventory classification with multiple-criteria using weighted linear optimization, Computers & Operations Resarch, Vol. 33, No. 3, pp. 695-700, 2006.

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

[9] C.W. Chu, G.S. Liang, C.T. Liao: Controlling inventory by combining ABC analysis and fuzzy classification, Computers & Industrial Engineering, Vol. 55, No. 4, pp. 841-851, 2008.

[10] J.C. Pomerol, S. Barba - Romero: *Multicriterion Decision in Management: principles and Practice*., Kluwer Academic Publishers, 2000.

[11] Bass, S.M., &Kwakernaak, H. (1977). Rating and Ranking of multiple-aspect Alternatives using Fuzzy sets.*Automatica*, *3*(1), 47-58.

[12] D. Dubois, H. Prade: Decision –making under fuzziness, In M.M. Gupta, R.K. Ragade, R.R. Yager (Eds.), *Advances in Fuzzy set Theory and Applications*, North-Holland, pp. 279-302, 1972.

[13] K.P. Yoon, C.I. Hwang: *Multiple Attribute Decision Making: An Introduction (Quantitative Applications in the Social Sciences)*, Sage University Paper Inc, 1995.

[14] D. Pavličić: Normalization of Attribute Values in MADM the Conditions of Consistent Choice IV, DI and α, Yugoslav journal of operations research, Vol. 10, No. 1, pp. 109-122, 2000.