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:

\[ n, z_1, z_2, ..., z_\nu, \Theta, n_1(0), n_2(0), ..., n_\nu(0) \]

- the number of the operation states of the system operation process \( \nu \),
- the operation states of the system operation process \( z_1, z_2, ..., z_\nu \);

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 \( \Theta \),
- 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 \( z_1, z_2, ..., z_\nu \), at the initial moment \( t = 0 \) of all \( n(0) \) observed realizations of the system operation process,
– the vector \([n_b(0)]_{v	imes v}\) 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 \(n_{bl}, b, l = 1,2,...,v, b \neq l\), 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 \([n_{bl}]_{v	imes v}\) of the realizations of the transitions’ numbers of the system operation process between the operation states,
– the numbers \(n_b, b = 1,2,...,v\), 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 transient probabilities between the system operation states:
– the realizations \(\theta_{bl}^k, k = 1,2,...,n_{sl}\), (at least \(n_{sl} = 40\) realizations for each \(b, l = 1,2,...,v, b \neq l\)) of the conditional sojourn times \(\theta_{bl}\) of the system operation 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 \([p(0)]_{v	imes v}\) of the realizations of the probabilities \(p_b(0), b = 1,2,...,v\), of the initial states of the system operation process, according to the formula

\[
p_b(0) = \frac{n_b(0)}{n(0)} \text{ for } b = 1,2,...,v,
\]

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

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

\[
p_{bl} = \frac{n_{bl}}{n_b} \text{ for } b, l = 1,2,...,v, b \neq l,
\]

\[
p_{bb} = 0 \text{ for } b = 1,2,...,v,
\]

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

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 \(\bar{\theta}_{sl}\) of the conditional sojourn times \(\theta_{sl}\) of the system operation process at the operation state \(H_{sl}(t)\) when the next transition is to the operation state \(\theta_{sl}\), according to the formula

\[
\bar{\theta}_{sl} = \frac{1}{n_{sl}} \sum_{i=1}^{n_{sl}} \theta_{sl}, z_k b \neq l
\]

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 \(H_{sl}(t)\) of the system conditional sojourn time \(\theta_{sl}\) at the operation state \(z_b\) when the next transition is to the operation state \(z_l\), on the basis of its realizations \(\theta_{sl}^k, k = 1,2,...,n_{sl}\), 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 \(\theta_{sl}\) at the operation state, defined by the following formula

\[
\bar{H}_{sl}(t) = \frac{n_{sl}}{n_b} \text{ for } t \in I_j,
\]
to analyze the realization of the histogram \( h_{n_d} (t) \), comparing it with the graphs of the density functions \( h_{u} (t) \) 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 \( H_u(t) \) of the conditional sojourn time \( \theta_{d_l} \) in the following form:

\( H_0 \): The system conditional sojourn time \( \theta_d \) at the operation state \( z_i \), when the next transition is to the operation state \( z_j \), has the distribution function \( H_{u} (t) \),

– to join each of the intervals \( I_j \) that has the number \( n_{j_l} \) 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 \( \bar{I}_{d_l} \),

– to determine new intervals \( \bar{I}_j = < \bar{a}_{j_l}, \bar{b}_{j_l} > \),

\( j = 1, 2, ..., \bar{I}_{d_l} \),

– to fix the numbers \( \bar{a}_{j_l} \) of realizations in new intervals \( \bar{I}_j \), \( j = 1, 2, ..., \bar{I}_{d_l} \),

– to calculate the hypothetical probabilities that the variable \( \theta_{d_l} \) takes values from the interval \( \bar{I}_j \), under the assumption that the hypothesis \( H_0 \) is true,

– to calculate the realization of the \( \chi^2 \) -Pearson’s statistics \( U_{n_{d_l}} \),

– to assume the significance level \( \alpha \) (\( \alpha = 0.01, \alpha = 0.02, \alpha = 0.05 \) or \( \alpha = 0.10 \)) of the test,

– to fix the number \( \bar{a}_{d} - l - 1 \) of degrees of freedom,

– to read from the Tables of the \( \chi^2 \) -Pearson’s distribution the value \( u_{\alpha} \) for the fixed values of the significance level \( \alpha \) and the number of degrees of freedom \( \bar{a}_{d} - l - 1 \) such that the following equality holds \( P(U_{n_{d_l}} > u_{\alpha}) = 1 - \alpha \), 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 \( u_{n_{d_l}} \) of the realization of the statistics \( U_{n_{d_l}} \) with the read from the Tables critical value \( u_{\alpha} \) of the chi-square random variable and to decide on the previously formulated null hypothesis \( H_0 \) in the following way: if the value \( u_{n_{d_l}} \) does not belong to the critical domain, i.e. when \( u_{n_{d_l}} \leq u_{\alpha} \), then we do not reject the hypothesis \( H_0 \), otherwise if the value \( u_{n_{d_l}} \) belongs to the critical domain, i.e. when \( u_{n_{d_l}} > u_{\alpha} \), 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 Operationnelle (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](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 \( [n_{l(0)}]_{v \times 1} \) of the realizations of the numbers of staying of the operation process in the operation states at the initial moment,

– the matrix \( [n_{l}^t]_{v \times v} \) 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 $\theta_{bl}^k$, $k = 1,2, \ldots, n_{bl}$, (at least
  $n_{bl} = 40$ realizations for each $b, l = 1,2,\ldots,\nu$,
  $b \neq l$) of the conditional sojourn times $\theta_{bl}$ 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 $a_i$, $b,l=1,2,\ldots,\nu$,
  $b \neq l$, 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 $\bar{M}_{bl}$, $b,l=1,2,\ldots,\nu$, $b \neq l$, (in case
  of the hypothesis acceptance),
- determines the empirical values of the mean
  values $\bar{\theta}_{bl}$, $b,l=1,2,\ldots,\nu$, $b \neq l$, (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 $\nu = 18$ [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 $[p(0)]_{\nu\nu}$ of the realizations of the
  probabilities $p_b(0)$, $b=1,2,\ldots,18$, of the initial
  states of the ferry system operation process
  (Figure 1).

![Figure 1. The vector of realizations of the probabilities](image1)

- the matrix $[p_{bl}]_{\nu\nu}$ of the realizations of the
  probabilities $p_{bl}$, $b,l=1,2,\ldots,18$, 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](image2)
- density functions of conditional sojourn times $\theta_{\omega}$ of the ferry operation process in the particular operation states,
- mean values $M_{\omega}$ of conditional sojourn times $\theta_{\omega}$ 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).

References


Computer-aided identification of complex technical systems operation processes