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Integrated software tools supporting decision making on identification, prediction and optimization of complex technical systems operation, reliability and safety

Part 2

Integrated software tools application – Exemplary system operation and reliability unknown parameters identification

Keywords

system operation process, reliability parameters, identification, software tools

Abstract

There is presented the application of the integrated software tools to the operation and reliability models of an exemplary complex technical system unknown parameters identification. There are performed in the paper, the exemplary system operation and reliability analysis and modelling. The identification of the probabilities of transitions this system operation process between the operation states and the conditional mean values of this process sojourn times at the particular operation states because of the lack of statistical data is performed through the arbitrary fixing their values assumption. Next using the computer program CP 8.3 the automatic evaluation of the system components unknown intensities of departures the reliability state subsets and the identification of the exponential forms of their multistate reliability functions on the arbitrarily fixed statistical data coming from the system components states changing processes are performed as well.

3. The exemplary system operation process unknown parameters identification

3.1. The exemplary system analysis

We analyze [8] the reliability of an exemplary system S that consists of two subsystems S_1, S_2 . The subsystem S_1 is composed of two series subsystems, each of them composed of 3 components, denoted respectively by

$$E_{ij}^{(1)}, \quad i = 1, 2, \quad j = 1, 2, 3,$$

with the reliability structure presented in *Figure 1*.

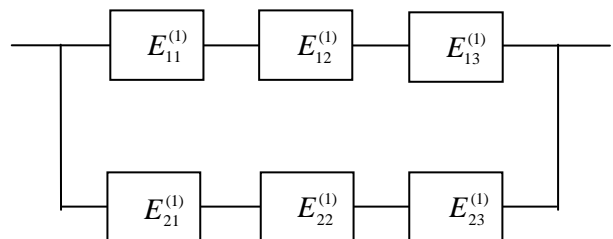


Figure 1. The scheme of the system S_1 reliability structure

The subsystem S_2 is composed of four series subsystems, each of them composed of 2 components, denoted respectively by

$$E_{ij}^{(2)}, i = 1,2,3,4 \quad j = 1,2,$$

with the reliability structure presented in Figure 2.

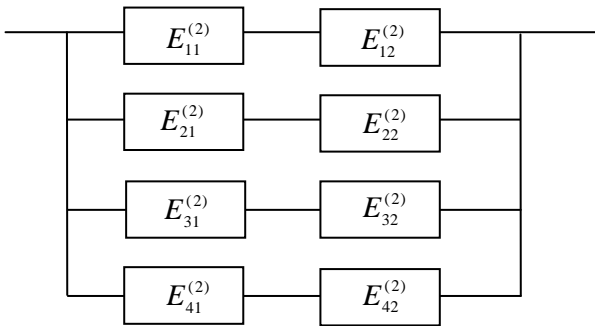


Figure 2. The scheme of the system S_2 reliability structure

The subsystems S_1, S_2 , illustrated in Figures 1–2 are forming a series reliability structure presented in Figure 3.

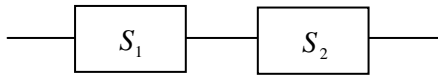


Figure 3. The general scheme of the system S reliability structure

3.2. The exemplary system operation process modelling

Under the assumption that the exemplary system structure and the subsystem components reliability depend on its changing in time operation states, we arbitrarily fix the number of the system operation process states $\nu = 4$ and we distinguish the following as its four operation states [7], [8]:

- an operation state z_1 – the system is composed of the subsystem S_1 , with the scheme showed in Figure 1, that is a series-parallel system,
- an operation state z_2 – the system is composed of the subsystem S_2 , with the scheme showed in Figure 2 that is a series-parallel system,
- an operation state z_3 – the system is composed of the subsystems S_1 and S_2 , with the scheme showed in Figure 3 that are series-parallel system with the schemes given in Figures 1-2,

- an operation state z_4 – the system is composed of the subsystem S_1 and S_2 , with the scheme showed in Figure 3, while the subsystem S_1 is a series-parallel system with the scheme given in Figure 1 and the subsystem S_2 is a series-“2 out of 4” system.

Moreover, we assume that there are possible the transitions between all system operation states. Thus, according to Section 2 of [IS&RDSS], the parameters of the system operation process semi-Markov model are [5]:

- the initial probabilities $p_b(0), b = 1,2,3,4$, of the system operation process $Z(t)$ staying in the particular states z_b at the moment $t = 0$,
- the matrix $[p_{bl}]_{4 \times 4}$ of probabilities of the exemplary system operation process $Z(t)$ transitions between the operation states,
- the matrix $[H_{bl}(t)]_{4 \times 4}$ of conditional distribution functions of the exemplary system operation process $Z(t)$ conditional sojourn times θ_{bl} in the operation states,
- the mean values of the conditional sojourn times θ_{bl} .

To identify all these parameters of the exemplary system operation process the statistical data about this process is needed and we can do it automatically using the computer program CP 8.1 “Identification of the operation processes”. As the considered system is an exemplary one and its operation process parameters are arbitrarily assumed then we do not have the statistical data collected that are needed for estimating these parameters.

3.3. The exemplary system operation process identification

In this case, we do not have statistical data on the exemplary system operation process and we fix the process parameters defined by (2.1) and (2.3) in IS&RDSS 2 [5] arbitrarily.

The arbitrarily fixed transient probabilities from the operation state z_b into the operation state z_l , defined by p_{bl} (2.1), are given in the matrix below

$$[p_{bl}] = \begin{bmatrix} 0 & 0.22 & 0.32 & 0.46 \\ 0.20 & 0 & 0.30 & 0.50 \\ 0.12 & 0.16 & 0 & 0.72 \\ 0.48 & 0.22 & 0.30 & 0 \end{bmatrix}.$$

As we do not have the realizations of the conditional sojourn times θ_{bl} , $b, l = 1, 2, 3, 4$, of the exemplary system operation process at the particular operation states, then it is not possible to identify their distributions defined by (2.2) in [IS&RDSS 2].

The arbitrarily fixed conditional mean values $M_{bl} = E[\theta_{bl}]$, $b, l = 1, 2, 3, 4$, defined by (2.3) in [IS&RDSS 2], of the system sojourn times in the particular operation states are as follows:

$$M_{12} = 192, M_{13} = 480, M_{14} = 200,$$

$$M_{21} = 96, M_{23} = 81, M_{24} = 55,$$

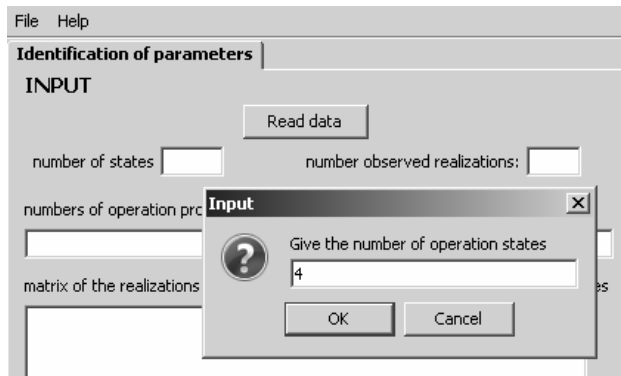
$$M_{31} = 870, M_{32} = 480, M_{34} = 300,$$

$$M_{41} = 325, M_{42} = 510, M_{43} = 438.$$

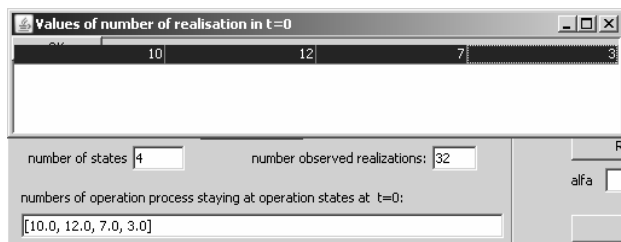
In case we have in disposal data about the system operation process we can use the computer program CP 8.1 to determine the parameters of the system operation process. Below there is given illustration of this computer program running [3].

First the computer program is reading in [6]:

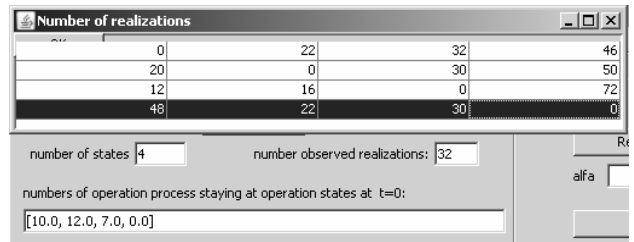
- the number of operation states of the operation process,
- the number of the observed realisation of the operation,



- the vector of the realizations of the numbers of staying of the operation process in the operation states at the initial moment,

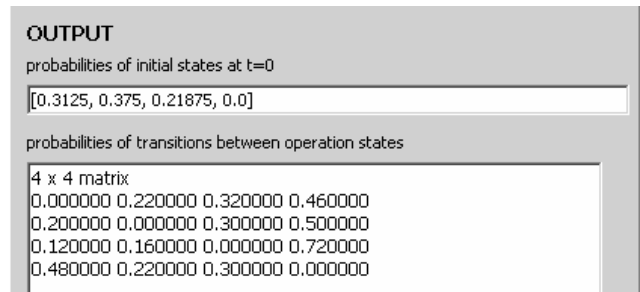


- the matrix of the realizations of the numbers of the system operation process transitions between the operation states.



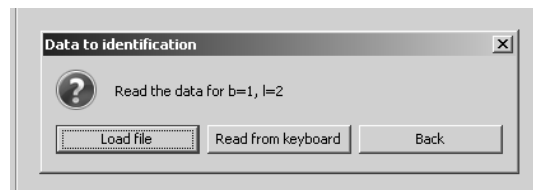
The computer program estimates the following parameters of the operation process [3]:

- i) the vector of the probabilities $p_b(0)$, $b = 1, 2, \dots, \nu$, of the initial states of the system operation process,
- ii) the matrix of the probabilities p_{bl} , $b, l = 1, 2, \dots, \nu$, of the system operation process transitions from the operation state z_b to the operation state z_l .



Then the computer program is reading in:

- the realizations θ_{bl}^k , $k = 1, 2, \dots, n_{bl}$, $b, l = 1, 2, \dots, \nu$, $b \neq l$, 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 .



After reading the realizations the computer program CP 8.1 [6]:

- testifies successively the hypotheses that the form of the distribution functions of the conditional sojourn times θ_{bl} , $b, l = 1, 2, \dots, \nu$, $b \neq l$, at the operation state z_b when the next transition is to the operation state z_l , is one of the following: uniform distribution, triangular distribution, double-trapezium distribution, quasi-trapezium distribution, exponential distribution, Weibull distribution, normal distribution, chimney distribution,
- determines the best fitting distribution and gives its name,

- determines the mean value from the fitted distribution M_{bl} , $b, l = 1, 2, \dots, v$, $b \neq l$, (in case of the hypothesis acceptance),
- determines the empirical values of the mean values $\bar{\theta}_{bl}$, $b, l = 1, 2, \dots, v$, $b \neq l$, (in case of the hypothesis rejecting).

The exemplary results of the computer program CP 8.1 are given in the window below.

```

Identification of the distribution parameters
xbl: 0|
ybl: 2,668.8
Number of subintervals: 6
Length of subintervals: 444.8
EXPONENTIAL DISTRIBUTION
DENSITY FUNCTION

0.0 for t <= 0
0.0020833*exp(-0.0020833*t) for t > 0

Mean value Mbl: 480
    
```

4. The exemplary system reliability model unknown parameters identification

4.1. The exemplary system components reliability modelling

We assume that the exemplary system and its components have four reliability states 0, 1, 2, 3, i.e. $z = 3$. And consequently, at all operation states z_b , $b = 1, 2, 3, 4$, we arbitrarily distinguish the following reliability states of the system and its components:

- a reliability state 3 – the system operation is fully effective,
- a reliability state 2 – the system operation is less effective because of ageing,
- a reliability state 1 – the system operation is less effective because of ageing and more dangerous,
- a reliability state 0 – the system is destroyed.

We assume that there are possible the transitions between the components reliability states only from better to worse ones and we fix that the system and components critical reliability state is $r = 2$. Moreover, we assume that the changes of the operation states of the system S operation process $Z(t)$ have an influence on the system reliability structure and the system multi-state components reliability as well.

The system operation process influence on the system reliability structure is expressed as follows.

At the system operation state z_1 , the system is composed of the series-parallel subsystem S_1 containing two series subsystems ($k = 2$), each

composed of three components ($l_1 = 3, l_2 = 3$) with the reliability structure showed in *Figure 1*.

At the system operation state z_2 , the system is composed of the series-parallel subsystem S_2 containing four series subsystems ($k = 4$), each composed of two components ($l_1 = 2, l_2 = 2, l_3 = 2, l_4 = 2$) with the reliability structure showed in *Figure 2*.

At the system operational state z_3 , the system is a series system with the reliability structure showed in *Figure 3*, composed of two series-parallel subsystems S_1, S_2 illustrated in *Figures 1-2*.

The subsystem S_1 consists of two series subsystems ($k = 2$), each composed of three components ($l_1 = 3, l_2 = 3$) with the reliability structure showed in *Figure 1*. The subsystem S_2 consists of four series subsystems ($k = 4$), each composed of two components ($l_1 = 2, l_2 = 2, l_3 = 2, l_4 = 2$) with the reliability structure showed in *Figure 2*.

At the system operation state z_4 , the system is a series system with the scheme showed in *Figure 3*, composed of the subsystem S_1 and S_2 illustrated in *Figures 1-2*, whereas the subsystem S_1 is a series-parallel system and the subsystem S_2 is a series-“2 out of 4” system.

The subsystem S_1 consists of two series subsystems ($k = 2$), each composed of three components ($l_1 = 3, l_2 = 3$) with the reliability structure showed in *Figure 1*. The subsystem S_2 consists of four series subsystems ($k = 4$), each composed of two components ($l_1 = 2, l_2 = 2, l_3 = 2, l_4 = 2$) and is a series-“2 out of 4” system ($m = 2$).

The system operation process influence on the system components reliability is expressed by the assumption that the subsystems S_v , $v = 1, 2$, are composed of four-state, i.e. $z = 3$, components $E_{ij}^{(v)}$, $v = 1, 2$, having the conditional four-state reliability functions

$$\begin{aligned}
 & [R_{ij}^{(v)}(t, \cdot)]^{(b)} \\
 & = [1, [R_{ij}^{(v)}(t, 1)]^{(b)}, [R_{ij}^{(v)}(t, 2)]^{(b)}, [R_{ij}^{(v)}(t, 3)]^{(b)}], \\
 & t \geq 0, b = 1, 2, 3, 4, v = 1, 2,
 \end{aligned}$$

with the exponential co-ordinates

$$\begin{aligned}
 & [R_{ij}^{(v)}(t, 1)]^{(b)} = \exp[-[\lambda_{ij}^{(v)}(1)]^{(b)} t], \\
 & [R_{ij}^{(v)}(t, 2)]^{(b)} = \exp[-[\lambda_{ij}^{(v)}(2)]^{(b)} t],
 \end{aligned}$$

$$[R_{ij}^{(v)}(t,3)]^{(b)} = \exp[-[\lambda_{ij}^{(v)}(3)]^{(b)} t],$$

$$t \geq 0, b = 1,2,3,4, v = 1,2,$$

different in various operation states z_b , where $[\lambda_{ij}^{(v)}(1)]^{(b)}$, $[\lambda_{ij}^{(v)}(2)]^{(b)}$, $[\lambda_{ij}^{(v)}(3)]^{(b)}$, $b = 1,2,3,4$, $v = 1,2$, are the subsystems components unknown intensities of departures respectively from the reliability state subsets $\{1,2,3\}$, $\{2,3\}$, $\{3\}$.

4.2. The exemplary system components reliability identification

4.2.1. Data collections coming from system components reliability state changing processes

To estimate existing in the formulae (5.1)-(5.2) the subsystems components unknown intensities $[\lambda_{ij}^{(v)}(1)]^{(b)}$, $[\lambda_{ij}^{(v)}(2)]^{(b)}$, $[\lambda_{ij}^{(v)}(3)]^{(b)}$, $b = 1,2,3,4$, $v = 1,2$, of departure respectively from the reliability state subsets $\{1,2,3\}$, $\{2,3\}$, $\{3\}$, we suppose that we have in disposal data collected from the system components reliability states changing processes due to the experiment *Case 2* described in Section 6.1.1 of IS&RDSS 6 [6]. Namely, we have in disposal the following data for particular components $E_{ij}^{(v)}$, $v = 1,2$, of the system [5]:

- the numbers of identical experiment posts $n^{(b)} = n_{ij}^{(b)}$,
- the observation times $\tau^{(b)} = \tau_{ij}^{(b)}$,
- the numbers $m^{(b)}(u) = m_{ij}^{(b)}(u)$ of components that have left the reliability states subset $\{u, u + 1, \dots, 3\}$, $u = 1,2,3$,
- the sets $A_{ij}^{(b)}(u) = \{t_i^{(b)}(u) : i = 1,2, \dots, m^{(b)}(u)\}$ of realizations $t_i^{(b)}(u) = t_{ij}^{(b)}(u)$ of the component lifetimes $T_{ij}^{(b)}(u)$ in the reliability states subset $\{u, u + 1, \dots, 3\}$, $u = 1,2,3$, at the operation state z_b , $b = 1,2,3,4$.

The data for all components are presented in [7].

4.2.2. Estimating system components intensities of departures from reliability state subsets

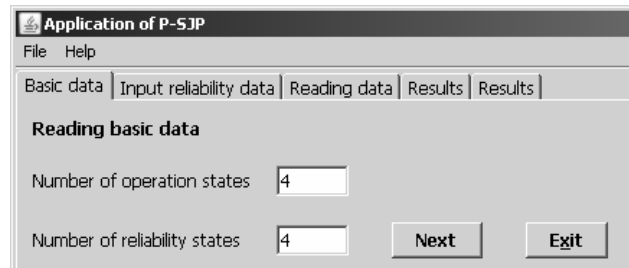
As there are data collected from the exemplary system components reliability states changing processes, then their reliability functions unknown parameters identification using the methods described in Section 6.2.1.1 of IS&RDSS 6 [6] is possible. To find the approximate values $[\hat{\lambda}_{ij}^{(v)}(1)]^{(b)}$, $[\hat{\lambda}_{ij}^{(v)}(2)]^{(b)}$ and $[\hat{\lambda}_{ij}^{(v)}(3)]^{(b)}$ of the subsystems S_b ,

$v = 1,2$, components unknown intensities $[\lambda_{ij}^{(v)}(1)]^{(b)}$, $[\lambda_{ij}^{(v)}(2)]^{(b)}$ and $[\lambda_{ij}^{(v)}(3)]^{(b)}$ of departure respectively from the reliability states subsets $\{1,2,3\}$, $\{2,3\}$, $\{3\}$, while the system is operating in the operation state z_b , $b = 1,2,3,4$, existing in (5.1)-(5.2), we can use statistical data presented in Section 6.1 and the formula (6.9) from IS&RDSS 6 [6]. We can also use the formula (6.10) from IS&RDSS 6 [6] to get their pessimistic evaluations.

Using the computer program CP 8.3 "Reliability models identification of the components" we can find automatically these evaluations and the results are presented below [4].

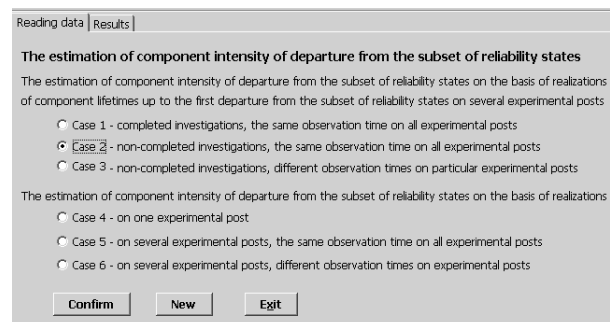
First the computer program is reading in:

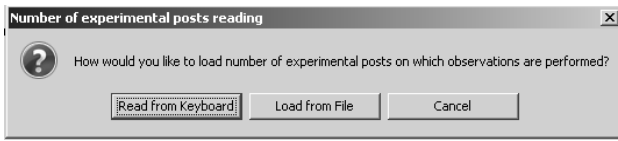
- the number of operation states v ,
- the number of reliability states $z + 1$.



As we have in disposal data coming from components reliability states changing process due to the experiment *Case 2* the computer program is reading in [1]:

- the number of experimental posts $n^{(b)}$ on which the observation is performed at the operation state z_b , $b = 1,2, \dots, v$, the observation time $\tau^{(b)}$, $\tau^{(b)} > 0$, of components at the operation state z_b , $b = 1,2, \dots, v$,
- the numbers of components $m^{(b)}(u)$, $m^{(b)}(u) \leq n^{(b)}$, that have left the reliability states subset $\{u, u + 1, \dots, z\}$, $u = 1,2, \dots, z$, at the operation state z_b , $b = 1,2, \dots, v$,
- the moments $t_i^{(b)}(u)$, $i = 1,2, \dots, m^{(b)}(u)$, of departure of the component on the i -th observational post from the reliability states subset $\{u, u + 1, \dots, z\}$ at the operation state z_b , $b = 1,2, \dots, v$.





Then after reading all necessary data mentioned above, in case we have in disposal data coming from components reliability states changing process, the computer program CP 8.3 determines [1]:

- the maximum likelihood evaluation of the unknown component intensity of departure $[\lambda(u)]^{(b)}$ from the reliability states subset $\{u, u + 1, \dots, z\}$, $u = 1, 2, \dots, z$, at the operation state z_b , $b = 1, 2, \dots, \nu$, (in all cases),
 - the pessimistic evaluation of the intensity of departure $[\lambda(u)]^{(b)}$ from the reliability states subset $\{u, u + 1, \dots, z\}$, $u = 1, 2, \dots, z$, at the operation state z_b , $b = 1, 2, \dots, \nu$, (in all cases except case 1),
- The results are presented below:
- for the components $E_{11}^{(1)}$ and $E_{21}^{(1)}$ of the subsystem S_1 ;

The maximum likelihood evaluation of component intensity of departure from the subset of reliability states

The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 1 at operation state z1: 0.0008378498677768177.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 2 at operation state z1: 0.0008730526832728563.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 3 at operation state z1: 0.0009131638272978911.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 1 at operation state z3: 0.0009352349777881693.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 2 at operation state z3: 0.0009742104835872595.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 3 at operation state z3: 0.0010185892538833714.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 1 at operation state z4: 0.001346908053718624.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 2 at operation state z4: 0.001434417584272033.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 3 at operation state z4: 0.0015389489883673561.

The pessimistic evaluation of component intensity of departure from the subset of reliability states

The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 1 at operation state z1: 0.0010473123347210223.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 2 at operation state z1: 0.0010913158540910703.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 3 at operation state z1: 0.001141454784122364.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 1 at operation state z3: 0.0010391499753201882.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 2 at operation state z3: 0.0010824560928747327.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 3 at operation state z3: 0.0011317658376481907.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 1 at operation state z4: 0.0013865229964742701.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 2 at operation state z4: 0.0014766063367506223.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 3 at operation state z4: 0.0015842121939075725.

- for the components $E_{12}^{(1)}$ and $E_{22}^{(1)}$ of the subsystem S_1 ;

The maximum likelihood evaluation of component intensity of departure from the subset of reliability states

The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 1 at operation state z1: 0.0010953759486738127.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 2 at operation state z1: 0.0011412113142950304.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 3 at operation state z1: 0.0011934191458528684.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 1 at operation state z3: 0.0011903837693760836.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 2 at operation state z3: 0.001239791930571652.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 3 at operation state z3: 0.001296030203138647.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 1 at operation state z4: 0.0015403451953078715.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 2 at operation state z4: 0.0016401715871814282.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 3 at operation state z4: 0.0017592926741248646.

The pessimistic evaluation of component intensity of departure from the subset of reliability states

The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 1 at operation state z1: 0.0013040189865164437.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 2 at operation state z1: 0.0013585848979702742.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 3 at operation state z1: 0.001420737078396272.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 1 at operation state z3: 0.001293895401495743.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 2 at operation state z3: 0.0013475999245344042.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 3 at operation state z3: 0.0014087284816724425.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 1 at operation state z4: 0.0015798412259567913.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 2 at operation state z4: 0.001682227268904029.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 3 at operation state z4: 0.001804402742692169.

- for the components $E_{13}^{(1)}$ and $E_{23}^{(1)}$ of the subsystem S_1 ;

The maximum likelihood evaluation of component intensity of departure from the subset of reliability states

The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 1 at operation state z1: 0.001058121079283501.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 2 at operation state z1: 0.0011008308652006396.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 3 at operation state z1: 0.0011493309252113948.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 1 at operation state z3: 0.0011481915982327834.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 2 at operation state z3: 0.0011962655709567523.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 3 at operation state z3: 0.0012485411068588333.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 1 at operation state z4: 0.0015004039549109376.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 2 at operation state z4: 0.001594896331738437.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 3 at operation state z4: 0.0017073063958324213.

The pessimistic evaluation of component intensity of departure from the subset of reliability states

The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 1 at operation state z1: 0.0012596679515279772.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 2 at operation state z1: 0.0013105129347626661.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 3 at operation state z1: 0.0013682511014421366.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 1 at operation state z3: 0.0012480343459051993.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 2 at operation state z3: 0.0013002886640834266.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 3 at operation state z3: 0.0013571098987956015.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 1 at operation state z4: 0.0015388758511907053.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 2 at operation state z4: 0.00163579110947532.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 3 at operation state z4: 0.0017510834829050474.

- for the components $E_{11}^{(2)}$ and $E_{21}^{(2)}$ of the subsystem S_2 ;

The maximum likelihood evaluation of component intensity of departure from the subset of reliability states

The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 1 at operation state z2: 0.0012714558169103624.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 2 at operation state z2: 0.0013543253766717454.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 3 at operation state z2: 0.001453356344808793.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 1 at operation state z3: 0.0009352349777881693.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 2 at operation state z3: 0.0009742104835872595.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 3 at operation state z3: 0.0010185892538833714.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 1 at operation state z4: 0.0013469080537178624.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 2 at operation state z4: 0.001434417584272033.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 3 at operation state z4: 0.0015389489883673561.

The pessimistic evaluation of component intensity of departure from the subset of reliability states

The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 1 at operation state z2: 0.0013906547997457087.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 2 at operation state z2: 0.0014812933807347216.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 3 at operation state z2: 0.001589608502134617.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 1 at operation state z3: 0.0010391499753201882.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 2 at operation state z3: 0.0010824560928747327.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 3 at operation state z3: 0.0011317658376481907.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 1 at operation state z4: 0.0013865229964742701.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 2 at operation state z4: 0.0014766063367506223.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 3 at operation state z4: 0.0015842121939075725.

- for the components $E_{12}^{(2)}$ and $E_{22}^{(2)}$ of the subsystem S_2 .

The maximum likelihood evaluation of component intensity of departure from the subset of reliability states

The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 1 at operation state z2: 0.0014628553354683114.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 2 at operation state z2: 0.0015576979749926325.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 3 at operation state z2: 0.0016709569615679899.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 1 at operation state z3: 0.001188845527614814.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 2 at operation state z3: 0.0012381234355233763.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 3 at operation state z3: 0.0012942070168528261.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 1 at operation state z4: 0.0015388864775283115.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 2 at operation state z4: 0.0016384489350081922.
 The maximum likelihood evaluation of component intensity of departure from the subset of reliability states not worse than 3 at operation state z4: 0.0017573108637858785.

The pessimistic evaluation of component intensity of departure from the subset of reliability states

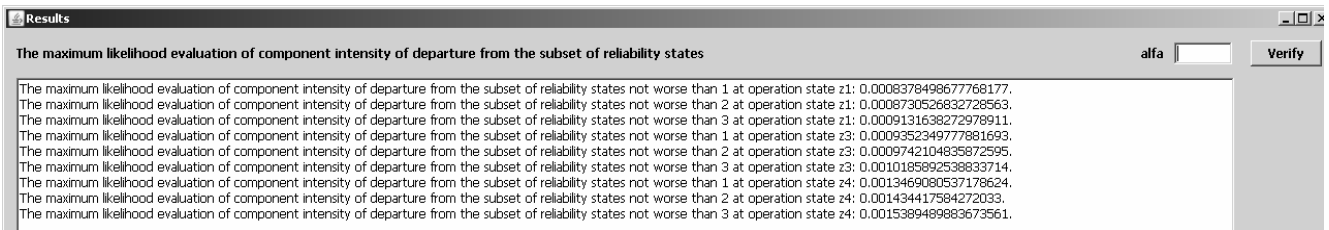
The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 1 at operation state z2: 0.0015814652275330097.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 2 at operation state z2: 0.0016839978108028459.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 3 at operation state z2: 0.001806439958451881.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 1 at operation state z3: 0.0012922233995813195.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 2 at operation state z3: 0.0013457863429601916.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 3 at operation state z3: 0.0014067467574487241.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 1 at operation state z4: 0.0015783451051572426.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 2 at operation state z4: 0.0016804604461622484.
 The pessimistic evaluation of component intensity of departure from the subset of reliability states not worse than 3 at operation state z4: 0.001802370116703465.

4.2.3. Identifying system components exponential reliability functions

As there are data collected from the system components reliability states changing processes, then it is possible to verify the hypotheses on the exponential forms of the system components conditional reliability functions. To this end, we use the procedure given in Section 6.2.2.1 of IS&RDSS 6 [6] and data collected in Section 6.1.

We may verify the hypotheses on the conditional exponential four-state exemplary components reliability functions $[R_{ij}^{(v)}(t, \cdot)]^{(b)}$, $v = 1, 2$, $b = 1, 2, 3$, at the particular operation states z_b , $b = 1, 2, 3$.

In order to perform this verification we can use the second part of the program CP 8.3 “Reliability models identification of the components”. Then the significance level α ($\alpha = 0.01$, $\alpha = 0.02$, $\alpha = 0.05$ or $\alpha = 0.10$) of the test in the field “alfa” should be given and next after pressing the button “Verify” the program verify the hypothesis.



As a result the computer program [4]:

- testifies the hypothesis that the coordinates of the conditional multistate reliability function of the system component are the exponential reliability functions,

- gives the answer whether the hypothesis is rejected or there are no arguments to reject it,
- if there are no arguments to reject the hypothesis about the exponential distribution gives the coordinates of the conditional multistate reliability function of the system component.

The maximum likelihood evaluation of component intensity of departure from the subset of reliability states

THERE ARE NO ARGUMENTS TO REJECT HYPOTHESIS ABOUT EXPONENTIAL DISTRIBUTION
 At operation state z1 component has conditional reliability function co-ordinates:
 $R(t,1) = \exp(-0.0008378498677768177*t)$ for $t > 0$.

THERE ARE NO ARGUMENTS TO REJECT HYPOTHESIS ABOUT EXPONENTIAL DISTRIBUTION
 At operation state z1 component has conditional reliability function co-ordinates:
 $R(t,2) = \exp(-0.0008730526832728563*t)$ for $t > 0$.

THERE ARE NO ARGUMENTS TO REJECT HYPOTHESIS ABOUT EXPONENTIAL DISTRIBUTION
 At operation state z1 component has conditional reliability function co-ordinates:
 $R(t,3) = \exp(-0.0009131638272978911*t)$ for $t > 0$.

The pessimistic evaluation of component intensity of departure from the subset of reliability states

THERE ARE NO ARGUMENTS TO REJECT HYPOTHESIS ABOUT EXPONENTIAL DISTRIBUTION
 At operation state z1 component has conditional reliability function co-ordinates:
 $R(t,1) = \exp(-0.0010473123347210223*t)$ for $t > 0$.

THERE ARE NO ARGUMENTS TO REJECT HYPOTHESIS ABOUT EXPONENTIAL DISTRIBUTION
 At operation state z1 component has conditional reliability function co-ordinates:
 $R(t,2) = \exp(-0.0010913158540910703*t)$ for $t > 0$.

THERE ARE NO ARGUMENTS TO REJECT HYPOTHESIS ABOUT EXPONENTIAL DISTRIBUTION
 At operation state z1 component has conditional reliability function co-ordinates:
 $R(t,3) = \exp(-0.001141454784122364*t)$ for $t > 0$.

In *Case 2*, the computer program also testifies the hypothesis about the conditional multistate reliability function of the system components for the pessimistic evaluation of the intensities of departure. Below there are presented the results of the verification the hypothesis that coordinates of the conditional four-state reliability function of the system component $E_{11}^{(1)}$ are exponential reliability functions.

The maximum likelihood evaluation of component intensity of departure from the subs

THERE ARE NO ARGUMENTS TO REJECT HYPOTHESIS ABOUT EXPONENTIAL DISTRIBUTION
At operation state z3 component has conditional reliability function co-ordinates:
 $R(t,1) = \exp(-0.0009352349777881693*t)$ for $t > 0$.

THERE ARE NO ARGUMENTS TO REJECT HYPOTHESIS ABOUT EXPONENTIAL DISTRIBUTION
At operation state z3 component has conditional reliability function co-ordinates:
 $R(t,2) = \exp(-0.0009742104835872595*t)$ for $t > 0$.

THERE ARE NO ARGUMENTS TO REJECT HYPOTHESIS ABOUT EXPONENTIAL DISTRIBUTION
At operation state z3 component has conditional reliability function co-ordinates:
 $R(t,3) = \exp(-0.0010185892538833714*t)$ for $t > 0$.

The pessimistic evaluation of component intensity of departure from the subset of reli

THERE ARE NO ARGUMENTS TO REJECT HYPOTHESIS ABOUT EXPONENTIAL DISTRIBUTION
At operation state z3 component has conditional reliability function co-ordinates:
 $R(t,1) = \exp(-0.0010391499753201882*t)$ for $t > 0$.

THERE ARE NO ARGUMENTS TO REJECT HYPOTHESIS ABOUT EXPONENTIAL DISTRIBUTION
At operation state z4 component has conditional reliability function co-ordinates:
 $R(t,2) = \exp(-0.0010824560928747327*t)$ for $t > 0$.

THERE ARE NO ARGUMENTS TO REJECT HYPOTHESIS ABOUT EXPONENTIAL DISTRIBUTION
At operation state z3 component has conditional reliability function co-ordinates:
 $R(t,3) = \exp(-0.0011317658376481907*t)$ for $t > 0$.

The maximum likelihood evaluation of component intensity of departure from the subs

THERE ARE NO ARGUMENTS TO REJECT HYPOTHESIS ABOUT EXPONENTIAL DISTRIBUTION
At operation state z4 component has conditional reliability function co-ordinates:
 $R(t,1) = \exp(-0.0013469080537178624*t)$ for $t > 0$.

THERE ARE NO ARGUMENTS TO REJECT HYPOTHESIS ABOUT EXPONENTIAL DISTRIBUTION
At operation state z4 component has conditional reliability function co-ordinates:
 $R(t,2) = \exp(-0.001434417584272033*t)$ for $t > 0$.

THERE ARE NO ARGUMENTS TO REJECT HYPOTHESIS ABOUT EXPONENTIAL DISTRIBUTION
At operation state z4 component has conditional reliability function co-ordinates:
 $R(t,3) = \exp(-0.0015389489883673561*t)$ for $t > 0$.

The pessimistic evaluation of component intensity of departure from the subset of reli

THERE ARE NO ARGUMENTS TO REJECT HYPOTHESIS ABOUT EXPONENTIAL DISTRIBUTION
At operation state z4 component has conditional reliability function co-ordinates:
 $R(t,1) = \exp(-0.0013865229964742701*t)$ for $t > 0$.

THERE ARE NO ARGUMENTS TO REJECT HYPOTHESIS ABOUT EXPONENTIAL DISTRIBUTION
At operation state z4 component has conditional reliability function co-ordinates:
 $R(t,2) = \exp(-0.0014766063367506223*t)$ for $t > 0$.

THERE ARE NO ARGUMENTS TO REJECT HYPOTHESIS ABOUT EXPONENTIAL DISTRIBUTION
At operation state z4 component has conditional reliability function co-ordinates:
 $R(t,3) = \exp(-0.0015842121939075725*t)$ for $t > 0$.

The hypotheses verification for the remaining components of the subsystems at various operation states is analogous as for the component $E_{11}^{(1)}$ [7].

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