Blokus-Roszkowska Agnieszka

Kołowrocki Krzysztof
Gdynia Maritime University, Gdynia, Poland

Salahuddin Habibullah Mohamed
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 4
Integrated software tools application – Exemplary system operation and reliability optimization

Keywords

operation process optimization, optimal characteristics, reliability, availability, renewal, software tools

Abstract

There is presented the application of the integrated software tools to the operation and reliability of an exemplary complex technical system optimization. First using the computer program CP 8.9 there are determined the optimal limit transient probabilities of the exemplary system operation process at the particular operation states maximizing the system lifetime in the reliability states not worse than the critical reliability state and its optimal sojourn times at the particular operation states. Program CP 8.9 allows also for automatic evaluation of the exemplary system optimal unconditional multistate reliability function, the optimal expected values and standard deviations of its unconditional lifetimes in the reliability state subsets and the optimal mean values of its lifetimes in the particular reliability states. Moreover, in the case when the system is repairable, its optimal renewal and availability characteristics are obtained using the computer program CP 8.11.

8. The exemplary system operation process optimization

8.1. Optimal transient probabilities of the system operation process at operation states

Considering the results given in [5], it is natural to assume that the system operation process has a significant influence on the system reliability. This influence is also clearly expressed for the mean values of the system unconditional lifetimes in the reliability state subsets that can be used for the system operation process optimization performed in the accordance with the procedure proposed in Section 9.2.1 of IS&RDSS 9 [7].

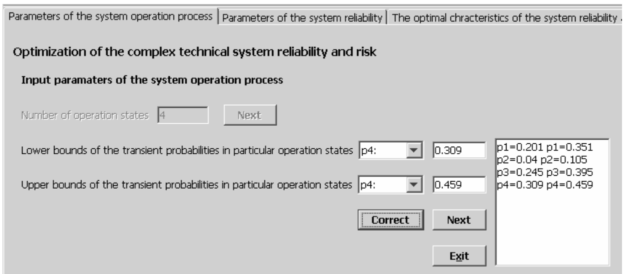
To determine the optimal characteristics of the exemplary system reliability and risk: the optimal unconditional reliability function, the optimal mean values of unconditional lifetimes in the reliability state subsets, the optimal risk function of the system and the optimal moment when the system risk exceeds a permitted level we use the computer program CP 8.9 "Optimization of system operation and reliability" [2].

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 [6]:

– the number of operation states of the system operation process v,

– the lower bounds of the transient probabilities p_b, $b = 1,2,...,\nu$, in particular operation states $\breve{p}_1$, $\breve{p}_2$, …, $\breve{p}_\nu$,
– the upper bounds of the transient probabilities p_b, $b = 1,2,...,\nu$, in particular operation states $\hat{p}_1$, $\hat{p}_2$, …, $\hat{p}_\nu$,

fixed in [9].



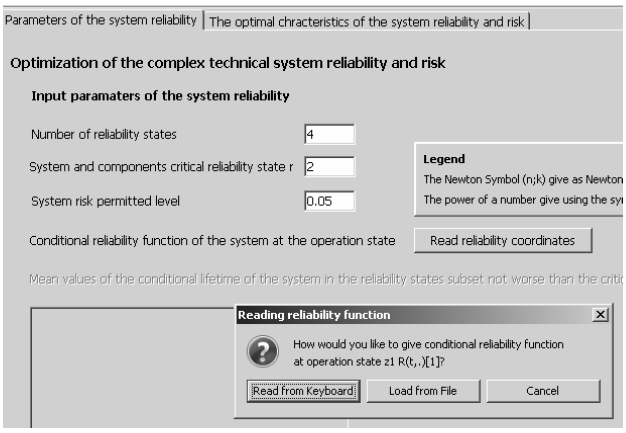
The second panel "Parameters of the system reliability" is served for reading input parameters of the system reliability model [2]:

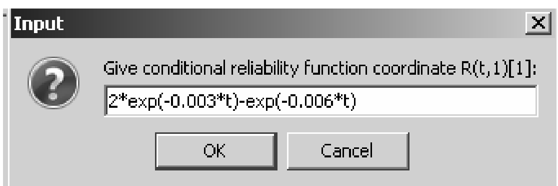
– the number of the system and components reliability states $z + 1$,
– the system and components critical reliability state r,
– the conditional reliability function of the system at the operation state z_b, $b = 1,2,...,\nu$,

$$[\boldsymbol{R}(t,\cdot)]^{(b)} = [1,[\boldsymbol{R}(t,1)]^{(b)},\ldots,[\boldsymbol{R}(t,z)]^{(b)}],$$

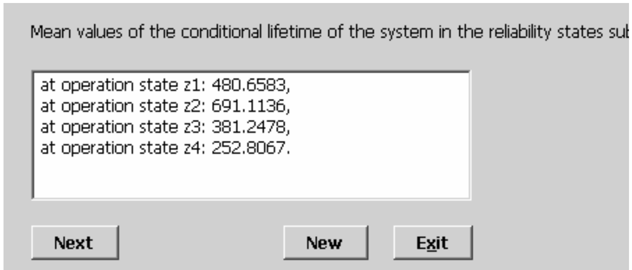
for $b = 1,2,...,\nu$, determined in Section 6 [5],

– the system risk permitted level δ.

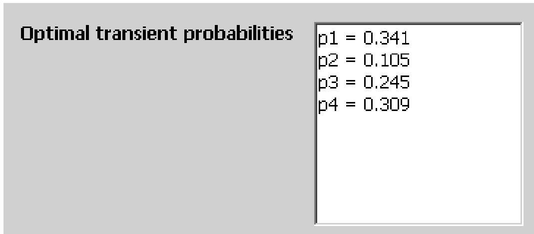




After giving the last coordinate of the conditional reliability function, the computer program determines and shows in the Text Area the mean values of the system conditional lifetimes $\mu_b(r)$, $b = 1,2,...,\nu$, in the reliability states subset not worse than the system critical reliability state r.



Then the computer program determines [6] the optimal transient probabilities $\dot{p}_1, \dot{p}_2, \ldots, \dot{p}_\nu$, of the complex technical system operation process.



8.2. Optimal sojourn times of the system operation process at operation states

Having the values of the optimal transient probabilities determined in Section 8.1, it is possible to find the optimal unconditional and conditional mean values of the sojourn times of the exemplary system operation process at the operation states and the optimal mean values of the total unconditional sojourn times of the exemplary system operation process at the operation states during the fixed operation time as well.

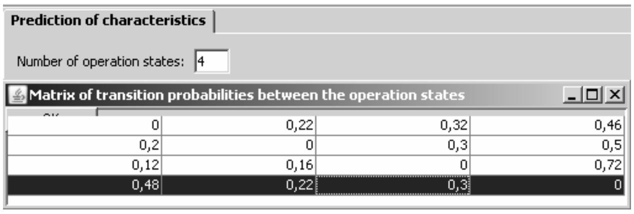
Considering, obtained from Section 8.1, the optimal transient probabilities at operation states

$$\dot{p}_1 = 0.341,\ \dot{p}_2 = 0.105,\ \dot{p}_3 = 0.245,\ \dot{p}_4 = 0.309,$$

in [9] there are determined the optimal mean values $\dot{M}_b$ of the exemplary system unconditional sojourn times in the operation states

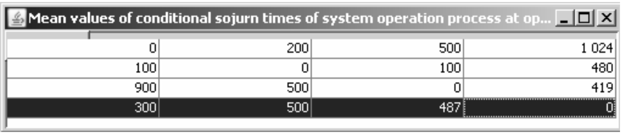
$$\dot{M}_1 \cong 675,\ \dot{M}_2 \cong 290,\ \dot{M}_3 \cong 490,\ \dot{M}_4 = 400.$$

Then using the probabilities [4]


Prediction of characteristics
Number of operation states: 4
Matrix of transition probabilities between the operation states

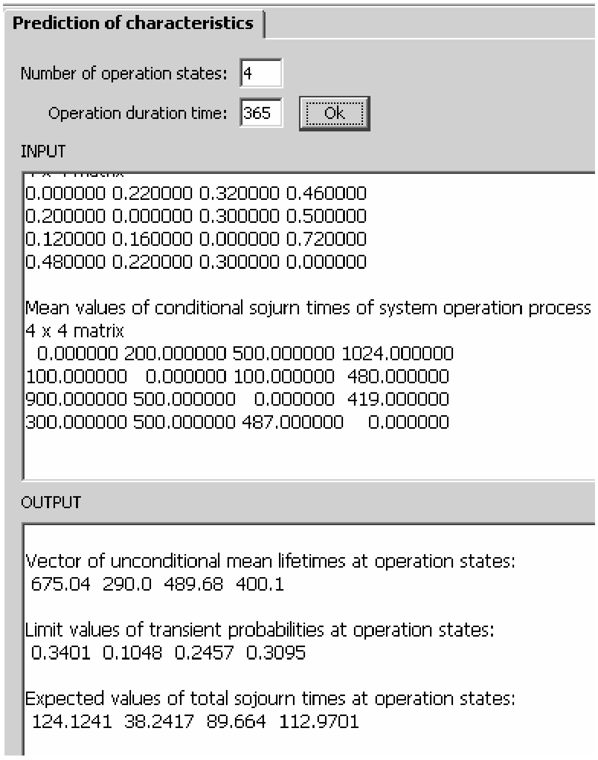
0	0,22	0,32	0,46
0,2	0	0,3	0,5
0,12	0,16	0	0,72
0,48	0,22	0,3	0

and the optimal values $\dot{M}_{bl}$ of the mean values M_{bl} of the conditional sojourn times at operation states


Mean values of conditional sojourn times of system operation process at op...

0	200	500	1 024
100	0	100	480
900	500	0	419
300	500	487	0

determined in [9], applying the computer program CP 8.5 we can obtain the optimal mean values of the total unconditional sojourn times of the exemplary system operation process at the operation states during the fixed operation time $\theta = 1$ year = 365 days. In the window below there are presented results of the computer porgram CP 8.5.


Prediction of characteristics

Number of operation states: 4
Operation duration time: 365 Ok

INPUT

0.000000 0.220000 0.320000 0.460000
0.200000 0.000000 0.300000 0.500000
0.120000 0.160000 0.000000 0.720000
0.480000 0.220000 0.300000 0.000000

Mean values of conditional sojourn times of system operation process
4 x 4 matrix
0.000000 200.000000 500.000000 1024.000000
100.000000 0.000000 100.000000 480.000000
900.000000 500.000000 0.000000 419.000000
300.000000 500.000000 487.000000 0.000000

OUTPUT

Vector of unconditional mean lifetimes at operation states:
675.04 290.0 489.68 400.1

Limit values of transient probabilities at operation states:
0.3401 0.1048 0.2457 0.3095

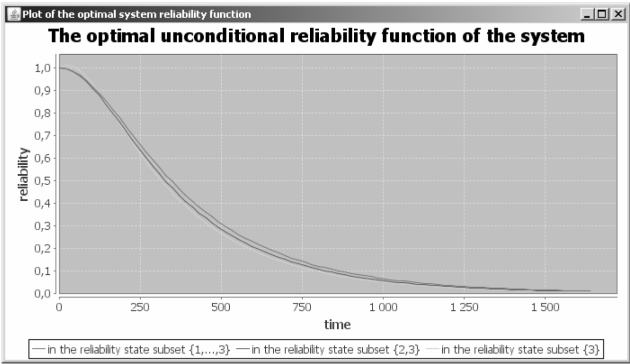
Expected values of total sojourn times at operation states:
124.1241 38.2417 89.664 112.9701

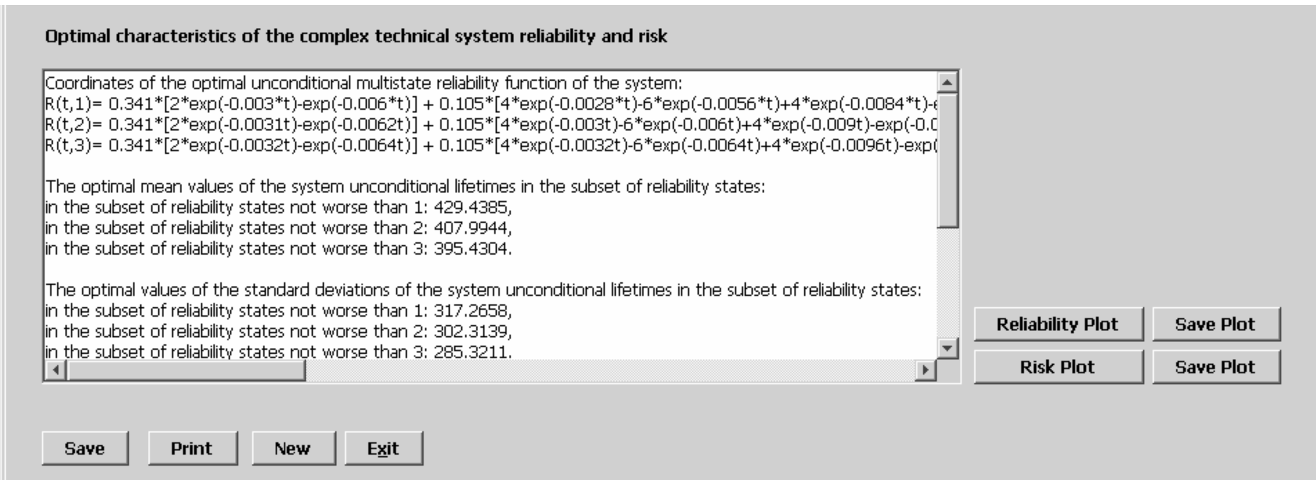
9. The exemplary system reliability optimization

In the third panel "The optimal characteristics of the system reliability and risk" there are presented the results of the program. Namely, the computer program CP 8.9 determines the following characteristics [6]:

– the coordinates of the optimal unconditional multistate reliability function of the system (with plotting)

$$\dot{\boldsymbol{R}}(t,\cdot) = [1, \dot{\boldsymbol{R}}(t,1), \ldots, \dot{\boldsymbol{R}}(t,z)], \quad t \geq 0,$$




Optimal characteristics of the complex technical system reliability and risk

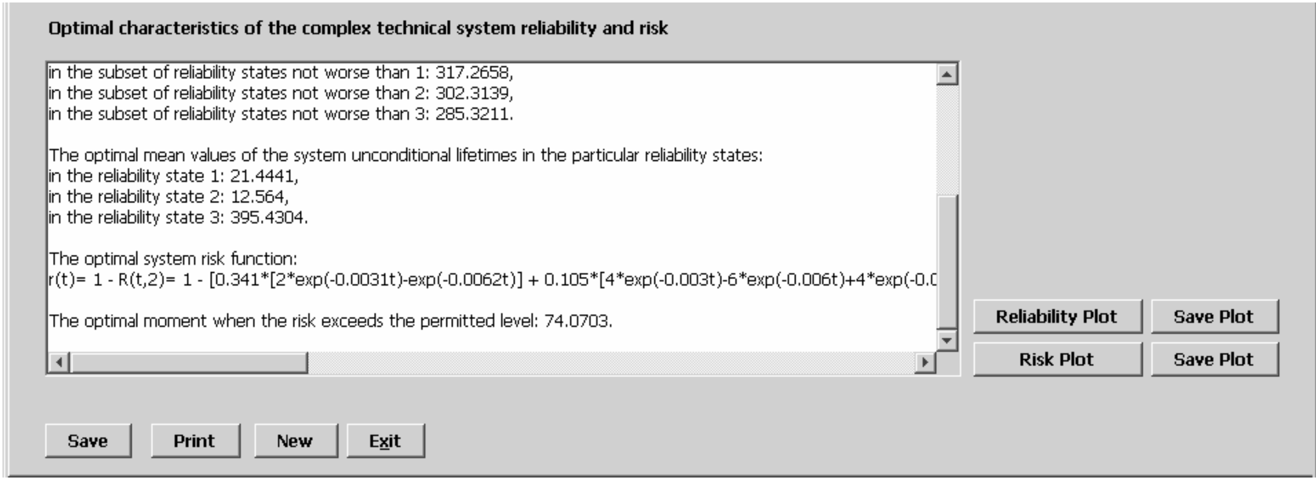
Coordinates of the optimal unconditional multistate reliability function of the system:
R(t,1)= 0.341*[2*exp(-0.003*t)-exp(-0.006*t)] + 0.105*[4*exp(-0.0028*t)-6*exp(-0.0056*t)+4*exp(-0.0084*t)-
R(t,2)= 0.341*[2*exp(-0.0031t)-exp(-0.0062t)] + 0.105*[4*exp(-0.003t)-6*exp(-0.006t)+4*exp(-0.009t)-exp(-0.0
R(t,3)= 0.341*[2*exp(-0.0032t)-exp(-0.0064t)] + 0.105*[4*exp(-0.0032t)-6*exp(-0.0064t)+4*exp(-0.0096t)-exp(

The optimal mean values of the system unconditional lifetimes in the subset of reliability states:
in the subset of reliability states not worse than 1: 429.4385,
in the subset of reliability states not worse than 2: 407.9944,
in the subset of reliability states not worse than 3: 395.4304.

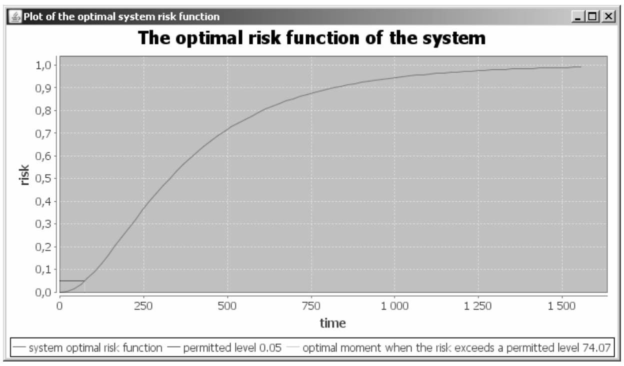
The optimal values of the standard deviations of the system unconditional lifetimes in the subset of reliability states:
in the subset of reliability states not worse than 1: 317.2658,
in the subset of reliability states not worse than 2: 302.3139,
in the subset of reliability states not worse than 3: 285.3211.

Reliability Plot | Save Plot
Risk Plot | Save Plot

Save | Print | New | Exit



- the optimal mean values $\dot{\mu}(u)$ of the system unconditional lifetimes in the reliability state subsets $\{u, u+1, ..., z\}$, $u = 1,2,..., z$,
- the optimal values $\dot{\sigma}(u)$ of the standard deviations of the system unconditional lifetimes in the system reliability state subsets $\{u, u+1, ..., z\}$, $u = 1,2,..., z$,
- the optimal mean values $\dot{\bar{\mu}}(u)$ of the system unconditional lifetimes in the particular reliability states $u = 1,2,..., z$,
- the optimal system risk function (with plotting) $\dot{\boldsymbol{r}}(t)$, $t \ge 0$,
- the optimal moment $\dot{\tau}$ when the risk exceeds the permitted level δ.



10. The exemplary system renewal and availability optimization

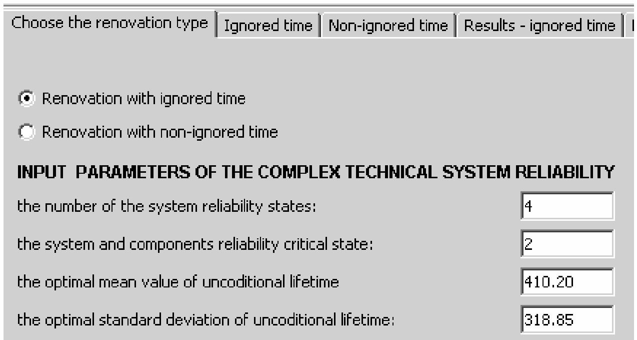
To determine the optimal renewal and availability characteristics of the exemplary system after its operation process optimization, we use the results of the system reliability characteristics optimization performed in Sections 8 and 9 and the results of the Section 11.2 of IS&RDSS 11 [7].

In the case when the exemplary system renovation time is ignored, considering the optimal values $\dot{\mu}(2)$ and $\dot{\sigma}(2)$ determined in Section 9, we predict the optimal renewal and availability characteristics of the exemplary system using the computer program CP 8.11 "Optimization of system availability" [3].

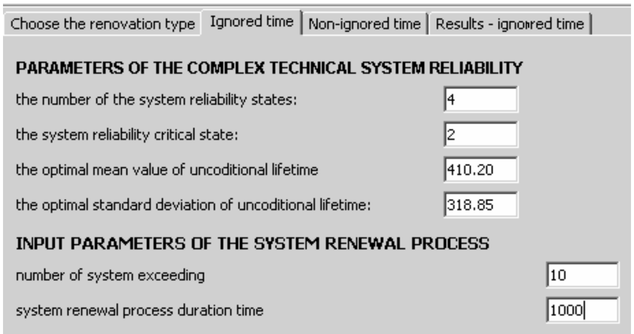
The computer program is reading:

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

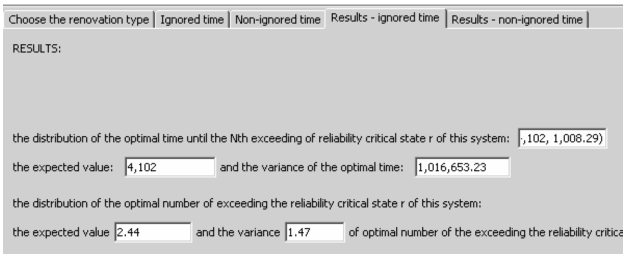
from results of Section 9 and from [9],



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



The results of the predicting the optimal 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 optimal time until the *Nth* exceeding the reliability critical state and the table of distribution values of the optimal number exceeding the reliability critical state are shown below.

Distribution of number of eceeding the reliability critical state

N	Values
0	0.095778460010645
1	0.241075791391216
2	0.319250684940067
3	0.222591129838546
4	0.081637804892566
5	0.015713480636288
6	0.001581987497007
7	0.000082988446833
8	0.000002259588423
9	0.000000031817583
10	0.000000000230967
11	0.000000000000862
12	0.000000000000002
13	0

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

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

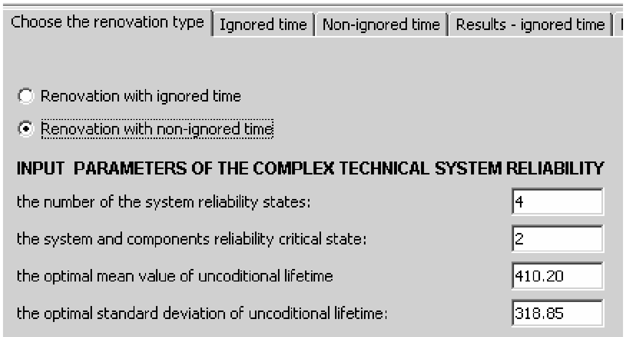
Distribution of time until Nth exceeding

t	Values
0	0.00002368224814
1	0.000023783230095
2	0.000023884620216
3	0.000023986420052
4	0.00002408863116
5	0.000024191255099
6	0.000024294293435
7	0.00002439774774
8	0.000024501619592
9	0.000024605910573
10	0.00002471062227
11	0.000024815756279
12	0.000024921314197
13	0.000025027297631
14	0.000025133708191
15	0.000025240547493
16	0.000025347817159
17	0.000025455518817
18	0.0000255636541

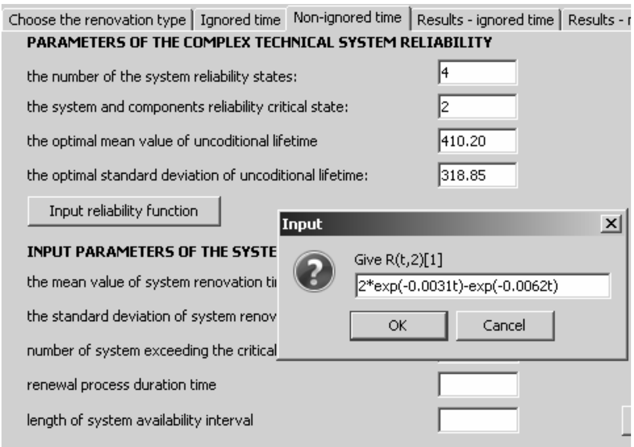
Further, to make the estimation of the renewal and availability of the exemplary system in the case when the time of renovation is non-ignored, considering the optimal values $\dot{\mu}(2)$ and $\dot{\sigma}(2)$ determined in Section 9, assuming the mean value of the system renovation time $\mu_0(2) = 10$ years and the standard deviation of the system renovation time $\sigma_0(2) = 5$ years, we use the computer program CP 8.11 in the following way [3].

The computer program is reading:

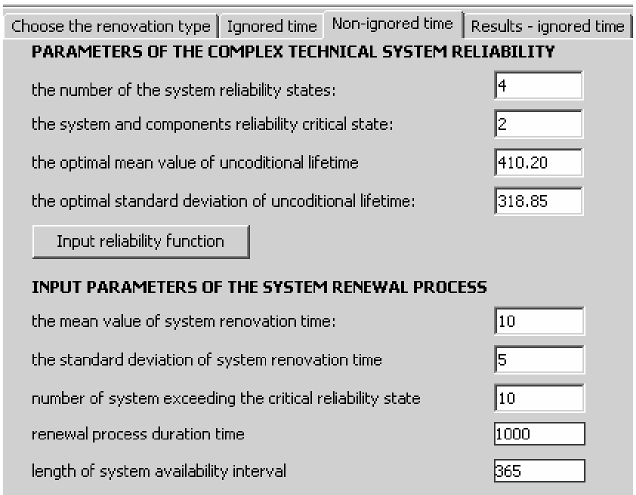
– the number of the system reliability states,
– the system critical reliability state *r*,
– the optimal mean value $\dot{\mu}(r)$ of the unconditional lifetime of the system in the reliability states subset not worse than the system critical reliability state *r*,
– the optimal standard deviation $\dot{\sigma}(r)$ 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 $\dot{\boldsymbol{R}}(t,r)$, $t \ge 0$, of the system optimal unconditional reliability function $\dot{\boldsymbol{R}}(t,\cdot)$ determined in Section 6 [5],



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

– the optimal steady availability coefficient $\dot{A}(t,\tau,r),\ t \geq 0,\ \tau > 0,\ r \in \{1,2,...,z\}$ of the system in the time interval $< t, t+\tau), \tau > 0$.

The optimal 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.

Distribution of number of exceeding

N	Values
0	0.095908318587048
1	0.249342555383982
2	0.328100270939511
3	0.218698074211274
4	0.07375411090405
5	0.012546889098876
6	0.001072228036685
7	0.000045815848068
8	0.000000974380799
9	0.000000010271193
10	0.000000000053474
11	0.000000000000137
12	0

Choose the renovation type | Ignored time | Non-ignored time | Results - ignored time | Results - non-ignored time

the distribution function of the optimal time until the Nth exceeding the reliability critical state: N(4,192, 1,008.4) Values

the expected value 4,192 and the variance of the optimal time 1,016,878.23

the distribution of the optimal number of exceeding the reliability critical state - table Values

the expected value 2.4 and the variance 1.38 of the optimal number of exceeding the reliability critical state

the distribution function of the optimal time until the Nth system's renovation N(4,202, 1,008.42) Values

the expected value 4,202 and the variance 1,016,903.23 of the optimal time until the Nth system's renovation

the distribution of the optimal number of system's renovations Values

the expected value 2.38 and the variance of the optimal number of system's renovations 1.37

the optimal availability coefficient of the system at the moment t 0.98 in the time interval 0

Print

Values of distribution of the optimal 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 optimal number of system's renovation and the optimal number of exceeding the reliability critical state for fixed parameter *t*.

Distribution of time until the Nth system's renovation

t	Values
0	0.000015436442335
1	0.000015503704885
2	0.000015571245883
3	0.000015639066415
4	0.00001570716757
5	0.000015775550444
6	0.000015844216132
7	0.000015913165738
8	0.000015982400367
9	0.00001605192113
10	0.000016121729139
11	0.000016191825513
12	0.000016262211374
13	0.000016332887847
14	0.000016403856064
15	0.000016475117158
16	0.000016546672267

Distribution of time until the Nth exceeding

t	Values
0	0.000016118124899
1	0.000016188207249
2	0.000016258579036
3	0.000016329241384
4	0.000016400195424
5	0.00001647144229
6	0.00001654298312
7	0.000016614819057
8	0.000016686951246
9	0.000016759380838
10	0.000016832108988
11	0.000016905136854
12	0.000016978465601
13	0.000017052096394
14	0.000017126030406
15	0.000017200268812

Distribution of number of system's renovation

N	Values
0	0.098240863389695
1	0.253527475649781
2	0.329047604779527
3	0.214953115678213
4	0.070585118459535
5	0.011614702978496
6	0.000953564740319
7	0.000038873308073
8	0.000000783193852
9	0.000000007765402
10	0.000000000037754
11	0.00000000000009

Acknowledgements

The paper describes 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

[1] Blokus-Roszkowka, A., Guze, S., Kołowrocki, K. & Soszyńska, J. (2010). The computer program for prediction of operation processes of complex technical systems. Task 8.5 in WP8: Packages of Tools for Complex Industrial Systems and Processes Safety and Reliability Optimization. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0.Gdynia Maritime University.

[2] Blokus-Roszkowka, A., Guze, S., Kołowrocki, K. & Soszyńska, J. (2010). The computer program for optimization of complex technical systems operation and reliability. Task 8.9 in WP8: Packages of Tools for Complex Industrial Systems and Processes Safety and Reliability Optimization. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0.Gdynia Maritime University.

[3] Blokus-Roszkowka, A., Guze, S., Kołowrocki, K. & Soszyńska, J. (2010). The computer program for optimization of complex technical systems availability. Task 8.11 in WP8: Packages of Tools for Complex Industrial Systems and Processes Safety and Reliability Optimization. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0.Gdynia Maritime University.

[4] Blokus-Roszkowka, A., Kołowrocki, K. & Fu Xiuju (2011). Integrated software tools supporting decision making on operation, identification, prediction and optimization of complex technical systems reliability and safety. Part 2. Integrated software tools application – Exemplary system operation and reliability unknown parameters identification. *Summer Safety & Reliability Seminars. Journal of Polish Safety and Reliability Association*, Issue 5, Vol. 2, 279-288.

[5] Blokus-Roszkowka, A., Kołowrocki, K. & Fu Xiuju (2011). Integrated software tools supporting decision making on operation, identification, prediction and optimization of complex technical systems reliability and safety. Part 3. Integrated software tools application – Exemplary system operation and reliability characteristics prediction. *Summer Safety & Reliability Seminars. Journal of Polish Safety and Reliability Association*, Issue 5, Vol. 2, 289-296.

[6] Blokus-Roszkowska, A., Kołowrocki, K. & Soszyńska, J. (2009). Methods of complex technical systems operation, reliability, availability, safety and cost optimization. Task 7.5 in WP7: Integrated Package of Solutions for Complex Industrial Systems and Processes Safety and Reliability Optimization. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0. Gdynia Maritime University.

[7] Kołowrocki, K. & Soszyńska, J. (2010). Integrated Safety and Reliability Decision Support System – IS&RDSS. Tasks 10.0-10.15 in WP10: Safety and Reliability Decision Support Systems for Various Maritime and Coastal Transport Sectors. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0. Gdynia Maritime University.

[8] Kołowrocki, K., Soszyńska-Budny, J. & Ng Kien Ming (2011). Integrated package of tools supporting decision making on operation, identification, prediction and optimization of complex technical systems reliability and safety. Part 2. IS&RDSS Application – Exemplary system operation and reliability unknown parameters identification. *Summer Safety & Reliability Seminars. Journal of Polish Safety and Reliability Association*, Issue 5, Vol. 2, 373-386.

[9] Kołowrocki, K., Soszyńska-Budny, J. & Xie, M. (2011). Integrated package of tools supporting decision making on operation, identification, prediction and optimization of complex technical systems reliability and safety. Part 4. IS&RDSS Application – Exemplary system operation and reliability optimization. *Summer Safety &*

Reliability Seminars. Journal of Polish Safety and Reliability Association, Issue 5, Vol. 2, 399-406.