Blokus-Roszkowska Agnieszka

Kołowrocki Krzysztof
Gdynia Maritime University, Gdynia, Poland

Fu Xiuju
Institute of High Performance Computing, Singapore

Integrated software tools supporting decision making on identification, prediction and optimization of complex technical systems operation, reliability and safety
Part 3
Integrated software tools application – Exemplary system operation and reliability characteristics prediction

Keywords

system operation process, reliability characteristics, availability, prediction, software tools

Abstract

There is presented the application of the integrated software tools to the operation and reliability of an exemplary complex technical system prediction. The computer program CP 8.5 is used to determine the unconditional mean sojourn times and the limit transient probabilities of the exemplary system operation process at the particular operation states evaluations. Using the computer program CP 8.6 there are performed the evaluations of the exemplary system unconditional multistate reliability function, the expected values and the standard deviations of its unconditional lifetimes in the reliability state subsets and the mean values of its lifetimes in the particular reliability states. Finally, in the case when the system is repairable, its renewal and availability characteristics are estimated from the results of computer program CP 8.8.

3. The exemplary system operation prediction

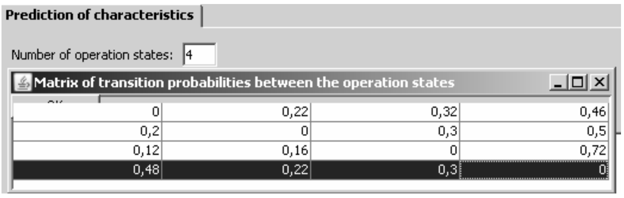
To determine the mean values of the unconditional sojourn times of the exemplary system operation process at the operation states, the limit values of the transient probabilities of the system operation process at the particular operation states and the system operation process total sojourn times at the particular operation states for the fixed sufficiently large system operation time we use the computer program CP 8.5 “Prediction of the operation process” [2].

The computer program is reading in [7]:

- the duration time θ of the system operation process,
- the number ν of the operation states of the system operation process,
- the matrix of probabilities of the system operation process transitions between the operation states given in [8]

$$[p_{bl}]_{\nu x \nu} = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1\nu} \\ p_{21} & p_{22} & \cdots & p_{2\nu} \\ \cdots & & & \\ p_{\nu 1} & p_{\nu 2} & \cdots & p_{\nu\nu} \end{bmatrix},$$

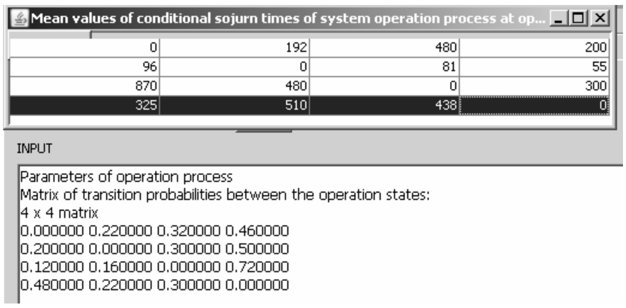
where $p_{bb} = 0$ for $b = 1,2,...,\nu$;



– the matrix of mean values of the conditional sojourn times θ_{bl} at the operation states z_b when its next operation state is z_l, from [8]

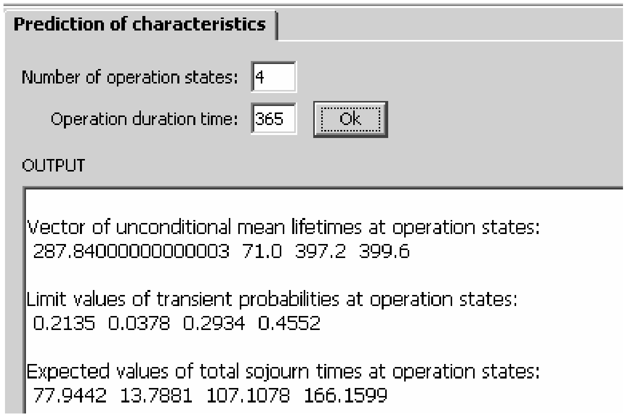
$$[M_{bl}]_{v\times v} = \begin{bmatrix} M_{11}\ M_{12}\ \ldots M_{1v} \\ M_{21}\ M_{22}\ \ldots M_{2v} \\ \ldots \\ M_{v1}\ M_{v2}\ \ldots M_{vv} \end{bmatrix},$$

where $M_{bl} = E[\theta_{bl}]$ and $M_{bb} = 0$ $b, l = 1,2,...,v$, $b \neq l$.



After reading all necessary data the computer program is estimating the following characteristics of the system operation process [7]:

– the mean values $M_b = E[\theta_b]$, $b = 1,2,...,v$, of the unconditional sojourn times θ_b, $b = 1,2,...,v$, of the system operation process at the particular operation states,
– the limit values of the transient probabilities p_b, $b = 1,2,...,v$, of the system operation process at the particular operation states,
– the mean values $E[\hat{\theta}_b] = p_b \theta$, $b = 1,2,...,v$, of the system operation process total sojourn times $\hat{\theta}_b$, $b = 1,2,...,v$, at the particular operation states z_b, for the fixed large operation time θ.



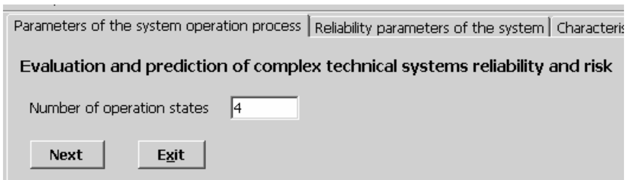
In above window there are given the unconditional mean sojourn times, the limit values of the exemplary system operation process transient probabilities at the particular operation states and the expected values of the total sojourn times $\hat{\theta}_b$, $b = 1,2,3,4,$ of the system operation process at the particular operation states z_b, $b = 1,2,3,4,$ during the fixed operation time $\theta = 1$ year = 365 days.

6. The exemplary system reliability prediction

Considering the results of the system components reliability modeling from Section 3 [9] concerned with the fixed system reliability structures and their shape parameters and with the assumed the exponential models of the reliability functions of the system components in various operation states and the results of the evaluations of the system components intensities of departures from the reliability state subsets from Section 4 [5], we may to perform the prediction of the exemplary system reliability characteristics.

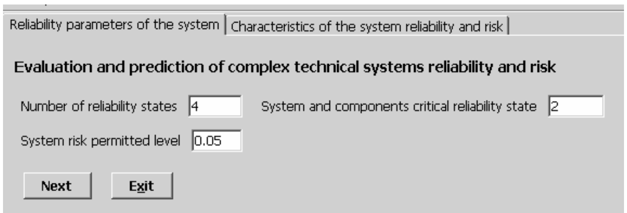
The computer program CP 8.6 "Evaluation and prediction of system reliability and risk" allows to evaluate and predict complex technical system reliability and risk characteristics [3]. The computer program is composed of three panels. The first panel "Parameters of the system operation process" is used for reading input parameters of the system operation process:

– the number of operation states of the system operation process v,
– the transient probabilities in particular operation states p_1, p_2, …, p_v.

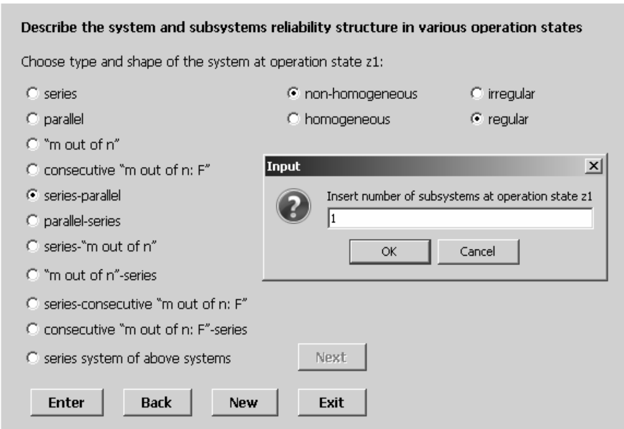


The second panel “Reliability parameters of the system” is served for reading input parameters of the system reliability model:

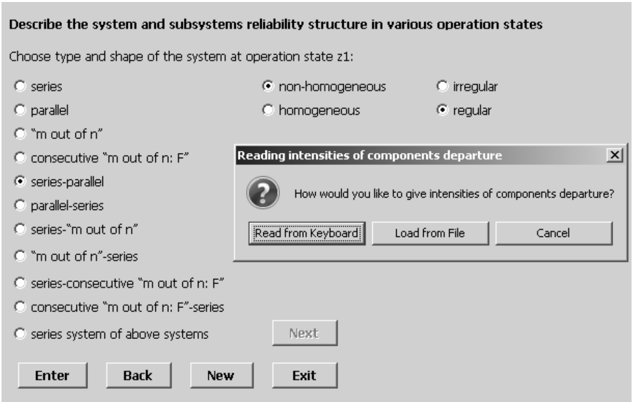
– the number of the system and components reliability states $z + 1$,
– the system and components critical reliability state r,
– the system risk permitted level δ,



– the parameters of a system reliability structure in various operation states fixed in [8],



– the intensities of components departure (equivalently $[\lambda_i(u)]^{(b)}$ or $[\lambda_{ij}(u)]^{(b)}$) from the reliability states subset $\{u, u+1, ..., z\}$, $u = 1,2,...,z$, at the operation state z_b, $b = 1,2,...,\nu$, assuming that the reliability functions of the system components are exponential, determined in Section 4 [5].

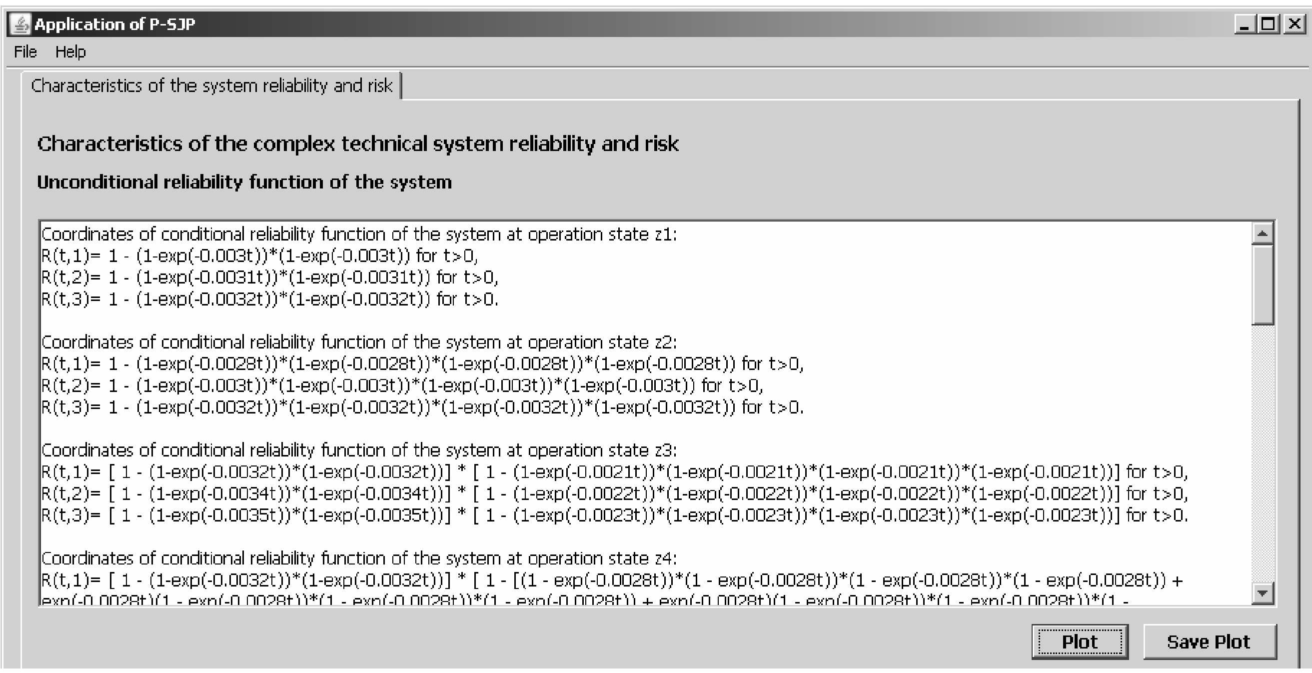


After finishing giving data mentioned above the computer program automatically comes to the next panel “Characteristics of the system reliability and risk” where are shown the results. Namely, there are determined the following characteristics [1]:

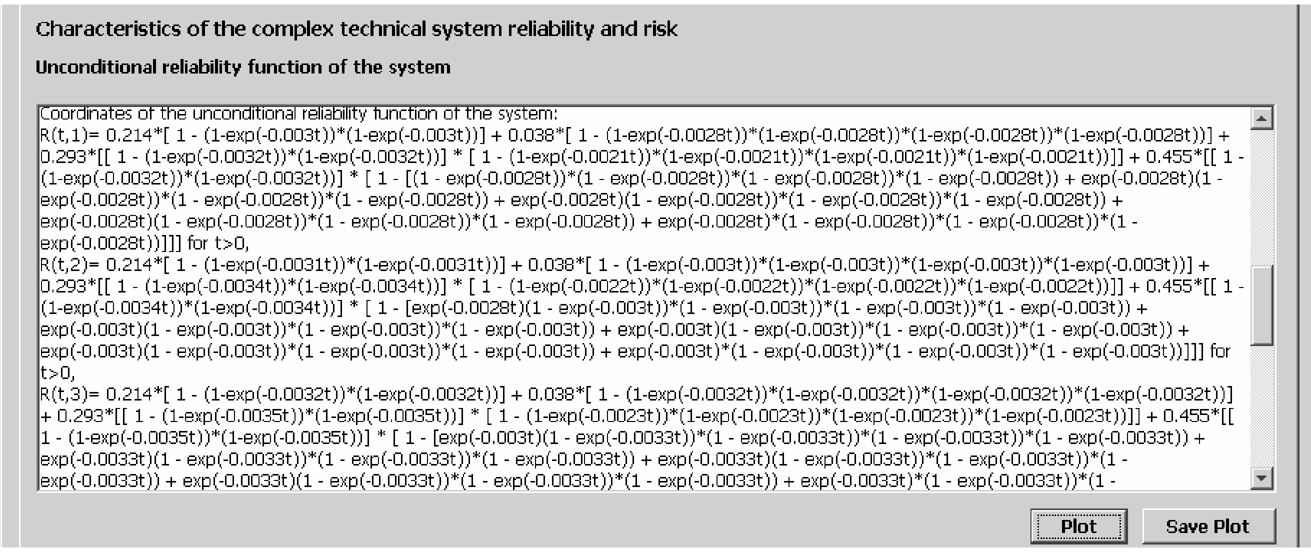
– the conditional reliability functions of the system while the system is at the operational states z_b

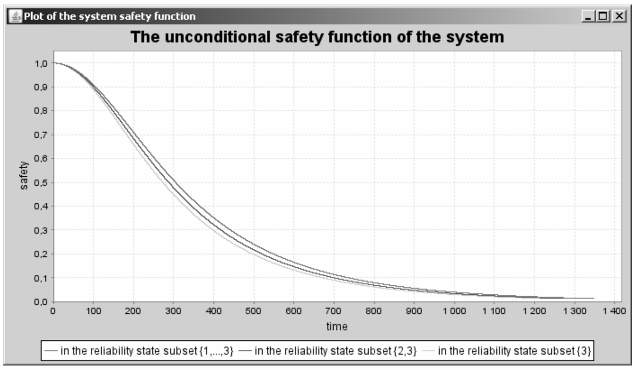
$$[\boldsymbol{R}(t,\cdot)]^{(b)} = [,[\boldsymbol{R}(t,1)]^{(b)}, ..., [\boldsymbol{R}(t,z)]^{(b)}, \; t \in <0, \infty),$$

for $b = 1,2,...,\nu$,

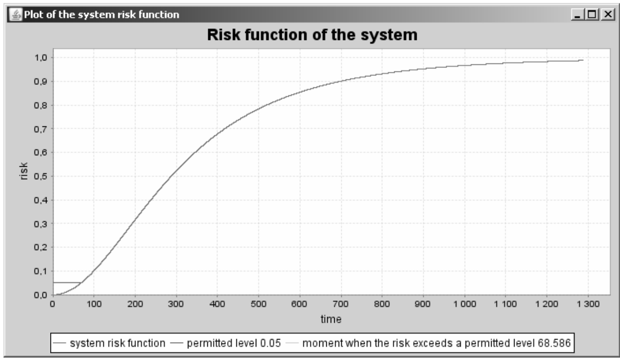


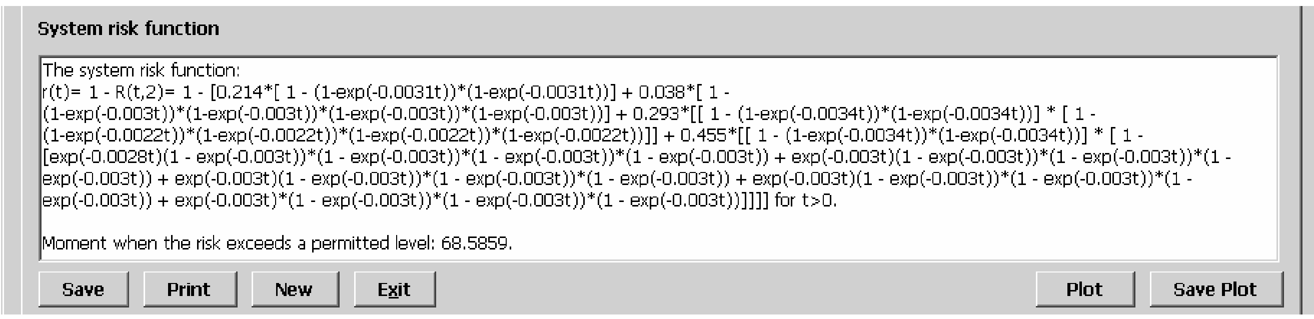
$\boldsymbol{R}(t,\cdot) = [1, \boldsymbol{R}(t,1),..., \boldsymbol{R}(t,z)], \ \ t \in <0,\infty),$





– the mean values $\mu_b(u)$ of the system conditional lifetimes in the reliability state subsets $\{u, u+1,..., z\}$, $u = 1,2,..., z,$ while the system is at the operational state z_b, $b = 1,2,..., v,$
– the mean values $\mu(u)$ of the system unconditional lifetimes in the reliability state subsets $\{u, u+1,..., z\}$, $u = 1,2,..., z,$
– the standard deviations $\sigma(u)$ of the system unconditional lifetimes in the reliability state subsets $\{u, u+1,..., z\}$, $u = 1,2,..., z,$
– the mean values $\bar{\mu}(u)$ of the system unconditional lifetimes in the particular reliability states $u = 1,2,..., z,$
– the system risk function (with plotting) $\boldsymbol{r}(t)$, $t \in <0,\infty),$
– the moment τ when the risk exceeds a permitted level δ.



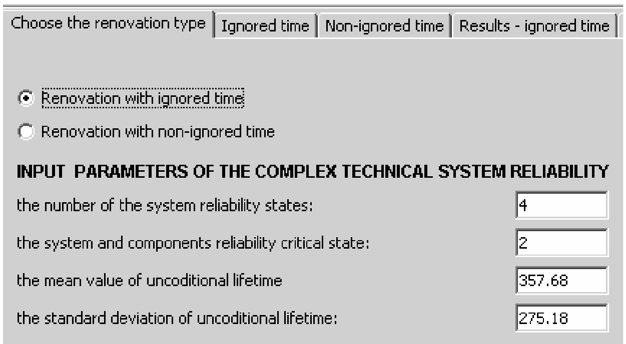


7. The exemplary system renewal and availability prediction

Using the results of the exemplary system reliability prediction given by (6.51)-(6.52) and the results of the classical renew theory presented in IS&RDSS 8 [6], we may predict the renewal and availability characteristics of this system in the case when it is repairable and its time of renovation is either ignored or non-ignored. In order to do predict them we use the computer program CP 8.8 “Prediction of system renewal and availability” [4].

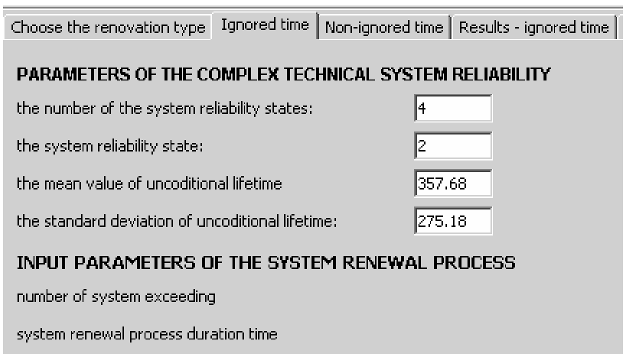
First, we assume that the system is repaired after the exceeding its reliability critical state r = 2 and that the time of the system renovation is ignored. Then the computer program is reading following reliability data, fixed in [8]:

– the number of the system reliability states,
– the system critical reliability state r,
– the mean value $\mu(r)$ of the unconditional lifetime of the system in the reliability states subset not worse than the system critical reliability state r,
– the standard deviation $\sigma(r)$ of the unconditional lifetime of the system in the reliability states subset not worse than the system critical reliability state r.



The computer program also needs following input renewal parameters:

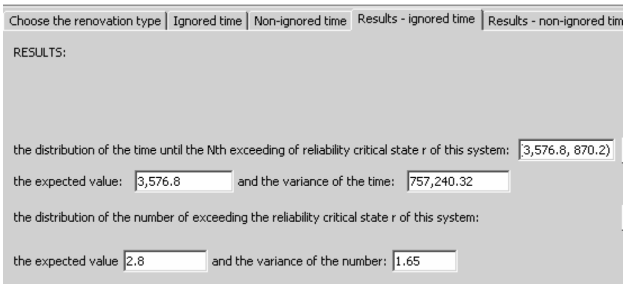
– the number N of the system exceeding the critical reliability state r and renovations,
– the system renewal process duration time t.



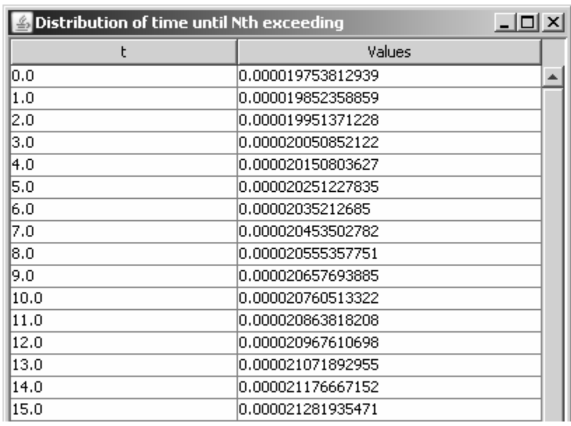
After reading data and pressing button “Calculate” the computer program is predicting the following characteristics of the complex technical system renewal and availability [6]:

– the distribution $F^{(N)}(t,r),\ t \in (-\infty,\infty)$, $r \in \{1,2,...,z\}$ of the time $S_N(r)$ until the *Nth* exceeding of reliability critical state r of this system, for sufficiently large N,
– the expected value $E[S_N(r)]$ and the variance $D[S_N(r)]$ of the time $S_N(r),\ r \in \{1,2,...,z\}$ until the *Nth* exceeding the reliability critical state r of this system ,
– the distribution $P(N(t,r) = N),\quad N = 0,1,2,...$, $r \in \{1,2,...,z\}$ of the number $N(t,r)$ of exceeding the reliability critical state r of this system up to the moment $t,\ t \ge 0$, for sufficiently large t,
– the expected value $H(t,r)$ and the variance $D(t,r)$ of the number $N(t,r),\ r \in \{1,2,...,z\}$ of exceeding the reliability critical state r of this system at the moment $t,\ t \ge 0$, for sufficiently large t.

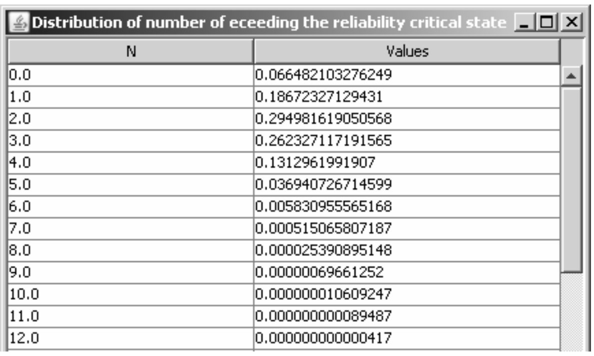
The results of the predicting the renewal process characteristics of the exemplary system in case the renovation time is ignored are given in the “Results – ignored time” tab below.



Each characteristic can be presented in the table of values for fixed parameter t. For example, the table of distribution values of the time until the *Nth* exceeding the reliability critical state and the table of distribution values of the number exceeding the reliability critical state are shown below.


Distribution of time until Nth exceeding

t	Values
0.0	0.000019753812939
1.0	0.000019852358859
2.0	0.000019951371228
3.0	0.000020050852122
4.0	0.000020150803627
5.0	0.000020251227835
6.0	0.00002035212685
7.0	0.000020453502782
8.0	0.000020555357751
9.0	0.000020657693885
10.0	0.000020760513322
11.0	0.000020863818208
12.0	0.000020967610698
13.0	0.000021071892955
14.0	0.000021176667152
15.0	0.000021281935471

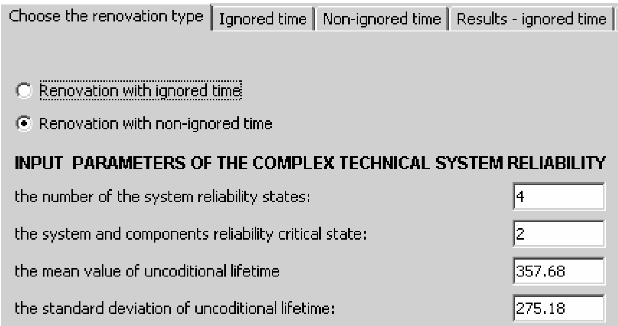

Distribution of number of eceeding the reliability critical state

N	Values
0.0	0.066482103276249
1.0	0.18672327129431
2.0	0.294981619050568
3.0	0.262327117191565
4.0	0.1312961991907
5.0	0.036940726714599
6.0	0.005830955565168
7.0	0.000515065807187
8.0	0.000025390895148
9.0	0.00000069661252
10.0	0.000000010609247
11.0	0.000000000089487
12.0	0.000000000000417

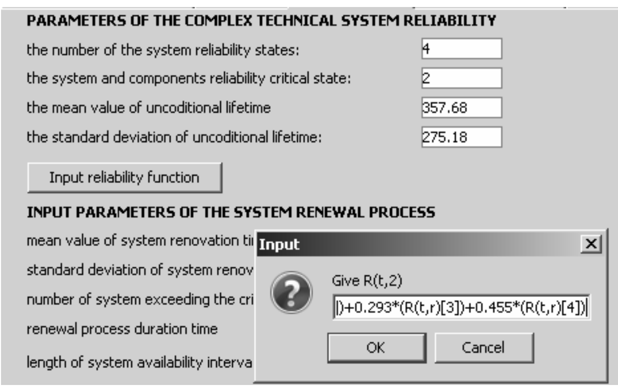
Further, assuming that the system is repaired after the exceeding its reliability critical state *r* = 2 and that the time of the system renovation is non-ignored and it has the mean value $\mu_0(2) = 10$ and the standard deviation $\sigma_0(2) = 5$, we follow the procedure.

The computer program is reading:

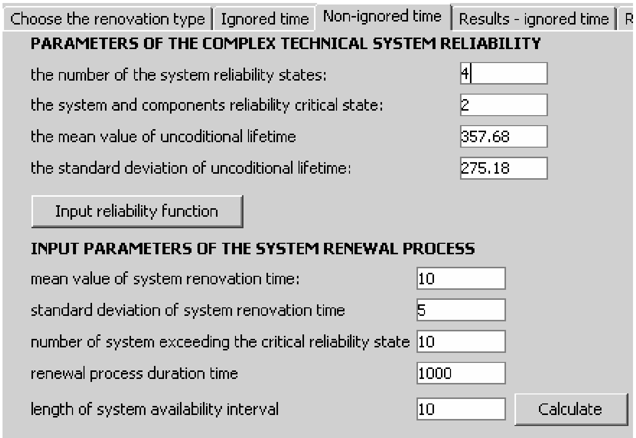
– the number of the system reliability states,
– the system critical reliability state *r*,
– the mean value $\mu(r)$ of the unconditional lifetime of the system in the reliability states subset not worse than the system critical reliability state *r*,
– the standard deviation $\sigma(r)$ of the unconditional lifetime of the system in the reliability states subset not worse than the system critical reliability state *r*,



– the r-th coordinate $\boldsymbol{R}(t,r)$, $t \ge 0$, of the system unconditional reliability function $\boldsymbol{R}(t,\cdot)$, determined in Section 6,



– the mean value $\mu_0(r)$ of the system renovation time,
– the standard deviation $\sigma_0(r)$ of the system renovation time,
– the number N of the system exceeding the critical reliability state *r* and renovations,
– the system renewal process duration time t,
– the length of the system availability interval τ.



The computer program is predicted the following characteristics of the complex technical system renewal and availability [6]:

– the distribution function $\overline{F}^{(N)}(t,r) = P(\overline{S}_N(r) < t)$, $t \in (-\infty,\infty)$, of the time $\overline{S}_N(r)$, $r \in \{1,2,...,z\}$, until the *Nth* exceeding the reliability critical state *r* of this system $N = 1,2,...$,
– the expected value $E[\overline{S}_N(r)]$ and the variance $D[\overline{S}_N(r)]$ of the time $\overline{S}_N(r)$, $r \in \{1,2,...,z\}$, until the *Nth* exceeding the reliability critical state *r* of this system,
– the distribution $P(\overline{N}(t,r) = N)$, $N = 1,2,...$ of the number $\overline{N}(t,r)$, $r \in \{1,2,...,z\}$ of exceeding the reliability critical state *r* of this system up to the moment t, $t \ge 0$,
– the expected value $\overline{H}(t,r)$ and the variance $\overline{D}(t,r)$ of the number $\overline{N}(t,r)$, $r \in \{1,2,...,z\}$ of exceeding the reliability critical state *r* of this system up to the moment t, $t \ge 0$, for sufficiently large *t*,
– the distribution function $\overline{\overline{F}}^{(N)}(t,r)$, $t \in (-\infty,\infty)$ of the time $\overline{\overline{S}}_N(r)$, $r \in \{1,2,...,z\}$ until the *Nth* system's renovation, for sufficiently large *N*, $N = 1,2,...$,
– the expected value $E[\overline{\overline{S}}_N(r)]$ and the variance $D[\overline{\overline{S}}_N(r)]$ of the time $\overline{\overline{S}}_N(r)$, $r \in \{1,2,...,z\}$ until the *Nth* system's renovation,

– the distribution $P(\overline{\overline{N}}(t,r) = N)$, $N = 1,2,...$, of the number $\overline{\overline{N}}(t,r)$, $r \in \{1,2,...,z\}$ of system's renovations up to the moment t, $t \ge 0$,
– the expected value $\overline{\overline{H}}(t,r)$ and the variance $\overline{\overline{D}}(t,r)$ of the number $\overline{\overline{N}}(t,r)$, $r \in \{1,2,...,z\}$ of system's renovations up to the moment t, $t \ge 0$,
– the availability coefficient $A(t,r)$, $t \ge 0$, $r \in \{1,2,...,z\}$ of the system at the moment t,
– the availability coefficient $A(t,\tau,r)$, $t \ge 0$, $\tau > 0$, $r \in \{1,2,...,z\}$ of the system in the time interval $< t, t+\tau), \tau > 0$.

The renewal and availability characteristics of the exemplary system in the case when it is repairable and its time of renovation is non-ignored are presented in the "Results – non-ignored time" tab shown below.
Values of distribution of time until the *Nth* exceeding reliability critical state and until the *Nth* system's renovation are presented in first two tables. In the next two tables there are given values of distribution of the number of system's renovation and the number of exceeding the reliability critical state for fixed parameter *t*.

Distribution of time until the Nth exceeding

t	Values
0.0	0.000012592267498
71.536	0.000012656506436
143.072	0.000012721057016
214.608	0.000012785920663
286.144	0.000012851098811
357.68000000000006	0.000012916592898
429.216	0.000012982404367
500.75200000000007	0.000013048534671
572.288	0.000013114985266
643.8240000000001	0.000013181757615
715.3600000000001	0.000013248853187
786.8960000000001	0.000013316273459

Distribution of number of exceeding

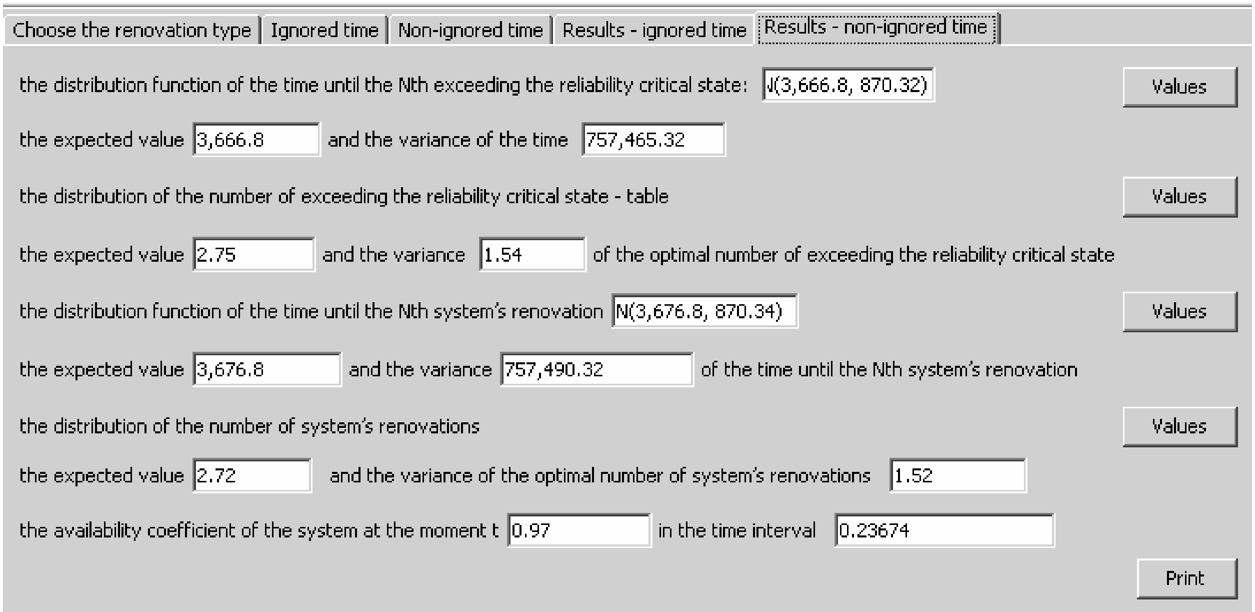
N	Values
0.0	0.066139733509541
1.0	0.194013637732962
2.0	0.307246959075043
3.0	0.262943627596745
4.0	0.121564856415622
5.0	0.030312232412999
6.0	0.004065851209418
7.0	0.000292419130553
8.0	0.000011237986186
9.0	0.000000230013728
10.0	0.000000002499698

Distribution of time until the Nth system's renovation

t	Values
0.0	0.000011970413754
1.0	0.000012031630406
2.0	0.00001209314484
3.0	0.000012154958423
4.0	0.000012217072528
5.0	0.000012279488534
6.0	0.000012342207824
7.0	0.00001240523179
8.0	0.000012468561827
9.0	0.000012532199339
10.0	0.000012596145734
11.0	0.000012660402426
12.0	0.000012724970835
13.0	0.000012789852388
14.0	0.000012855048518
15.0	0.000012920560664

Distribution of number of system's renovation

N	Values
0.0	0.068002588822857
1.0	0.198137311458707
2.0	0.30986194264382
3.0	0.260355455637689
4.0	0.11748697121065
5.0	0.028424315123408
6.0	0.003676845705717
7.0	0.000253449440036
8.0	0.000009276852453
9.0	0.000000179689517



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