MAINTENANCE COSTS MODELING OF SMALL ROAD VEHICLE FLEET

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Abstract: Reliability of the transport system shall be defined as the ability of a system or component to perform its required functions under stated conditions for a specified period of time. It is often reported in terms of a probability. Transport system, in theory defined as a „ system" is a complex of a few jointly working parts, which is intended to perform its required functions. Single part of the system is called unit. Margin of system reliability is probability of failure-free operation. Providing of transport system reliability means spend preventive and corrective maintenance costs.

Keywords: maintenance costs, maintenance interval, Weibull distribution

1. Introduction

The model consists of four vehicle combinations. Every vehicle can comes to failure state in operation and failure of every vehicle can evoke partial vehicle fleet failure. Complete vehicle fleet failure occurred, when two or more vehicle combinations are in failure, because remaining two or less vehicle combinations cannot fulfill transport tasks and this situation causes penalties for transport operator in case of the complete system breakdown. When a vehicle combination comes to failure state, promptly begins recovery of this vehicle combination.

In term of reliability the vehicle combination consist of two serial sequenced units (road tractor, semi-trailer) and a failure of one unit is a failure of whole vehicle combination. Four vehicle combinations make four parallel branches and every branch consist of two serial sequenced units.

2. Maintenance model

Failure occurrence probability of one vehicle combination or two vehicle combinations at once (1) presents system, where k-vehicles of n-vehicle combination are in failure. Vehicle combination presents serial sequencing of two units, the road tractor and semi-trailer (3). Solution of the model comes from source [2.].

$$p(k)=\frac{n!}{k!(n-k)!}F(x)^k(1-F(x))^{n-k} \qquad \begin{matrix} k = 0, 1, 2, ..n \\ 0 \le F(x) \le 1 \end{matrix} \qquad (1)$$

p(k) - probability density of Binomial distribution (-)
k - number of vehicle combinations in failure (-)

n - overall number of vehicle combinations (-)
F(x) - probability of elementary event occurrence, concretely failure occurrence probability of vehicle combination (-)

$$F(x) = 1 - \prod_{i=1}^{n} R_i(x) \qquad i = 1, 2, 3 .., n \qquad (2)$$

F(x) - failure probability of vehicle combination (-),
$R_i(x)$ - reliability of system units (-).

Behavior of system unit reliability in dependence on mileage is given by complement to distribution function of Weibull distribution (3):

$$R(x) = e^{-\left(\frac{x-c}{x_0}\right)^m} \qquad (3)$$

R(x) - reliability in dependence on vehicle combination mileage (-),
x - mileage (km),
x_0 - scale parameter (km),
m - shape parameter (-),
c - location parameter (km).

From formulas showed above we state the following result. Elementary failure probability F(x) is a continuous function, whose value changes in dependence on vehicle combination mileage.
Values of distribution function parameters used in model come from LCC analysis of vehicle combinations [3.].

Tab. 1. Parameters used for reliability

Vehicle	**c** (km·10^3)	**m**	**x_0** (km·10^3)
Road tractor	0	1,8	150
Semi-trailer	0	1,6	280

3. Model of the maintenance costs

Preventive maintenance system strategy is based on researching the influence of scheduled maintenance interval change to the final maintenance costs. Model of the system assumes, that due the preventive maintenance a partial and critical failure of the vehicle fleet was not prevent. But the needed costs to repair these failures will have different trends depended preventive maintenance interval.

System renewal final costs:

$$N_c = N_o + N_p + N_k \qquad (4)$$

N_o - preventive maintenance costs of vehicle fleet (MU – monetary unit),
N_p - partial failure clearing costs of vehicle fleet (MU),
N_k - complete failure clearing costs of vehicle fleet (MU).

$$N_o= Q/O \times D_0 \tag{5}$$

$$N_p = P_1 \times D_1 \tag{6}$$

$$N_k = P_2 \times D_2 \tag{7}$$

O - scheduled maintenance interval (km),
Q - total vehicle combination distance moved in 1 year (km),
D_0 - scheduled maintenance costs (MU),
P_1 - partial failure occurrence probability of vehicle fleet (-),
D_1 - partial failure clearing costs of vehicle fleet (MU),
P_2 - complete failure occurrence probability of vehicle fleet (-),
D_2 - complete failure clearing costs of system with penalties (MU).

The costs D_0 and D_1 are maintenance costs of the vehicle fleet, in the situation when only one vehicle combination is in failure state and other vehicle combinations are in operation. Because other three vehicle combinations can fulfill transport task this situation causes no penalties. The sum of these costs D_0 and D_1 is 1. Cost model D_2 includes penalties for transport operator in case of complete system breakdown (as multiple "u" of sum D_1+D_2), because rest of the vehicle fleet cannot fulfill transport task.

Tab. 2. Maintenance costs of vehicle combination

D_0 = 0,6 (MU)	D_1 = 0,4(MU)	D_2 =(D_1+D_2).u (MU)

Lengthening of the preventive maintenance interval means grow of the partial failure probability and complete failure probability of fleet. But preventive maintenance costs will be lower.

Is possible to find preventive maintenance interval, where the sum of all costs (preventive maintenance, repair maintenance) will be minimal.

Tab. 3. Calculated results (for multiple u=12)

Failure origination probability of vehicle fleet (Q = 300 000 km/year)							
O – maintenance interval (km*10^3)	20	40	60	80	100	120	140
N – number of inspection (-)	60	30	20	15	12	10	8,57
F(x) - failure occurrence vehicle combination probability (-)	0,0404	0,1281	0,2421	0,3670	0,4906	0,6043	0,7027
P_1 – partial failure probability (1 of 4) vehicle combination (-)	0,1429	0,3396	0,4216	0,3723	0,2594	0,1498	0,0738
P_2 - complete failure probability (2 and more of 4) vehicle combination (-)	0,0093	0,0824	0,2485	0,4671	0,6733	0,8257	0,9183
Vehicle fleet maintenance costs (MU/year)							
N_o – preventive maintenance costs of fleet (MU)	36	18	12	9	7,2	6	5,1428
N_p - partial failure clearing costs of fleet (MU)	0,0571	0,1359	0,1686	0,1489	0,1038	0,0599	0,0295
N_k - complete failure clearing costs of fleet (MU)	0,1114	0,9893	2,9817	5,6054	8,0794	9,9080	11,0201
N_c - Total maintenance costs of fleet (MU):	36,1685	19,1252	15,1503	14,7543	15,3831	15,9679	16,1925

From formulas showed above come maintenance costs of vehicle fleet. Example of the maintenance costs calculations for parameter u=12 in the Tab. 3. is described. Number of preventive repair actions depends on maintenance interval and is shown in first part of Tab. 3. Also see vehicle combination failure probability F(x) (elementary event - see formula (1)). There are consequently showed failure probability of just one vehicle combination (formula (1)) and failure probability of two or more vehicle combinations (also see formula (1)).

Vehicle fleet maintenance costs from formulas (5), (6) and (7) are described in the second part of tab. 3. Sums of the all vehicle fleet maintenance costs N_c (formula (4)) are in the last row of the Tab. 3. and on Fig. 1.

This sum is also optimization criterion for preventive maintenance interval strategy.

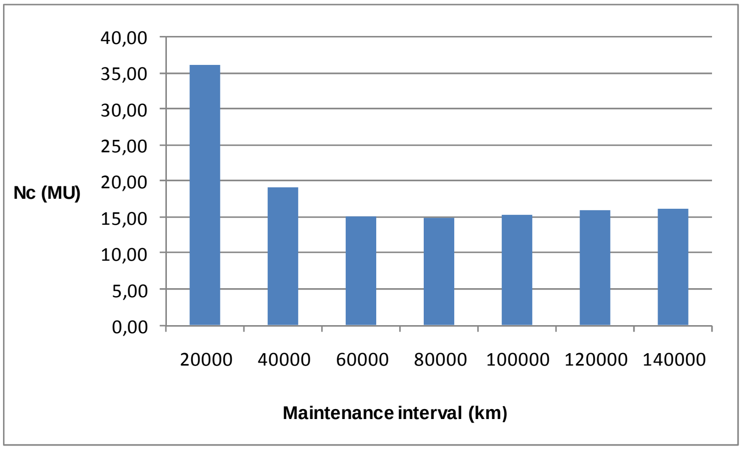

Fig. 1. Trend of vehicle fleet maintenance costs

The concrete optimal maintenance interval L_{opt} = 73604 km was calculated numericaly.

4. Conclusions

Simulation models of the vehicle fleet maintenance make it possible to optimize maintenance costs. Suitable maintenance strategy leads to achieving minimal maintenance costs also respects system failure exposure.

References

[1.] DANĚK, A.; ŠIROKÝ, J; FAMFULÍK, J. **Matematické metody obnovy dopravních prostředků.** Ostrava: Repronis Ostrava, 1999. ISBN 80-86122-41-7

[2.] FAMFULÍK, J. **Teorie údržby.** Skriptum VŠB TU Ostrava, Fakulta strojní, 2006, ISBN 80-248-1029-8

[3.] ŠIROKÝ, J.; NEUGEBAUER, J. **Podklady pro ověřování LCC v provozu vozidel.** In: TD 2005 – Diagon 2005. Zlín: Univerzita Tomáše Bati ve Zlíně. 2005. ss: 172. s: 30-35. ISBN 80-7318-293-9

[4.] MÍKOVÁ, J. **Ekonomické aspekty spolehlivosti dopravních prostředků v oblasti poskytování služeb.** In Nová železniční technika, vol. 2000, č. 4, ISSN 1210-3942.

[5.] MONOŠI, M., PALÚCH. B. **Posúdenie prevádzkovej spoľahlivosti hasičskej techniky.** In Opotřebení, spolehlivost, diagnostika 2007, ISBN 978-80-7231-294-8.