Computer aided maintenance management of electronic equipment used in transport

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Key words: maintenance, reliability, routine inspections

Abstract
Electronic equipment used in transport operates under various conditions. Due to characteristic nature of their application, they should be highly reliable. This paper presents a methodology of optimising a bistable operation process of those systems factoring in economic factors, i.e. the funding allocated to routine inspections. Its practical application was also discussed, which would entail computer aided maintenance software.

Introduction
The issue of maintaining electronic equipment, particularly those used in transport is an important problem. This stems from the fact correct reliability and operating parameters have to be assured. Many renowned papers have already been written on the matter [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11]. By carrying out an adequate reliability analysis of systems, their reliability structures are determined which provide correct reliability parameters. This applies both to the entire system [12, 13, 14, 15, 16], as well as its constitution elements, e.g. power supply [17, 18] and transmission media [19]). Due to this approach, the designed system becomes more reliable. It does not, however, assure high enough availability of the system. Hence, maintenance analysis has to be carried out taking account of selected operating properties of the systems (e.g.: failure rate, routine maintenance intensity) [20]. Findings of that analysis enable to fine-tune the maintenance strategy, including rationalisation of routine inspections and their length relative to requirements to those systems in respect of their availability in the transport process [21, 22, 23, 24]. The costs it generates are also factored in by the strategy [25, 26, 27].

Computer aided maintenance is the latest trend in maintaining maintenance. This solution could be used in the subsystem of maintaining electronic equipment used in transport. From the standpoint of travel security this is an exceptionally important issue. If applied, computer systems collect data (databases containing information about operation of given equipment) and then process them. This enables to draw conclusions about basic operating parameters. Thus, optimum decisions concerning operation process could be made (e.g.: routine inspections and their length, overhaul), which assured to maximise the end effects provided given base conditions were met. Among the effects were maximised availability, minimised repair times, optimised servicing intensity. In face of limited funding for maintenance, a decisional issue arises: how to maintain continuity of operations (system’s availability) with restricted financial resources whilst assuring desired security level and meeting all objectives (e.g.: maximisation of operating parameters, cost-cutting, maximisation of financial efficacy). The answer is creating many computer programmes, which support decision making.

Bistable maintenance strategy maximising availability
The availability rate is given by:

$$K_g = \frac{T_m}{T_m + T_n}$$

(1)

where: $T_m$ – mean correct operation time between failures, $T_n$ – mean time to repair.
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The given relation shows that the system can be in one of two states (Fig. 1):
- usage state ($S_0$);
- repair state ($S_1$).

![Graph showing switching between usage and repair states; $\lambda$ - failure rate, $\mu$ - repair rate](image)

Through analysing electronic equipment operating in transport the following state were determined:
- usage state $S_{00}$;
- repair state $S_{01}$;
- I type inspection $S_{01}$ (basic servicing required by specification);
- II type inspection $S_{11}$ (extended servicing required by specification).

The graph in figure 2 illustrates switching between above states. Switching between states includes the coefficients:

- $k_1$ – I type inspection coefficient – determines linear relation between current I type inspection rate, and optimum I type inspection rate for which availability rate is maximum;
- $k_2$ – II type inspection coefficient – determines linear relation between current II type inspection rate, and optimum II type inspection rate for which availability rate is maximum.

An important issue occurring in practice, is limited funding allocated for routine inspections of electronic equipment used in transport, available to the user. Hence, the impact has to be determined of financial outlays allocated to routine inspections on availability rate of the system. Therefore, the $C$ coefficient was introduced, which determined available financial resources allocated to I and II type inspections. Let us assume that:
- $C = 2$ for optimum I and II type inspection rates ($K_g$ = max. for $\lambda_1 = \lambda_{1optym}$ and $\lambda_2 = \lambda_{2optym}$; because in equation (2) $k_1 \cdot C = 1$ and $k_2 \cdot C = 1$);
- $C = 0$ for I and II type inspection rates equal naught (no inspections; because in equation (2) $k_1 \cdot 1_{optym} \cdot C = 0$ and $k_2 \cdot 2_{optym} \cdot C = 0$).

By carrying out a mathematical analysis the following relation was obtained (2).

![Graph showing switching between usage state ($S_{00}$), repair state ($S_{01}$), I inspection state ($S_{01}$) and II inspection state ($S_{11}$); $\lambda$ - failure rate, $\mu$ - repair rate, $\lambda_1$ – I type inspection rate, $\mu_1$ – I type routine maintenance rate, $\lambda_2$ – II type inspection rate, $\mu_2$ – II type routine maintenance rate, $k_1$ – I type inspection coefficient, $k_2$ – II type inspection coefficient](image)

$$
K_g = \frac{(\lambda + k_1 \lambda_{1optym} C + k_2 \lambda_{2optym} C) \mu_1 \mu_2}{(\lambda + k_1 \lambda_{1optym} C + k_2 \lambda_{2optym} C) \mu_1 \mu_2 + \lambda_2 \mu_1 \mu_2 + (k_1 \lambda_{1optym} C) \mu_2 + (k_2 \lambda_{2optym} C) \mu_1} \quad (2)
$$

$$
K_g = \frac{(\lambda + k_1 \lambda_{1optym} C + (1-k_1) \lambda_{2optym} C) \mu_1 \mu_2}{(\lambda + k_1 \lambda_{1optym} C + (1-k_1) \lambda_{2optym} C) \mu_1 \mu_2 + \lambda_2 \mu_1 \mu_2 + (k_1 \lambda_{1optym} C) \mu_2 + ((1-k_1) \lambda_{2optym} C) \mu_1} \quad (3)
$$

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3D graphical representation of equation (2) is impossible due to three variables: $k_1$, $k_2$, $C$. Therefore, the following relation was used:

$$k_1 + k_2 = 1$$

and the following equation was obtained (3).

**Example 1**

Assumptions taken were:

- failure rate $\lambda = 1.2027 \times 10^{-5}$ [1/h] (representing system whose reliability is 0.9);
- repair rate $\mu = 0.0666$ [1/h] (representing repair time of 15 [h]);
- I type routine maintenance rate $\mu_1 = 0.5$ [1/h] (representing inspection time of 2 [h]);
- II type routine maintenance rate $\mu_2 = 0.1666$ [1/h] (representing inspection time of 6 [h]);
- I type inspection rate $\lambda_{1optym} = 2 \times 10^{-5}$ [1/h];
- II type inspection rate $\lambda_{2optym} = 6 \times 10^{-6}$ [1/h].

For the assumptions taken, a chart was obtained illustrated in figures 3 and 4.

End of example 1.
By studying figures 3 and 4 the following could be concluded:
- availability rate $K_g$ reaches its maximum for $C = 2$ and $k_1 = 0.5$. For lower $C$ (lower financial outlays) $K_g$ decreases;
- there is a non-linear relation between financial outlays coefficient $C$ and inspection coefficient $k_1$. Therefore, in case of financial outlays lower than optimum to get the maximum $K_g$, one should determine new inspection rates for both types of inspections generating maximum availability rate.

**Computer aided maintenance**

In order to facilitate managing the maintenance and reliability process for users of electronic equipment used in transport, a programme has been developed: “Support of Maintenance Decisions in Transport Surveillance Systems” [27] (WDNETSN in short) (Fig. 5). Initial values:
- number of studied systems;
- time spent on studying systems;
- mean time to repair;
- mean time to completion of I type inspection;
- mean time to completion of II type inspection;
- financial outlays coefficient;
- number of elements damaged in studied system and by using equations and relation given in the previous chapter, the programme determines the following:
  - reliability of individual constitutive elements;
  - reliability of the entire system;
  - failure rate of individual constitutive elements;
  - failure rate of the entire system;
  - mean operating time of individual constitutive elements;
  - availability rate of individual constitutive elements;
  - availability rate of the entire system;
  - for systems of mixed and parallel structure:
    - the likelihood function of system in state of full operational capability $R_{0i}$;
    - the likelihood function of system in state of security threat $Q_{ZBi}$;

![Fig. 5. Screenshot of “Support of Maintenance Decisions in Transport Surveillance Systems”](image-url)
- the likelihood function of system in state of failing security $Q_B$;
- repair rate;
- I type inspection rate;
- II type inspection rate;
- max. availability rate of the system;
- optimum I and II type inspection rates for max. availability rate of the system;
- optimum coefficient of inspection types;
- availability rate of the system including financial outlays;
- optimum I and II type inspection rates for availability rate of the system including financial outlays.

Screenshot in figure 5 gives a glance at the programme.

Another function of the SMDTSS programme is visualisation of obtained results:
- comparison of all systems (Fig. 6):
  - availability rates of the entire system;
  - max. availability rates of the system;
  - availability rates of the system including financial outlays;
- comparison of likelihood function of system in following states, Fig. 7 (for systems of mixed and parallel structure):
  - full operational capability $R_O$;
  - security threat $Q_{ZBi}$;
  - failing security $Q_B$.

Fig. 6. Graphical representation of availability rates

SSNiW WMTI RS-485

0.0 0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4 0.45 0.5 0.55 0.6 0.65 0.7 0.75 0.8 0.85 0.9 0.95 1.0

0.998290452167 Availability rates of the entire system
0.99996358452 Max. max. availability rates of the system
0.999963157397 Max. availability rates of the system including financial outlays

Fig. 7. Graphical representation of likelihood functions of the system in $R_O$, $Q_{ZBi}$, $Q_B$ states

0.76 Full operational capability $R_O$
0.17944329 Security threat $Q_{ZB1}$
0.01514317 Security threat $Q_{ZB2}$
0.00054936 Security threat $Q_{ZB3}$
0.04486417 Failing security $Q_B$
Conclusions

A method of optimising maintenance of electronic systems (for two types of routine inspections) was presented in this paper, which factors in selected reliability parameters (failure rate), operating parameters (repair rate, routine maintenance rate) and economic parameters (financial outlays on routine inspections). It enables to determine optimum routine inspection rates, provided the optimisation criterion is taken as maximisation of the availability rate.

In the author’s computer application is used, among the others, the equation (3) which allows to determine analytically the values of intensity of periodic inspections for which the value of the availability rate is maximal.

Presented computer application is being used as a learning aid by students at Faculty of Transport of Warsaw University of Technology (specialisation of Transport Telematics) and students at Faculty of Military Electronics of Warsaw Academy of Technology (specialisation of Security System Engineering). Hence they were able to acquaint themselves with reliability analysis and functional properties of different systems.

References