Blokus-Roszkowska Agnieszka

Guze Sambor

Kołowrocki Krzysztof

Soszyńska-Budny Joanna
Maritime University, Gdynia, Poland

Computer-aided identification of complex technical systems operation processes

Keywords

operation processes, statistical identification, complex systems, transport system

Abstract

In the paper, the procedures of the identification of complex technical system operation process and identifying the distributions of the system conditional sojourn times in the operation states are described. Furthermore, the computer program for identification of the operations processes capabilities with description are presented. As the application of this computer program, the identification of the ferry technical system operation process is shown.

1. Introduction

Most real technical systems are very complex and it is difficult to analyze their reliability and availability. Large numbers of components and subsystems and their operating complexity cause that the evaluation and optimization of their reliability and availability is complicated. The complexity of the systems' operation processes [5], [6] and these processes influence on changing in time the systems' structures and their components' reliability characteristics [3] is often very difficult to fix and to analyse. A convenient tool for solving this problem is semi-Markov [1], [4] approach to describe the systems operation processes [7].

2. Identification of complex technical system operation processes

To make the estimation of the unknown parameters of semi-Markov [1], [4] model of the complex technical system operation processes [7], it is necessary perform the following steps:

i) to analyze the system operation process;
ii) to fix or to define its following general parameters:
   - the number of the operation states of the system operation process ν,
   - the operation states of the system operation process $z_1, z_2, \ldots, z_\nu$;
iii) to fix the possible transition between the system operation states;
iv) to fix the set of the unknown parameters of the system operation process semi-Markov model.

To estimate the unknown parameters of the system operations process, during the experiment we should collected necessary statistical data:

i) to evaluating the probabilities of the initial states of the system operations process as follows:
   - the duration time of the experiment Θ,
   - the number $n(0)$, of the investigated (observed) realizations of the system operation process,
   - the numbers $n_1(0)$, $n_2(0)$, …, $n_\nu(0)$, of staying of the operation process respectively in the operations states z_1, z_2, …, z_ν, at the initial moment $t = 0$ of all $n(0)$ observed realizations of the system operation process,

- the vector $[n_b(0)]_{1\times\nu}$ of the realizations of the numbers of staying of the operation process in the operation states at the initial moments;

ii) to fix and to collect the following statistical data necessary to evaluating the transient probabilities between the system operation states:

- the numbers n_{bl}, b, l = 1,2,…,ν, $b \neq l$, of the transitions of the system operation process from the operation state z_b to the operation state z_l during all observed realizations of the system operation process,
- matrix $[n_{bl}]_{\nu\times\nu}$ of the realizations of the transitions' numbers of the system operation process between the operation states,
- the numbers n_b, b = 1,2,…,ν, of departures of the system operation process from the operation states z_b;

ii) to fix and to collect the following statistical data necessary to evaluating the unknown parameters of the distributions of the conditional sojourn times of the system operation process in the particular operation states:

- the realizations θ_{bl}^k, k = 1,2, …, n_{bl}, (at least $n_{bl} = 40$ realizations for each b, l = 1,2,...,ν, $b \neq l$) of the conditional sojourn times θ_{bl} of the system operations process at the operation state z_b when the next transition is to the operation state z_l during the observation time.

After collecting the above statistical data, it is possible to estimate the unknown parameters of the system operation process performing the following steps [7]:

i) to determine the vector $[p(0)]_{\nu\times\nu}$ of the realizations of the probabilities $p_b(0)$, $b = 1,2,...,\nu$, of the initial states of the system operation process, according to the formula

$$p_b(0) = \frac{n_b(0)}{n(0)} \text{ for } b = 1,2,...,\nu, \quad (1)$$

where $n(0) = \sum_{b=1}^{\nu} n_b(0)$, is the number of the realizations of the system operation process starting at the initial moment $t = 0$;

ii) to determine the matrix $[p_{bl}]_{\nu\nu}$ of the realizations of the probabilities p_{bl}, $b, l = 1,2,...,\nu$, of the system operation process transitions from the operation state z_b to the operation state z_l during the experiment time Θ, according to the formula

$$p_{bl} = \frac{n_{bl}}{n_b} \text{ for } b, l = 1,2,...,\nu,\ b \neq l, \quad (2)$$

$$p_{bb} = 0 \text{ for } b = 1,2,...,\nu,$$

where $n_b = \sum_{b \neq l}^{\nu} n_{bl}$, $b = 1,2,...,\nu$, is the realization of the total number of the system operation process departures from the operation state z_b during the experiment time Θ;

iii) to determine the following empirical characteristics of the realizations of the conditional sojourn time of the system operation process in the particular operation states:

the realizations of the mean values $\bar{\theta}_{bl}$ of the conditional sojourn times θ_{bl} of the system operation process at the operation state $H_{bl}(t)$ when the next transition is to the operation state θ_{bl}, according to the formula

$$\bar{\theta}_{bl} = \frac{1}{n_{bl}} \sum_{k=1}^{n_{bl}} \theta_{bl}^k \quad z_l \ \ b \neq l, \quad (3)$$

iv) to estimate the parameters of the distributions of the conditional sojourn times of the system operation process in the particular operation states [7].

3. Identifying parameters of distributions of conditional sojourn times of system operation process in particular operation states

To formulate and next to verify the hypothesis concerning the form of the distribution function $H_{bl}(t)$ of the system conditional sojourn time θ_{bl} at the operation state z_b when the next transition is to the operation state z_l, on the basis of its realizations θ_{bl}^k, $k = 1,2,...,n_{bl}$, it is necessary to proceed according to the following scheme [7]:

- to construct and to plot the realization of the histogram of the system conditional sojourn time θ_{bl} at the operation state, defined by the following formula

$$\bar{h}_{n_{bl}}(t) = \frac{n_{bl}^j}{n_{bl}} \text{ for } t \in I_j, \quad (4)$$

- to analyze the realization of the histogram $\bar{h}_{nbl}(t)$, comparing it with the graphs of the density functions $h_{bl}(t)$ of the previously distinguished typical distributions [8], to select one of them and to formulate the null hypothesis H_0, concerning the unknown form of the distribution function $H_{bl}(t)$ of the conditional sojourn time θ_{bl} in the following form:

  H_0: The system conditional sojourn time θ_{bl} at the operation state z_b when the next transition is to the operation state z_l, has the distribution function $H_{bl}(t)$,
- to join each of the intervals I_j that has the number n_{bl}^j of realizations less than 4 either with the neighbour interval I_{j+1} or with the neighbour interval I_{j-1} this way that the numbers of realizations in all intervals are not less than 4,
- to fix a new number of intervals $\bar{\bar{r}}_{bl}$,
- to determine new intervals $\bar{I}_j = <\bar{a}_{bl}^j, \bar{b}_{bl}^j)$, $j = 1,2,..,\bar{\bar{r}}_{bl}$,
- to fix the numbers $\bar{n}_{bl}^j$ of realizations in new intervals $\bar{I}_j$, $j = 1,2,..,\bar{\bar{r}}_{bl}$,
- to calculate the hypothetical probabilities that the variable θ_{bl} takes values from the interval $\bar{I}_j$, under the assumption that the hypothesis H_0 is true,
- to calculate the realization of the χ^2(chi-square)-Pearson's statistics U_{nbl},
- to assume the significance level α ($\alpha = 0.01$, $\alpha = 0.02$, $\alpha = 0.05$ or $\alpha = 0.10$) of the test,
- to fix the number $\bar{\bar{r}}_{bl} - l - 1$ of degrees of freedom,
- to read from the Tables of the χ^2 – Pearson's distribution the value u_α for the fixed values of the significance level α and the number of degrees of freedom $\bar{\bar{r}}_{bl} - l - 1$ such that the following equality holds $P(U_{n\,bl} > u_\alpha) = 1 - \alpha$, and next to determine the critical domain in the form of the interval $(u_\alpha, +\infty)$ and the acceptance domain in the form of the interval $< 0, u_\alpha >$,
- to compare the obtained value u_{nbl} of the realization of the statistics U_{nbl} with the read from the Tables critical value u_α of the chi-square random variable and to decide on the previously formulated null hypothesis H_0 in the following way: if the value $u_{n_{bl}}$ does not belong to the critical domain, i.e. when $u_{n_{bl}} \le u_\alpha$, then we do not reject the hypothesis H_0, otherwise if the value $u_{n_{bl}}$ belongs to the critical domain, i.e. when $u_{n_{bl}} > u_\alpha$, then we reject the hypothesis H_0.

4. Description of the computer program for identification of the operation processes of complex technical systems

The presented computer program is based on methods of identification the complex technical system operation processes shown in Sections 2 and 3, given in [7]. The computer program is written in Java language with using SSJ V2.1.3 library. The SSJ library is a Java library, developed in the Department d'Informatique et de Recherche Operationelle (DIRO) at the Universite de Montreal, gives the support of stochastic simulations. The on-line documentation of SSJ can be found at the website http://www.iro.umontreal.ca/~simardr/ssj/indexe.html..

This program is composed of one panel with two parts. The first one is used for reading basic data of operation process, i.e.:

- the number of system operation states *v*,
- the number of observed realizations of the system operation process *n*(0),
- the vector $[n_b(0)]_{1\times v}$ of the realizations of the numbers of staying of the operation process in the operation states at the initial moment,
- the matrix $[n_{bl}]_{v\times v}$, of the realizations of the transitions' numbers of the system operation process between the operation states.

When the reading data is finished, the following results of the program are show in the section „Output":

- the components of initial probabilities vector of operation process,
- the components the matrix of probabilities of transition of operations process between the states.

In the second part of this panel, the computer program estimates the unknown parameters of the distributions of the conditional sojourn times of the system operation process in the particular operation states. To do it, the following statistical data should be fixed:

- the realizations θ_{bl}^k, k = 1,2, …, n_{bl}, (at least $n_{bl} = 40$ realizations for each b, l = 1,2,...,v, $b \neq l$) of the conditional sojourn times θ_{bl} of the system operations process at the operation state z_b when the next transition is to the operation state z_l ,
- the observation time,
- the significance level of the test.

When the above data is loaded, the computer program estimates:

– beginning x_{bl} and the end y_{bl} of distribution domain intervals,
– the empirical mean value z_{bl}, (for triangular and double trapezium distributions only),
– values of q_{bl}, w_{bl}, (for double trapezium and quasi-trapezium distribution only),
– the values of z_{bl}^1, z_{bl}^2, (for quasi-trapezium distribution only).

In the next step, the computer program:

– testifies successively the hypotheses that the form of the distribution functions of the conditional sojourn times a_1 $b,l = 1,2,...,v$, $b \neq l$, at the operation state $a_2 = b_1$ when the next transition is to the operation state b_2, is one of the given in [8] distribution function,
– determines the best fitting distribution and gives its name,
– determines the mean value from the fitted distribution M_{bl}, $b,l = 1,2,...,v$, $b \neq l$, (in case of the hypothesis acceptance),
– determines the empirical values of the mean values $\bar{\theta}_{bl}$, $b,l = 1,2,...,v$, $b \neq l$, (in case of the hypothesis rejecting).

5. Computer-aided identification of unknown parameters of operation process of the ferry technical system

We consider the operation process of the ferry technical system. This ferry is operating in Baltic Sea between Gdynia and Karlskrona ports on regular everyday line [2], [7], according to the time table. Taking into account the expert opinion on the operation process of the considered ferry we have fixed number of operation states $v = 18$ [2], [7]. Furthermore, the ship operation process observation/experiment time is 42.

Input statistical data of ferry technical system operation process, which is Reading by the computer program are:

- the vector of realizations of the numbers of the system operation process transients in the particular operation states z_b at the initial moment t = 0,
- the matrix of realizations n_{bl} of the numbers of the ferry operation process transitions from the state z_b into the state z_l during the experiment time.

After Reading the input data and after computer program's computations, as results, we have got the estimations of the following parameters for considered ferry operation process:

- the vector $[p(0)]_{v \times v}$ of the realizations of the probabilities $p_b(0)$, $b = 1,2,...,18$, of the initial states of the ferry system operation process (*Figure 1*),

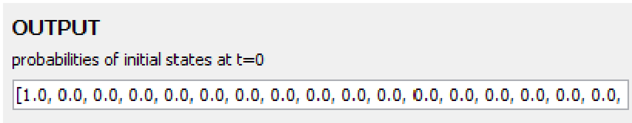

Figure 1. The vector of realizations of the probabilities

- the matrix $[p_{bl}]_{vv}$ of the realizations of the probabilities p_{bl}, $b,l = 1,2,...,18$, of the system operation process transitions from the operation state z_b to the operation state (*Figure 2*).

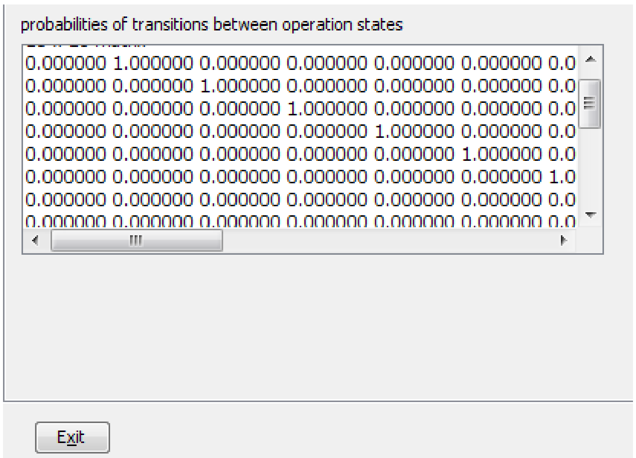

Figure 2. The matrix of the realizations of the probabilities

Next, the unknown parameters of the distributions of the conditional sojourn times of the ferry operation process in the particular operation states. After entering required statistical data as a result, we get the following output parameters:

- parameters of distributions of conditional sojourn Times θ_{bl} of the ferry technical system at the particular operation states,

- density functions of conditional sojourn times θ_{bl} of the ferry operation process in the particular operation states,
- mean values M_{bl} of conditional sojourn times θ_{bl} of the ferry operation process in the particular operation states.

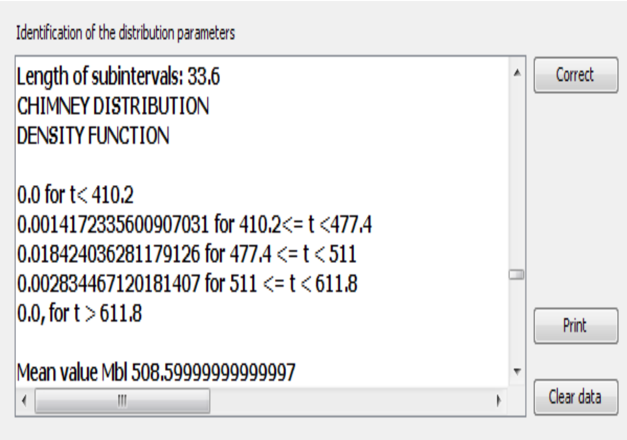

Figure 3. Statistical identification of operation process

After receiving the final results, they can be printed and then quit the program or restart.

6. Conclusion

Presented in the paper computer program is used for identification of the unknown parameters of complex technical systems operation processes and for testing the hypotheses concerning with unknown forms of the distribution functions of these operation processes conditional sojourn times at the particular operation states. It is based on methods and algorithms given in [7]. This program allows us to automatically find the unknown parameters of complex technical systems operation processes. In the article presented program have been used to identification unknown parameters of the ferry operation process.

Acknowledgements

The paper describes the part of the work in the Poland-Singapore Joint Research Project titled "Safety and Reliability of Complex Industrial Systems and Processes" supported by grants from the Poland's Ministry of Science and Higher Education (MSHE grant No. 63/N-Singapore/2007/0) and the Agency for Science, Technology and Research of Singapore (A*STAR SERC grant No. 072 1340050).

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