BALKANTRIB'O5
5th INTERNATIONAL CONFERENCE ON TRIBOLOGY
JUNE.15-18. 2005
Kragujevac, Serbia and Montenegro

DETERMINATION OF THE OPTIMAL STRATEGY FOR PREVENTIVE MAINTENANCE OF HIGH PRESSURE PUMPS VEHICLES USING POLYCRITERION OPTIMIZATION

Prof. dr Božidar V. Krstić
Faculty of Mechanical Engineering,
Kragujevac, Serbia $ Montenegro

Abstract

This work presents a possibility to find the optimum solution in the maintenance ofhigh pressure pump systems when the criteria functions are maximal avalability and minimal costs maintenance. These two criterions lead to several solutions of the maintenance of high pressure pump systems therefore it was necessary to seek for a trade off solution.

Key words: *motor vehicle, maintenance, optimisation, reliability, availability, costs*

1. INTRODUCTION:

The optimisation of maintenance system with application model of preventive maintenance, is often completed findingn answer if it is usefull to applicate preventive maintenance, and if it is, fluid how much work time is to applicate dealings of preventive maintenance.
The aim of work is determinating optimal maintenance strategics of the high pressure pumps vehicles using polycriterion optimization, ordered concrete vehicle, on base shoving its reliability, as follows frow data of exploatation.

2. DETERMINATION OF THE PARAMETER RELIABILITY THE HIGH PRESSUR PUMPS VEHICLES

By reasai of planing maintenance measure a motor vehicle, foreseeing its duration life and quality mark of vehicle constituent parts, as whole vehicle, it's necessary to find parameters its maintenance.
The best frequent ordered parameters of maintenance are: frequency phenomenon of notice, reliability, unreliability, notice intensity and work time without notice.
If it's possibly find laufulness, which desobey function of reliability distribution, it's possibly find all maintenance parameters, too that lawfulness is possibly find if exist data about phenomenon of notice the vehicle during its using.
On base those data, it's possibly find lawfullness of notice phenomenon during the work time.
Finding corresponding matematics model, which can present lawfulness of wehicle behavior, in point of wiew phenomenon of incorrectivess, is one of fundamental elements for prognosis vehicle behaviour in the future and optimization of system its maintenance.
In consideration of correctivess fortifying of model reliability distribution dependent all other conclusions and determination maintenance denand level of vehicle reliability, there ought to initiate special cantion this analysis phase. On base fortified model of reliability distribution, there can plan measure of vehicle maintenance, there can foresee duration life same vehicle elements, as whole vehicle, there can plan dynamics praiding.
A for reserved parts and get conclusions about canse of notice phenomenon. On conkrete example selected rehicle there represent methodology order the most acceptable model of high pressure pumps vehicles maintenance.
Namely, there is used high pressure pumps vehicles which built in motor vehicle TAM110T7B/BV-4x4 as research object. The worth of work time till notice phenomenon,

preliminary quoted working motor, which follow from escorting vehicle in exploatation, there get in the table 1.

Appraised worths of reliability indicators high pressure pumps vehicles, which follow from table 1, are ordered using known methodology [9,11,12]and presented in the table 2.

Using known methodology to order laufllueѕs reliability distribution [11,12], and an base abstain worth theory distribution from results appraisede worths and exploitation data, there is reached till

Table 1. The worth of work time till notice phenomenon the high pressure pumps of vehicle TAM110T7B/BV

Ordinal number of notice i	Path till notice (km)	Work time till notice (h)	Ordinal number of notice i	Path till notice (km)	Work time till notice (h)	Ordinal number of notice i	Path till notice (km)	Work time till notice (h)
1	5908	197	18	10273	342	35	14521	484
2	6397	213	19	10715	357	36	15574	519
3	6998	233	20	10805	360	37	16384	546
4	7127	238	21	11126	371	38	17200	573
5	7195	240	22	11367	379	39	17255	575
6	7494	250	23	11636	388	40	17725	591
7	7538	251	24	11864	395	41	17856	595
8	7856	262	25	11973	399	42	18263	609
9	7963	265	26	11997	400	43	18693	623
10	7976	266	27	12351	412	44	19840	661
11	8472	282	28	12395	413	45	19947	665
12	8793	293	29	12705	424	46	22067	736
13	9020	301	30	13973	466	47	22167	739
14	9563	319	31	14167	472	48	22736	758
15	9870	329	32	14209	474	49	24317	811
16	9892	330	33	14286	476	50	25863	862
17	10234	341	34	14314	477	51	28396	947

Tabela 2. Apprais worth of reliability indicators high pressure pumps of vehicle TAM110T7B/BV

Ordinal number (i)	Time (t_i)	Number of notice $n(t_i)$	Frequency of notice phenomenon $f(t_i)$	Reliability $R(t_i)$	Underliability $F(t_i)$	Notice intensity $\lambda(t_i)$
1	100	2	0,000364	0,9636	0,0364	0,00036
2	200	8	0,001455	0,8182	0,1818	0,00150
3	300	12	0,002182	0,6000	0,4000	0,02667
4	400	11	0,002000	0,4000	0,6000	0,00333
5	500	8	0,001454	0,2546	0,7454	0,00363
6	600	6	0,001091	0,1455	0,8545	0,00428
7	700	4	0,000727	0,0728	0,9272	0,00500
8	800	2	0,000364	0,0364	0,9636	0,00500
9	900	2	0,000365	0,0181	0,9818	0,01000

conclusion that Raily reliability distribution is the most acceptable model for analytic high pressure pumps vehicles.

Accepting this law of reliability distribution, expresions for ordering reliability, frequency of notice phenomenon, notice intensuty and mean work time without notice can be in these forms:

$$R(t) = e^{-(\frac{t}{450})^{1,8}} \quad (1)$$

$$f(t) = \frac{1,8}{450} \cdot (\frac{t}{450})^{0,8} \cdot e^{-(\frac{t}{450})^{1,8}} \quad (2)$$

$$\lambda(t) = \frac{1,8}{450} \cdot (\frac{t}{450})^{0,8} \quad (3)$$

On base preliminary expressions there can order optimal frequency of work time, after which it's to do preventive rewiew, prewentive changes, repairings or general revision, and optimal worths of reserved parts store [9,10,11,12].

3. DETERMINATION OPTIMAL WORTH OF MAINTENANCE FREQUENCE HIGH PRESSURE PUMPS VEHICLES BY CRITERION OF MINIMAL COSTS

Using model of optimization of maintenance frequency high pressure pumps vehicles, by maintenance costs, there is ordered optimal frequency of converging the process of preventive maintenance, which brings the least costs with provision demanded availability. Strategy of preventive maintenance and preventive changes is used when intensity of notice is increasing function for time and costs of corective maintenance are larger then costs of preventive maintenance. Than, it's possibly order optimal frequency of preventive maintenance.

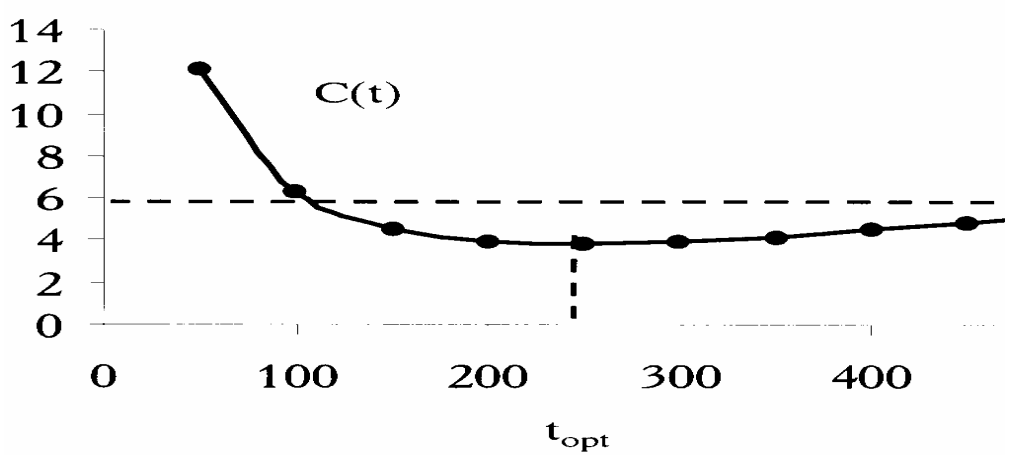
Maintenance costs can be in this form [9]:

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

In the expresion (6) sing have these mainings: C(t) – all specific costs of maintenance; C_k – costs of corective maintenance, C_p – costs of preventive maintenance.Using expresion (6), for different frequency of preventive maintenance high pressure pumps vehicles, there are got worths of maintenance costs, which are presented in the table 3 and picture 1.

Table 3. Costs of maintenance high pressure pumps vehicles of vehicle TAM110T7B/BV, for diferent frequency its preventive maintenance

Frequency of maintenance (h)	100	150	200	250	300	350	400
Costs of corective maintenance C_k (n.j.)	6	6	6	6	6	6	6
Costs of preventive maintenance C_p (n.j.)	12	12	12	12	12	12	12
Reliability R(t)	0,9355	0,8707	0,7927	0,7067	0,6176	0,5293	0,4453
$\int_0^T R(t)dt$	98,63	143,82	185,41	222,88	255,94	285,77	308,86
All specific cists C(t) (n.j.)	15,31	12,66	11,84	11,70	11,86	12,16	12,51
$f_{i,,2}$	15,31	12,66	11,84	11,70	11,86	12,16	12,51



Picture 1. *Reviev dependence of maintenance costs high pressure pumps vehicles, from frequency its maintenance*

On base presented results in table 3 and picture 1, there can be concluded that the least maintenance costs high pressure pumps vehicles of vehicle TAM110T7B/BV are got for maintenance frequency of 250 work hours.

4. DETERMINATION OPTIMAL WORTH OF MAINTENANCE FREQUENCY WORKINGHIGH PRESSURE PUMPS VEHICLES BY CRITERION OF MAXIMAL AVAILABILITY

When maximal avilability is found by vehicle, optimisation of maintenance system its constituentn parts is done by criterion of maximal availability, vhile the most, but still acceptable, maintenance costs present limitation.

It's need to know law of reliability distribution, and time in work and notice for using maintenance model, on base availability[9].

The vorth of exploatation availability can be ordered using expression [9]:

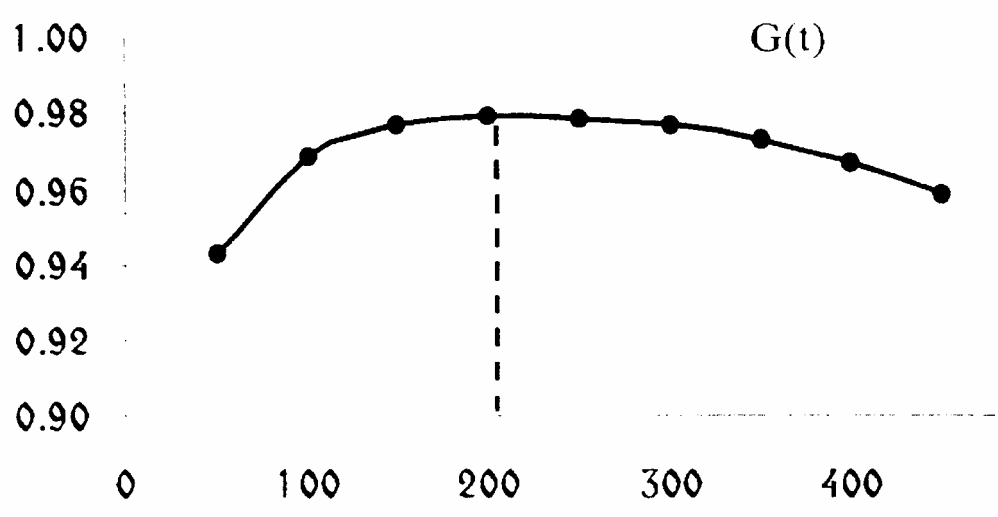
$$G(t) = \frac{t_r + t_{cr}}{t_r + t_{cr} + t_p + \frac{F(t)}{R(t)} \cdot t_k} \qquad (5)$$

vhere are: t_r – vork time; t_{cr} – waiting time for work in accurate state; t_p – preventive maintenance time; t_k – corective maintenance time.

Variating frequency time betven preventive maintenance, there is got function dependent availability from maintenance frequency, an base which it can order maintenance frequency which brings maximal availability. The results of ordering availability are gat in the table 3, for different maintenance frequency.

Table 4. Tabular review of availability dependence vehicle TAM110T7B/BV from preventive maintenance frequency its high pressure pumps vehicles

Maintenance frequency (h)	100	150	200	250	300	350	400
Work time t_r (h)	100	150	200	250	300	350	400
Time of preventive maintenance t_p (h)	21	21	21	21	21	21	21
Unreliability F	0,0645	0,1293	0,2073	0,2933	0,3824	0,4707	0,5547
Reliability R	0,9355	0,8707	0,7927	0,7067	0,6176	0,5293	0,4453
Number of corective maintenances between two preventive maintenajnces	0,0689	0,1485	0,2615	0,4150	0,6192	0,8893	1,2457
Time of corective maintenance k_k (h)	7,23	15,59	27,46	43,58	65,02	93,38	130,80
Waiting time for work t_{cr} (h), in accurate state	300	450	600	750	900	1050	1200
Availability G(t)	0,9341	0,9425	0,9429	0,9393	0,9331	0,9251	0,9133
$f_{I,2}$	0,9341	0,9425	0,9429	0,9393	0,9331	0,9251	0,9133



Picture 2. *Review of availability dependence vehicle TAM 110T7B/BV from preventive maintenance frequency its high pressure pumps vehicles*

On base results which it's got in table 4. And in picture 2 there can be concluded that the best availability high pressure pumps vehicles of vehicle TAM110T7B/BV is got for maintenance frequency of 200 work hours, by using criterion of maximal availability.

5. DETERMINATING OPTIMAL FREQUENCY OF PREVENTIVE MAINTENANCE HIGH PRESSURE PUMPS VEHICLES USING POLYCRITERION OPTIMIZATION

Optimal frequency of preventive maintenance high pressure pumps vehicles vorth is between time with minimal costs, and time with maximal availability. This period could be diskrezation. Each diskrete worth got by diskretization is join to considered conception of preventive maintenance. In that way we get corresponding number of conception variants of preventive maintenance, which are only diferent in length of frequency they work, after which preventive maintenance procedure is done. As the worths of optimal period while processes of preventive maintenance of analizing motor vehicle are done, are diferent to maximal availability and minimal costs criterians (inthis work, part 4 and 5) in this part of work, results of it's determinating using polycriterion optimization methods are shown, polyeriterion optimization methods are known in literature as MCDM (Multi Criteria Decision Making) problem [3]. Fundamental characteristic of MCDM problem, and according to a problem which is being analyzed in this work, is that the best alternative is in sense with more atribut simultano, or limitedgroupm of alternatives we have.

In literature can be faund great number of polycriterian optimization methods. On the most use in Analytic Hiearchy Process (AHP). AHP method was developed an principle of decision, man knowledge, as like on date which experts hove in procedure of decision. Decision procedure is creative procedure, which is scientific planned on three fundamental principles [6]: Analytic, Hiearchy and Procedure.

The optimization criterion dissition could be benefit or cost [1].

Either we use benefit or cost optimization criterion, if its worth is less, that is better and inverse.

Group of alternatives is presented as group of alternatives indexes, I=(1,…,I,…,I), where I is number of all considered alternatives. Problem is presentede with matrix $F=[f_{ik}]_{1xK}$. With f_{iK} is presented the worth of optimization criterion k for alternative i. In general case, optimization criterions are with diferent disposition, they aave different worths, and diferent measures. That means that the worths of optimal criterion, for alternative I aren't parallel. From that reason it is necessary daing normalization procedure, with whom all worths f_{ik} are copyed to interval [0,1]. There is a great number of normalization types in use [4]: simple, linear, vector etc. Withaut regard to which type of normalization is used, we use different analytic formula for benefoit and for cost criterion of optimization.

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

Each considered alternative is join to determined worth [2]. Normalizing worth $f_{i,,1}$ is done using expression for vector normalization, and using benefit optimal criterion.

For solving concrete task, there can be used next expressions:

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

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

The worth of factory on whom it is determined the best alternative of periodic maintenance a_I is determined using suppositing that importances of adopted optimization criterions (maximum availability, minimal maintenance costs) are equal, and they are given normalized, which is case in concrete task using expresions:

[1,2,3,4,5,6,7,8]:

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

Examine time interval between 100 and 400 work hours of high pressure pumps vehicles, because the worth of costs and the worth of availability anylysed working vehicle motor have acceptable worth. Espeid time interval is parted an 11 equal parts, with step of 100 working hours (Table 5).

Elements of matrix F, are got, in this way by equalizing the worths of maximal availability, from view of its motor vehicle, for different disposition of preventive maintenance which corresponds to single alternatives ($f_{i,1}$) and equalizing with the worth of total costs of maintenance motor vehicle, for different periods of preventive maintenance which correspond to single alternative ($f_{i,2}$).

On based data got by atterding analyzed vehicle from vien of its worhing motor, in real conditions of exploitation worths of elements $f_{i,,1}$ were got (respectively availability) using expressions (5) to determine availability, and the worths of elements $f_{i,,2}$ were got (respectively costs of maintenance), using expressions (6) to determine costs of maintenance.

**Table 5. Availability from view of high pressure pumps vehicles (the worths of $f_{i,1}$ in matrix F) and costs of maintenance (the worth of $f_{i,2}$ in matrix F) for different frequency of high pressure pumps vehicle TAM110T7B/BV, prevent maintenance, normalized worths of matrix's F elements ($(f_{i,1})$, $f_{i,2})_n$) and worth of factor on based which is determined the best alternative of periodic maintenance a_i **

Alternative ordinal number (i)	Periodic maintenance of working motor (h)	Availability of motor vehicle (G) from view of working motor	$f_{i,1}$	$(f_{i,,1})_n$	Total specific costs of maintenance (C)	$f_{i,,2}$	$(f_{i,,2})_n$	a_I
1	100	0,8453	0,8453	0,3593	41,47	41,47	1,6482	1,0037
2	150	0,9031	0,9031	0,3839	23,54	23,54	2,9020	1,6429
3	200	0,9155	0,9155	0,3892	19,40	19,40	3,5303	1,9597
4	210	0,9188	0,9188	0,3899	19,35	19,35	3,5346	2,0012
5	220	0,9201	0,9201	0,3913	19,33	19,33	3,5412	2,0124
6	230	0,9212	0,9212	0,3922	19,25	19,25	3,5543	2,0872
7	240	0,9168	0,9168	0,3822	19,00	19,00	3,5554	2,0751
8	250	0,9132	0,9132	0,3832	18,63	18,63	3,5563	2,0301
9	300	0,9028	0,9028	0,3838	19,22	19,22	3,6764	1,9692
10	350	0,8854	0,8854	0,3764	20,30	20,30	3,3740	1,8752
11	400	0,8605	0,8605	0,3658	21,64	21,64	3,1651	1,7654

The best alternative is are for which the worth of factor a_I is the biggest. The worth of this factor, determinated used expression (8) are given in Table 5. On based that worths and with

appreciation before told, it can be conclude that optimal periodic daing procedure of preventive maintenance, high pressure pumps vehicles TAM 110 T7B/BV – 4x4, from view of its high pressure pumps vehicles, after each 230 using hours.

6. CONCLUSIONS

The Results of datailed research of parameters reliability high pressure pumps vehicles to which was came, attending disposition of 400 vehicles in real conditions of exploatation, from view of high pressure pumps vehicles vehicle warning appearance, and with use of corresponding scientific krow ledge of probability theory, mathematic statistic, theory of systems, and availability theory, serve as base for finding optimal periodic of high pressure pumps vehicles maintenance, taking into consideration maximum availability and minimal cost criterions.

How optimal periods of doing preventive maintenance procedure, determined to maximal availability and to minimal cost criterion are diferent, it is necessary to use polycriterion analyses and determine wanted optimal frequencu of doing preventive maintenance procedure, include maximal availability and minimal costs criterons. The worth of optimal period of doing preventive maintenance, is determined to maximal availability criterion of vehicle is 200 working hours, and to minimal cost of maintenance criterion is 250 working hours.

Using methods of polycriteron analyze, it was determinated worth of wanted optimal frequency of doing preventive maintenance procedure, taking into consideration both criterions of optimization, and it is 200 working hours. Using compromise choice's'method, limits of optimal frequency of doing preventive maintenances procedure, which corresponds to extrem worth functions of criterions. Using polycriterion analyze's methods, discrete worth of periodic frequence of doing preventive maintenance procedure were determined, whose working depends upan choice of step size analyzing time interval. Shown methodology of polycriterion could be used for determinating the reliable worth of period of doing preventive maintenance the vehicle.

It is necessary free use of data, to which is came analyzing vehicle during its exploitation, on based which could be determinated its reliability, and system characteristics its maintenance.

7. LITERATURE

[1] Yoon K.P., Hwang C.I.: Multiple Attribute decision making, and introduction, Series: Quantative Aplications in the Social Sciences 104, Sage Universitz Paper, Thousland Oaks, 1995.

[2] Bass. M.S., Kwakernak H.: Rating and Ranking of Multiple Aspect Alternatives Using, Fuyy Sets Automatics, Vol13, 47-58, 1977.

[3] Milanović D., ... :Informacioni sistemi menad`menta, Megatrend, Beograd, 2003.

[4] Pavličić D.: Normalization of atribute Values in MADM the Conditions of Consistent Choise IV, DI, EJOR, Vol.10, No. 1, Belgrade, 2000.

[5] Vincke P.: Multicriteria Decision – aid, John Wiely Sons, 1992.

[6] Saty T.L.:How to make a decision: The Analytic Hierarchy Process, EJOR 48, 9, 1990.

[7] Vargas L.: An overviev of the Analytic Hierarchy Process, EJOR 48, 1990.

[8] Harker T.P.: The Art and Science of Descision Making: The Analytic Hierarchy Process, Universyty of Pennsylvania, USA, 1988.

[9] Krstić B.: Eksploatacija motornih vozila i motora, Ma{inski fakultet, Kragujevac,1997

[10] D. Zelenović, J. Todorović: Efektivnost sistema u mašinstvu, Naučna knjiga, Beograd, 1990.

[11] British standard, BS5760, Part 2, Guide to the assessment of reliability, Reliability of systems, eqipments and components, BSI, London, 1981.

12] S. Vukadinović: Elementi teorije verovatnoće i matematičke statistike, Privredni pregled, Beograd, 1981.

[13] B. Krstić: Odredjivanje optimalne periodičnosti preventivnog održavanja vitalnih delova motornih vozila, Zbornik radova "KOD 2002", Herceg Novi, 2002., str. 37-49

[14] B. Krstić: Upravljanje random sposobnošću vozila radi obezbedjenja zadovoljavaju}ih eksploataciono-tehničkih karakteristika , " Savremena poljoprivredna tehnika", Novi Sad, 2002., str. 95-103

[15] B. Krstić: Utvrdjivanje zakonitosti promene tehničkog stanja vozila tokom eksploatacije sa ciljem pove}anja bezbednosti njegovog korišćenja, , Zbornik radova sa 12.Medjunarodne konferencije" IS'2002", Novi Sad, 2002., str. 295-299

[16] B. Krstić: Mogu}nost odredjivanja optimalne periodičnosti preventivnog održavanja vitalnih delova motornih vozila, Zbornik radova sa IV Simpozijuma sa medjunarodnim učešćem "Prevencija saobraćajnih nezgoda na putevima 98"", Novi Sad, 1998, str.347 - 352

[17] B. Krstić:Analysis of the motor vehicles reliability on the base of the data from service, Fiftin international scientific-tehnical conference on internal combustion engines and motor vehicles "MOTAUTO 98", Sofia-Vitosha, 14-16. October 1998., Bulgaria, p.88-93