RELIABILITY FORECASTING OF VEHICLES BASING UPON THE GRAPH OF STATES

M. S. Abramovich, Yu. G. Prikhodko
Research Institute for Applied Problems of Mathematics and Informatics
Belarusian State University
Minsk, Belarus
e-mail: `AbramovichMS@bsu.by`, `pug@tut.by`

Abstract

The forecasting technique of reliability measures is described for the vehicle MAZ in monitoring maintenance. The base of the technique is mathematical model of vehicle maintenance as stochastic walk over a graph of state. The offered model enables to make a forecast of reliability measures both in time, and under the changing maintenance conditions or maintenance policy.

1 Introduction

The basic way of the description of process of complex technical systems operation is its representation like wandering process on some transition graph. Such process is approximated, as a rule, as Markov or semiMarkov process [1]. Complex systems with strictly standard maintenance policy has the transition graph with a steady relatively fixed structure [2]. In vehicles system the structure of this transition graph can greatly fluctuate. According to [3] a number of nodes in such transition graph can change from 4 to 14 with a corresponding variety of links between them. It does not allow to elaborate a universal model, suitable for any set of vehicles. For each set of vehicles we need to work out a separate model corresponding to maintenance policy of a given set of vehicles.

2 Model of the maintenance process

The research describes methodology of forecasting reliability of the set of vehicles MAZ in monitoring maintenance. This set of vehicles has the basic set of states presented by table 1.

Service life limit of vehicles considerably surpasses time in monitoring maintenance. Therefore it makes it possible to suppose that the probability of transition in condition S_∞ during monitoring maintenance will be about zero. Thus it is possible to exclude state S_∞ from the model. Another simplifying factor is a one-stage start of monitoring maintenance for all cars. It makes it possible to exclude state S_0 from the model. Thus the final transient graph acquires the form presented in fig. 1.

The model has the only one restriction on the transition flows between states. It must be Poisson flows. Requirements for a constancy of flows intensity is not imposed [4]. We will use the following designations for the elements of this model.

Table 1: Base states of the vehicle

S_0	Production	Start of monitoring maintenance
S_1	Relocation	Vegicle moving without cargo
S_2	Traffic	Vegicle moving with cargo
S_3	Waiting	Vehicle parking in the garage or in the open area
S_4	M1	Maintenance category
S_5	M2	expanded maintenance category
S_6	Current repairs	Failure removal or defect removal
S_7	Capital repair	Recovery of good technical state of vehicle
S_∞	Retirement	Ending use of the vehicle

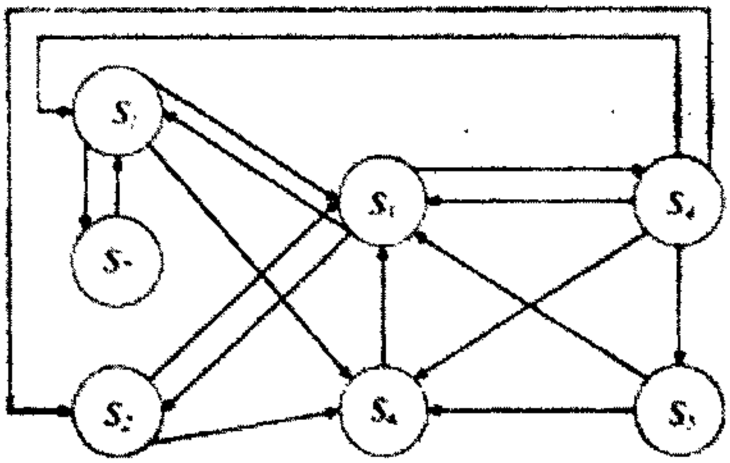

Figure 1: Transition graph

We will designate the probability of stay of a vehicle in state S_i as $P_i(t)$. We will designate the intensity of transitions between state S_i and S_j according to the existing practice as $\lambda_{ij}(t)$. In these designations every state's probability of a vehicle at a first approximation can be described at any moment by system of the linear equations (1).

Usually the solution of this system of the equations is carried out to define probabilities $P_i(t)$ or their part necessary for the calculation of the required reliability measures. For this purpose theoretical models of dependences $\lambda_{ij}(t)$ are assigned. However in the given research we have interest in inverse problem - definition of unknown dependences $\lambda_{ij}(t)$ which conform the known values $P_i(t)$.

These dependences are fixed by means of possibilities of the system of failures data collections and they processing in monitoring maintenance [5]. The complex of reliability measures defined with its help includes also following indicators:

- *survival function* $P_s(t)$;
- *steady state availability factor* K_u;
- *availability function* K_a.

$$
\begin{aligned}
(\lambda_{13}(t) + \lambda_{16}(t))P_1(t) &= \lambda_{31}(t)P_3(t) + \lambda_{41}(t)P_4(t)\\
(\lambda_{23}(t) + \lambda_{26}(t))P_2(t) &= \lambda_{32}(t)P_3(t) + \lambda_{42}(t)P_4(t)\\
(\lambda_{31}(t) + \lambda_{32}(t) + \lambda_{34}(t))P_3(t) &= \gamma\\
\lambda_{17}(t)P_1(t) &= \lambda_{71}(t)P_7(t)\\
\lambda_{34}(t)P_3(t) &= (\lambda_{41}(t) + \lambda_{42}(t) + \lambda_{43}(t) + \lambda_{45}(t) + \lambda_{46}(t)P_4(t)\\
(\lambda_{53}(t) + \lambda_{56}(t))P_5(t) &= \lambda_{45}(t)P_4(t)\\
\lambda_{53}(t)P_6(t) &= \lambda_{16}(t)P_1(t) + \lambda_{26}(t)P_2(t) + \lambda_{46}(t)P_4(t) + \lambda_{56}(t)P_4(t)
\end{aligned} \tag{1}
$$

where $\gamma = \lambda_{13}(t)P_1(t) + \lambda_{23}(t)P_2(t) + \lambda_{43}(t)P_4(t) + \lambda_{53}(t)P_5(t) + \lambda_{63}(t)P_6(t)$.

Corresponding values are calculated according to the values fixed in the course of monitoring maintenance [5]. This complex of reliability's measures is functionally links with probabilities Pi (t) by system of the equations (2). However this system isn't full relative to P(t). This system require four more equations.

$$
\begin{aligned}
P_s(t) &= P_1(t) + P_2(t) + P_3(t) + P_4(t) + P_5(t) + P_6(t)\\
K_u &= P_2(t)\\
K_a &= P_1(t) + P_2(t) + P_3(t) + P_4(t)
\end{aligned} \tag{2}
$$

As one of them it is natural to use a normalization condition (3).

$$P_1(t) + P_2(t) + P_3(t) + P_4(t) + P_5(t) + P_6(t) + P_7(t) = 1 \tag{3}$$

Three more equations can be obtained by direct calculation of some of the probabilities $P_i(t)$ or the known functions of them.

The probility $P_7(t)$ can be obtained as:

$$P_7(t) = T_{crt}/(T_t * N), \tag{4}$$

where T_{crt} is the full time of capital repair for time interval T_t all N vehicles.

The probilities $P_1(t)$ and $P_2(t)$ can be linked as:

$$P_1(t)/(P_1(t) + P_2(t)) = L_{2t}/(L_{1t} + L_{2t}), \tag{5}$$

where L_{1t} and L_{2t} is the full kilometrage all N vehicles for time interval T_t without and with cargo.

The last equation can be obtained as:

$$P_1(t) + P_2(t) = K_{ot}, \tag{6}$$

where K_{ot} is the vehicles output factor for all N vehicles for time interval T_t is obtained in [5].

Definition of probabilities $P_1(t)$ - $P_7(t)$ through obtained estimation of maintenance measures enables to find the solution of the initial system of the equations for vehicle's states relative to transitions intensity. The system of the equations must be supplement with used of the normalizing factor obtained from the maintenance measures estimations [5].

3 Reliability measures forecasting

The considered model of the maintenance process allows to solve two classes of problems of forecasting reliability measures. The first problem of the forecast is prediction of reliability measures in the future time interval. Next steps lead to the solution of this problem.

At the first stage the calculated empirical dependences $\lambda_{ij}(t)$ are used to make approximation a suitable functional basis:

$$\lambda_{ij}(t) = \sum_{k=0}^{m} a_k f_{ijk}(t), \tag{7}$$

If polynomial functions are used as basis the problem is reduced to a standard estimation of a polynomial regression.

The second stage includes substitution of dependences $\lambda_{ij}(t)$ into the primary system of equations and to be solving this system relative to $P_i(t)$. Indeterminacy of the forecast will be defined by quality of approximation of functions $\lambda_{ij}(t)$. Estimation of this area without information about their joint distribution is possible only by statistical modelling in the assumption of their independent behaviour.

The second class of problems of forecasting on the basis of considered model allows to predict change of reliability's measures on change of conditions or modes of maintenance or level of reliability of units. In the first case change of such parameters of maintenance as periodicity of different category of the maintenance and planned repairs, volume of these works are considered. In this case different functions $\lambda_{ij}(t)$ must be proportionally scaled. It make possible their recalculation into reliability's measures according the scheme considered above. Change of level of reliability of units can be considered similar by scaling of dependences $\lambda_{ij}(t)$, connected with repair.

References

[1] Silvestrov D.S. (1980). *SemiMarkov process with discret states* (in Russian). Sovietscoe Radio, Moscow.

[2] Ushakov I.A. (ed.) (1985). *Reliability of engineering systems. Handbook* (in Russian) (in Russian). Radio i Sviaz, Moscow.

[3] Rotenberg R.V. (1986). *Bases of reliabiliy of system the driver - the car - the road - environment.* Mashinistroenie, Moscow.

[4] Epstein B., Weissman I. (2008) *Mathematical models for systems reliability.* Taylor and Francis Group, N-Y.

[5] Abramovich M.S., Mitskevich M.H., Pyzhik N.N. (2010). Algorithmics and the software of statistical estimation of reliability's measures on censoring samples. *Informatika.*